Advanced Batteries: Longer-Lasting Power for Cordless Power Tools and Plug-In Hybrid Electric Vehicles

Challenge

In the early 1990s, high-power consumer electronics relied mainly on nickel cadmium (NiCd) and nickel metal hydride (NiMH) batteries. These batteries were heavy, bulky, and expensive to use, causing manufacturers of high-power applications to seek lightweight, cost-effective, and more efficient alternatives. However, design modifications to boost battery power proved challenging as they risked reducing battery life or even causing explosions.

At that time, the first generations of lithium-ion (Li) batteries were delivering long-lasting power to small consumer electronics devices, such as laptop computers and cell phones. Their compact size and light weight, combined with high energy density, provided an efficient means of generating power on a small scale. While these characteristics were appealing to high-power application manufacturers, first-generation Li batteries were not well suited for those applications due to a short life span, capacity losses over time, and long recharge times.

Innovating Solutions

Researchers at MIT had been working on an innovative lithium cathode material with great potential to help meet the need for better batteries for high-power applications. They had begun developing the material, primarily for power generation in the hybrid electric vehicle (HEV) market, but faced a major technical challenge: producing it in sufficient amounts to demonstrate commercial potential. In 2001, the MIT team successfully applied for a DOE SBIR Phase I grant to complete development of the material and establish their start-up company, A123Systems. The company was awarded a Phase II grant in 2003 to demonstrate a cost-effective, pilot-scale process for manufacturing the lithium cathode materials for hybrid electric vehicle batteries. The funding enabled A123Systems to test and refine their technology, yielding a proof-of-concept to market to potential investors.

The A123Systems cathode is made of a highly conductive, chemically doped nanophosphate material. This material eliminates problems usually associated with high-power batteries, yet still meets the most aggressive battery life cycle requirements. Unlike conventional Li metal oxide cathode materials—which can go to thermal runaway when handled improperly—the material is intrinsically stable and does not combust or release oxygen when exposed to high temperatures. As a result, it increases power capability without compromising safety or battery lifetime.

With proprietary high-performance, laser-welded, dual-plate tubular construction, the A123Systems cells weigh only 70 grams, are capable of high discharge rates, and offer high electrical efficiency. Their low impedance ensures longer life and effective temperature management because they can be operated without the artificial cooling that is required for higher impedance products. In addition, the technology offers the highest volumetric power density of comparable products now commercially available. It also functions effectively at low temperatures, while displaying a four-fold improvement in life cycle at high temperatures. Compared to conventional batteries—which lose as much as 20% capacity at 77°F and up to 35% capacity at 104°F—the A123Systems Li battery delivers power effectively at temperatures ranging from -22° to >140°F.

The A123Systems battery provides enhanced safety and environmental benefits due to the use of phosphates instead of the toxic heavy metals found in current Li batteries. The chemically doped nanophosphate material provides a level of safety that is essential in vehicle applications, as its unique chemistry reduces the risk of explosive runaway oxidation reactions that can occur with conventional oxide-based Li cells. Those metal oxide cathodes release oxygen when exposed to high voltage or temperature. This exothermic reaction creates a positive feedback loop that promotes further oxygen production, eventually leading to thermal runaway. A123's nanophosphate material does not release oxygen and thus does not cause thermal runaway.

DOE Small Business Innovation Research (SBIR) support enabled A123Systems to develop their pioneering product—the M126650 Lithium-Ion Battery—offering higher performance than high power NiCd and NiMH batteries and current generations of standard consumer Li batteries. They offer:

- Improved battery life by up to 10 times compared to Li batteries
- More than twice the power density compared to high power NiCd and NiMH batteries
- Improved electronic and ionic transport, delivering power more efficiently than Li batteries
- Operation over a wide temperature range, from -30 to >60°C
- Charging to more than 90% capacity within 5 minutes
- Capability for discharge rates as high as 100 rated capacity, >200 Amps, in short pulses
- Potential for reduced emissions and increased fuel economy in hybrid electric vehicles

A123Systems (Watertown, MA) was founded in 2001 by a team of MIT materials scientists when they received SBIR funding to develop their advanced battery technology. The effort was a success, leading the company to enter the cordless power tool market and giving them standing to compete in the HEV market, their ultimate goal. The firm has attracted substantial capital investment and grown exponentially as a direct result of the technology developed with SBIR support.

www.a123systems.com

A case study from the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy SBIR program, providing competitive grants for scientific excellence and technological innovation to advance critical American priorities and build a strong national economy – one small business at a time.

Advanced Batteries for Longer-Lasting Power

A123Systems' SBIR research enabled the company to develop—and ultimately manufacture—lightweight, rechargeable Li batteries as an alternative to NiCd, NiMH, and current Li batteries for high-power applications.

UPDATE: A123System continues to make progress in its HEV market strategy. Among the major milestones:

- In 2008, the company began taking consumer orders for its Hymotion plug-in conversion modules, capable of converting the Toyota Prius to a plug-in hybrid with a fuel economy of more than 100 miles per gallon.
- In 2009, they formed a strategic partnership with Chrysler for a new line of HEVs.

They are on track for increased domestic manufacturing capacity and a share of the hybrid car market for Li technology, which overall is projected to reach $2.17 billion/year in 2013.

SBIR Impacts

Benefits of A123 Li Batteries in Power Tools & Hymotion™ Hybrid Vehicle Range Extender

Energy	Increased power density (A123 Li vs. NiMH in power tools)	3,000 W/kg vs. 1,000 W/kg[1]	
	Reduced gasoline usage (vehicle with Hymotion plug-in vs. typical mid-sized gas-powered car)		4,820 gallons[2]
Economic	Revenue from battery and battery system sales (2006 – 2008)	$96 million	
Environmental	Reduced CO_2 emissions		46.77 tons
	Reduced Greenhouse Gas (CH_4, N_2O, HFCs) emissions		2.46 tons

Innovation

Power Tools

Black & Decker introduced the DEWALT product line of heavy-duty, 36-volt power tools using A123Systems' battery technology. This line delivers substantially more power for tools currently used by builders and contractors, including circular saws, reciprocating saws, hammer drills, and a powerful impact wrench.

Hybrid Electric Vehicles

Replacing conventional vehicles with HEVs will increase fuel efficiency and reduce emissions per gallon of gasoline, allowing drivers to fuel less frequently. A123Systems' battery overcomes barriers to wider HEV adoption such as cost, reliability, and performance, which can help increase potential HEV market share and associated benefits.

Company Success

SBIR support enabled university researchers with a powerful idea to demonstrate its feasibility and attract venture capital. With initial financial backing following their SBIR award, A123Systems was able to recruit a CEO and management team to develop their business plan and raise additional funds. Prior to its initial public offering in 2009, the company had raised over $250 million.

A123Systems has grown from a new Massachusetts start-up company in 2001 to an international business with 1700 employees and over $70 million in revenue in 2008. In late September 2009, A123 closed its initial public offering of 32.4 million shares and raised $437.5 million—the second-best IPO of the year.

A123Systems' ultimate target market is hybrid electric vehicles. Before approaching automakers, the company established a strong customer base by collaborating with Black & Decker in the power tools industry, the second largest battery market after hybrid cars. This partnership enabled A123Systems to become the world's second-largest producer of high-power Li batteries and paved the way for it to raise $20 million to finance manufacturing operations in Asia. As of 2008, A123Systems facilities had the capacity to produce over 10 million batteries per year.

[1] Power density indicates how much power a battery can deliver on demand, a major advantage of the A123 battery over conventional high-power batteries (the A123 figure is from A123's website; the other battery figure estimated is from various on-line sources).

[2] 143 gallons (Hymotion™) vs. 625 gallons (gas car) of gas consumed per year over 10 years (estimated using A123's online calculator).

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New, Cost-Competitive Solar Plants for Electric Utilities

Challenge

The price of photovoltaic solar panels fell rapidly from about $30 per Watt in 1975 to about $5 per Watt a decade later. However, the production cost of a standard solar panel for the most part leveled off for a number of years at just under $5 per Watt, remaining too costly for most large, utility-scale installations. With the advent of new solar concentrator systems, it became possible to replace expensive solar cells with inexpensive plastic lenses that focus sunlight onto small cells. This technological advance enabled lower panel manufacturing costs, improved cell performance, and increased utility-scale solar system efficiencies.

In the 1980s, the U.S. Department of Energy supported innovative research at the National Renewable Energy Laboratory that led to the development of multijunction solar cells with the world's highest conversion efficiencies—up to 50% higher than the highest silicon solar cell efficiencies. By the late 1980s, the Electric Power Research Institute (EPRI) had developed a high-concentration photovoltaic (HCPV) system which they believed to be a promising option for utility-scale solar power plants. However, one technical challenge they faced was the rapid degradation of solar cells under the intense ultraviolet radiation in concentrated sunlight.

Innovating Solutions

In 1989, staff at the newly-formed Amonix tackled the solar cell degradation problem. Within a year, they had stabilized the cell and started working with EPRI to develop the remaining system, including the lens, structure, and tracking system. With DOE EERE SBIR funding, Amonix redesigned the photovoltaic cell unit and integrated the cell, circuit board, and heat sink into a single cell receiver plate for economical, large-scale production. The company also redesigned the rest of the system for improved manufacturability using funding from EPRI, DOE, and private sources. The result: the Amonix MegaModule®.

Although Amonix holds the world record for silicon solar cell efficiency at 27.6%, the world record for multijunction cells is now 50% higher. Amonix has been able to increase MegaModule® performance by 50% by replacing its production silicon cells with production multijunction cells having efficiencies over 37%. Today's commercial and defense satellites use multijunction solar cells with conversion efficiencies above 35% (the record is over 41%). Performance in space is critical and multijunction solar cells have demonstrated unbeatable performance. By bringing these multijunction solar cells "down to earth" and incorporating them into the MegaModule® design, Amonix has significantly improved MegaModule® efficiency—further reducing the cost of utility-scale solar electricity.

The MegaModule® sections are manufactured in a plant and easily trucked to the installation site (the photo depicts the 7700 system with 7 MegaModules® on each pedestal). In 2001, Amonix was awarded a patent for their method of making the cell receiver plate. Since then, Amonix has worked with electric utilities throughout the southwestern U.S. to develop and test six generations of this system, which has allowed the company to resolve remaining technical problems and produce an efficient, reliable system.

Amonix began producing the improved MegaModule® in 1998 and has already installed 28 systems in the U.S., with a combined peak power capacity of 700 kW. Since 2006, Guascor Fotón has installed over 400 hundred of these systems in Spain, where market incentives provided the opportunity for cost-effective utility power plant projects. Amonix found Guascor Fotón's experience to be invaluable for identifying how best to deploy MegaModule® systems on a large scale and help make the most of future market opportunities.

DOE Small Business Innovation Research (SBIR) support enabled Amonix to develop its 7700 system, which drastically reduces the requirement for costly solar cells by using Fresnel lenses to concentrate sunlight 500 times onto small, highly efficient photovoltaic cells. This reduces the cell area so that expensive solar cell materials can be replaced with inexpensive plastic lenses.

Amonix Inc. (Torrance, CA), founded in 1989, develops and manufactures high concentration photovoltaic (HCPV) systems and high-performance silicon solar cells. In 1994, the company won *R&D Magazine's* R&D 100 award for silicon solar cell performance with record conversion efficiency. Around the same time, Amonix also developed the large MegaModule® platform suitable for use with all high performance solar cells. Since the early 1990's, Amonix has developed and tested six successive generations of MegaModules® and in 2005 the company licensed this technology to Guascor Fotón, which built a 10 MW/year manufacturing plant and has installed over 12 MW of MegaModule® systems in Spain.

www.amonix.com

A case study from the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy SBIR program, providing competitive grants for scientific excellence and technological innovation to advance critical American priorities and build a strong national economy – one small business at a time.

Solar Plants for Electric Utilities

In 2009, Amonix is introducing the newest generation of its high concentration photovoltaic product to the utility market. The Amonix 7700 is the seventh generation MegaModule® system and combines decades of advances in MegaModule® design and technology, combined with the world's highest efficiency multijunction solar cells. DOE funding through the Solar America Initiative (SAI) is also supporting development of this powerful combination. Amonix won an SAI award in 2007 for its proposal to reduce the cost of the MegaModule® structure, improve product reliability in actual operating conditions, build a MegaModule® manufacturing plant in the U.S., and reduce the cost of solar electricity to meet national goals (measured as the levelized cost of electricity) of 6 cents per kilowatt hour by 2015. Amonix is on track to achieve these objectives.

Amonix received DOE SBIR Phase I & II funding in 2000-2001 for two related projects.

- The first was to develop a tightly packed array of cells for use with a parabolic mirror concentrating system. However, Amonix ultimately discovered it required far more cell cooling than the more efficient MegaModule®.
- The second was to integrate the MegaModule® unit with an electrolyzer to create an efficient, cost-effective system for producing hydrogen. The project results emphasized the most effective lever for reducing the cost of solar hydrogen production was higher solar cell efficiency.

SBIR Impacts

Projected Benefits of Amonix MegaModule® HCPV Systems: 2009 to 2020

Estimates assuming a 2008 base of 8750 kW installed and 200 kW installed per year from 2009 to 2020[1]

Energy[2]	Energy generation	323 MWh
Environmental[3]	Cumulative NO_X emissions avoided	314 tons
	Cumulative SO_X emissions avoided	850 tons
	Cumulative CO_2 emissions avoided	215,000 tons

Innovation

The Amonix MegaModule®:

- Reduces system cost, potentially below $3 per Watt
- Reduces levelized cost of energy to meet DOE Solar America Initiative cost goals for U.S. utilities
- Uses high-efficiency multijunction photovoltaic cells to achieve AC system efficiency of over 25%
- Does not require water because it is passively air-cooled
- Has a small footprint, reducing land-use requirements
- Yields energy paybacks in less than one year

In addition, long-term field experiences have shown improved system durability and reliability, easy scale-up for any size installation, plus reduced field assembly labor due to the modular design.

Company Success

For Amonix, SBIR support enabled them to both develop a platform suitable for any high performance solar cell, and to design for economical manufacture and assembly with sustainable operational reliability.

Amonix has grown from a staff of 15 in 2006 to a staff of 44 in 2009.

Amonix has been successful in the marketplace, in part due to business planning and networking with potential commercial partners enabled under the Phase III program. As a technology-driven engineering company, Amonix has also benefited from SBIR evaluation of its efforts to commercialize its technology.

Amonix' partnership with Guascor Fotón in Spain has been key to rapid commercialization. Although the U.S. market is less subsidized, the outlook is positive as Amonix anticipates domestic sales of $500 million in 2010. With 70% of the concentrating photovoltaic (CPV) market, Amonix has more CPV technology installed in the world than any other company.

[1] It is assumed that the estimated installed systems will run full-time, which is not under the control of Amonix.
[2] Energy generation based on Amonix "rule of thumb": approximately 145,000 kWh for a 53kW(ac) system, depending upon the location where the system is installed (Amonix website).
[3] Environmental data calculated using EPA National Average Emissions.

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Advanced Membrane Systems: Recovering Wasteful and Hazardous Fuel Vapors at the Gasoline Tank

Challenge

A typical gasoline station can release over 3,000 gallons of fuel as vapor each year. These vapors represent an economic loss as well as pose a hazard for health, safety, and the environment. One of the constituents of gasoline vapor (benzene) is a carcinogen, and hydrocarbon vapors contribute to low-level ozone and smog formation.

Gasoline stations store fuel in underground storage tanks, which are filled from tanker trucks and then emptied slowly as fuel is pumped into customer vehicles. Gasoline vapor escapes during both filling and emptying, and Stage I and Stage II vapor recovery systems are used for these operations. In Stage I systems, vapor displaced from the underground storage tank during filling is directed to the tanker truck, so the truck leaves with a tank full of vapor that would otherwise have been vented. In Stage II systems, vapor from refueling customer vehicles is directed back to the underground storage tank.

As gasoline stations were installing Stage II vapor recovery systems, the California Air Resources Board (CARB) and the Environmental Protection Agency (EPA) required new cars to be equipped with another approach to solving the same problem: on-board refueling vapor recovery (ORVR) systems to capture vapors at the vehicle. However, testing subsequently showed that these ORVR systems caused Stage II systems to release more fugitive emissions through tank vents.

In response to this problem, CARB required gasoline stations to reduce fugitive emissions using equipment compatible with ORVR systems. It was believed that gasoline stations could meet the regulations with vent processors that remove fuel vapor from the air passing out of tank vents. However, fugitive emissions can also escape from other system leaks, so some vent processors needed to be designed to maintain fuel tanks at a slightly negative pressure. Any leak in a negative-pressure tank will draw air in rather than release emissions.

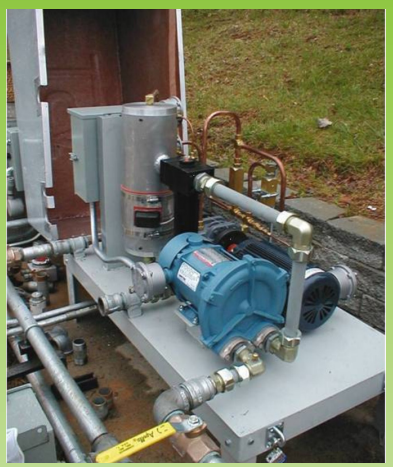
Innovating Solutions

CMS saw vent processors as a natural application for their proprietary fluorinated polymer membrane. The CMS membrane is well suited for use with solvents and other aggressive chemicals. It is also unique in that it lets air pass through and retains volatile organic compound (VOC) vapor. Other membranes used for vent processors work in a reverse manner, permitting vapors to pass and retaining air, thus requiring systems that are more complicated.

CMS began research on VOC-air separation with EPA SBIR Phase I funding in 1993, followed by a Phase II award the following year. This funding supported a feasibility study, initial testing, and economic evaluation. DOE EERE SBIR funding, beginning in 2000, allowed CMS to continue developing the membrane and improve its vapor recovery efficiency by about 75%. The State of Delaware augmented DOE's Phase I and II funding.

During the DOE SBIR-funded work, CMS partnered with Innovative Membrane Systems, Inc., a subsidiary of Praxair, Inc., to develop the membrane and double its efficiency. CMS chose Innovative Membrane Systems as a supplier for the membrane fiber because of their well-established expertise in producing membranes for air separation and gas processing.

The DOE SBIR project also allowed CMS to develop the rest of the vapor processing system in collaboration with Vapor Systems Technologies, Inc. This relationship began during the EPA SBIR project when Vapor Systems contacted CMS and introduced them to the gasoline recovery application. While developing the system with Vapor Systems Technologies during the DOE SBIR project, CMS was again able to double the system's performance.



DOE Small Business Innovation Research (SBIR) support enabled CMS to develop a membrane vapor processor that recovers fuel vapors from gasoline refueling with 99 percent efficiency. This membrane system enables gasoline stations to surpass environmental regulations while reducing fuel losses.

Compact Membrane Systems, Inc. (CMS) was founded in 1993 in Wilmington, DE, with the acquisition of rights to certain DuPont polymer membrane patents. CMS focuses on research, development, and commercialization of these polymer membranes and thin films, which offer high gas transport properties and chemical resistance. SBIR programs have funded much of CMS' feasibility and prototype work. To commercialize their technology, CMS licenses, sells membrane products, and partners with other companies to develop specific applications.

www.compactmembrane.com

A case study from the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy SBIR program, providing competitive grants for scientific excellence and technological innovation to advance critical American priorities and build a strong national economy – one small business at a time.

Advanced Membrane Systems for Vapor Recovery

The CMS membrane system retains vapor in the storage tank and prevents further evaporation. By contrast, some lower-cost vapor processors simply flare the vapor, creating additional fuel losses and greenhouse gas emissions. Other competing membrane systems have been developed as alternatives to combustion-based systems. These differ from the CMS system in that they pass the hydrocarbon vapor through the membrane and vent the retained gas. Such systems are more complex, requiring a condenser and extra safeguards to prevent the system from releasing vapor if it fails. The CMS polymer membrane retains the hydrocarbon vapor and passes air through the membrane to the vent—a simpler, safer system.

Field tests conducted by Vapor Systems Technologies established that the system reduces vapor emissions to about 0.08 pounds per 1,000 gallons of liquid gasoline dispensed—well below the CARB limit of 0.38 pounds per 1,000 gallons dispensed (based on an average unmitigated emissions of 7.6 pounds/1,000 gallons dispensed). The complete system—including special fuel dispensing equipment—recovers about 1,800 gallons of fuel per year for a typical gas station. In addition, it requires little maintenance, due to the simple design and durable membranes.

Gasoline stations began purchasing units from Vapor Systems Technologies, and the first began operation in 2006. Vapor Systems Technologies tested the system for CARB certification and was certified in mid-2007—the only membrane system to be certified in California. Certification is important in accessing the primary market of nearly 200,000 U.S. retail gasoline stations.

SBIR Impacts

Projected Benefits of the ENVIRO-LOC™ System: 2009 to 2020

Energy	Potential gas recovery (all US)[1]	2.5 million gallons or 0.36 quadrillion Btus
Economic	Savings from recovered fuel (all US)[2]	$5,700 million
	Direct capital, operating, and maintenance cost savings over 5 years compared to typical system (per installation)[3]	$50,000
Environmental	Potential VOC capture (all US)[4]	7.7 to 11.5 million tons

Innovation

ENVIRO-LOC™ Vapor Recovery System

- Primary Application: Underground storage tanks at gasoline stations
- Vapor Recovery Efficiency: 99%
- Average Emissions Level: 0.08 lb per 1,000 gallons of dispensed gasoline
- Air-Vapor Separator: Hollow-fiber, polymer membrane
- Fuel savings for a typical gas station estimated to pay for the system in less than two years[3]

Company Success

Thanks to SBIR funding, CMS was able to conduct initial development and later improve their membrane system's performance for commercialization. In addition, the EPA and DOE SBIR awards provided CMS with critical exposure to industry stakeholders.

CMS has grown from a staff of 15 and annual revenue of $2.1 million in 2000 to 26 staff and $3.8 million in revenue in 2008.

Vapor Systems Technologies, Inc. learned of the CMS technology through an SBIR project publication, launching their relationship and successful commercialization partnership. Vapor Systems Technologies worked with CMS during final development of the system and has invested heavily in developing their vent processor product, the ENVIRO-LOC™ system, based on the CMS membrane, which they are now marketing to gasoline stations.

[1] Based on average 9 million barrels/day and 5.253E6 Btu/barrel (Energy Information Administration.) The portion of fuel savings retained by the membrane vapor processor depends on how many cars using the gasoline station have ORVR systems. As new cars with ORVR systems replace older vehicles, vapor processors will become responsible for most of the fuel savings, as well as reduced emissions.

[2] Based on estimated gas recovery over the period at $2.30/gallon (estimated current price per Energy Information Administration).

[3] Vapor Systems Technologies estimate, comparison of ENVIRO-LOC™ to typical Healy system ("The $50,000 Decision", http://www.vsthose.com).

[4] Based on Vapor Systems Technologies ENVIRO-LOC™ fact sheet and Energy Information Administration information.

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New Energy-Saving Fiber Optic Lighting System Lights Up Public Spaces

Challenge

Accent lighting accounts for 0.19 quadrillion Btus (quads) of energy used each year in the United States. It differs from general lighting in that the light is more directed, comes in smaller lumen packages, requires more specific color characteristics, and uses instant on/re-strike with no detectable delay between switching. The most common accent light is the 50W MR-16 halogen, which is used in the majority of accent lighting because it delivers the centerbeam candle power (CBCP) and cone angle desirable for most applications. CBCP ranges from 1200 to 20000, with a range of 40 to 8 degrees of cone angle between "flood" and "high-bay spot" accent light applications. The CBCP and cone angle are chosen in order to get a desired brightness ratio (typically 3:1 or more) between the object being illuminated and the ambient light.

As public sentiment and regulations are driving consumers toward lighting choices that save energy and reduce environmental impacts, new solutions that meet these lighting requirements are needed. However, they must also have a low first cost—the biggest challenge for energy efficient lighting systems for all applications. More energy efficient technologies existed, but did not satisfy both technical and cost requirements. The major problem for compact fluorescent (CFL) lamps is low brightness, which means that a tight beam cannot be formed. The major problem for metal halide (MH) lamps is the inability to scale to very low wattages and the prohibitive cost of buying one lamp and one ballast per light point.

Innovating Solutions

Energy Focus received DOE EERE SBIR Phase I and II funding for two separate projects to tackle these challenges. The first project was aimed at developing the crucial instant-on feature of the lights. The second sought to lower the cost of producing the lighting system so that the technology would be more competitive with standard technologies from a first-cost standpoint.

In Phase I of the first project, a series of lamp and ballast design tests were conducted to determine the starting characteristics needed to have instant light-starting while preserving 80% of system efficiency. Lamp parameters that were tested included electrode design, fill gas type, and fill gas pressure. Ballast characteristics such as starting pulse voltage, pulse width, pulse repetition, and minimum warm-up drive current were also determined in this phase. In Phase II, final lamp parameters were determined through structured engineering tests on lamp body size, wall thickness, and inner wall shape. The gas and electrodes were optimized for manufacturability, and the ballast concept was developed into a manufacturable design.

In Phase I of the second project, the goal was to reduce the cost of a high intensity discharge distributed accent lighting systems by optimizing fabrication of the system's plastic optical fiber component, reducing the cost per point below conventional halogen sources. Eight new polymer processing approaches aimed at reducing cure time were identified and assessed, with two of the alternatives offering dramatically reduced post-extrusion processing time and lower costs. In Phase II, the two reduced-cost polymer processing alternatives were further developed.

Energy Focus received additional support for developing these new lighting solutions from other U.S. government agencies, including the Departments of Defense and Commerce. In 2006, the company installed its lighting systems in engineering control rooms, hangar bays, berths, welldecks, and weatherdeck locations on three U.S. Navy ships, replacing fluorescent and incandescent lighting. Nine-month sea trials were then conducted, demonstrating lower maintenance costs with no failures during the tials, increased lifetime, increased efficiency to greater than 30 lumens per Watt, and improved lighting (daylight spectrum).

DOE Small Business Innovation Research (SBIR) support enabled Energy Focus to develop a breakthrough lighting technology that delivers light comparable to conventional lamps while using significantly less energy per lumen, reducing watts per square foot without sacrificing light levels. As a result of DOE SBIR and other government funding, EFO (efficient fiber optics) Lighting Systems can deliver as much as 80% energy savings over halogen or other incandescent lighting with the instant-on ability of a halogen lamp. Because EFO uses only one lamp and one ballast for multiple light points, the cost is comparable to that for halogen systems.

Energy Focus, Inc. (Solon, Ohio) designs, develops, manufactures, and markets fiber optic lighting systems for a wide range of uses in the general commercial and pool and spa markets. The company's EFO lighting system was first introduced in 2004. The company sells both EFO lighting systems and traditional fiber optic lighting systems. Their markets include energy efficient accent lighting, specialty decorative and special effects lighting, LED lighting systems, and underwater pool and spa lighting systems.

www.energyfocusinc.com

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Fiber Optic Lighting System Saves Energy

The EFO system is in use in warehouses; accent, display, and special effects lighting; underwater pool and spa lighting; and other commercial applications. Using supermarkets as a case in point, advantages of EFO ICE (Energy Focus' freezer case lighting product line) compared to commonly used technology include:

- Better food—the lack of infrared radiation in the beam allows food to stay fresh longer.
- Less compressor load—it lights products in the case without adding as much heat as conventional lights.
- Better light—EFO systems provide full brightness even in the most frigid temperatures while fluorescent lamps lose up to half of their intensity when chilled.
- Easier maintenance—one lamp replaces three to five fluorescent lamps; there is easy access for lamp changes, only one ballast for every three doors, and no tools needed; fixtures have no electricity, eliminating lamp socket destruction during case cleaning; and, they contain no glass so there is never a possibility of shattering a lamp inside the case.

SBIR Impacts

Realized Benefits of EFO Lighting vs. 50W MR-16 Halogen Lighting: 2004 to 2008[1]

Energy[2]	Energy savings (EFO vs. MR-16 bulbs)	EFO-44: 83%, EFO-33: 77%
	Energy savings over entire MR-16 accent lighting market (both EFO-44 and EFO-33)	0.06 quads
Economic[3]	Reduced energy cost (based on EFO-44 and EFO-33 units sold)	$3 million
	Average bulb life (EFO/MR-16)	15,000/5000 hours
	Ratio of bulbs needed (EFO-44:MR-16; EFO-33: MR-16)	1:8, 1:6
	Reduced annual O&M costs (both EFO-44 and EFO-33 systems)	75%
Environmental[4]	Reduction of SO_X emissions (over total EFO-44 and EFO-33 bulb life)	39,000 lbs
	Reduction of NO_X emissions (over total EFO-44 and EFO-33 bulb life)	103,000 lbs
	Reduction of CO_2 emissions (over total EFO-44 and EFO-33 bulb life)	26 million lbs

Innovation

The EFO Lighting System meets the two main requirements for more energy- and environmentally-friendly lighting—quality and cost—and has many added benefits, including:

- Elimination of nearly 100% of IR and UV. This reduces the emission of heat at the fixture, reducing air conditioning needs (one Watt of HVAC is saved on average for every three Watts of lighting).
- Cheaper to install—because they use fiber, they require far fewer electrical service connection points than traditional systems, reducing installation costs for new construction and energy retrofits.
- Reduced mercury by up to 75% compared to fluorescent lighting technologies.

Company Success

SBIR funding enabled Energy Focus, Inc. to refine an efficient fiber optic lighting system for use in commercial applications, allowing Energy Focus to enter additional lighting markets. As the company's website asks, "What do Victoria's Secret, the Magna Carta, U.S. naval vessels, and the fresh fish display at Whole Foods have in common? Each has been illuminated by Energy Focus lighting solutions." By adding an instant-on capability to fiber optic accent lighting designed for applications such as swimming pools, EFO has been able to compete with incandescent and other commonly used accent lighting methods. Additionally, their SBIR projects allowed Energy Focus to work on improving manufacturing processes in order to lower costs.

EFO product sales had grown to $10.9 million for the twelve months ended December 31, 2008, compared to $7.1 million for the same period of the prior year — a 55% increase. Total revenue for the company in 2008 was $23.0 million with EFO lighting systems accounting for 47.4% of total sales.

EFO now generates more revenue than any other Energy Focus product line. In 2007, Energy Focus was awarded a DARPATech SBIR Award for Excellence for their advanced naval lighting.

1 Equivalent benefits are expected to continue for systems currently in place but will not increase because the EFO-44 and EFO-33 are no longer being marketed.
2 Energy savings were calculated based on EFO and MR-16 lighting configurations and sales data from Energy Focus (www.energyfocusinc.com).
3 Economic benefits based on actual sales and performance data.
4 Emissions reduction calculated based on bulb performance data and typical emissions reported for electricity generation.

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Improving Hybrid Poplars as a Renewable Source of Ethanol Fuel

Challenge

The National Biofuels Initiative aims to replace 30% of fossil fuel used for light duty vehicle transportation in the United States by 2030. Cellulosic biomass—including wastes (agricultural, forestry, municipal, industrial/food processing) and energy crops (fast-growing grasses and trees)—is expected to be an important source for ethanol production. In addition, it can be burned to produce steam and electricity.

Most ethanol from biomass now comes from starch-based biomass, such as corn, which easily breaks down into sugars for fermentation. Starch-based ethanol production is a well-developed, relatively mature technology, but lacks a low-cost, large-volume alternative to corn for feedstock. Cellulose and hemicellulose make up the bulk of all trees, grasses, and other plant matter—a supply large enough to compete with oil fields—and researchers are developing processes to produce ethanol from those renewable resources.

Innovating Solutions

GreenWood Resources saw potential in growing poplar trees—remarkable for their sheer biomass productivity—to make ethanol. GreenWood's objective was to develop fast-growing and disease-resistant hybrid poplars that offer maximum levels of cellulose and/or hemicellulose, optimizing the growing cycle and economics of farming poplars as an energy feedstock.

With DOE EERE SBIR Phase I funding, GreenWood was able to conduct a study that established the feasibility of hybridizing poplar trees for biomass feedstock. This study identified the primary traits needing improvement in order to make poplars a better fuel source for biochemical (fermentation) conversion to ethanol, including wood-specific gravity, lignin content, ratio of syringyl-to-guaicyl (S/G) lignin forms, and glucose and xylose content. With a follow-on DOE SBIR Phase II award, GreenWood began a hybridization program with an inheritance study to examine how selective breeding can improve the biofuels properties of the world's most productive hybrid poplar pedigree: *Populus x generosa*. GreenWood built on an existing relationship with Washington State University in conducting this program and in developing a rapid assessment technique for efficiently determining critical energy characteristics of trees in the field.

The DOE SBIR Phase II project also involved field trials of a range of elite hybrid varieties in demonstration plots established at 12 locations throughout the western U.S. to test the range of genetic adaptability. To explore the benefits possible through tree farm management, GreenWood closely integrated their research and development efforts with their operational tree farms and with local energy developers.

The inheritance study was the foundation for continuing work in selective breeding of poplars for high energy value. The rapid assessment technique, which uses near-infrared spectroscopy to characterize the calorific value, chemical composition, and specific gravity of a feedstock tree, enables staff to determine the essential energy properties of trees during regular in-field measurements, avoiding expensive and time-consuming lab tests.

Poplars have a wide range of uses beyond energy conversion, as well—including chips for pulping and logs for veneers and sawn wood products. The demonstration plots showed the economic feasibility of growing poplars solely for energy production and for a combination of saw logs and residual ethanol feedstock. On one plot located near an ethanol production facility in Boardman, Oregon, poplar is being grown as a dedicated energy crop to supply feedstock for

DOE Small Business Innovation Research (SBIR) support enabled GreenWood Resources to advance scientific understanding of the ways chemical traits are inherited in hybrid poplars and the extent of variations in characteristics such as lignin content and forms of lignin—enabling the best traits to be developed and significantly advancing the potential of hybrid poplars to provide a substantial, renewable source of ethanol fuel.

GreenWood Resources (Portland, Oregon) is an integrated forest products company involved in research, plantation management, and product marketing. Established in 1998, GreenWood's staff has extensive experience in poplar research and the company is a leading developer of commercial poplar breeding stock. Initially, GreenWood's specialty in developing high-yield hybrid poplar varieties as well as tree farm management and product sales and trading was primarily aimed at the pulp and paper and solid wood industries. A downturn in those businesses prompted GreenWood to seek other opportunities, leading the company to pursue the great potential of hybrid poplars as cellulosic biomass to make biofuels.

www.greenwoodresources.com

A case study from the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy SBIR program, providing competitive grants for scientific excellence and technological innovation to advance critical American priorities and build a strong national economy – one small business at a time.

either liquid fuel conversion or combined heat and power production. At a second demonstration plot in Clatskanie, Oregon, poplars are being grown to produce two products: mature, 12-year-old trees will be used for saw logs, and the sawmill waste and trees thinned after 5 years can be used as energy feedstock.

By studying these demonstration plots, GreenWood gained valuable data on the economics of managing plantations for energy feedstock under a diversity of management scenarios. GreenWood's SBIR demonstration plots and varietal-site trials have already helped the company commercialize the use of hybrid poplars for biofuels. Data from test plots in a wide range of climates and drought conditions in the western U.S. show that specially-bred varieties can grow 10 feet in height annually, producing up to 10 tons of dry biomass per acre each year. Unlike many other trees, poplars can be easily hybridized with related species and readily reproduced by clonal propagation from hardwood cuttings. Both are features that accelerate the rate of genetic improvement. As other energy facilities are built in this region, GreenWood will have the data needed to show which varieties are best suited for specific areas, and will be well positioned to supply those facilities with poplar feedstock based on data developed in the varietal site trials.

SBIR Impacts

Projected Benefits of Hybrid Poplar- vs. Corn-based Ethanol Biofuel: 2009 to 2020[1]

Energy	Increased ethanol output	200 gallons ethanol/acre/year
	Reduced energy required for producing the feedstock	15,600 Btu/gallon of ethanol
Environmental	Reduced fertilizer, herbicide, and insecticide use	470 lb/acre
	Reduced CO_2 emissions	160 tons of CO_2 equivalent/acre

Innovation

Poplar has many advantages as an ethanol feedstock.

- As a perennial, poplars require only 1/6 of the fossil energy needed to produce traditional feedstock, such as corn.
- The reduced petroleum requirement results in reduced CO_2 emissions. Poplar plantations are also a large carbon sink.
- High-yield, short-rotation tree farms need less fertilizer and chemical input to produce than many other cellulosic biomass crops, resulting in less water pollution from field run-off. In addition, poplars can be grown on land that is unsuitable for other uses.
- They have a relatively rapid growth cycle of 6 to 12 years, depending on climate, which is longer than annual crops but creates a more stable wildlife habitat because it is not disturbed by annual harvests.
- They can be harvested any time of the year and, unlike other energy crops, do not require the extended storage after harvesting that exposes other biomass crops to degradation from microbial activity.

Company Success

GreenWood credits the SBIR program with opening many doors in the areas of renewable energy and carbon sequestration, adding a vital new component to the company's hybridization program and enabling it to make rapid progress in this area. Previously focused on agronomic qualities such as growth rate, stem form, pest resistance, etc., GreenWood is now able to look at chemical content and lignin form and exploit those traits for energy production.

GreenWood has grown from a staff of 25 to a staff of about 60, and is now a global company with offices in Beijing, China, and Los Angeles, Chile, as well as their Portland, Oregon headquarters.

GreenWood today has a vision based on managing short- and medium-rotation tree farms for multiple markets in timber, energy, CO_2 sequestration, and other environmental applications. They are already breeding poplar for liquid fuels production and entered into a long-term agreement with ZeaChem to provide poplar feedstock for an initial 1.5 million gallon per year cellulosic bio-refinery located near their Boardman, Oregon, tree farm. They are also building on the SBIR contacts they made with companies, universities, and government agencies for future research, partnerships, and collaboration—such as working with USDA's National Agroforestry Center to develop methods of treating industrial and municipal waste in poplar plantations, thereby recycling nutrients as fertilizer.

[1] All benefits are hypothetical using data and conversion factors from the U.S. Department of Energy, GreenWood Resources, and the U.S. Department of Agriculture (USDA). Poplars as a feedstock is a recent option for Greenwood Resources plantations so long term process data is not available.

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New Membrane Technology Boosts Efficiency in Industrial Gas Processes

Challenge

Membrane technology was first commercialized in the 1960s and 1970s for well-known applications such as water filtration and kidney dialysis. Membranes offered inexpensive, compact, and energy-efficient separations for other processes, as well—such as industrial gas processing. For example, chemical feedstocks—or monomers (e.g., ethylene and propylene)—are the single largest operating cost in the manufacture of polyolefins. Due to the intensely competitive nature of the industry, monomer losses in vent streams are a major concern for producers. These vent streams represent a significant opportunity for recovery and recycling of raw materials.

To help achieve the potential of membranes for this and other gas separation processes, innovation was needed. In addition to membrane material research, development of robust industrial membrane module devices was required, followed by process design and scale-up for commercial application. This required a multi-year, multi-step research and development (R&D) effort.

Innovating Solutions

MTR was founded in 1982 as an R&D company with a long-term goal of developing marketable membrane technologies, especially in the newly-emerging field of industrial gas separations. For a small company, the initial challenges were daunting. However, with funding from the SBIR programs of several agencies, including the Departments of Energy (DOE), Defense, and Agriculture (USDA), the Environmental Protection Agency (EPA), and the National Science Foundation, the company was able to succeed in developing these technologies.

Because MTR was competing against firmly-entrenched technologies in well-established industries, Phase II SBIR support of early field testing was essential to commercial acceptance of the new membrane technologies. The outcome was their process to remove organic vapors from air and nitrogen, leading to the first of MTR's R&D efforts that resulted in a commercial product.

An early version of this system was first sold in the early 1990s; since then, more than 100 units have been installed worldwide in chemical and petrochemical plants. In 1997, the first VaporSep® system—which has 10 times the capacity of most of the prior systems—was installed to treat ethylene- and propylene-containing nitrogen purge gas streams in polyolefin plants. Similar systems continue to be sold worldwide and have been used to recover a variety of chemicals, including vinyl chloride monomer, isopentane, and 1-hexene, in addition to ethylene and propylene.

Over the last decade, with support from SBIR and DOE follow-on funding, MTR has been able to conduct the R&D needed to add membrane separation products for the oil and gas and refinery businesses to its product portfolio.

MTR's VaporSep® systems have recovered about 2.1 million tons of volatile organic compounds (VOCs) since 1992, which has saved over 115 trillion Btus in fuel. The value of fuel savings in 2008 was estimated at 33 trillion Btus and is expected to grow in subsequent years. Considering data available for VaporSep® systems installed between 1992 to 2008, the capital investment has typically been recovered in one to two years from the fuel value alone of the recovered monomer.

DOE EERE Small Business Innovation Research (SBIR) support enabled MTR to complete development of their VaporSep® process, which separates and recovers organic vapors from air and nitrogen. The process is now widely used to minimize monomer losses in polyolefin plant vent streams. For a world-scale polyolefin plant, a VaporSep® unit typically recovers about 2,000 to 200,000 tons/year of monomer, valued at $1-10 million/year.

Membrane Technology and Research, Inc. (MTR), based in Menlo Park, CA, is a privately-owned developer, manufacturer, and supplier of customized membrane process solutions. Currently, the company's principal membrane products are

- VaporSep® systems to remove organic vapors from air and nitrogen
- NitroSep™ and fuel gas conditioning systems for natural gas treatment
- Hydrogen recovery systems for refinery and other applications

MTR's current R&D is extending use of membranes to carbon sequestration and biofuels separations.

www.mtrinc.com

A case study from the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy SBIR program, providing competitive grants for scientific excellence and technological innovation to advance critical American priorities and build a strong national economy – one small business at a time.

Membranes for Industrial Gas Separations

MTR is exploring new applications for membrane gas and vapor separations in the areas of greenhouse gas mitigation and sustainable energy development. The inherently energy-efficient, environmentally-friendly nature of membrane separation processes make them particularly good candidates for such applications. DOE, EPA, and USDA are all contributing funds to advance early-stage development for such applications as carbon capture and sequestration, alcohol/water separations in biofuel production, coal-bed methane recovery, and biogas.

Benefits of Membrane technology over other gas separation processes include:

- Greater energy efficiency
- Lower operating costs
- Shorter payback times
- Simpler, often unmanned operations
- No or few moving parts
- Smaller footprint
- Easier expansion due to their modular nature

SBIR Impacts

Benefits of VaporSep® Membrane Technology[1]

		Realized Benefits 1992 to 2008	Potential Benefits 2009 to 2020
Energy	Fuel value (energy content) of cumulative recovered VOCs (1 quad is 1 quadrillion Btus)	0.115 quads	0.78 quads
Economic	Estimated value of cumulative recovered VOCs	$1 billion[2]	$6.2 billion
Environmental	VOC recovery	2.1 million tons	14.1 millions tons
	NO_X emissions saved	3,500 tons	23,900 tons
	CO_2 emissions saved	19,300 tons	130,300 tons

Innovation

A complete, skid-mounted VaporSep® unit includes membrane modules, compressor, heat exchangers, piping, instrumentation, and controls. Unit dimensions are 10m (L) X 3.5m (W) X 5m (H); the compressor is mounted on a separate skid of similar size. Key system facts:

- Suitable for vent streams from 135 to 4,550 kg (300 to 10,000 pounds) per hour, with monomer concentration from 10 to 80% volume
- Monomer recovery up to 99+%
- Nitrogen recovery up to 99+% with purities of 99+% volume

Company Success

As of 2009, cumulative VaporSep® sales and bookings exceeded $140 million and total company revenues in 2009 were projected to be $30-40 million.

Development of the VaporSep® process with SBIR support allowed MTR to expand from an R&D focus to commercial success, and enabled it to bring a simple, energy-efficient, environmentally-friendly industrial gas separations technology to the petrochemical, natural gas, and refining industries. The company is now able to pursue exciting new opportunities for the technology in greenhouse gas mitigation and sustainable energy processes that can bring economic and environmental benefits to the company, their customers, and energy consumers worldwide.

In recognition of the innovative nature and importance of this process, MTR received *Chemical Engineering Magazine's* Kirkpatrick Award, the first small business to be so recognized.

[1] Calculations are based on approximately 100 units in operation to date, recovered VOCs valued at approximately $0.20/lb, EPA emissions data, and projected growth rate of 10%/year.

[2] Note the estimated installation capital cost during the period was $100 million, indicating a significant return on investment.

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Sonic Energy Improves Industrial Separation and Mixing Processes

Challenge

Advanced membrane separation technologies offered improvements over conventional processes, but were not being adopted in industrial operations because of the tendency of ultrafiltration membranes to foul while in service. Considering biotechnology as a case in point, while membrane filtration with micro-sized pores was the separation technology of choice, the protein solutions tended to foul the membranes during filtration. However, none of the techniques commonly used to improve ultrafilter performance, such as high cross-flow velocity, could be used with proteins.

In addition to many applications in biotechnology, enhanced membrane filtration technology has broad potential for other industrial separations processes with fouling problems, such as pharmaceuticals, cosmetics, food, chemicals, ceramics, electronic materials, bioreactors (cell culturing and microbial production), nanomaterials, and municipal water and waste treatment—as well as energetics studies.

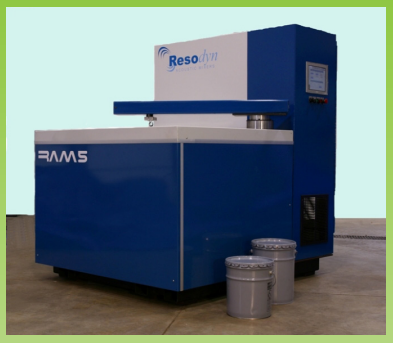
The economical conversion of many commodity production lines to environmentally-friendly processes was limited by downstream operations to separate product from biocatalyst, rather than by the complex technology associated with the directed evolution of enzymes. New technology was needed to improve the performance of membrane separations and enable biotechnology and other industrial applications to become more economical.

Innovating Solutions

With DOE EERE SBIR support in 1999 and 2000—and follow-on DOE and other Federal agency SBIR support for specific applications—Resodyn worked to address the membrane-fouling problem by coupling filtration technology with a mechanically-driven, low-frequency acoustic resonator. This new approach—which was distinct from both conventional impeller agitation and ultrasonic mixing—involved acoustic pulses from the resonator impinging on the membrane, creating micro-turbulence near the face of the membrane to assist in keeping the flux of permeate from falling due to the buildup of a resistive gel layer.

Phase I demonstrated the enhancement of permeate flux through a 10,000 molecular weight cut-off membrane from solutions with 1 to 5 percent protein (such as pepsin). Enhancements were most pronounced for conditions with no cross-flow velocity. These are precisely the conditions in which a free enzyme bioreactor would need to function because of the detrimental effect of cross-flow shear on proteins. In Phase II, Resodyn worked to optimize the design of the membrane bioreactor for use in specific industrial processes and to further demonstrate that enzymes proposed for use in these processes are not degraded in the sonic environment. A pilot-scale modulator bioreactor was fabricated and mobilized for continuous testing of the new enzymatic-based process.

Resodyn's acoustic mixing technology works by inducing low-frequency resonant sonic energy in a fluid, resulting in an increased rate of energy dissipation per unit mass of the fluid and allowing rapid and efficient dispersion of solids, gases, and immiscible liquids. The technology is essentially a vessel with no moving parts inside and runs at approximately 60 Hertz. A patented drive system on the outside of the vessel serves as the resonant mechanical driver that radiates an acoustic energy field that mixes the vessel contents.



DOE Small Business Innovation Research (SBIR) support enabled Resodyn to develop a simple, new technology that improves membrane performance by a factor of 5 to 10 compared to conventional mixing, offering far better separations capability for a wide variety of industries and applications.

Resodyn Corporation (Butte, MT) is a small high-technology business whose objective is to develop, manufacture, and sell advanced technologies for high-value industrial processes. To this end, the firm develops new processes and technologies, leverages strategic partnerships, enters into joint ventures, and establishes the infrastructure to manufacture products with both original equipment manufacturers and direct customer sales. Resodyn relies on strategic relationships to provide insight into the technology advances within these companies and enable them to target innovation to the most important areas of growth and need.

www.resodyn.com

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Sonic Energy Improves Industrial Separation and Mixing Processes

"You end up in essence causing an earthquake within that material," which fluidizes it, says Lawrence Farrar, Resodyn's president, "High-acceleration loads are put on that material."

This research produced a simple new process that has been developed as an advanced mixing technology. Resodyn has been able to demonstrate the commercial viability of the technology that was developed with DOE SBIR support. Today, the company manufactures and sells a laboratory scale mixer and is on track to produce a 5-gallon and a 55-gallon version.

SBIR Impacts

Benefits of ResonantAcoustic® Mixing Technology[1]

- Suitable for mixing gases, liquids, solids, powders, or very viscous compounds (ideal for thermally-sensitive and high-value materials)
- Reduces mixing time by 80-90% yet preserves product quality—so that production cycle times can be reduced or process steps eliminated
- Uses less horsepower (hp) than impeller-type mixing—reducing energy use and expense (e.g., if the required power input for impeller mixing is around 500-700 hp, the power input for ResonantAcoustic® Mixing would be approximately 25 hp)
- Direct scaling from laboratory to production—mixing time would be approximately the same for 0.5 kg and 35 kg of material
- Mixing can occur in any container, including the original shipping container, eliminating the transfer/handling step (particularly desirable for hazardous materials or pharmaceutical compounds)
- Yields greater density by reducing the potential for gas bubbles, which can degrade the overall quality of the material being mixed
- Low localized shear and low heat generation minimize material damage
- No impellers/paddles means reduced/no clean-up or handling of potentially hazardous equipment or material by workers

Innovation

Resodyn's ResonantAcoustic® Mixing (RAM) technology employs low-frequency, high-intensity acoustic energy to create a uniform shear field throughout the entire mixing vessel. The result is rapid fluidization and dispersion of material, yielding a consistent mixture very quickly. This provides a solution for ingredients that are hard to mix—usually high-value—and where clean-up is problematic.

For example, for a propellant manufacturer routinely mixing a material with a viscosity greater than $2x10^6$ centipoise (cP)*, the benefits of using RAM would be:

- Reduced total mix time by 85% (was >24 hours)
- Reduced manufacturing labor >70%
- Eliminated handling of volatile material
- Eliminated pinch-risk from impellers
- Mix-in-case potential to eliminate cast/cure process

Of note, the technology has also been demonstrated to work well for hard-to-wet and highly viscous materials, mixing of solids, and many other applications.

* The viscosity of water is 1 cP; the higher the number, the more viscous the material.

Company Success

One of Resodyn's three main business units is now focused on designing, manufacturing, and marketing ResonantAcoustic® Mixing technology for a variety of applications.

In 2000, Resodyn's revenues were about $1.5 million, with 5 people on staff. In 2008, revenue was about $5.5 million and by the end of 2009 staff was projected to reach more than 30.

Production-scale technology for mixing commercially is now being used by customers with complex mixing applications, including the defense and chemical industries. Testing by Dow Corning using a RAM technology demonstrated that they could mix viscous materials at 100 million CP in five minutes, compared with conventional methods that could take as long as an hour and a half.

Resodyn officials estimate the market potential to be hundreds of millions of dollars, since many industries have very specific mixing needs for the substances they produce. Conventional mixing methods involving impellers would require running equipment at high speeds to produce the desired degree of gas-liquid mass transport (the movement of gas into a liquid during the mixing process)—but the high speeds of the impellers can destroy cells being mixed. Resodyn's technology, however, can produce good gas-liquid mass transport with little or no cell damage.

[1] Benefits calculations will vary widely by mixing application and volume. This listing of general benefits of the technology was compiled from the Resodyn Accoustic Mixer, Inc. website: http://www.resodynmixers.com/technologies/features-benefits.

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More Economical Sulfur Removal for Fuel Processing Plants

Challenge

Sulfur is naturally present as an impurity in fossil fuels. When the fuels are burned, the sulfur is released as sulfur dioxide—an air pollutant responsible for respiratory problems and acid rain. Environmental regulations have increasingly restricted sulfur dioxide emissions, forcing fuel processors to remove the sulfur from both fuels and exhaust gases.

The cost of removing sulfur from natural gas and petroleum in the United States was about $1.25 billion in 2008*. In natural gas, sulfur is present mainly as hydrogen sulfide gas (H_2S), while in crude oil it is present in sulfur-containing organic compounds which are converted into hydrocarbons and H_2S during the removal process (hydrodesulfurization). In both cases, corrosive, highly-toxic H_2S gas must be converted into elemental sulfur and removed for sale or safe disposal.

At large scales, the most economical technology for converting hydrogen sulfide into sulfur is the Claus process. This well-established process uses partial combustion and catalytic oxidation to convert about 97% of the H_2S to elemental sulfur. In a typical application, an amine treatment unit concentrates the H_2S before it enters the Claus unit, and a tail gas treatment unit removes the remaining 3% of the H_2S after it exits the Claus unit.

This multi-step process has low operating costs but high capital costs—too expensive for plants recovering less than about 20 tons of sulfur per day. These plants were using liquid-phase reduction-oxidation (redox) processes to remove sulfur. While these processes removed essentially all of the sulfur and offered a lower capital cost, they also imposed high chemical and operating costs ($300 to $600 per ton of sulfur), too costly for many small fuel processing plants.

Innovating Solutions

TDA Research became aware of the need for improved sulfur treatment processes while working with the Gas Technology Institute. Building on their experience with catalytic processes, they began research on H_2S oxidation with internal research and development (R&D) funding in 1995. In 1996, TDA was awarded DOE EERE SBIR funding to advance their research to the bench scale during Phase I and II SBIR projects. This funding supported proof-of-concept and scale-up of both the catalyst synthesis and the process. The R&D project continued until 1999, when TDA obtained funding from the National Petroleum Technology Office (now the Strategic Center for Natural Gas and Oil) to perform a full-scale field test at a gas plant in Texas. Additional cost-shared funding from the Gas Technology Institute was used to design and fabricate the field test unit.

TDA collaborated with Saint-Gobain NorPro (NorPro), a global leader in ceramics and catalysts that scaled up the catalyst formulation to 1 ton for the field test. Butcher's Welding of Houston, Texas, built and installed the test unit at a Whiting oil and gas facility in Plains, Texas. By 2002, 1,200 hours of field testing had been successfully completed, processing 300,000 cubic feet of sour (high sulfur) gas per day.

As a result of these efforts, TDA developed a new, simple, low-capital cost process that sweetens "sour gas" streams (those containing H_2S) by oxidizing the H_2S into elemental sulfur and water without requiring upstream H_2S separation. This process removes the bulk of the sulfur (about 90%), leaving about 10% of the original H_2S in the product gas. The remaining H_2S can be removed by a second stage of direct oxidation and/or a tail gas treatment process, such as a scavenger or small liquid redox unit.

* Ober, J.A. (2009) "Sulfur" USGS commodity minerals data sheet; Leppin, D. (1997) GRI Program in Small Scale Sulfur Removal and Recovery, 1997 Update (production costs adjusted to 2008 dollars).

DOE Small Business Innovation Research (SBIR) support enabled TDA to develop and commercialize its direct oxidation process—a simple, catalyst-based system for removing sulfur from natural gas and petroleum—that was convenient and economical enough for smaller fuel processing plants to use.

TDA Research, Inc. (TDA) of Wheat Ridge, CO, formed in 1987, is a privately-held R&D company that brings products to market either by forming internal business units or by partnering with larger Global 2000 manufacturing companies. TDA has primarily been a research company but is increasingly generating revenue through sales of products and technology. TDA's R&D focus areas include new materials, catalytic and sorbent-based chemical processes, and military and aerospace components.

www.tda.com

A case study from the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy SBIR program, providing competitive grants for scientific excellence and technological innovation to advance critical American priorities and build a strong national economy – one small business at a time.

Sulfur Removal for Fuel Processing Plants

In 2000, TDA received a patent covering its catalyst formulations and process for oxidizing H_2S to sulfur, and in 2004, the firm licensed the direct oxidation technology to SulfaTreat, a business unit of M-I, LLC (a joint venture between Smith International and Schlumberger). They now market the technology to small- and medium-sized gas and petroleum processing plants.

The first two direct oxidation plants, commissioned in 2006, are located in Southern California and are designed to treat gas associated with steam-driven heavy oil recovery.

SBIR Impacts

Benefits of the SulfaTreat Direct Oxidation Process vs. Conventional Liquid Redox Plants[1]

The TDA/SulfaTreat direct oxidation process provides a convenient and economical alternative for desulfurizing natural gas and gas associated with petroleum recovery, especially for small-scale applications (1-20 tons of sulfur per day). By enabling smaller producers to remove sulfur economically, the process can:

- Reduce energy consumption by about 30% compared to conventional liquid redox plants
- Reduce capital and operating costs by over 30% compared to conventional liquid redox plants
- Produce marketable, bright yellow sulfur
- Replace liquid chemicals with a long-lasting, non-toxic, dry catalyst—eliminating hazardous waste disposal
- Reduce system complexity and maintenance requirements

Innovation

The TDA/SulfaTreat direct oxidation process catalytically converts toxic hydrogen sulfide in natural gas and petroleum into safe elemental sulfur which can then be sold or stored away. Key features are:

- Process Type: Dry catalytic oxidation
- Capacity: Up to 30,000 ppm per stage and 25 tons of sulfur per day
- Conversion Efficiency: Greater than 80% per stage
- Sulfur Selectivity: 99%
- Catalyst Life: Minimum of 2–3 years

Company Success

Since the start of this SBIR project in 1995, TDA has grown from a staff of 30 with annual revenue of $3.5 to a staff of 80 and annual revenue of $12 million.

SBIR funding was vital to TDA in performing the initial proof-of-concept work for its direct oxidation process. Other factors in successful commercialization of the technology were the availability of follow-on funding and the numerous successful teaming relationships that were initiated and nurtured during the project. Funding provided by DOE and the Gas Technology Institute supported the field testing that was crucial to successful licensing of the technology.

TDA's choice of Saint-Gobain NorPro as catalyst manufacturer for the project built on a successful relationship that began in the early 1990s. NorPro successfully scaled up TDA's catalyst formulation for the field test and manufactured the catalyst for SulfaTreat's first two commercial plants. Westfield Engineering constructed these plants, and TDA supported SulfaTreat on technical issues during and after commissioning.

TDA chose to commercialize the technology through licensing, and recognized the importance of selecting the right firm. By exhibiting the technology at gas processing conferences, TDA was able to identify and build relationships with several potential license partners. TDA spent about a year screening potential licensees and then negotiating a license with SulfaTreat. SulfaTreat participated enthusiastically after seeing TDA's field test results, attractive economic analysis, and support from DOE and the Gas Technology Institute.

[1] Information provided by TDA based on experimental and operational experience.

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Wind Turbine Towers Establish New Height Standard and Reduce Cost of Wind Energy

Challenge

Wind energy is an important part of the global push for clean, renewable energy alternatives. Over the past fifteen years, the wind industry has successfully reduced the cost of wind-produced electricity by, among other advances, increasing turbine capacities from 0.2 Megawatts (MW) to 2 MW+. At the same time, towers have increased in height from 65 meters (m) to today's mammoth 80m towers that can weigh as much as 225 tons. Taller towers are desirable because winds are stronger at higher altitudes, thereby producing more power for each turbine installed. However, tower height stalled at 80m due to unacceptable economics with taller tubular towers. The opportunity to achieve 12% more power output per installed-turbine could not be realized without addressing these key height issues:

- Weight scalability with height: There are greater overall forces acting on a 100m tall tower compared to an 80m tower, just as there would be on a taller vs. shorter building structure. Conventional tubular-steel towers combat these forces by adding lots of steel mass to increase stiffness. As a result, the cost of steel towers grows exponentially with tower height, making taller towers economically impractical.
- Transportation limitations: The cost of transporting large, tubular-steel wind towers is high. The towers come in four sections with the heaviest weighing over 50 tons. Highly specialized $500,000 trailers are needed to move each section, which makes the resulting tower transport costs $140 to $180 per mile.
- Construction challenges: Due to the immense weight of steel tube towers, ultra-large crawler-cranes are required to install the towers and turbines. The 600-1,000 ton cranes needed to erect turbines at 100m height are in scarce supply and exceedingly expensive. The high "mobilization/demobilization" cost for the largest cranes is a key inhibitor of smaller, community wind projects, and a recurring problem for wind turbine heavy maintenance operations. Finally, the excessive 32-foot wide roads-footprint required by large crawlers engenders significant community opposition in many areas due to the amount of woodland clear-cutting required.

Innovating Solutions

A DOE EERE SBIR Phase I grant received in 2002 enabled Wind Tower Systems (WTS) to run thousands of computerized optimization routines to analyze a 1.5 MW turbine at tower heights of 62.5m, 80m, and 100m. The following year, WTS received a Phase II grant to explore new tower designs that would be height-scalable, less expensive, and more easily deployed than tubular-steel towers. Initially exploring the possibility of a lightweight, all-composite tower, WTS' research and development (R&D) efforts eventually led to a modular, steel tower design that is lighter than a tubular steel tower, more transportable, scales linearly in cost vs. height, and features an integrated crane-free lifting system.

Initial research showed that, while a composite tower would reduce weight, it would not be able to achieve the required stiffness levels and thus would be subject to unacceptable resonance oscillation forces. The company applied its learning and adapted the composite design to a highly innovative steel Space Frame structure that achieved all of the design objectives.

The final Space Frame design is the most weight- and cost-effective tower design on the market, scaling to 100 meters in a linear cost relationship. Notably, the 100m tower with integrated lifting systems carries the same lifetime installed cost as today's 80m tubular/crawler crane solutions, thereby lowering the cost of wind energy by up to 12%. The current tower and lifting systems designs are applicable to turbines up to 3 MW nameplate capacity (i.e., the maximum rated output).

DOE Small Business Innovation Research (SBIR) support enabled Wind Tower Systems to develop the Space Frame tower, a new concept for wind turbine towers. Instead of a solid steel tube, the Space Frame tower consists of a highly optimized design of five custom-shaped legs and interlaced steel struts. With this design, Space Frame towers can support turbines at greater heights, yet weigh and cost less than traditional steel tube towers.

Wind Tower Systems LLC (now Wasatch Wind LLC) was founded in Heber City, Utah, in 2002 to research, develop, and commercialize lighter-weight, taller, readily-deployable modular wind turbine towers for utility-scale, multi-megawatt turbines. The company provides innovative, taller wind turbine towers and crawler crane-free installation systems, enabling wind energy projects to reduce electricity cost and execution risks.

www.wasatchwind.com

A case study from the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy SBIR program, providing competitive grants for scientific excellence and technological innovation to advance critical American priorities and build a strong national economy – one small business at a time.

Taller Tower Breakthrough for Large Wind Turbines

The Space Frame design opens new heights and locations to wind energy by significantly reducing the costs associated with manufacturing, transporting, and installing the towers, both on land and offshore. Tower cost is reduced because the Space Frame cost grows linearly with height rather than exponentially as with steel tube towers. The Space Frame structure is covered with a non-structural, architectural fabric that mimics the aesthetics of tubular towers and addresses concerns over avian perching and mortality. Transportation cost is reduced because the modular Space Frame tower ships on standard flatbed trucks, eliminating the need for expensive transportation permits and shipping carriers.

To address construction challenges, WTS developed a crane-free wind tower erection system. Inspired by the process used to erect broadcast towers, the WTS system employs an integrated tower-climbing "gin-pole" device to erect the tower sections, and a tower-top mounted Hi-Jack lifting frame for raising the heavy turbine nacelle and rotor components. The company's system removes tower height limitations imposed by crane height and reduces wind farm construction expenses. As a result, the system enables smaller community wind projects and is very attractive for projects in less-developed nations.

WTS has filed multiple patents globally covering the design of specific system components and processes. The firm's wind farm development division is leveraging opportunities enabled by the technology to build wind farms in areas where competition is low and returns for investors are high. These sites include ridge tops, developing countries, and remote locations such as islands.

SBIR Impacts

Potential Benefits of the WTS Space Frame Towers vs. Conventional Steel Towers (per tower)[1]

Energy	Increased energy generation due to taller tower	10%
Economic	Reduced cost of energy	12%
	Reduced cost of installation	$164,000

Potential Benefits of Wind Power vs. Conventional Electricity Generation[2]

Environmental	SO_X emission offset from a 1.5 MW wind turbine	8 million lbs/year
	NO_X emission offset from a 1.5 MW wind turbine	23 million lbs/year
	CO_2 emission offset from a 1.5 MW wind turbine	11 million lbs/year

Innovation

The Space Frame Tower and Hi-Jack Systems increase the attractiveness of wind power by:

- reducing tower weight by 30–50% compared to conventional tubular-steel towers
- reducing wind project developers' cost of building wind farms by 3% to 5% for the same size installation
- reducing transportation and construction risks via non-specialized transportation and elimination of crawler cranes
- taking advantage of the stronger winds available at 100 meters height
- enabling economical development of small and hard-to-access wind sites

Company Success

SBIR funding was critical for WTS' proof-of-concept work, invention, and development of the Space Frame Tower and, subsequently, the Hi-Jack Lifting System. Design flexibility afforded by the DOE's SBIR grant set it apart from similar programs—the project had to take a new direction when WTS discovered that the initial design for an all-composite tower was too costly.

Wasatch Wind is commercializing the Space Frame Tower and Hi-Jack Systems and is in the process of transitioning from a research company.

The wind energy industry typically has long development times that involve many years of research, development, and refinement before a product reaches the market. The duration of the SBIR grant was not long enough for WTS to develop and construct a completed demonstration tower, but it provided the resources necessary to complete a final engineering design. It also provided a business advisor who facilitated communication with potential investors and helped open the door to funding to support the Space Frame's path to commercialization. It also positioned WTS for a $1.5 million matching grant from the California Energy Commission (CEC), that supported construction, testing, and certification of the new tower with a commercial turbine as well as development of the crane-free erection system.

[1] Energy and economic benefits of WTS Space Frame tower based on data on the Wasatch Wind website (http://www.wasatchwind.com).
[2] Environmental benefits calculated using EPA and DOE emissions and power generation data.

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New Membrane Technology Boosts Efficiency in Industrial Gas Processes

Challenge

Membrane technology was first commercialized in the 1960s and 1970s for well-known applications such as water filtration and kidney dialysis. Membranes offered inexpensive, compact, and energy-efficient separations for other processes as well—such as industrial gas processing. For example, chemical feedstocks—in this case, monomers (e.g., ethylene and propylene) are the single largest operating cost in the manufacture of polyolefins. Due to the intensely competitive nature of the industry, monomer losses in vent streams are a major concern for producers. These vent streams represent a significant opportunity for recovery and recycling of raw materials.

To help achieve the potential of membranes for this and other gas separation processes, innovation was needed. In addition to membrane material research, development of robust industrial membrane module devices was required, followed by process design and scale-up for commercial application. This required a multi-year, multi-step research and development (R&D) effort.

UPDATE!

As described in this case study, DOE EERE Small Business Innovation Research (SBIR) support enabled MTR to complete development of their VaporSep® process, which separates and recovers organic vapors from air and nitrogen. The process is now widely used to minimize monomer losses in polyolefin plant vent streams.

Building on that research, MTR has been working on membrane separation for greenhouse gas mitigation and sustainable energy processes. In late 2010, MTR received an SBIR Phase III XLERATOR award from DOE to build a complete pilot-scale system that will simultaneously produce turbine-ready hydrogen and high-pressure CO_2 (for sequestration), using a real syngas feed. A successful long-term field test of the membrane modules in an operating environment will help MTR gain initial customer acceptance and commercialize this new technology more rapidly.

Innovating Solutions

MTR was founded in 1982 as an R&D company with a long-term goal of developing marketable membrane technologies, especially in the newly-emerging field of industrial gas separations. For a small company, the initial challenges were daunting. However, with funding from the SBIR programs of several agencies, including the Departments of Energy (DOE), Defense, and Agriculture (USDA), the Environmental Protection Agency (EPA), and the National Science Foundation, the company was able to succeed in developing these technologies.

Because MTR was competing against firmly-entrenched technologies in well-established industries, Phase II SBIR support of early field testing was essential to commercial acceptance of the new membrane technologies. The outcome was their process to remove organic vapors from air and nitrogen, leading to the first of MTR's R&D efforts that resulted in a commercial product.

An early version of this system was first sold in the early 1990s; since then, more than 100 units have been installed worldwide in chemical and petrochemical plants. In 1997, the first VaporSep® system—which has 10 times the capacity of most of the prior systems—was installed to treat ethylene- and propylene-containing nitrogen purge gas streams in polyolefin plants. Similar systems continue to be sold worldwide and have been used to recover a variety of chemicals, including vinyl chloride monomer, isopentane, and 1-hexene, in addition to ethylene and propylene. For a world-scale polyolefin plant, a VaporSep® unit typically recovers about 2,000 to 200,000 tons/year of monomer, valued at $1-10 million/ year.

MTR's VaporSep® systems have recovered about 2.1 million tons of volatile organic compounds (VOCs) since 1992, which has saved over 115 trillion Btus in fuel. The value of fuel savings in 2008 was estimated at 33 trillion Btus and is expected to grow in subsequent years. Considering data available for VaporSep® systems installed between 1992 to 2008, the capital investment has typically been recovered in one to two years from the fuel value alone of the recovered monomer.

Membrane Technology and Research, Inc. (MTR), based in Menlo Park, CA, is a privately-owned developer, manufacturer, and supplier of customized membrane process solutions. Currently, the company's principal membrane products are

- VaporSep® systems to remove organic vapors from air and nitrogen
- NitroSep™ and fuel gas conditioning systems for natural gas treatment
- Hydrogen recovery systems for refinery and other applications

MTR's current R&D is extending use of membranes to carbon sequestration and biofuels separations.

www.mtrinc.com

A case study from the DOE/EERE SBIR Program portfolio, providing competitive grants for scientific excellence and technological innovation to advance critical American priorities and build a strong national economy – one small business at a time.

Membranes for Industrial Gas Separations

Over the last decade, with support from SBIR and DOE follow-on funding, MTR has been able to conduct the R&D needed to add membrane separation products for the oil and gas and refinery businesses to its product portfolio, and is now working on greenhouse gas/sustainable energy applications. The inherently energy-efficient, environmentally-friendly nature of membrane separation processes make them particularly good candidates for such applications. DOE, EPA, and USDA are all contributing funds to advance early-stage development for such applications as carbon capture and sequestration, alcohol/water separations in biofuel production, coal-bed methane recovery, and biogas.

Benefits of membrane technology over other gas separation processes include:

- Greater energy efficiency
- Lower operating costs
- Shorter payback times
- Simpler, often unmanned operations
- No or few moving parts
- Smaller footprint
- Easier expansion due to their modular nature

SBIR Impacts

Benefits of VaporSep® Membrane Technology[1]

		Realized Benefits 1992 to 2008	Potential Benefits 2009 to 2020
Energy	Fuel value (energy content) of cumulative recovered VOCs (1 quad is 1 quadrillion Btus)	0.115 quads	0.78 quads
Economic	Estimated value of cumulative recovered VOCs	$1 billion[2]	$6.2 billion
Environmental	VOC recovery	2.1 million tons	14.1 millions tons
	NO_X emissions saved	3,500 tons	23,900 tons
	CO_2 emissions saved	19,300 tons	130,300 tons

Innovation

A complete skid-mounted VaporSep® unit includes membrane modules, compressor, heat exchangers, piping, instrumentation, and controls. Unit dimensions are 10m (L) X 3.5m (W) X 5m (H); the compressor is mounted on a separate skid of similar size. Key system facts:

- Suitable for vent streams from 135 to 4,550 kg (300 to 10,000 pounds) per hour, with monomer concentration from 10 to 80 volume%
- Monomer recovery up to 99+%
- Nitrogen recovery up to 99+% with purities of 99+ volume

Company Success

Development of the VaporSep® process with SBIR support allowed MTR to expand from an R&D focus to commercial success, and enabled it to bring a simple, energy-efficient, environmentally-friendly industrial gas separations technology to the petrochemical, natural gas, and refining industries. The company is now pursuing exciting new opportunities for the technology in greenhouse gas mitigation and sustainable energy processes that can bring economic and environmental benefits to the company, their customers, and energy consumers worldwide.

As of 2009, cumulative VaporSep® sales and bookings exceeded $140 million and total company revenues in 2009 were about $30-35 million.

In recognition of the innovative nature and importance of this process, MTR received *Chemical Engineering Magazine's* Kirkpatrick Award, the first small business to be so recognized.

[1] Calculations are based on approximately 100 units in operation to date, recovered VOCs valued at approximately $0.20/lb, EPA emissions data, and projected growth rate of 10%/year.

[2] Note the estimated installation capital cost during the period was $100 million, indicating a significant return on investment.

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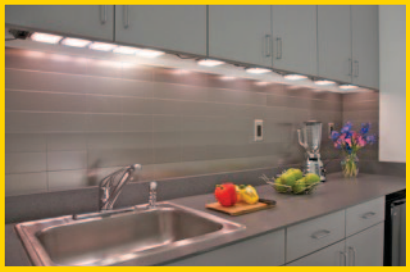
New OLED Lighting Systems Shine Bright, Save Energy



Challenge

Lighting consumes over 22% of the total electricity produced in the U.S. and, according to industry estimates, accounts for over $200 billion per year in electric bills worldwide. A majority of this energy consumption and cost comes from traditional light sources such as incandescent lamps used for general lighting in residential and linear fluorescent lamps used in commercial and industrial applications. Spurred by regulatory actions and the Energy Independence and Security Act of 2007, interest and demand for more energy-efficient products for general lighting purposes is growing rapidly. However, alternative light sources have some limitations—such as comparable output, lamp lifetime, and production costs—that need to be addressed for the technology to achieve wider application.

Innovating Solutions

Organic light emitting diodes (OLEDs) hold promise for use in display applications and for general illumination for many reasons, including improved efficiency and performance and low cost. These devices typically consist of a series of organic thin films sandwiched between two thin-film conductive electrodes. When electricity is applied to an OLED, charge carriers are injected from the electrodes into the organic thin films. Under the influence of an electrical field, these carriers migrate through the device until they recombine; forming electron-hole pairs at elevated energy states (excitons) which upon relaxation may release energy in the form of light. By careful engineering of the energies of these excitons, light with specific properties (such as color) can be achieved. In addition to light, a natural byproduct of this relaxation process is unwanted heat. By using certain technical advancements such as phosphorescence as described below, this can be minimized resulting in a very efficient light producing process.

In the late 1990's, Universal Display Corporation (UDC), working with partners from Princeton University and the University of Southern California, developed phosphorescent OLED (PHOLED) technology that increases the energy efficiency of OLEDs up to four times, enabling white OLEDs to become a potential new source of "green" solid-state lighting. Since then, UDC has made tremendous progress in demonstrating the use of its proprietary UniversalPHOLED® phosphorescent OLED technology and materials in energy-efficient white lighting panels. Along with UDC's strategic partnerships, the U.S. Department of Energy (DOE) and its SBIR program have supported a variety of efforts to advance and commercialize the technology.

UDC and Armstrong World Industries were able to develop a prototype ceiling luminaire that can snap into Armstrong's TechZoneTM ceiling system. Building on this success, UDC developed an under cabinet luminaire system shown in the photograph above. This luminaire system is comprised of 15cm x 7.5cm PHOLED lamp modules including a high efficiency power supply and dimming controls. It successfully demonstrated the target specification of > 60 lm/W, LT70 > 20,000 hours and CRI > 85. This performance compares favorably with typical under cabinet products currently on the market, as shown below:

	Under Cabinet Luminaire	
	PHOLED UDC Demo	Linear Fluorescent Typical T-5*
Luminaire efficacy (lm/W)	60	20
Estimated lifetime (hours)	>20,000	<10,000
Color rendering index (CRI)	85	82 (est.)

* Representative values from "benchmark" testing to support 2005 SSL Energy Star specifications for this category. Some values are average of 5 representative products tested.

UPDATE!

For over ten years, UDC and their technology partners have worked closely with the DOE's SBIR/STTR program and the DOE's SSL product development cooperative R&D grants to achieve numerous important OLED breakthroughs. Most of the highest risk and pioneering basic research has been achieved through the SBIR program with many world records for performance recorded. This enabling research has paved the way for more product-oriented demonstrations often performed with industry partners.

In 2010, UDC (teaming with Acuity Brands, a leading provider of innovative, technologically advanced sustainable lighting products and lighting-related solutions) won a $2 million grant through DOE's SBIR Phase III Xlerator program to adapt its PHOLED lighting technology for high-end commercial and institutional building applications. This project builds on a number of SBIR-funded and other efforts that demonstrated how this technology can be manufactured cost effectively to match conventional technologies in mainstream lighting applications, such as Armstrong's TechZone.

Universal Display Corporation (UDC) (Ewing, NJ), founded in 1994, provides OLED innovations and helps commercialize new generations of OLED products through technology licensing, UniversalPHOLED® materials sales, technology development, and technology transfer services. UDC is a world leader in the development of innovative OLED technology for use in flat panel displays, lighting, and organic electronics. It holds one of the largest patent portfolios in the OLED field.

www.universaldisplay.com

A case study from the DOE/EERE SBIR Program portfolio, providing competitive grants for scientific excellence and technological innovation to advance critical American priorities and build a strong national economy – one small business at a time.

New Phosphorescent OLED Lighting Systems Shine Bright, Save Energy

UDC recently announced a technology and licensing agreement with Moser Baer Technologies to take PHOLED to the next level. The agreement follows a $4 million DOE American Recovery and Reinvestment Act of 2009 award the team received for a two-year DOE project to create a phosphorescent OLED lighting panel manufacturing facility. Both this effort—and the DOE Xlerator-funded work for commercial applications—are major steps toward establishing volume manufacturing of energy-efficient and environmentally friendly white PHOLED lighting panels in the U.S., and can serve as a basis for new manufacturing investment and job growth in the country.

"The U.S. Department of Energy is very pleased with Universal Display's continued advances toward the demonstration of white OLED lighting with commercially-viable performance…through programs like these, Universal Display is among the innovative companies that are helping to accelerate the commercialization of white OLEDs for solid-state lighting."

Dr. James Brodrick, DOE Lighting Program Manager

SBIR Impacts

Projected Benefits of Replacing Traditional Systems with Phosphorescent OLED Lighting (2012 to 2018)

		Cumulative Estimated Savings by 2018[1]
Energy	Estimated potential U.S. energy savings	0.22 quadrillion Btus
Economic	Estimated potential worldwide electricity cost savings	$20 billion
Environmental	Estimated potential worldwide carbon emissions reductions Composed of organic materials, white OLEDs are environmentally benign	3.7 million metric tons

Innovation

Based on UDC's UniversalPHOLED® phosphorescent OLED technology and materials, white PHOLEDs offer power efficiencies superior to those of today's incandescent bulbs and approaching those of fluorescent lamps, having the potential to significantly reduce energy consumption, environmental impacts, and white lighting costs. Additionally, white PHOLEDs offer a novel form factor for more effective and imaginative application of white light, with the ability to tune light across a range of color temperatures. This functionality is neither feasible nor practical when using traditional light sources. As of 2010, UDC has demonstrated the following breakthrough research results with 15 cm x 15 cm white PHOLED panels and 2 mm^2 white PHOLED pixels:

Panels

- Efficacy of 66 lm/W; CRI = 79
- Efficacy of 58 lm/W; CRI = 81; with LT70 extrapolated panel lifetime over 15,000 hours

Pixels

- Efficacy of 113 lm/W; CRI = 80; with LT70 extrapolated pixel lifetime over 10,000 hours

Company Success

Thanks in large part to DOE support, Universal Display Corporation has become a recognized leader in developing and commercializing phosphorescent OLED technology. Their proprietary UniversalPHOLED® technology is part of a comprehensive patent portfolio which the company licenses as it provides customized technology development and transfer services for specific lighting needs worldwide. Advances in the technology have allowed a number of UDC's customers and partners to exhibit white OLED prototypes at industry conferences and major trade shows. In addition to Armstrong World Industries, Acuity Brands Lighting, and Moser Baer Technologies, UDC has established relationships with LG Chem, NEC Lighting, Panasonic Electric Works, Konica Minolta, and Showa Denko K.K.

Since its founding in 1994, UDC has developed one of the largest patent portfolios in the OLED field, with licensing rights to over 1000 issued and pending patents worldwide, and has entered into business agreements with leading manufacturers in the U.S., Japan, Korea, Taiwan, China, and Europe.

For four consecutive years, Universal Display Corporation was recognized by DOE for its achievements in solid-state lighting research and development, especially for its advances in white OLED lighting performance using its high-efficiency PHOLED technology and materials.

[1] Projections provided by Universal Display Corporation. Assumes niche products are commercially available by 2012, with PHOLED lighting panels replacing 2-3% of traditional light sources in commercial and residential applications over six years.

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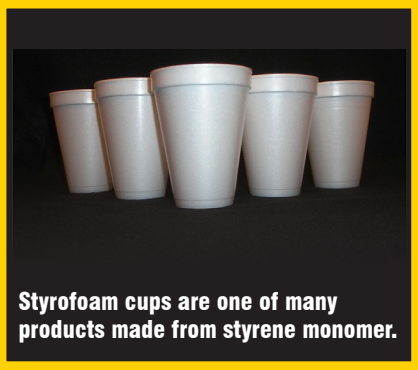
New Process for Producing Styrene Cuts Costs, Saves Energy, and Reduces Greenhouse Gas Emissions



Styrofoam cups are one of many products made from styrene monomer.

With support from the U.S. Department of Energy's (DOE) Small Business Innovation Research (SBIR) program, Exelus Inc. has developed the Exelus Styrene Monomer (ExSyM) process, which uses novel catalytic technology to maximize styrene monomer (SM) production using toluene and methanol feedstocks. The ExSyM process requires less capital investment, operates at lower temperatures, uses less energy, and produces fewer greenhouse gas (GHG) emissions than conventional SM production methods.

Challenge

SM, a colorless oily liquid, is a valuable, large-volume commodity chemical used in making polystyrene plastics, protective coatings, polyesters, and resins, and as a chemical intermediate. Global production of styrene in 2010 was 25 million metric tons (27.5 million U.S. tons), of which approximately 4 million metric tons (4.4 million U.S. tons) originated in the U.S. The global market is valued at approximately $32.5 billion[1] and is forecast to grow an average of 3.6% per year. However, the conventional process for producing SM consumes tremendous amounts of energy—up to ten times as much as the production of similar chemicals—and is a major contributor to emissions of GHGs such as methane and carbon dioxide.

Conventional SM production methods—in use for more than 70 years—usually require a two-step process. The first step involves the alkylation[2] of ethylene with benzene over an acid catalyst to form ethylbenzene (EB). The second step combines EB with high-temperature steam (near 900°C), then dehydrogenates the EB over an iron oxide catalyst under vacuum at temperatures in excess of 600°C. The cost of production is elevated by the high-priced feedstocks and the severity and endothermicity of the second step. Attempts to reduce the energy consumption in this two-step process, through measures such as process optimization and catalyst upgrades, have not had a significant impact. A single-step SM production method was investigated using a side chain alkylation reaction of toluene with methanol; however, reaction complications limited the SM yields. Many past efforts to improve SM yields in the toluene-methanol approach have primarily concentrated on conventional catalyst improvements.

Innovating Solutions

To overcome reaction limitations, Exelus Inc., with support from the DOE's SBIR program and the New Jersey Commission on Science & Technology, has been able to make significant strides in developing an innovative new process known as ExSyM. This process uses the toluene-methanol approach and employs a proprietary, engineered solid catalyst in a one-step reaction that enables the production of SM under relatively mild operating conditions with reaction temperatures around 400°C. Results thus far show dramatic improvement in SM product selectivity (the ratio of the desired product quantity to the total quantity of products) of around 80%. The process has been tested in bench-scale reactors, with the catalyst showing no signs of deactivation in long-term stability tests. As a retrofit for existing plants, the ExSyM process has great potential as a cost-effective alternative to conventional SM production methods.

In addition to its novel catalyst, ExSyM incorporates reactor design improvements and process innovations that reduce the decomposition of methanol, minimize the formation of EB, and improve energy efficiency. At production scale, any EB by-product produced via the ExSyM process could be separated and sold to a conventional SM producer, or dehydrogenated on-site to boost the overall SM yield. Hydrogen by-product could also be burned to produce steam to help heat product distillation columns. The single-step ExSyM method eliminates the energy-intensive dehydrogenation step, allowing for significant energy use reduction and concomitant cost savings and lower GHG emissions.

[1] A current value of styrene is $1300/metric ton.

[2] Alkylation is the transfer of an alkyl group of chemical compounds from one molecule to another.

Commercializing ExSyM

In 2010, Exelus was selected to receive funding under DOE's SBIR Phase III Xlerator program. With this support, Exelus aims to advance the commercialization of ExSyM technology by constructing and operating a pilot-scale testing unit that meets industry-standard specifications for capacity and design. With lower feedstock and capital costs, ExSyM is an exciting new pathway for SM production.

Exelus Inc. (Livingston, NJ), established in 2000, develops and licenses "Cleaner-by-Design" chemical technologies to produce a vast array of products and materials used in consumer goods, transportation, and food processing. Currently, the company's principal process technologies are:

ExSact – a refining technology that overcomes the environmental concerns, safety hazards and rising costs associated with conventional liquid acid technologies

ExSyM – energy efficient, low cost SM production technology

BTG – efficient, cost-effective conversion of biomass to clean, high-octane, gasoline-compatible fuel

http://www.exelusinc.com/

A case study from the DOE/EERE SBIR Program portfolio, providing competitive grants for scientific excellence and technological innovation to advance critical American priorities and build a strong national economy – one small business at a time.

New Process Chemistry for Producing Styrene Monomer Saves Energy, Reduces Emissions

The cost reduction realized with the implementation of the new SM production process could increase global competitiveness of U.S. SM manufacturers, thereby saving jobs and increasing exports.

SBIR Impacts

Projected Benefits of ExSyM vs. Conventional Styrene Monomer Production[3]

	Conventional SM Production	→	ExSyM
Energy	• Second-step dehydrogenation required • Operation temperature >600°C; steam ~900°C • Vacuum operation requires large compressor		• Energy-intensive dehydrogenation step is eliminated • Reaction temperatures between 400-425°C • 50% less endothermic • Energy savings up to 40%
Environmental	• Large contributor to GHG emissions such as methane and CO_2		• Lower GHG emissions by 40% • Possible recovery and reuse of up to 50% of hydrogen byproduct for use as an energy supply, thereby reducing carbon emissions • Replaces carcinogenic benzene feed with toluene, which is much less toxic
Economic	• Higher feedstock costs of ethylene ($1100/metric ton) and benzene ($940/metric ton)[4] • Investment cost to build a 250,000 metric ton/year plant: $125 million		• Reduced feedstock costs of toluene ($650/metric ton) and methanol ($350/metric ton) result in operating cost savings of $250/ton of styrene[4] • Investment cost to build a 250,000 metric ton/year plant: $63 million (ExSyM retrofit: $10-15 million)

Innovation

The ExSyM system is configured to resemble conventional SM process units to facilitate retrofitting of existing plants. ExSyM replaces the more expensive feedstocks of benzene and ethylene with toluene and methanol in a more cost-effective, energy efficient one-step route for SM production. Characteristics of the novel proprietary catalyst that facilitates the required reaction include:

- the ability to be used in standard fixed-bed reactors
- 'active sites' that selectively adsorb toluene to limit methanol decomposition
- highly-structured pores optimize diffusion and residence time of reactants and products

Company Success

Exelus Inc. has grown from three employees when founded in 2000 to 18 employees in 2011, with projected 2012 revenue of $2.5 million.

DOE support has been an integral part of the success achieved by Exelus Inc. and their 'Engineered Catalysts' (EnCats) technology platform, a unique class of reactive systems that aim to blur the line of distinction between a catalyst and reactor by incorporating many characteristics that one associates with a reactor within the catalyst structure.

EnCats facilitate the development of, next-generation, clean process technologies. As a part of the EnCats family, ExSyM represents a breakthrough in industrial catalysis as a low cost SM production technology based on new process chemistry, with its potential highlighted in trade journals such as *Chemical & Engineering News*, *Chemical Engineering Magazine*, and *ICIS Chemical Business*.

From Phase I development to its most recent Phase III Xlerator award for pilot-scale testing and further manufacturing scale-up, SBIR support has been essential to Exelus Inc. in developing its promising new ExSyM technology.

[3] ExSyM projections provided by Exelus Inc. based on bench-scale test results.

[4] ICIS Price Reports.

For additional information, please contact:

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