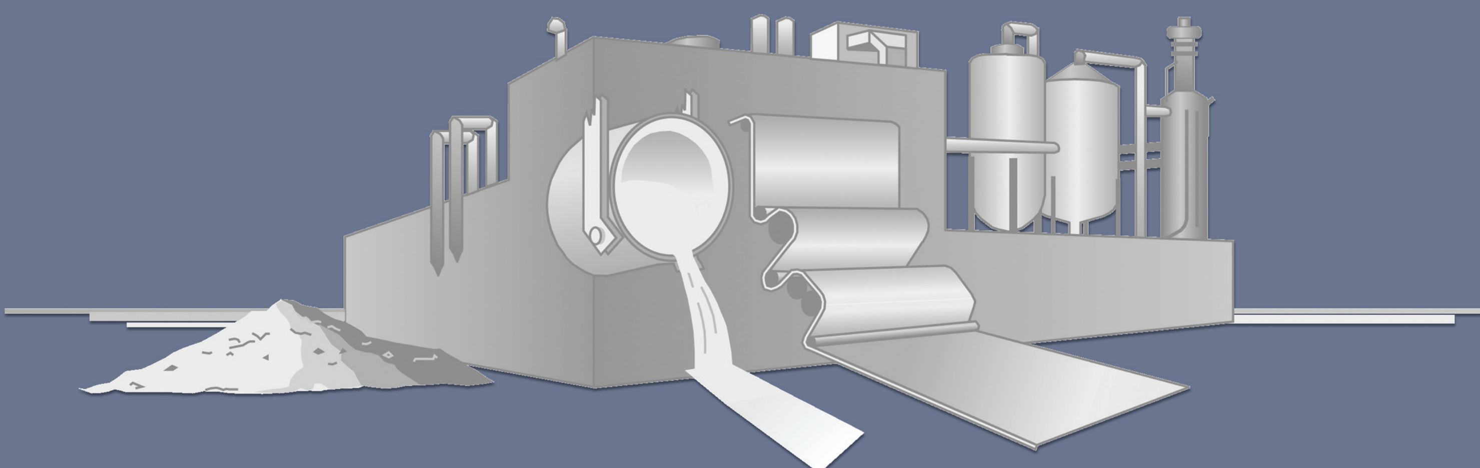
# IMPACTS

February 2006

## Industrial Technologies Program:
### Summary of Program Results for CY 2004

### Boosting the Productivity and Competitiveness of U.S. Industry



U.S. Department of Energy
Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

# Forward



## Foreword

Industry consumes 33% of all energy used in the United States. By developing and adopting more energy-efficiency technologies, U.S. industry can boost its productivity and competitiveness while strengthening national energy security, improving the environment, and reducing emissions linked to global climate change.

The U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) works in partnership with U.S. industry to increase the efficiency of energy and materials use, both now and in the future. EERE's Industrial Technologies Program (ITP) seeks to improve the energy intensity of the U.S. industrial sector through a coordinated program of research and development (R&D), validation, and dissemination of energy-efficient technologies and operating practices. ITP develops, manages, and implements a balanced portfolio that addresses industry requirements throughout the technology development cycle. ITP's primary long-term strategy is to invest in high-risk, high-return R&D. Investments focus on technologies and practices that will provide clear public benefit but have market barriers preventing adequate private-sector investment.

ITP's efforts have resulted in over 170 technologies successfully reaching the marketplace, providing significant economic and environmental impacts for the United States. This report summarizes some of these benefits – energy savings, waste reduction, increased productivity, lowered carbon dioxide and air pollutant emissions, and improved product quality. These benefits have been tracked by periodic interviews with industrial technology suppliers and users.

We encourage you to become part of this customer-driven strategy by using energy-efficient technologies already commercially available and those beginning to emerge in the marketplace from the technology development process. We invite your comments and suggestions on this document, as well as on products and services that would help you achieve a cleaner and more competitive energy future.

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# Executive Summary

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Working in partnership with industry, the U.S. Department of Energy's (DOE's) Industrial Technologies Program (ITP) is helping reduce industrial energy use, emissions, and waste while boosting productivity. Operating within the Office of Energy Efficiency and Renewable Energy (EERE), ITP conducts research, development, demonstration, and technology transfer that are producing substantial, measurable benefits to industry. This document summarizes some of the impacts of ITP's programs through 2004.

Industry is the largest and most diverse energy-consuming sector in the United States. In 2004, the industrial sector used one-third of the energy consumed in the nation. Many of the energy-intensive industries, including aluminum and steel, are limited in the choice of fuels and/or feed stocks that must be used in their processes. As a result, many opportunities for energy-efficiency improvements are very process-specific to one industry. However, because some important energy applications, such as motor drives, boilers, and compressed air systems, are common across the industrial sector, crosscutting energy-efficiency opportunities also exist.

Over the past 27 years, ITP has supported more than 600 separate research, development, and demonstration (RD&D) projects that have produced over 170 technologies. In 2004 alone, 90 successfully commercialized technologies saved 111 trillion Btu in measured savings. While these energy savings are impressive, industry has reaped even greater benefits from the productivity improvements, reduced resource consumption, decreased emissions, and enhancements to product quality associated with these technological advances. In addition, many ITP-supported projects have significantly expanded basic knowledge about complex industrial processes and have laid the foundation for developing future energy-efficient technologies.

ITP's primary role is to invest in high-risk, high-value RD&D that will reduce industry's energy requirements while stimulating economic productivity and growth. Because energy is an important input for many of the nation's key manufacturing industries, reducing energy requirements will also reduce energy costs, greenhouse gases, and other emissions and will improve productivity per unit of output. As a Federal program, ITP invests in advanced technologies that are anticipated to produce dramatic energy and environmental benefits for the nation. Investments focus on technologies and practices that will provide clear public benefit but have market barriers preventing adequate private-sector investment.

ITP has developed a six-part strategy to achieve its goals:

1. Focus on energy-intensive industries.

2. Use public-private partnerships to implement the program.

3. Identify impediments to improving industrial energy efficiency

4. Implement a balanced portfolio.

5. Perform both process-specific and crosscutting R&D.

6. Follow up with technology delivery activities to ensure efficiency improvements.

ITP tracks energy savings as well as other benefits associated with the successfully commercialized technologies resulting from its research partnerships. These benefits include current and cumulative energy savings and cumulative reductions of various air pollutants including particulates, volatile organic compounds, nitrogen oxides, sulfur oxides, and carbon.

In 2004, ITP programs were instrumental in achieving energy cost savings to industry of 366 trillion Btu and $2.06 billion. Over the entire history of ITP programs, these cumulative net benefits are about 4.72 quadrillion Btu, which is roughly equal to $23.1 billion (in 2004 dollars).

The bulk of this document consists of seven appendixes. Appendix 1 describes the 90 technologies currently available commercially, along with their applications and benefits. Appendix 2 describes the 142 ITP-supported emerging technologies that are likely to be commercialized within two or three years. Appendix 3 describes 79 ITP-sponsored technologies used in commercial applications in the past, the current benefits of which are no longer counted in this report. Appendixes 4 and 5 round out the reporting of impacts by showing the benefit of two ITP technical assistance activities: the Industrial Assessment Centers and BestPractices. Finally, Appendix 6 describes the methodology used to assess and track ITP-supported technologies.

# Summary of ITP Program Impacts



## Industrial Energy Use

Total energy consumption in the nation's industrial sector far exceeds any other sector and is more diverse. In 2004, the industrial sector used 33.25 quad of all types of energy (almost exactly one-third of the 99.7 quad used by the entire economy), including electricity losses of 7.69 quad (see Figure 1).

Petroleum (9.54 quad), natural gas (8.67 quad), and electricity (3.48 quad delivered) are the three fuels most used by industry, with coal and biomass providing another 3.84 quad combined. The industrial sector consumed a total of 25.56 quad, of which 21.06 quad were consumed by manufacturing industries. Of that 21.06 quad, energy-intensive industries consumed 16.60 quad. The non-energy-intensive industries (4.46 quad) and non-manufacturing industries (agriculture, mining, and construction – 4.50 quad combined) accounted for the remaining energy consumption. Industry uses nearly 7 quad of the fossil fuels for feed stocks – raw materials for plastics and chemicals – rather than as fuels. Energy expenditures in the industrial sector exceed $81 billion.

The energy-intensive industries – forest products, chemicals, petroleum refining, nonmetallic minerals (glass and cement, especially), and primary metals – account for about 75% of all industrial energy use (see Figure 2).

Many of the energy-intensive industries are limited in their choice of fuels because the technologies currently used in specific processes require a certain fuel. For example, aluminum production requires large amounts of electricity to reduce the alumina to metal. Paper pulping leaves a large residual of wood lignin that can be reprocessed for its chemical content and consequently supplies the industry with nearly half of its primary energy. Therefore, the wide variety of fuels (and feed stocks) used in the industrial sector partially reflects the specific requirements of the processes used to make specific goods or commodities. Because of specific energy requirements, the industrial sector offers a wide variety of opportunities for energy-efficiency improvements that are specific to particular industries and that crosscut many industries (i.e., are common to many industries or are needed by many process-specific technologies).

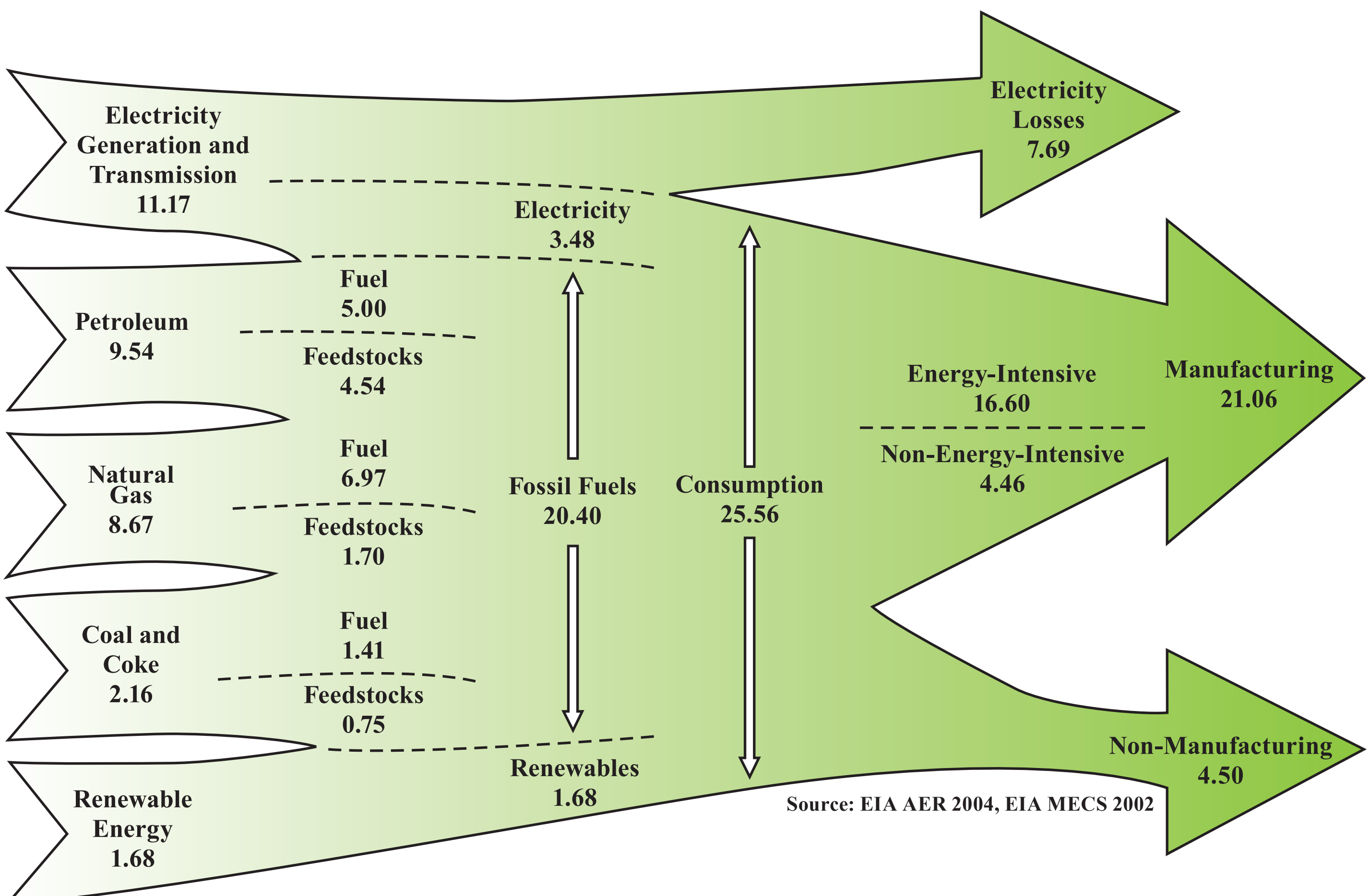


*Figure 1. Industrial Energy Flows (Quad), 2004*

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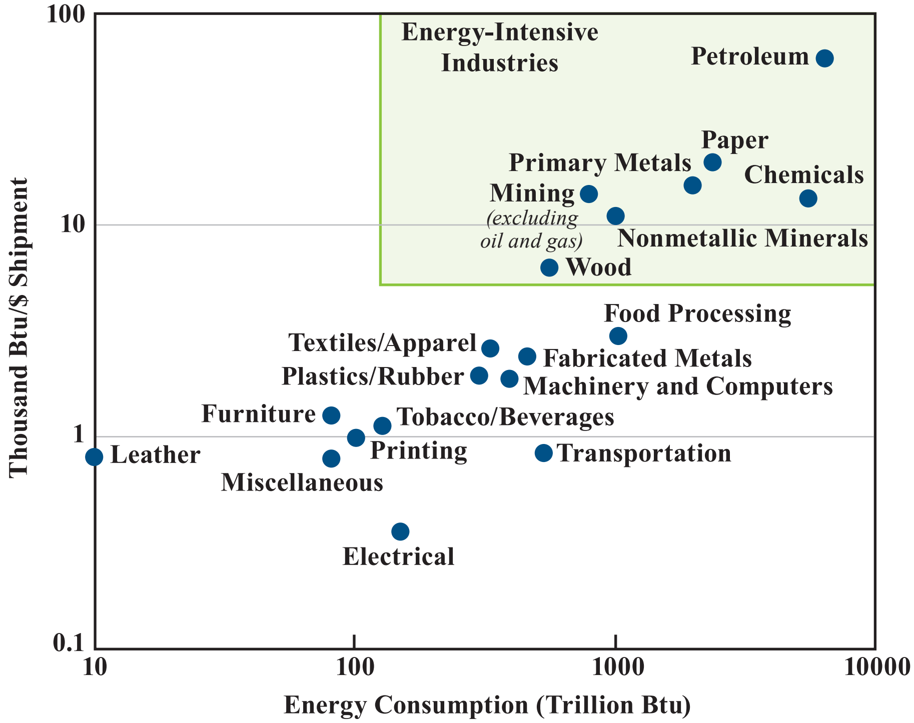
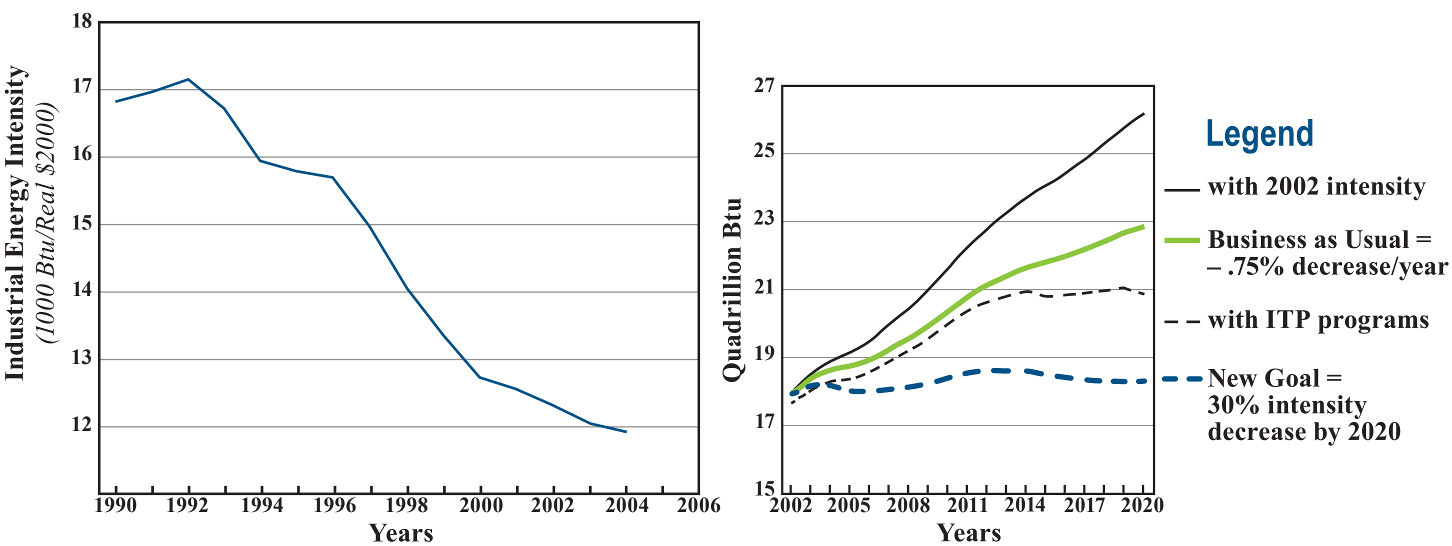



Sources: EIA MECS 2001, Bureau of Economic Analysis

*Figure 2. Energy Intensity of Manufacturing Industries*

The energy intensity of the industrial sector has been declining over the past decade, in part because of investments in energy-efficient technologies by the Industrial Technologies Program (ITP), previously the Office of Industrial Technologies (OIT). Since its peak in 1992, industrial sector energy intensity has declined from 17,138 Btu/dollar of industrial GDP to 11,984 Btu/dollar of real industrial sector GDP in 2004 (see Figure 3). These reductions are expected to continue into the future, as the second part of Figure 3 shows.




Sources: EIA Annual Energy Review, 2003, Table 2.1d and BEA, Value Added for Goods Producing Industries, 1990-2003, *(Constant $2000).*

Sources: EIA AEO 2004, EIA MECS 2001, ITP

*Figure 3. Historical Industrial Energy Intensity and Projected Energy Use*

# Summary of ITP Program Impacts



## The Industrial Technologies Program Office

ITP leads the Federal government's efforts to improve industrial energy efficiency and environmental performance. The program is part of the Office of Energy Efficiency and Renewable Energy (EERE) and contributes to its efforts to provide reliable, affordable, and environmentally sound energy for the nation's future.

ITP has a six-part strategy that focuses efforts on identifying the high-risk, high-payoff investments, balancing risk against rewards, and ensuring the delivery of new technologies to the marketplace:

- Focus on energy-intensive industries. A small number of energy-intensive materials and process industries account for about 75% of total industrial energy use. These industries' energy costs also are a significant portion of total costs, whereas most of manufacturing spends less than 2% of their costs on energy. ITP's Industries of the Future (IOF) process focuses on the energy-intensive industries and provides the bulk of the opportunities to improve energy efficiency.

- Use public-private partnerships to implement the program. These partnerships bring together the strengths of business and government to solve increasingly difficult and complex problems. Businesses and government work hand-in-hand to plan the collaborative research, focus on specific problems, jointly share the cost of the research, and ensure the commercialization and delivery of the research results to the cooperating parties.

- Identify impediments to improving industrial energy efficiency. Often an incremental improvement cannot overcome the major hurtles to achieving a breakthrough improvement in energy efficiency. To identify these "grand challenges," government and industry undertake analytical studies to assess the potential for improvement and then assess alternative routes, often using an entirely different process or technique to overcome impediments.

- Implement a balanced portfolio. ITP develops, manages, and implements a balanced portfolio to address the grand challenges throughout the development cycle. Three major topics are addressed: the R&D projects themselves, validation of the R&D results, and dissemination of the technologies to where they are needed to improve energy efficiency in industry.

- Perform both process-specific and crosscutting R&D. The long-term benefits from ITP's program – undertaking the high-risk, high-value research and development that will increase energy efficiency while stimulating economic productivity and growth – will only be realized if the focus is on technologies that provide clear public benefit but that would not normally be undertaken by industry. These opportunities exist both for process-specific and crosscutting technologies. The grand-challenge approach can identify the process-specific targets. Competitive solicitations help ensure that ITP is cost effective and that the best ideas are pursued.

- Follow up with technology delivery activities to ensure efficiency improvements. ITP provides a variety of assistance to ensure effective delivery of the technologies and management practices that result in industrial energy-efficiency improvements. Software toolsand training allow plants to assess their steam, compressed air, motor, pumps, insulation, and process-heating systems. Plant assessments and audits reveal inefficiencies that can lead to rapid payback investments which save both energy and money. These assessments and audits are provided to small- and medium-sized firms through the Industrial Assessment Center program and to major industrial users through a competitive solicitation process. Showcase demonstrations highlight the benefit of energy efficiency and expose managers from other companies to new and improved technologies. An extensive website library containing publications on process energy management practices helps plant managers achieve immediate savings.

In addition to these strategies, ITP partners with other program areas within EERE and performs ongoing program evaluation, including assessing past programs and the benefits that have accrued from investments.

Partnering with industry through a competitive solicitation process, the ITP provides financial assistance to selected research, development, and demonstration (RD&D) projects that can dramatically accelerate the pace of technology innovation.

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## Energy-Intensive Industries

ITP focuses on a small number of energy-intensive materials and process industries that represent the biggest opportunities for energy savings and provide industry organizations for coordinating activities. Partnerships have been established with these industries and their supporting industries to improve energy efficiency:

- Aluminum
- Chemicals
- Forest Products
- Glass
- Metal Casting
- Mining
- Steel

Crosscutting R&D targets opportunities to enable technologies that are common to many industrial processes – combustion, process heating, materials, heat treating, forging, and sensors and automation – find widespread application and yield large energy savings for even small efficiency improvements.

## Technology Delivery and Best Practices

Implementing off-the-shelf technologies and energy management practices can save enormous amounts of energy. ITP funds technical assistance activities to stimulate and replicate the near-term adoption of energy-saving technologies and best practices within the industry. This collaborative effort, called BestPractices, focuses resources in four areas: software tools and training, plant assessments and audits, showcase demonstrations, and publication dissemination.

For example, Industrial Assessment Centers are one effort toward achieving the benefits of BestPractices. Teams of faculty and students from universities across the country conduct energy audits and assessments and help small- and medium-sized manufacturers identify opportunities to realize the benefits of energy-efficient technologies and practices. Figure 4 shows the location of the 26 university-based centers.

ITP is designed to achieve EERE mission objectives, operate efficiently, and encourage staff interaction. ITP's headquarters organization in Washington, D.C., is responsible for developing, managing, and evaluating technology portfolios, using strategies to best achieve ITP goals. The Golden Field Office in Golden, Colorado, and the National Energy Technology Laboratory in Pittsburgh, Pennsylvania, are responsible for initiating, managing, and monitoring ITP projects. Regional offices in Atlanta, Boston, Chicago, Denver, Philadelphia, and Seattle are responsible for delivering technologies to their many partners at the local, state, and regional level.

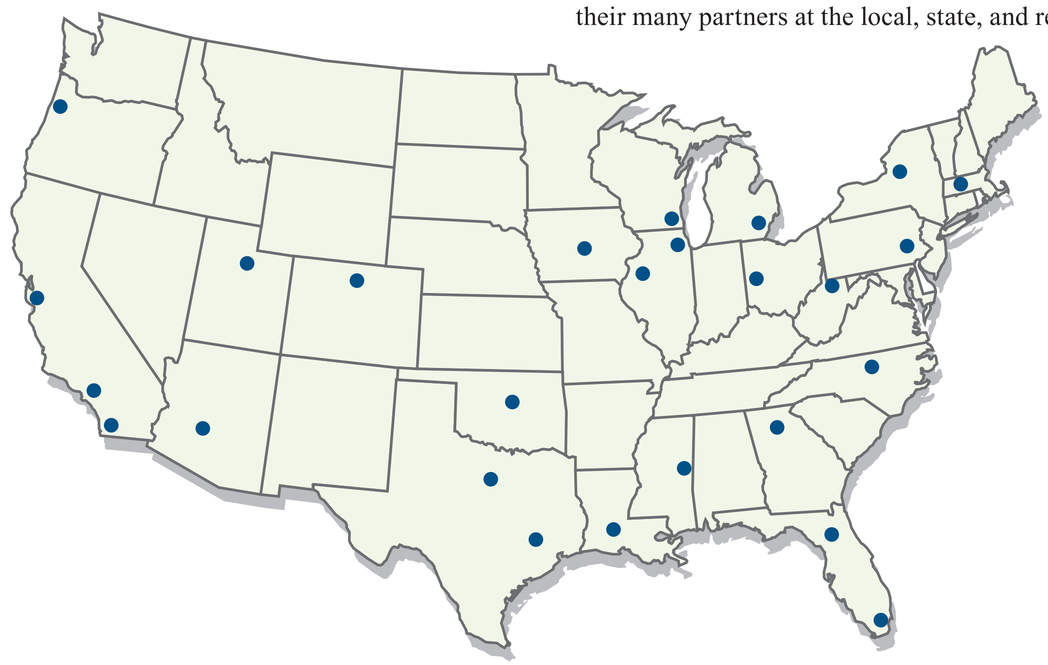

*Figure 4. Locations of University-Based Industrial Assessment Centers*

# Summary of ITP Program Impacts



The ITP website (http://www.eere.energy.gov/industry) provides a wealth of information about the program, and the EERE Information Center (1-877-337-3463, eereic@ee. doe. gov) fields questions and facilitates access to ITP resources for industrial customers.

This report also quantifies the benefits of projects in the EERE portfolio now managed through other program offices but initiated in ITP. For example, partnerships with an emerging bio-based products industry, now managed through the Biomass Program, bring expertise and technology from several industries – agriculture, forest products, and chemicals – to create plastics, chemicals, and composite materials from renewable resources. Also, the Inventions and Innovation (I&I) Program provides grants to individual inventors and small companies for conducting early development through to prototyping for innovative energy-saving ideas. In addition, projects are included that were funded by the discontinued NICE[3] (National Industrial Competitiveness through Energy, Environment, and Economics) Program that developed and demonstrated advances in energy efficiency and clean production technologies.

## Tracking Program Impacts

ITP has assessed the progress of the technologies supported by its research programs for more than 20 years. ITP managers have long recognized the importance of developing accurate data on the impacts of their programs. Such data are essential for assessing ITP's past performance and can help guide the direction of future research programs.

Energy savings associated with specific technologies are estimated by Pacific Northwest National Laboratory (PNNL) through a rigorous process for tracking and managing data. When a technology's full-scale commercial unit is operational in a commercial setting that technologyis considered commercially successful and is placed on the active tracking list. When a commercially successful technology unit has been in operation for about ten years, that particular unit is then considered a mature technology and typically is no longer actively tracked. The active tracking process involves collecting technical and market data on each commercially successful technology, including details on the following:

- Number of units sold, installed, and operating in the United States and abroad (including size and location)
- Units decommissioned since the previous year
- Energy saved
- Environmental benefits
- Improvements in quality and productivity achieved
- Any other impacts, such as employment and effects on health and safety
- Marketing issues and barriers.

Information on technologies is gathered through direct contact with either the technology's vendors or end users. These contacts provide the data needed to calculate the technology's unit energy savings, as well as the number of operating units. Therefore, unit energy savings are calculated in a unique way for each technology. Technology manufacturers or end users usually provide unit energy savings or at least enough data for a typical unit energy savings to be calculated. The total number of operating units is equal to the number of units installed minus the number of units decommissioned or classified as mature in a given year – information usually determined from sales data or end-user input. Operating units and unit energy savings can then be used to calculate total annual energy savings for the technology.

The cumulative energy savings measure includes the accumulated energy saved for all units actively tracked. These energy savings include the earlier savings from now mature and decommissioned units.

Once cumulative energy savings have been determined, long-term impacts on the environment are calculated by estimating the associated reduction of air pollutants. This calculation is based on the type of fuel saved and the pollutants typically associated with combustion of that fuel and uses assumed average emission factors.

Several factors make the tracking task challenging. Personnel turnover at developing organizations and user companies makes it difficult to identify applications. Small companies that develop a successful technology may be bought by larger firms or may assign the technology rights to a third party. As time goes on, the technologies may be incorporated into new products, applied in new industries, or even replaced by newer technologies that are derivative of the developed technology.

Program benefits documented by PNNL are conservative estimates based on technology users' and developers' testimonies. These estimates do not include either derivative effects, resulting from other new technologies that spin off of ITP technologies or the secondary benefits of the energy and cost savings accrued in the basic manufacturing industries downstream of the new technologies. Therefore, actual benefits are likely to be much higher than the numbers reported here. Nonetheless, the benefits-tracking process provides a wealth of information on the program's successes. The process of tracking these benefits is shown in Figure 5.

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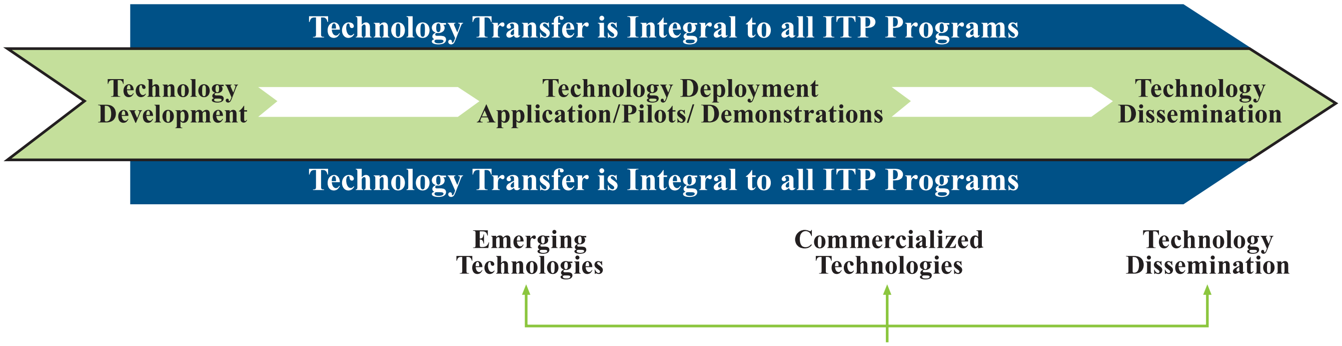



*Figure 5. Technology Tracking Process*

## Impact Tracking System—Database

**Key impact categories tracked:**

- **Cumulative energy savings, current energy savings, type of fuel saved, units operating**
- **Cumulative and annual pollution reductions** *(particulates, nitrogen oxides, volatile organic compounds, sulfur dioxide, carbon dioxide)*

Over the past 27 years, ITP has supported more than 600 separate R&D projects that have produced over 170 technologies in commercial use. In 2004, there were 90 technologies that were in commercial use and yielding benefits. Appendix 1 presents fact sheets on these 90 technologies. The fact sheets include applications data, both technical and commercial, that may enable industry organizations to identify significant opportunities for adapting technologies to their particular practices. Table 1, on pages 8 and 9, provides information on the 90 currently tracked technologies. This table shows energy savings in 2004, as well as cumulative energy savings and pollution reductions. Note that for some technologies, energy savings values are unavailable, very small, or too difficult to quantify. The 90 commercial technologies saved 111 trillion Btu in 2004 and have cumulatively saved 1060 trillion Btu.

Technologies that are likely to be commercialized within two or three years are identified in Appendix 2. Some of these 142 emerging technologies have already yielded scientific information that has improved current industrial processes.

After a commercial technology has contributed to energy and cost savings for about ten years, the technology is considered historical and presumed to be supplanted by newer, more effective technologies. Appendix 3 describes the 79 historical technologies that have been used in commercial applications in the past. The technologies in this category are no longer tracked. While some may still be in use, new applications of the technologies are unlikely. During the time they were tracked, these technologies yielded benefits that are counted in the cumulative tallies shown in Table 1. The 79 historical technologies cumulatively saved 2.21 quad.

The method of calculating the results for the Industrial Assessment Centers and the resulting benefits are described in Appendix 4. As Table 1 shows, the centers saved 133 trillion Btu in 2004 and cumulatively saved 1130 trillion Btu since its inception in 1977. The method of calculating the results for the BestPractices strategy and the resulting benefits are described in Appendix 5. As also shown in Table 1, BestPractices saved 122 trillion Btu in 2004 and has cumulatively saved 322 trillion Btu since its inception in 1998.

The determination of the net economic benefits of ITP programs is discussed in Appendix 6. Using the energy savings from the technologies as well as the Industrial Assessment Centers and BestPractices, the cost savings are determined annually for the fuels saved. The annual energy savings by fuel type is multiplied by the fuel's price, with prices adjusted to reflect the fuel's current costs. The sum of all energy saved times the average energy price yields an estimate of the annual savings in that particular year. To arrive at the net economic benefits, the cumulative energy savings are reduced by the appropriation allocated by the government for ITP programs and by the cost of the industry of adopting the new technologies. Details of this methodology are provided in Appendix 6. Cumulatively, since 1976 ITP technologies and programs have saved 4.72 quad and $23.1 billion. In addition the ITP programs have cumulatively reduced emissions of carbon by 95 million tons, of nitrogen oxides by 747 thousand tons, and of sulfur dioxides by 1.47 million tons, as Table 1 shows.

# Table 1. Technology Program Impacts

| Technologies Commercially Available | IMPACTS | | | | | | |
|---|---|---|---|---|---|---|---|
| | Cumulative Energy Savings *($10^{12}$ Btu)* | 2004 Energy Savings *($10^{12}$ Btu)* | Cumulative Pollution Reductions *(Thousand Tons)* | | | | |
| | | | Particulates | VOCs | $SO_X$ | $NO_X$ | Carbon |
| **Aluminum** | | | | | | | |
| Aluminum Reclaimer for Foundry Applications | 0.001 | 0.000 | — | 0.000 | — | 0.000 | 0.012 |
| Aluminum Scrap Decoater | 1.17 | 0.378 | — | 0.004 | — | 0.137 | 18.6 |
| Aluminum Scrap Sorting | 0.698 | 0.338 | 0.003 | 0.002 | 0.151 | 0.112 | 13.7 |
| Detection and Removal of Molten Salts from Molten Aluminum Alloys | — | — | — | — | — | — | — |
| Oxygen-Enhanced Combustion for Recycled Aluminum | 0.025 | — | — | 0.000 | — | 0.003 | 0.400 |
| Recycling of Aluminum Dross/Saltcake Waste | 9.48 | 2.04 | 0.023 | 0.033 | 1.13 | 1.34 | 170 |
| **Chemicals** | | | | | | | |
| Aqueous Cleaner and CleanRinse™ Recycling System | 0.119 | 0.015 | — | 0.000 | — | 0.014 | 1.88 |
| DryWash® | 0.031 | 0.008 | 0.000 | 0.000 | 0.005 | 0.005 | 0.574 |
| Dual-Cure Photocatalyst | 3.71 | 0.491 | 0.003 | 0.013 | 0.160 | 0.467 | 61.7 |
| Micell Dry-Cleaning Technology | 0.021 | 0.004 | 0.000 | 0.000 | 0.003 | 0.003 | 0.386 |
| No-VOC Coating Products | 0.004 | 0.001 | — | 0.000 | — | 0.001 | 0.070 |
| Powder Paint Coating System | 5.10 | 0.603 | 0.001 | 9.95 | 0.033 | 0.603 | 81.5 |
| Pressure Swing Adsorption for Product Recovery | 0.104 | 0.081 | — | 0.000 | — | 0.012 | 1.65 |
| Supercritical Purification of Compounds for Combinatorial Chemical Analysis | 1.21 | 0.466 | 0.005 | 0.004 | 0.261 | 0.195 | 23.8 |
| Ultrasonic Tank Cleaning | 0.040 | 0.005 | — | 0.000 | — | 0.005 | 0.640 |
| Use of Recovered Plastics in Durable Goods Manufacturing | 0.381 | 0.015 | 0.001 | 0.001 | 0.062 | 0.050 | 6.74 |
| Water-Washed Overspray Paint Recovery | — | — | — | — | — | — | — |
| **Forest Products** | | | | | | | |
| Chemical for Increasing Wood Pulping Yield | 8.08 | 1.09 | — | 0.028 | — | 0.946 | 128 |
| Continuous Digester Control Technology | 8.00 | 4.00 | — | 0.028 | — | 0.936 | 127 |
| Detection and Control of Deposition on Pendant Tubes in Kraft Chemical Recovery Boilers | 0.660 | 0.484 | 0.005 | 0.003 | 0.383 | 0.102 | 14.4 |
| Improved Composite Tubes for Kraft Recovery Boilers | 0.038 | 0.007 | 0.000 | 0.000 | 0.011 | 0.005 | 0.715 |
| METHANE de-NOX® Reburn Process | 1.16 | 0.218 | 0.003 | 0.003 | 0.168 | 0.180 | 21.7 |
| Optimizing Tissue Paper Manufacturing | — | — | — | — | — | — | — |
| Pressurized Ozone/Ultrafiltration Membrane System | 0.315 | 0.315 | — | 0.001 | — | 0.037 | 5.00 |
| Thermodyne™ Evaporator – A Molded Pulp Products Dryer | — | — | — | — | — | — | — |
| XTREME Cleaner™ – Removal of Light and Sticky Contaminants | 1.19 | 0.183 | 0.005 | 0.004 | 0.258 | 0.192 | 23.5 |
| **Glass** | | | | | | | |
| Advanced Temperature Measurement System | — | — | — | — | — | — | — |
| High Luminosity, Low-$NO_X$ Burner | — | — | — | — | — | — | — |
| Oxygen-Enriched Air-Staging *(OEAS)* Technology | — | — | — | — | — | — | — |
| **Metal Casting** | | | | | | | |
| Ceramic Composite Die for Metal Casting | — | — | — | — | — | — | — |
| Die Casting Copper Motor Rotors | 0.091 | 0.085 | 0.000 | 0.000 | 0.020 | 0.015 | 1.78 |
| Simple Visualization Tools for Part and Die Design | — | — | — | — | — | — | — |
| **Mining** | | | | | | | |
| Fibrous Monoliths as Wear-Resistant Components | — | — | — | — | — | — | — |
| Horizon Sensor™ | 0.169 | 0.072 | 0.001 | 0.001 | 0.036 | 0.027 | 3.32 |
| Imaging Ahead of Mining | 4.10 | 1.64 | 0.018 | 0.014 | 0.885 | 0.659 | 80.5 |
| Smart Screening Systems for Mining | 0.002 | 0.001 | — | — | — | — | |
| Wireless Telemetry for Mine Monitoring and Emergency Communications | — | — | — | — | — | — | — |
| **Steel** | | | | | | | |
| Automatic High-Temperature Steel Inspection and Advice System | 0.478 | 0.478 | — | 0.002 | — | 0.056 | 7.59 |
| Dilute Oxygen Combustion System | 0.042 | 0.007 | — | 0.000 | — | 0.005 | 0.667 |
| Electrochemical Dezincing of Steel Scrap | 0.030 | 0.017 | 0.000 | 0.000 | 0.019 | 0.008 | 0.831 |
| Laser Contouring System for Refractory Lining Measurements | — | — | — | — | — | — | — |
| Microstructure Engineering for Hot Strip Mills | — | — | — | — | — | — | — |
| Recovery of Acids and Metal Salts from Pickling Liquors | 0.011 | 0.001 | — | 0.000 | — | 0.001 | 0.209 |
| Shorter Spherodizing Annealing Time for Tube/Pipe Manufacturing | 0.084 | 0.017 | — | 0.000 | — | 0.010 | 1.33 |
| Steel Reheating for Further Processing | 1.00 | 0.154 | — | 0.004 | — | 0.117 | 15.9 |
| Transfer Rolls for Steel Production | 0.033 | 0.017 | — | 0.000 | — | 0.004 | 0.530 |

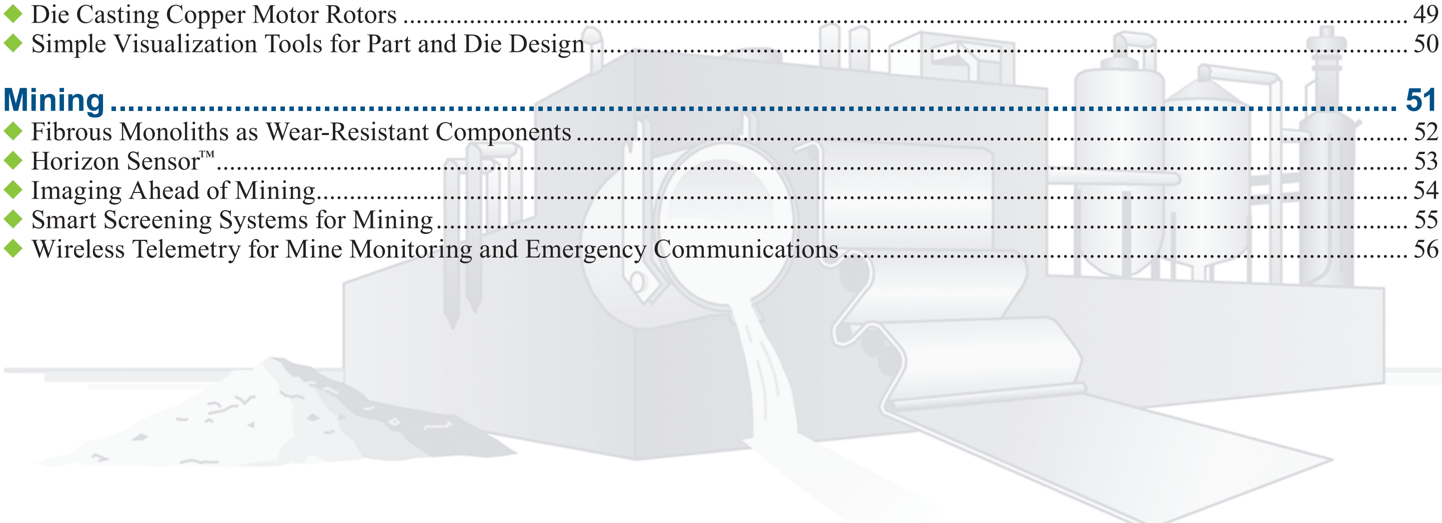
# Table 1. Technology Program Impacts

**IMPACTS**

| Technologies Commercially Available | Cumulative Energy Savings *(10¹²Btu)* | 2004 Energy Savings *(10¹² Btu)* | Cumulative Pollution Reductions *(Thousand Tons)* | | | | |
|---|---|---|---|---|---|---|---|
| | | | Particulates | VOCs | $SO_X$ | $NO_X$ | Carbon |
| **Crosscutting** | | | | | | | |
| Callidus Ultra-Blue *(CUB)* Burner | — | — | — | — | — | — | — |
| Catalytic Combustion | — | — | — | — | — | — | — |
| Chemical Vapor Deposition Optimization of Ceramic Matrix Composites | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.004 |
| Energy-Conserving Tool for Combustion-Dependent Industries | 0.004 | 0.002 | 0.000 | 0.000 | 0.001 | 0.001 | 0.077 |
| Evaporator Fan Controller for Medium-Temperature Walk-In Refrigerators | 0.054 | 0.016 | 0.000 | 0.000 | 0.012 | 0.009 | 1.06 |
| Fiber-Optic Sensor for Industrial Process Measurement and Control | — | — | — | — | — | — | — |
| Fiber Sizing Sensor and Controller | — | — | — | — | — | — | — |
| Foamed Recyclables | — | — | — | — | — | — | — |
| Forced Internal Recirculation Burner | — | — | — | — | — | — | — |
| Freight Wing™ Aerodynamic Fairings | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 |
| High-Temperature Radiant Burner | 9.47 | 2.19 | — | 0.033 | — | 1.11 | 150 |
| Improved Diesel Engines | 932 | 82.2 | 6.99 | 4.19 | 542 | 144 | 20,300 |
| Infrared Polymer Boot Heater | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.003 |
| In-Situ, Real Time Measurement of Melt Constituents | 0.259 | 0.222 | — | 0.001 | — | 0.030 | 4.11 |
| Materials and Process Design for High Temperature Carburizing | — | — | — | — | — | — | — |
| Method of Constructing Insulated Foam Homes | 0.033 | 0.005 | 0.000 | 0.000 | 0.002 | 0.004 | 0.560 |
| Mobile Zone Optimized Control System for Ultra-Efficient Surface-Coating Operations | 0.024 | 0.007 | 0.000 | 0.000 | 0.002 | 0.003 | 0.420 |
| Nickel Aluminide Trays and Fixtures Used in Carburizing Heat Treating Furnaces | 0.034 | — | — | 0.000 | — | 0.004 | 0.543 |
| PowerGuard® Photovoltaic Roofing System | 0.247 | 0.097 | 0.001 | 0.001 | 0.053 | 0.040 | 4.85 |
| Process Particle Counter | — | — | — | — | — | — | — |
| Radiation-Stabilized Burner | — | — | — | — | — | — | — |
| Real-Time Neural Networks for Utility Boilers | 57.8 | 11.2 | 0.736 | 0.068 | 36.1 | 15.8 | 1,600 |
| RR-1 Insulating Screw Cap | 0.008 | 0.002 | 0.000 | 0.000 | 0.001 | 0.001 | 0.148 |
| Solid-State Sensors for Monitoring Hydrogen | — | — | — | — | — | — | — |
| SpyroCor™ Radiant Tube Heater Inserts | 0.300 | 0.300 | — | 0.001 | — | 0.035 | 4.77 |
| SuperDrive – A Hydrostatic Continuously Variable Transmission *(CVT)* | 0.001 | 0.001 | 0.000 | 0.000 | 0.001 | 0.000 | 0.024 |
| Thin Wall Casting of Stainless Steel | 0.461 | 0.061 | 0.002 | 0.002 | 0.100 | 0.074 | 9.05 |
| Ultra-Low $NO_X$ Premixed Industrial Burner | — | — | — | — | — | — | — |
| Uniform Droplet Process for Production of Alloy Spheres | — | — | — | — | — | — | — |
| Uniformly Drying Materials Using Microwave Energy | 0.107 | 0.030 | 0.000 | 0.000 | 0.004 | 0.013 | 1.77 |
| Variable-Frequency Microwave Furnace | 0.047 | 0.009 | 0.000 | 0.000 | 0.010 | 0.008 | 0.925 |
| Waste Fluid Heat Recovery System | 0.088 | 0.025 | 0.000 | 0.000 | 0.009 | 0.012 | 1.55 |
| Waste-Minimizing Plating Barrel | 3.01 | 0.524 | 0.009 | 0.011 | 0.449 | 0.444 | 55.7 |
| **Others Industries** | | | | | | | |
| Absorption Heat Pump/Refrigeration Unit | 2.23 | 0.306 | 0.017 | 0.010 | 1.30 | 0.345 | 48.6 |
| Advanced Membrane Devices for Natural Gas Cleaning | — | — | — | — | — | — | — |
| Brick Kiln Design Using Low Thermal Mass Technology | 0.248 | 0.032 | — | 0.001 | — | 0.029 | 3.94 |
| Continuous Cascade Fermentation System for Chemical Precursors | 0.814 | 0.037 | — | — | — | — | 17.2 |
| Energy-Efficient Food Blanching | 0.007 | 0.001 | 0.000 | 0.000 | 0.002 | 0.001 | 0.125 |
| Ink Jet Printer Solvent Recovery | 0.345 | 0.051 | 0.145 | 0.113 | 6.96 | 5.18 | 633 |
| Irrigation Valve Solenoid Energy Saver | 0.014 | 0.003 | 0.000 | 0.000 | 0.003 | 0.002 | 0.268 |
| Restaurant Exhaust Ventilation Monitor/Controller | 0.605 | 0.236 | 0.003 | 0.002 | 0.131 | 0.097 | 11.9 |
| Stalk and Root Embedding Plow | 0.102 | 0.020 | — | — | — | — | 2.16 |
| Textile Finishing Process | 0.136 | 0.023 | 0.000 | 0.000 | 0.013 | 0.019 | 2.38 |
| Utilization of Corn-Based Polymers | 0.033 | 0.018 | 0.000 | 0.000 | 0.019 | 0.005 | 0.723 |
| **Commercial Technologies Total** | 1,060 | 111 | 7.98 | 14.5 | 590 | 174 | 23,700 |
| **IAC Total** | 1,130 | 133 | 5.41 | 4.08 | 354 | 173 | 22,400 |
| **BestPractices Total** | 322 | 122 | 1.55 | 1.18 | 103 | 49.3 | 6,400 |
| **Historical Technologies Total** | 2,210 | N/A | 8.20 | 6.72 | 426 | 351 | 42,400 |
| **Grand Total** | **4,720** | **366** | **23.1** | **26.5** | **1,470** | **747** | **94,900** |

# Appendix 1:
## ITP-Sponsored Technologies Commercially Available





# ITP-Sponsored Technologies Commercially Available

IMPACTS

# Aluminum

IMPACTS

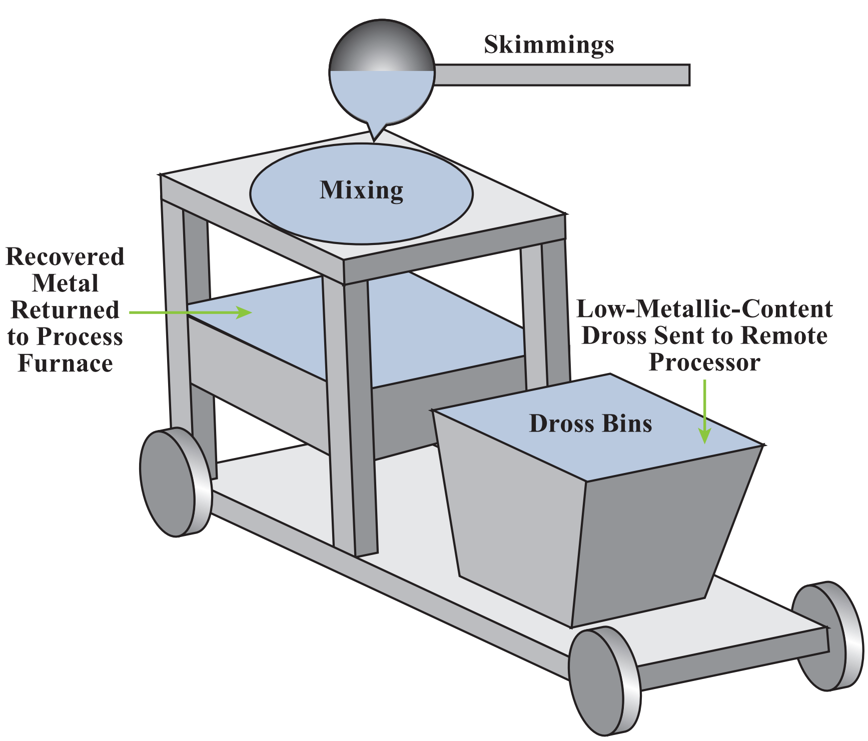
# Aluminum Reclaimer for Foundry Applications



## Affordable Metallic Recovery System Saves Energy and Reduces Landfill Waste Streams

Aluminum foundries and melters typically generate metallic skimming and drosses during industrial processes. While equipment is commercially available to recover a portion of the contained metallics from skimmings and drosses, the capital investment for the equipment has precluded its application with smaller melting units such as crucible or reverb melters. With assistance from DOE's Industrial Technologies Program, Q.C. Designs, Inc., developed an improved reclaiming process specifically to recover the metallics from small quantities of dross and skim. Recent advances in the technology permit an increase in the quantity of drosses being processed and allow the recovered metal to be returned to the generating furnace in molten form, in some cases. The process has recovered as much as 80% of the contained metal at the point of generation.

In operation, the process may be run either manually, with power-assisted stirring, or with a fully automatic programmed cycle. The operation is environmentally friendly reducing the amount of smoke and fumes normally associated with dross processing and furnace cleaning. Foundries reduce their melting losses by the in-plant recovery of drosses and their contained metals, which can then be reused directly without realloying.




*Portable Aluminum Reclaimer*

## Overview

- Available from Q.C. Designs, Inc.
- Commercialized in 2001
- Six units installed in the United States

## Applications

In-plant aluminum foundry dross and skimming recovery

## Capabilities

- Processes hot dross in quantities from 20 to 500 lb.
- Allows automatic processing or manual operation.
- Features sizes for applications in different foundry installations.

## Benefits

### Energy Savings

The recovered metal from the new system may be reintroduced into the process in molten form, saving the energy required to remelt an ingot recovered in a traditional process. Less energy is required to transport and move the dross to an outside processor because the system is on-site, and the material does not have to be remelted for secondary recovery of the metallics.

### Productivity

The improved ability to decrease melting losses contributes directly to profits. Typical compensation for dross materials from outside processors is 10% to 20% of true value because the generating foundry has to bear the costs of transportation, remelt and processing, landfill of the waste, and return of the recovered material. In-plant processing eliminates most of these costs.

### Waste Reduction

The technology avoids sending process salts to landfills and recovers a higher percentage (up to 80%) of metallics than current methods.

IMPACTS

## Indirect-Fired Kiln Turns Aluminum Scrap into Valuable Feedstock

Through a grant from DOE's NICE³ Program, Energy Research Company has further developed and demonstrated an innovative aluminum-scrap melting process. This process uses an indirect-fired controlled-atmosphere kiln to remove machining lubricants, oils, and other materials from the scrap aluminum. Once removed, these materials are combusted in an afterburner, destroying all volatile organic compounds (VOCs) and releasing heat used to drive the process.

This innovation de-coats scrap aluminum parts in a controlled atmosphere with limited oxygen to avoid scrap-oil combustion and scrap oxidation. The resulting gases are then combusted in an incinerator, apart from the scrap, to destroy the volatile organic compounds. The heat released from this atmospheric combustion drives the de-coating process. There are currently 3 units operating in the United States and an additional 15 worldwide.

## Overview

- Developed by Energy Research Company
- Commercialized in 1997
- 3 units operating in the United States in 2004

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 1.17 | 0.378 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.0 | 0.0 | 0.044 | 6.00 |

## Benefits

### Energy Savings

Energy savings of 55% over conventional kiln decoating.

### Environmental

Reduces solid-waste disposal needs because of reduced dross and oxidized product.

### Productivity

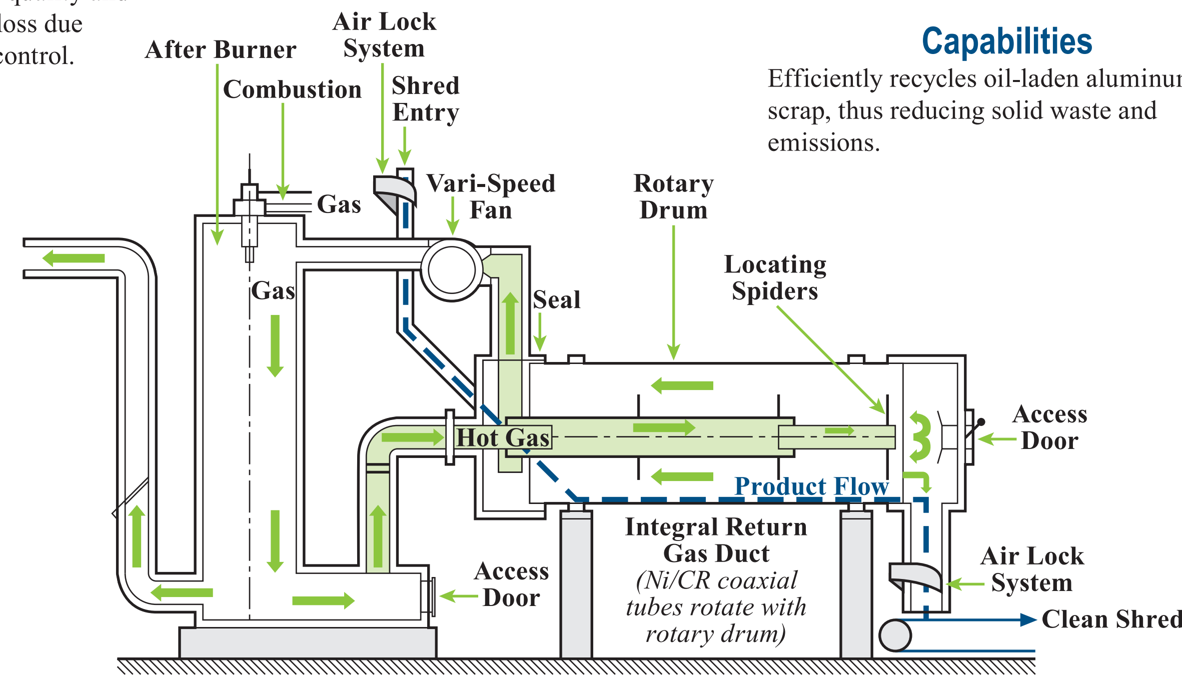
Improved product quality and reduced material loss due to better process control.

## Applications

- The secondary aluminum industry that processes scrap from the manufacturing process and used aluminum
- May also be used when processing other materials with organic binders or coatings, such as fiberglass recycling

## Capabilities

Efficiently recycles oil-laden aluminum scrap, thus reducing solid waste and emissions.




*Aluminum Scrap Decoater*

# Aluminum Scrap Sorting



## Effective Scrap Sorting Provides Large Energy Benefits

Huron Valley Steel (HVS) Corporation has developed new scrap sorting technologies, and with support from ITP, they demonstrated that aluminum scrap from aluminum-intensive vehicles can be recycled. The HVS technology assesses the composition and material recovery from the sorting steps required to produce alloy-sorted aluminum from mixed-alloy scrap. A proprietary HVS technology is used for wrought-cast separation. After the wrought fraction is tint-etched, color sorting groups the wrought iron alloys. Laser induced breakdown spectroscopy is used for real-time, remote chemical analysis of each scrap particle and allows the sorting line to separate individual alloys.

This particle-sorting technology focuses on demonstrating the capability to sort nonferrous metal scrap from the reusable materials from aluminum-intensive vehicles. The process includes physical property sorting and chemical composition sorting and is capable of real-time, piece-by-piece batching of specific alloy compositions from the analyzed scrap. This process will help improve the melt composition of recycled materials and is more efficient and less energy intensive than existing chlorination, fractional solidification, and electro-refining processes.

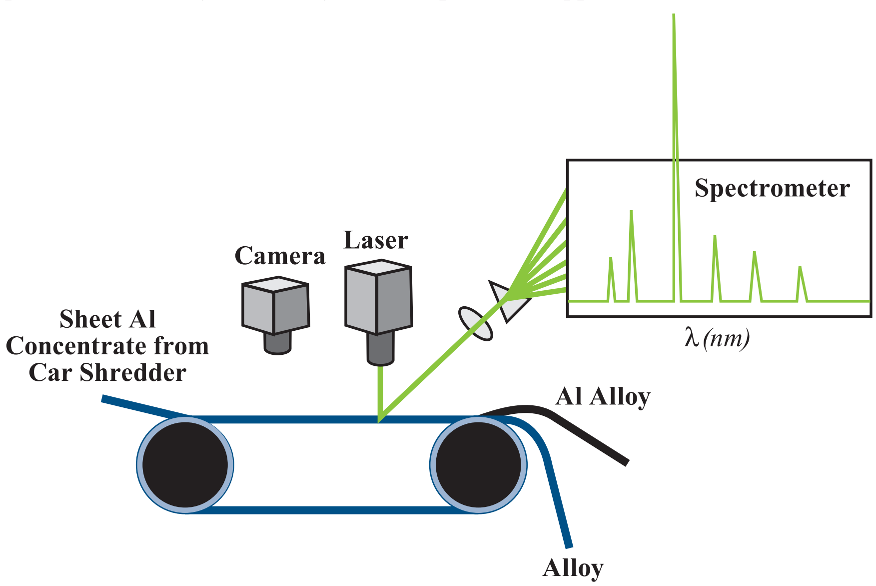
## Benefits

### Environmental

Using aluminum that otherwise would have been scrapped decreases the production of prime metal and thereby reduces greenhouse gas emissions.

### Use of Raw Materials/Feedstocks

The process can eliminate a portion of raw aluminum production and any other alloys that the process is applied to.




*Aluminum Scrap Sorting System*

## Overview

- Developed by Huron Valley Steel Corporation
- 7500 tons of sorted product processed in 2004

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 0.698 | 0.338 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.002 | 0.073 | 0.054 | 6.63 |

## Applications

- Sorting of mixed aluminum scrap streams
- Sorting of vehicle and other equipment scrap streams

## Capabilities

- Improves sorting of mixed aluminum scrap streams.
- Allows aluminum from scrapped motor vehicles to be separated and used as high value aluminum alloys.
- Separates cast aluminum from wrought, groups aluminum into alloy families, and differentiates between wrought alloys.

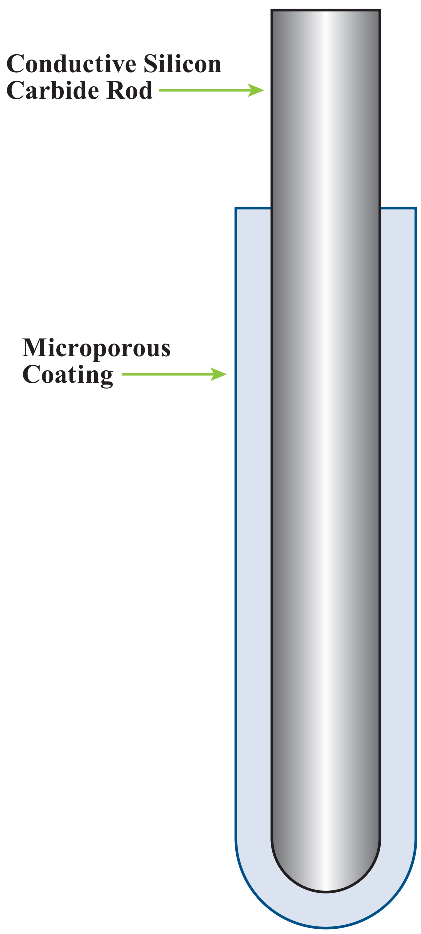
# Detection and Removal of Molten Salts from Molten Aluminum Alloys

IMPACTS

## New Probe and Filter Will Improve Metal Quality Through Detection and Removal of Impurities

With assistance from DOE's Inventions and Innovation Program, Selee Corporation and the Alcoa Technical Center have developed and commercialized this technology to detect and reduce chloride salts in molten aluminum. These salts have been shown to initiate defects when they agglomerate and migrate to the surface of an ingot or casting. Because they are liquid at aluminum casting temperatures, they can pass through conventional filter systems, which are designed to capture solid inclusions. Moreover, they tend to reduce the efficiency of filters by causing the release of solid inclusions.

The operation principle of the salt probe and filter is based on interfacial surface phenomena between the various liquid phases (salt and aluminum) and the solid salt system material. The probe is made up of a thin, microporous, ceramic layer that is coated onto an electrically conductive silicon carbide rod. The rod is immersed into the molten aluminum and a potential difference is applied to the probe. Salt can penetrate the coating on the probe and, due to the ionic nature of the salt, an electrical current that can be measured is formed. The filter also uses microporous ceramic to separate the salts from the liquid aluminum.




*Salt Probe*

## Overview

- Developed by Selee Corporation and the Alcoa Technical Center
- 2 units are in operation in the United States and Canada
- Commercialized in 1999

## Applications

The technology will improve metal quality by detecting and removing impurities and inclusions from molten aluminum

## Capabilities

The technology will improve metal quality by detecting and removing impurities and inclusions from molten aluminum

## Benefits

### Energy Savings

Elimination of melt rejection and recast due to salt contamination, with potential annual energy savings of 0.04 trillion Btus.

### Productivity and Cost

Estimated reduction in chlorine use and release of about 71,000 cubic feet per year.

### Product Quality

Improved metal quality, recovery, and reliability.

# Oxygen-Enhanced Combustion for Recycled Aluminum



## New Metal Melting System Results in Low $NO_X$ Emissions, Reduced Energy Use, and Increased Productivity

With ITP support, Air Products & Chemicals, Inc., in cooperation with Argonne National Laboratory, Wabash Alloys, L.L.C., and Brigham Young University, developed and demonstrated a low-$NO_X$ combustion burner integrated with an onsite vacuum-swing-absorption (VSA) oxygen-generation system. This new burner, operated at the Wabash Alloy recycled aluminum furnace, used controlled mixing of fuel, air, and high-purity oxygen streams to lower emissions and improve flame quality.

The VSA system uses a patented high-efficiency molecular sieve to remove nitrogen from the air. Conventional VSA plants are sized for peak demand, and the excess oxygen is vented to the air during off-peak operation. In this application, the oxygen VSA is improved to operate with a sieve-filled storage vessel that stores oxygen produced when demand is below the average oxygen requirement. The sieve-filled vessel provides 2.5 times the oxygen storage capacity of an empty tank of equal volume. The integration of the new burner with the VSA system greatly reduces $NO_X$ emissions while reducing energy usage and increasing melting productivity.

## Benefits

### Cost Savings

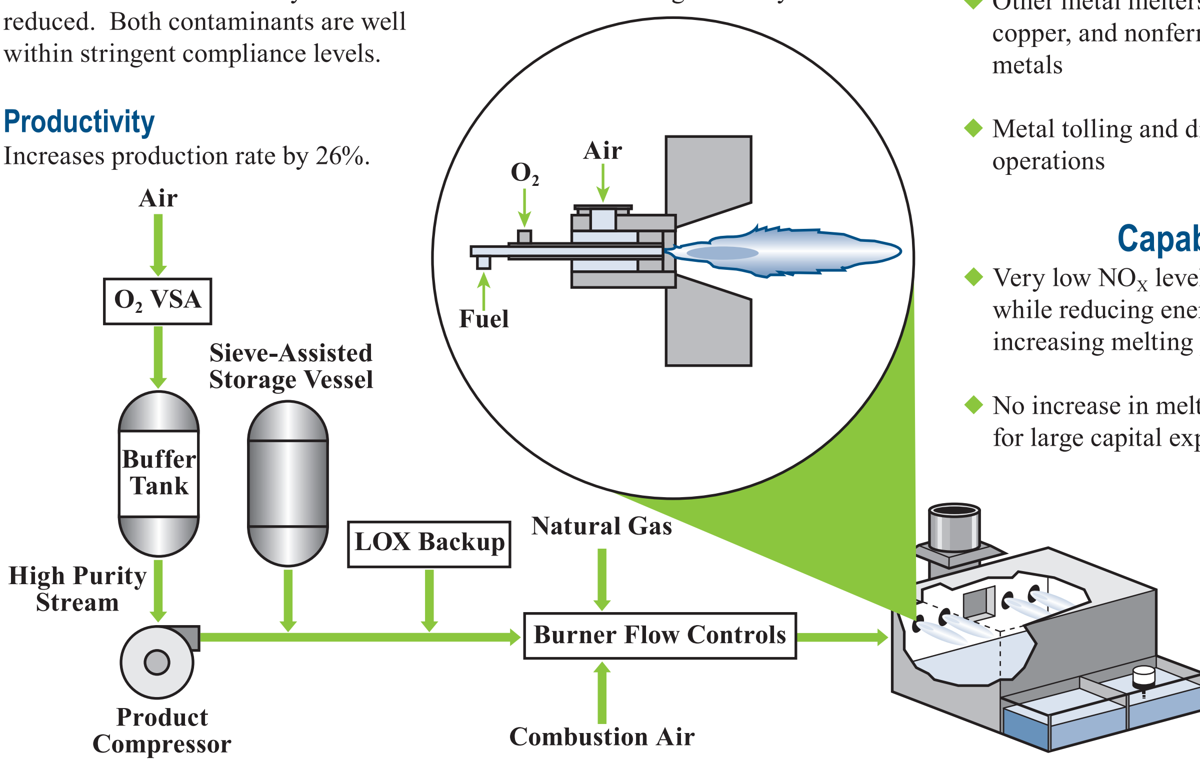
Using oxygen from storage reduces the overall oxygen consumption and costs by 33% compared to the previously installed burner.

### Environmental Quality

Reduces NOX emissions by 80%. Carbon monoxide is also significantly reduced. Both contaminants are well within stringent compliance levels.

### Productivity

Increases production rate by 26%.




*Oxygen-Enhanced Combustion*

## Overview

- Developed by Air Products & Chemicals, Inc.
- Demonstrated at Wabash Alloys in East Syracuse, NY
- Commercialized in 1999

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 0.025 | 0.0 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.0 |

## Applications

- Can be retrofit to reverberatory furnaces commonly used to melt recycled aluminum
- Other metal melters for zinc, lead, copper, and nonferrous and ferrous metals
- Metal tolling and dross recovery operations

## Capabilities

- Very low $NO_X$ levels maintained while reducing energy use and increasing melting productivity.
- No increase in melting cost or need for large capital expenditures.

# Recycling of Aluminum Dross/Saltcake Waste

IMPACTS

## New Technology for Recovering Aluminum Dross/Saltcake Waste Saves Energy and Reduces Waste

The melting process used by the secondary aluminum industry when recycling aluminum creates a waste stream known as black dross/saltcake (dross). It is estimated that up to 1 million tons of dross is generated and landfilled annually in the United States. In the past, efforts to recover useful material from the dross have resulted in recovery of only a small portion of aluminum (about 3% to 10% of processed dross). The remaining 90% + of the dross, at best some 900,000 tons, is landfilled. Significant embodied energy could be saved from recovering three different components of the dross: aluminum, spent salt flux, and nonmetallic products (NMP).

With assistance from the NICE$^3$ Program, Alumitech, Inc. undertook a successful 15-month plant construction and start-up project to commercialize a process to facilitate closed-loop recycling of dross through the manufacture of industrial ceramic products from recovered nonmetallic waste.

Starting with the dross material, Alumitech separates the dross into its basic components—aluminum metal, fluxing salts, and NMP. The aluminum metal and salt fluxes can be sold back to the secondary aluminum or other industries. In 2004, aluminum metal was recovered with an embodied energy savings of about 11 million Btu per ton of dross processed with this new system. A project goal was to commercialize a new process and to make NMP usable for a variety of product applications.

## Benefits

### Productivity

Alumitech process not only separates the aluminum and commercial oxides for reuse but also can recycle the remaining NMP into commercially salable products completely avoiding landfilling.

### Use of Raw Materials/Feedstocks

Recovers materials for use as feedstocks in other process operations, thus conserving raw materials.

### Waste Reduction

Products from NMP being developed will reduce landfill to zero for secondary aluminum operations.

## Overview

- Developed by Alumitech, Inc.
- Commercialized in 1997
- 3 units operating in 2004

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 9.48 | 2.04 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.005 | 0.242 | 0.287 | 36.5 |

## Applications

- Secondary aluminum process waste steams
- Steel-making slag products and ceramic fiber feedstock developed from waste material

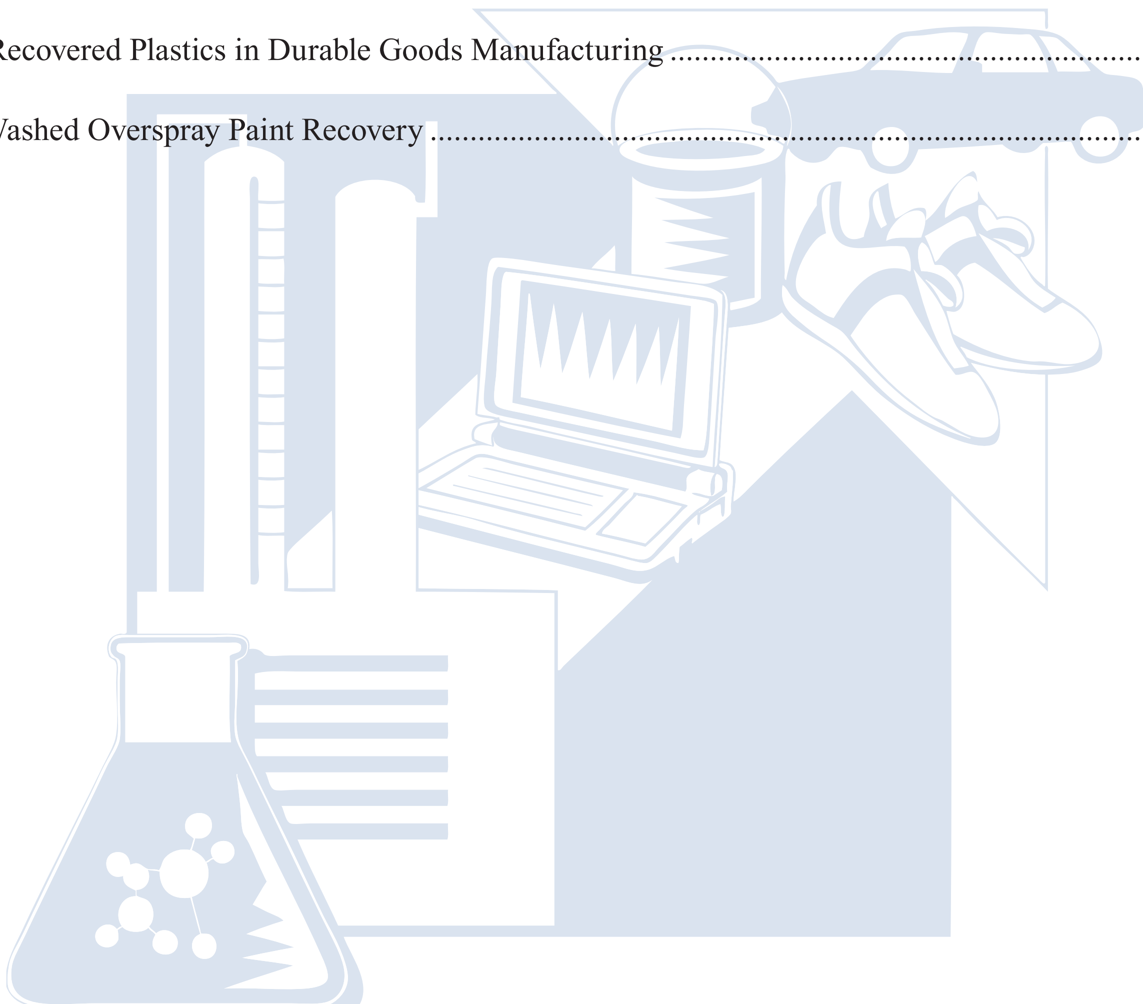
## Capabilities

Provides complete closed-loop recycling of secondary aluminum black dross/saltcake waste streams.

# Chemicals

**IMPACTS**





# Aqueous Cleaner and CleanRinse™ Recycling System

IMPACTS

## New Recycling System Improves Aqueous Cleaning System

Most traditional systems for pollution control focus on the end-of-pipe treatment and disposal of waste. The U.S. Environmental Protection Agency (EPA) has mandated a new emphasis on improved resource usage that focuses on source reduction. Many methods, including filtration, reverse osmosis, de-ionization, and distillation, could help meet this goal but often have high energy needs or produce additional waste streams.

With assistance from DOE's Inventions and Innovation Program, EcoShield Environmental Systems developed a simple mini-reactor system that chemically converts organic oily contaminants into surfactants and emulsifiers. This conversion increases the cleaning solution's ability to remove oil, grease, and dirt. The system regenerates the cleaning solution on site, creating less waste water and often decreasing the cleaning time required. The system has low energy needs and can be coupled with an energy-efficient bioreactor that will convert excess soap into biomass. The current applications of the technology have resulted in tremendous waste prevention and large cost savings.

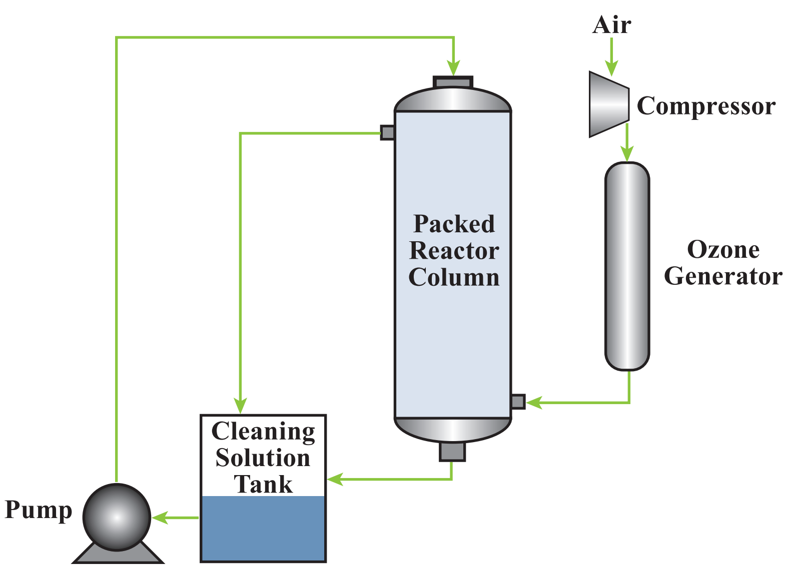
## Benefits

### Productivity

The system extends the life of the cleaning solution and rinse water, which reduces the costs associated with waste water disposal and chemical consumption. The system also has low operational costs (less than 5 cents per hour).

### Waste Reduction

The technology reduces the chemicals typically consumed in the traditional cleaning process and extends the life of the cleaning solution. The system can be integrated with EPA's permanent pollution prevention plans.




*EcoShield Aqueous Cleaner*

## Overview

- Developed by EcoShield Environmental Systems under an exclusive license from EcoShield Environmental Technologies Corporation
- Commercialized in 1997

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 0.119 | 0.015 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.0 | 0.0 | 0.002 | 0.235 |

## Applications

Neutral to basic pH applications where aqueous waste streams containing organic contaminants are to be cleaned

## Capabilities

- Converts excess soap to biomass using an optional companion bioreactor.
- Offers custom sizes and configurations for wash racks, cabinet washers, and automated lines.
- Is applicable for high-temperature installations.

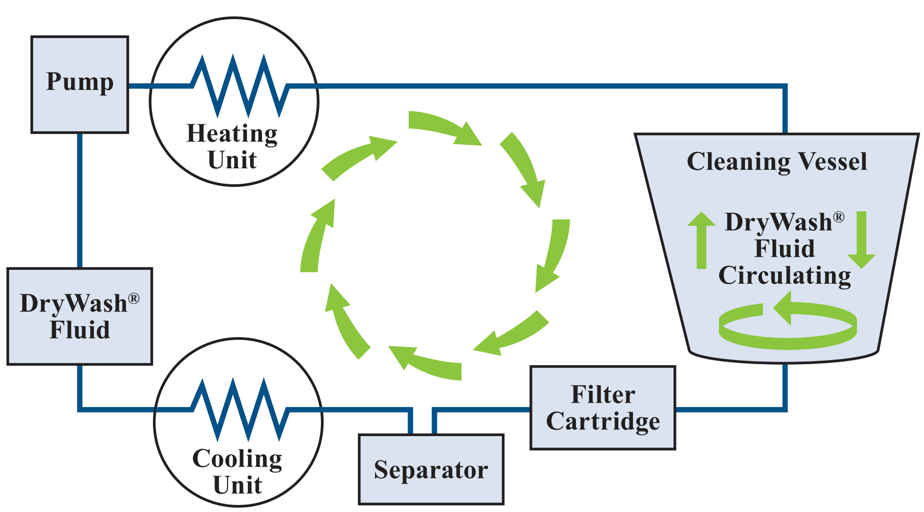
IMPACTS

## A New Generation of Chemicals for Cleaning Applications

With ITP support, Raytheon Technologies, Inc. (formerly Hughes Environmental) and Los Alamos National Laboratory used defense-related expertise in supercritical fluids to develop DryWash, an entirely new $CO_2$-based system for dry cleaning fabrics. Current dry-cleaning practice uses perchlorethylene as the cleaning solvent to loosen and remove dirt from the fibers of clothing material. However, the dry-cleaning industry must eliminate its use of perchlorethylene because both the atmospheric emissions and the chemical itself have significant environmental impacts. Based on the desirable characteristics of $CO_2$ – it is inert, stable, non-corrosive, and non-flammable – the DryWash system introduces a new generation of technology to the dry cleaning industry.

DryWash uses liquid $CO_2$-based fluid (not generic $CO_2$) as the base solvent, but adds a new surfactant (dirt removing detergent additive), and then applies this new combination of cleaning liquids with a unique spraying device and agitation mechanism – all in a self-contained system. The DryWash process soaks the clothes in a liquid $CO_2$ filled tub at a pressure of 700 to 750 pounds per square inch and 54°F to 58°F. The load is agitated and at the end of the cycle, the dirt and oily residue drop out and $CO_2$ pressure is lowered, allowing for the efficient recycling of $CO_2$.

Global Technologies LLC began introducing the DryWash system in Europe in the fall of 1998 and started marketing in the United States in mid-1999. Commercial systems are now being sold by Alliance Laundry Systems LLC and SailStar USA.




*Drywash Process*

## Overview

- Developed by Raytheon Technologies, Inc. and commercialized by Global Technologies, LLC
- Commercialized in Europe in 1998 and the United States in 2000 with over 56 machines in operation in the United States

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 0.031 | 0.008 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.0 | 0.001 | 0.001 | 0.155 |

## Applications

Replaces conventional dry-cleaning systems that use perchlorethylene or petroleum-based solvents

## Capabilities

- Uses an environmentally benign solvent (CO2 based fluid) rather than hazardous solvents.
- Cleans equal to or better than conventional systems.
- Reduces cycle time by eliminating the energy-intensive drying step in the process.

## Benefits

### Profitability

Reduces cycle time by 50% and lowers operating costs.

### Quality Improvement

Decreases dirt redeposition and dye transfer and has better performance in oily, particulate soil and stain removal. Reduces shrinkage and has better color retention.

# Dual-Cure Photocatalyst

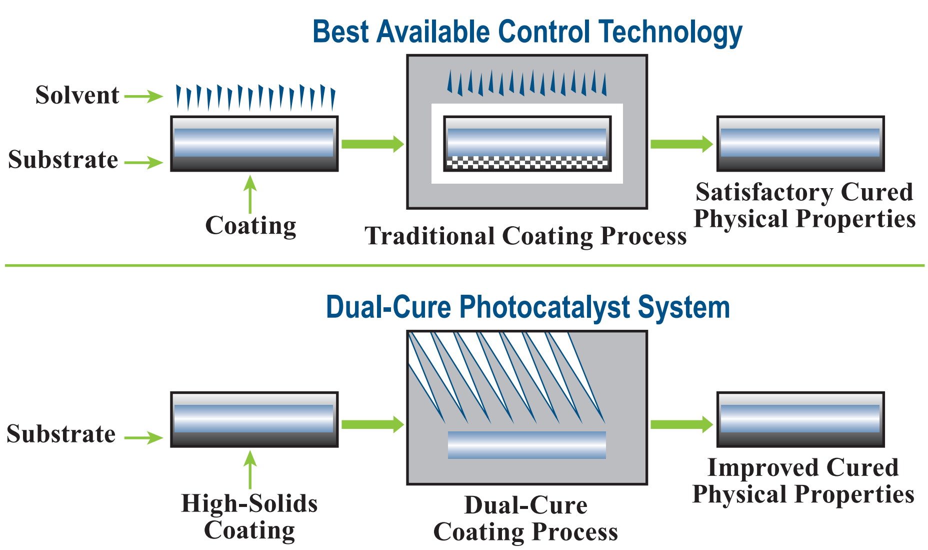


## Low VOC Coating Process Reduces Emissions

As part of a constant search for new technologies that protect our environment and use carbon-based resources most efficiently, 3M with support from ITP, developed a new generation of paints, coatings, adhesives, and sealants incorporating new binding systems for civilian and military applications. Traditional volatile organic compound (VOC)-based coatings release undesirable organic chemical vapors into the atmosphere during the drying or curing phase of the coating application. The new and replacement products do not sacrifice performance, appearance, or ease of application, and demonstrate superior consistency and reliability.

The basis of the dual-cure process is a novel photocatalyst system that allows light-activated, simultaneous polymerization of two monomers to produce a material consisting of two independent but interpenetrating polymer networks (IPNs). The properties of these IPNs are generally superior to either separate component.

Because of the variety of monomers that can be used, the dual-cure process allows greater flexibility in tailoring the final properties of the cured coatings for specific applications. The VOC emission levels from this process are substantially below those obtained using conventional coating technologies, and cure times are shorter.




*Coating Technologies*

## Overview

- Developed by the 3M Company
- Commercialized in 1993
- 5.52 million pounds of coating used in 2004

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 3.71 | 0.491 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.0 | 0.021 | 0.062 | 8.17 |

## Applications

Process used as a coating and binder system for a variety of coated products

## Capabilities

- Uses photocatalysts (activated by exposure to light) to simultaneously polymerize two monomers to produce a novel coating without VOC-emitting solvents.
- Demonstrated cure of the coatings at temperatures as low as 60°F.

## Benefits

### Cost Savings

Cost is comparable to that of current coatings. Requires no solvent.

### Productivity

Reduces application time and requires no solvent disposal or heat for evaporative drying. 3M reports a 4% to 6% increase in yield and a 20% to 30% increase in productivity.

### Product Quality

Has greater durability, tensile strength, and flexibility.

IMPACTS

## New Cleaning Method Eliminates Use of Harmful Chemicals while Saving Energy

Micell Technologies developed a new dry cleaning technology using patents and know-how that is based on ITP sponsored research on $CO_2$ surfactant technology performed by the Pacific Northwest National Laboratories. The Micell $CO_2$ dry cleaning technology is called the Micare™ system. Micell Technologies is the parent company of Hangers Cleaners, who offers franchises incorporating the Micare dry cleaning technology. Currently, there are over 75 Hangers Cleaners locations across the country.

The heart of the Micare system is the specially designed $MICO_2$ machine with a 60-pound capacity and able to hold liquid $CO_2$. Garments to be cleaned are placed inside a large rotating basket in the $MICO_2$ machine and the door is closed, sealing the system. Carbon dioxide is added from the storage tank along with the Micare detergent package. This patented detergent system enhances the cleaning ability of the liquid $CO_2$ allowing it to remove dirt from the garments. After the cleaning cycle, the machine pulls the solution of liquid $CO_2$ and cleaning detergents away from the clothes, and then cleans and recycles the $CO_2$. Most (98%) of the $CO_2$ is recycled, while a small amount of $CO_2$ gas is then vented to the atmosphere. The cleaned garments are then removed from the wash tank after a cycle time of 35-45 minutes.

## Benefits

### Energy Savings
Eliminates the energy-intensive drying cycle used by conventional dry-cleaning systems.

### Productivity
Reduces operating time and costs less to operate than the conventional perc systems.

### Quality
Cleans effectively with no unpleasant odors, treats garments gently, and eliminates the chance of heat-related damage or setting of stains, as there is no drying cycle.

### Waste Reduction
Eliminates harmful releases of perchlorethylene or other petroleum solvents to both the air and groundwater.

## Overview

- Commercialized in 1999 by Micell Technologies
- In 2004, there were 29 Micell machines serving 75 Hangers Cleaners stores throughout the United States.

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 0.021 | 0.004 |

## Emissions Reductions

*(Thousand Tons, 2004)*

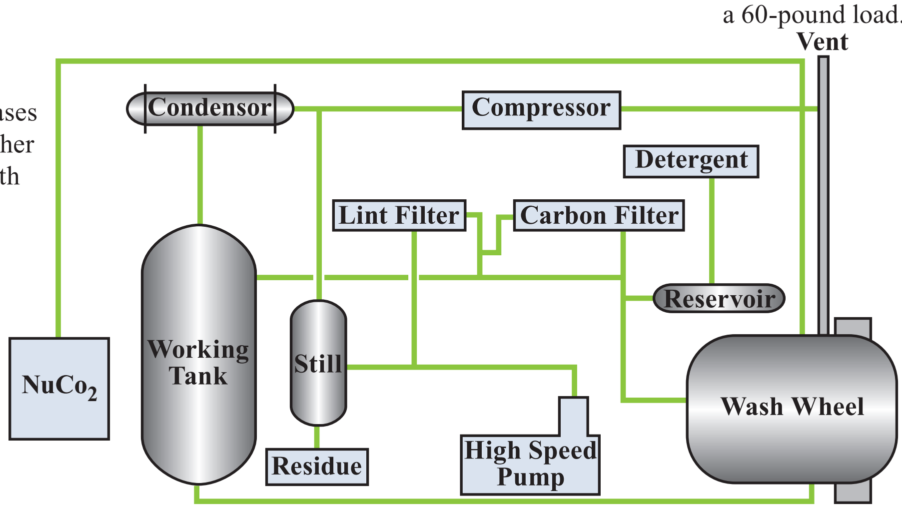
| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.0 | 0.001 | 0.001 | 0.080 |

## Applications

Replaces perchlorethylene or petroleum-based solvents used by conventional dry-cleaning systems

## Capabilities

- Cleans equal to or better than conventional systems.
- Is similar to conventional front-load, mechanical action machines and features gentle wash and extract cycles.
- Requires only 35 to 45 minutes to clean a 60-pound load.




*Micell Dry-Cleaning Process*

# No-VOC Coating Products



## New Water-Based Coating Products Reduce Drying Time and Environmental Impacts

At present, a major concern of the coatings industry is the emission of volatile organic compounds (VOCs), which react with sunlight to create photochemical ozone or smog. VOC-containing solvents used in conventional liquid coatings evaporate during application, curing, and during clean-up operations. With help from a DOE NICE$^3$ grant, Sierra Performance Coatings has developed new waterborne coatings that reduce or eliminate VOC emissions during formulation and application. The production of these new coatings requires lower processing temperatures, which reduces their energy impact. The coatings' quick-drying characteristics save further energy by avoiding heating and ventilation in the drying process.

Waterborne non-VOC coatings substitute water for a portion of the solvent used as the resin retainer in typical organic coating formulations. These new coatings can be applied to many surfaces including metal products. The quick-drying formulation reduces energy needs for drying and eliminates installation problems associated with harmful vapors. Many of these new products dry far more quickly than other products so multiple coats can be applied in one day rather than two or three. This dramatically cuts labor costs and returns the facility to use much sooner. Similarly, the corrosion resistance of Sierra's coatings are superior to any solvent-based coatings on the market.

## Benefits

### Energy Savings
Reduces or eliminates the energy for drying in-line production processes.

### Emissions Reductions
Reduces environmental impact and increases compliance with regulations and environmental requirements.

### Productivity
Speeds drying and uses simple water clean-up, thereby reducing downtime between coats and at the end of jobs. Reduced emissions also reduce ventilation equipment and labor.

### Safety
Eliminates skin irritation from solvent contact and reduces exposure to harmful vapors, the need for ventilation, and the risk of fire from organic vapors, resulting in safer installation.

## Overview

- Developed by Sierra Performance Coatings and being marketed by RPM International, Inc.
- Commercialized in 1998
- 478,950 gallons produced and applied through 2004

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 0.004 | 0.001 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.011 |

## Applications

No-VOC solvents can be found as components of exterior opaque stains, exterior and interior semitransparent stains, waterproofing sealers, clear wood finishes, varnishes, and sanding sealers

## Capabilities

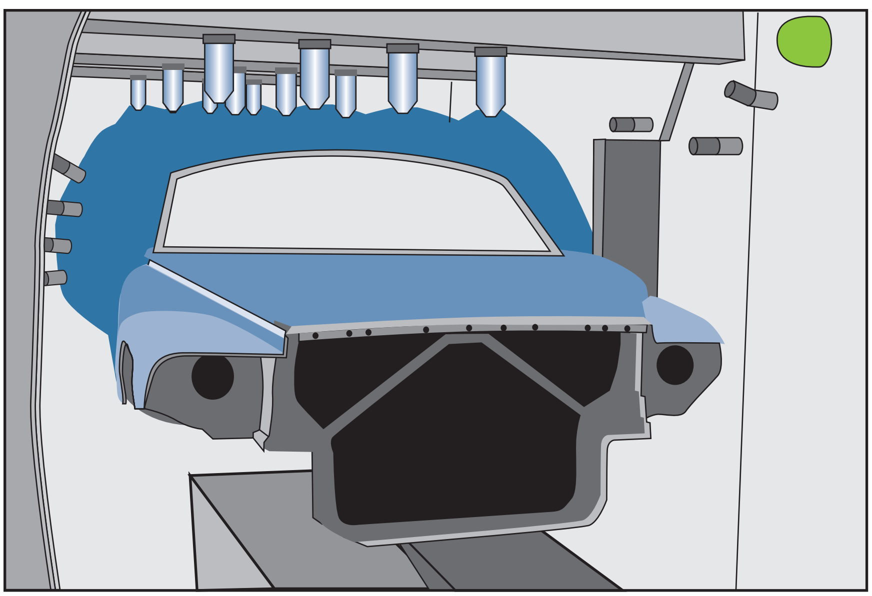
- Provides equal protection and material covering characteristics such as longevity and toughness with improved drying times and easier installation.
- Allows for quicker installation with none of the noxious fume problems associated with standard products.
- Reduces drying time and environmental impacts.

IMPACTS

## Full-Body Powder Antichip Process Reduces Waste Emissions

Chipping paint is a major cause of customer dissatisfaction with United States-produced automobiles. The current standard for applying antichip primer to vehicles is a solvent-borne paint spray system that has a transfer efficiency (ratio of paint solids deposited on the vehicle to total volume used) of about 50%. In addition to generating a paint sludge by-product that must be landfilled, the process emits volatile organic compounds (VOCs). Chrysler Corporation developed and demonstrated, using a NICE$^3$ grant, an innovative, new powder antichip process that contains no solvents and, considering recycling, has an effective transfer efficiency exceeding 99%. The new system virtually eliminates VOC emissions and paint sludge generation, eliminating the costs to transport and dispose of sludge.

Energy requirements for the powder process are much lower than for solvent-based processes. Though process air at 70°F is required for the application of either coating, in the new process a much smaller quantity of air needs to be heated, and the air from the powder booth can be recycled and reused directly because it contains no solvents. The energy that had been required to incinerate VOCs from the conventional process is conserved.



*New Powder Antichip Primer Process*

## Overview

- Developed by the Chrysler Corporation
- Commercialized in 1996

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 5.10 | 0.603 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.0 | 0.004 | 0.071 | 9.63 |

## Applications

Antichip primer application for automobiles

## Capabilities

- Has transfer efficiency exceeding 90%.
- Has greatly reduced air-heating requirements.

## Benefits

### Energy Savings

Reduced air requirements and ability to recycle process air leads to greatly reduced air-heating requirements. Also eliminates energy requirements for incinerating VOCs.

### Quality

Process gives better finish with reduced risk of delamination and chipping.

### Use of Raw Materials

Conserves raw materials used to manufacture virgin coatings.

### Waste Reduction

Contains no solvents, thereby reducing potential VOC emissions. Higher transfer efficiency reduces overspray, virtually eliminating solid waste generation.

# Pressure Swing Adsorption for Product Recovery

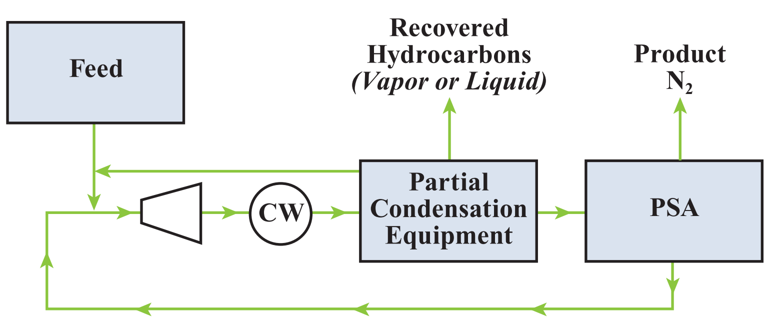


## Highly Selective Pressure Swing Adsorption Technology Recovers Valuable Components from Waste Streams

Many polyolefin plant designs use a polymer degassing step to remove unreacted monomer, solvents, and additives from the product polymer fluff before it is processed in downstream palletizing operations. When nitrogen is used as the stripping gas, the operation produces a low-pressure gas stream that typically contains nitrogen and valued hydrocarbons that can be recovered and recycled to the plant. If the gas is not processed for recovery, it is typically flared. The flaring step results in volatile organic compounds, $NO_X$, and $CO_2$ emissions. Flaring can also be costly, roughly equal to the value of the purchased nitrogen.

With assistance from DOE's Industrial Technologies Program, Air Products and Chemicals has developed a single unit operation to recover these gases. Pressure swing adsorption (PSA) is combined with partial condensation to essentially recover 100% of the hydrocarbons from the vent gas. In addition, QSA produces a high purity $N_2$ stream, with nearly 100% recovery of nitrogen. The recovered nitrogen can be recycled to the stripping operation or used elsewhere in the facility. Air Products' high recovery system eliminates waste streams and therefore emissions.

In this new process, the vapor stream from the partial condensation section flows into a PSA unit. Within the PSA, specially selected adsorbent materials extract hydrocarbons, thereby refining the nitrogen to a high purity with minimal pressure drop. Over time the adsorbent material in the bed becomes saturated and must be regenerated. Lowering the pressure in the saturated bed desorbs the hydrocarbon components from the adsorbent material in the PSA. The hydrocarbons are released and recovered in a low-pressure tail gas, which is recycled back to the compressor suction so the hydrocarbons are not lost. This technology provides a significant opportunity for energy and cost savings and reduced waste.




*Pressure Swing Adsorption Recovery*

## Overview

- Developed by Air Products and Chemicals
- Commercialized in 2003
- Installed in two locations in Texas

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 0.104 | 0.081 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.0 | 0.0 | 0.01 | 1.29 |

## Applications

Both chemical and refining industries, including polyethylene and polypropylene production processes that use $N_2$ for degassing the polymer fluff and for treating refinery off-gas streams. This process could be adapted to recover valuable products from other waste streams throughout the industry.

## Capabilities

- Recovers hydrogen, nitrogen, and hydrocarbons for reuse.
- Is flexible enough to operate using an external refrigeration source.

## Benefits

### Pollution Reduction

Exit streams from certain processes can be collected and separated for reuse, eliminating the emissions and need for disposal. Disposal typically involves flaring of the waste streams; therefore, this new process can save energy and costs by eliminating flaring.

### Profitability and Productivity

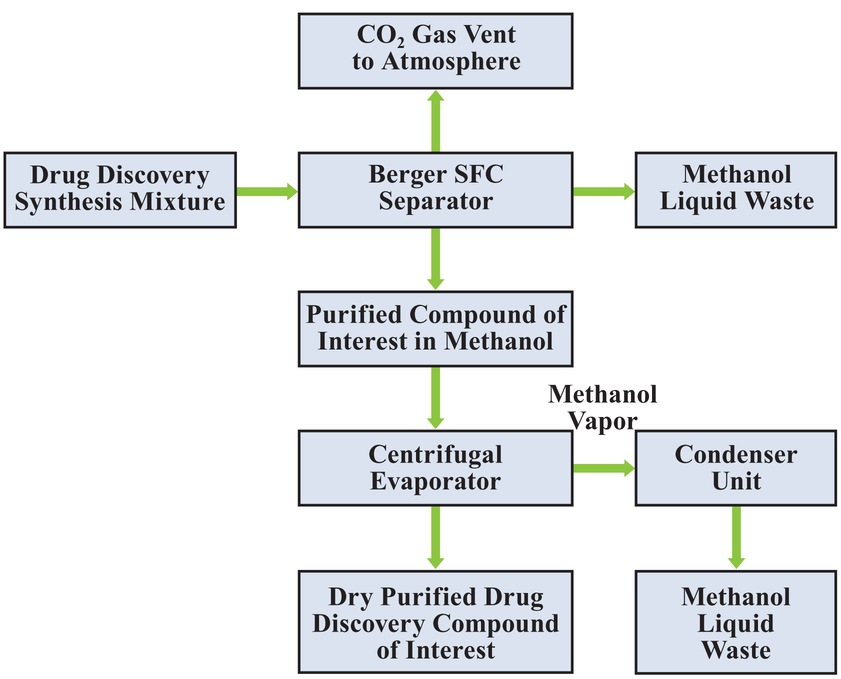
Operating and emission costs are reduced by eliminating flaring, and productivity is increased by reusing products in the feed streams.

# Supercritical Purification of Compounds for Combinatorial Chemical Analysis

## Innovative Purification Method Reduces Energy Use and Chemical Waste

With the support of a NICE[3] grant, Berger Instruments, Inc., developed and demonstrated an innovative approach to combinatorial chemistry for the drug discovery industry called supercritical fluid chromatography (SFC). Conventional liquid chromatography (LC) systems are capable of purifying only 5 to 10 compounds per day. In addition, because of the wide variation in the number of complex chemical compounds that need to be tested, the LC process requires several manual operations, two to three trial runs, and up to 48 hours to remove organic/aqueous waste and water from the purified products. This time-consuming work poses a bottleneck for the pharmaceutical industry, which depends on high levels of throughput and purity.

Using the new SFC process, samples can be purified and dried 20 to 100 times faster than by conventional LC systems. SFC, a packed column analysis technique similar to LC, uses compressed gases such as $CO_2$ rather than liquid solvents as the primary component of the mobile phase. The high diffusivity and low viscosity of $CO_2$ results in greater speed and resolution than possible with LC. Additionally, the SFC technology provides a solute purity of 95% or greater, very rapid fraction collection with full automation, and no need for manual intervention. This new process also significantly reduces energy consumption and liquid-solvent waste generation.




*Supercritical Fluid Purification System*

## Overview

- Developed by Berger Instruments, Inc.
- Commercialized in 2000
- 72 units operating in the United States in 2004

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 1.21 | 0.466 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.002 | 0.101 | 0.075 | 9.15 |

## Applications

Process science and engineering technology for the pharmaceutical, chemical, and drug discovery industries

## Capabilities

- Processes samples at higher speed with high purity.
- Approaches full automation without the need for manual intervention.

## Benefits

### Energy Savings

Uses 2% of the energy required by conventional LC technology.

### Productivity

Processes samples 20 to 100 times faster while producing a purity of 95% or greater.

### Waste Reduction

Reduces liquid chemical waste by 95% for each processed compound.

# Ultrasonic Tank Cleaning



## Ultrasonic Tank Cleaning Now a Viable Alternative to Solvent Cleaning

Although ultrasonic cleaning has long been the standard for small-scale cleaning applications, its technical limitations have precluded its use in larger applications. Chemical and pharmaceutical companies, for example, typically use volatile organic compound (VOC)-emitting solvents to clean their storage tanks in a process that is both labor- and energy-intensive. A new ultrasonic tubular resonator, developed by TELSONIC Ultrasonics and demonstrated using a NICE$^3$ grant at DuPont-Merck Pharmaceutical Company, overcomes these limitations and has cleaned tanks with capacities of up to 2,300 gallons. The tube resonator produces an energy wave that propagates in all directions, rather than in a single direction like conventional ultrasonic systems, so a tank can be cleaned with less ultrasonic energy. The unit is small and can be placed into the tank through an opening in the top, eliminating the need for maintenance workers to enter the tank as required with conventional cleaning. Energy savings from the use of this technology are based on decreased cleaning energy use as well as the reduced use of solvents.

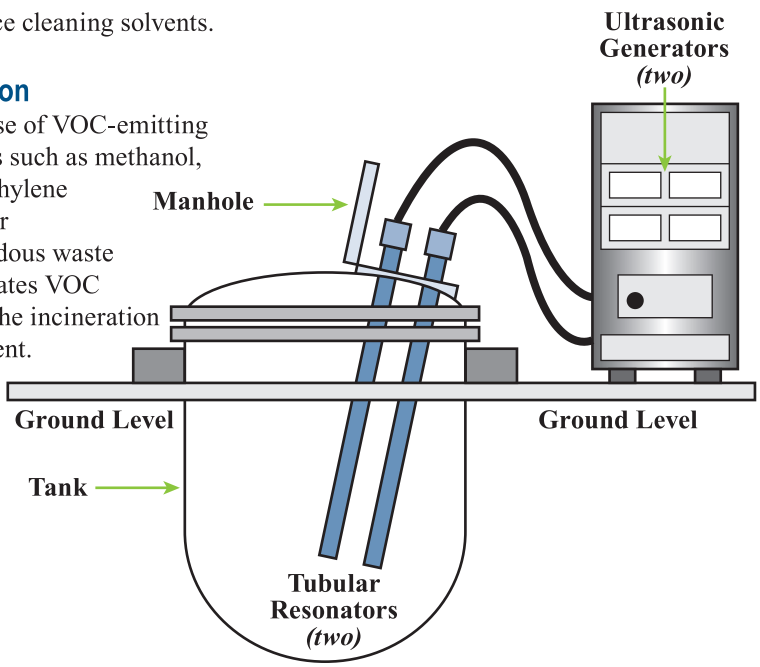
The resonator cleans tanks more quickly and thoroughly than solvents, uses less energy, and reduces labor and material costs. By eliminating the need to process spent solvents, ultrasonic cleaning also eliminates VOC emissions and hazardous wastes.

## Benefits

### Productivity
Reduces cleaning time from about 1 day to 1 hour.

### Use of Raw Materials/Feedstocks
Conserves the petroleum feedstock otherwise needed to produce cleaning solvents.

### Waste Reduction
Eliminates the use of VOC-emitting cleaning solvents such as methanol, ethanol, and methylene chloride and their associated hazardous waste streams. Eliminates VOC emissions from the incineration of the spent solvent.




*Ultrasonic Tubular Resonator*

## Overview

- Demonstrated by DuPont-Merck Pharmaceutical Company
- Commercialized in the United States in 1994
- 20 units operating in the United States in 2004

## Energy Savings
*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 0.040 | 0.005 |

## Emissions Reductions
*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.0 | 0.0 | 0.001 | 0.071 |

## Applications

- Cleaning residue from tanks used in chemical and pharmaceutical processing and remediation wells.
- Cleaning paint tanks such as those used in automotive painting operations

## Capabilities

- Can clean tanks with capacities up to 2,300 gallons.
- Produces bubbles that are small enough to penetrate microscopic crevices, resulting in superior cleaning.
- Typical cleaning cycle times range from 1 to 3 hours compared with 8 to 24 hours for conventional cleaning methods.
- Saves the thermal energy used to convert the solvents from liquid to vapor.

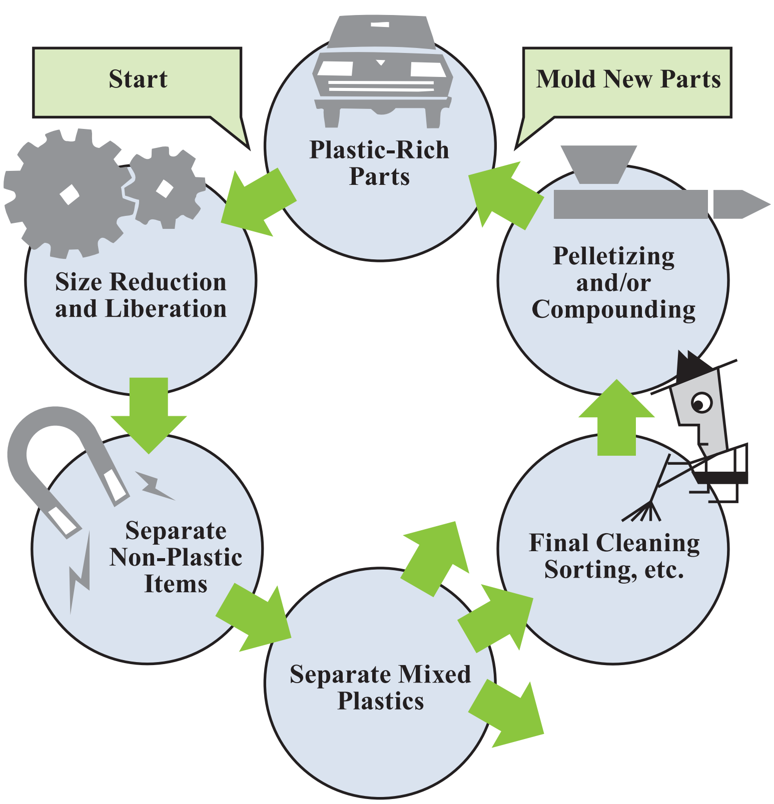
# Use of Recovered Plastics in Durable Goods Manufacturing

**IMPACTS**

## New Technology Helps Close the Recycling Loop for Plastics

An advanced mechanical recovery technology that can effectively recover plastic waste material has been developed by MBA Polymers, the American Plastics Council (APC) and plastic end-users, and demonstrated using a NICE$^3$ grant. MBA's process is capable of running at rates over 5000 lb/hr and purifying as many as three different plastics from a single mixed stream. Conventional plastics cleaning and sorting processes (e.g., as used for bottle recycling) are inadequate to handle multi-component waste streams. The new demonstrated process incorporates several refined technologies that can separate metal and metallic coatings, rubber, glass, foam, and fabric as well as mixed plastics. These technologies include (1) enhanced size reduction throughput and particle size and shape control, (2) reduced product and side-stream contamination, (3) enhanced process control of separation systems for multi-material separations, and (4) advanced material separation capabilities.

The combination of these refined technologies produces an advanced plastic recycling system that is capable of effectively recovering previously unrecoverable streams of multi-component materials. The energy and related pollution savings from the MBA plastic recovery process come primarily from reducing the need to produce virgin plastics. Half of this energy is contained in the plastic itself as processed material and is lost if the scrap is not recovered or is incinerated. Using this recovered plastic instead of additional virgin plastic results in energy savings of 17,000 Btu per pound of raw material or more than 85% of the energy required for producing virgin plastics.




*MBA Polymers' Recycle Loop*

## Overview

- Developed by MBA Polymers in 1995
- Commercialized in 1996
- Currently operating one plant in California
- Constructing plants in Austria and China

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 0.381 | 0.015 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.0 | 0.002 | 0.002 | 0.266 |

## Applications

Recovery of plastic from complex manufacturing scrap and end-of-life durable goods including automobiles, appliances, electrical, and electronic equipment

## Capabilities

- Separates as many as three different plastics at one time in a mixed waste stream.
- Segregates metal, metal coatings, rubber, glass, foam, and fabric from plastic waste.
- Recovers previously unrecoverable and discarded multi-component materials.

## Benefits

### Waste Reduction

Significantly reduces landfill requirements.

### Waste Utilization

Recover previously discarded re-usable plastic materials and allows more cost-effective raw plastic materials for industry.

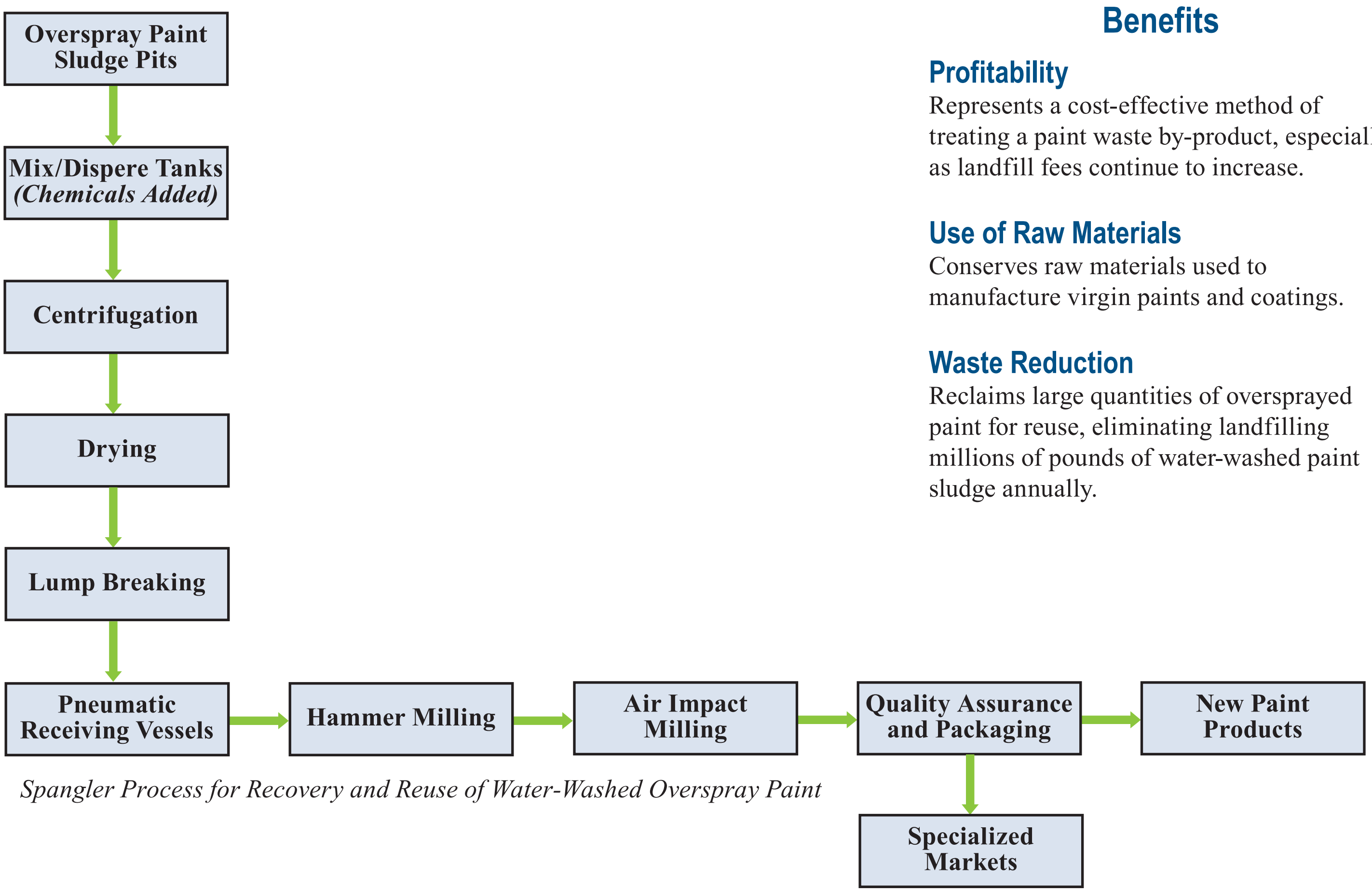
# Water-Washed Overspray Paint Recovery



## Process for Recovery and Reuse of Water-Washed Overspray Paint Reduces Waste

Industrial water-wash paint operations, such as those used to paint automobiles, have transfer efficiencies (the percentage of paint sprayed that actually adheres to the item being painted) ranging from 30% to 70%. As a result, approximately half of all paint purchased for these operations is essentially wasted. Landfilling has been the only feasible treatment option because no cost-effective recycling techniques exist to handle tacky, agglomerated paint sludge. Caterpillar, Inc. has developed and demonstrated the economically feasible Spangler process using a NICE$^3$ grant. This process recovers oversprayed paint and then chemically and physically processes it. The reclaimed material is used in new, high-performance paints and coatings.

In the Spangler process, oversprayed particles suspended in water are captured and encapsulated by hydrophobic fumed silica particles. This encapsulation essentially detackifies the paint by-product without detrimentally altering its chemistry as a recyclable feedstock. After drying, the product—known as Precured Pigment Resin (PPR)–is pulverized and packaged to be returned to coatings suppliers for blending into new paint. Not only does PPR have no negative effect on the quality of the coating to which it is added, it may actually improve the anticorrosion properties of some paints. In addition to paint, PPR can be used in products such as electrodeposition coatings, interior/exterior maintenance coatings, and polyurethane primer. Caterpillar is currently refining the process and expects to use the product in-house and sell it commercially to other users.




*Spangler Process for Recovery and Reuse of Water-Washed Overspray Paint*

## Overview

- Developed by Caterpillar, Inc.
- Commercialized in 1995

## Applications

Industrial water-wash paint operations such as automotive and construction equipment assembly plants

## Capabilities

- Recovers and processes oversprayed paint for reuse in high-performance coatings.
- Detackifies oversprayed paint waste without destructively altering its composition.

## Benefits

### Profitability

Represents a cost-effective method of treating a paint waste by-product, especially as landfill fees continue to increase.

### Use of Raw Materials

Conserves raw materials used to manufacture virgin paints and coatings.

### Waste Reduction

Reclaims large quantities of oversprayed paint for reuse, eliminating landfilling millions of pounds of water-washed paint sludge annually.

# Forest Products

**IMPACTS**

# Chemical for Increasing Wood Pulping Yield



## Novel Chemistry Improves Pulp Yield While Reducing Energy and Chemical Requirements

Unevenly processed wood chips in the pulp industry result in poor-quality pulp, often requiring reprocessing. ChemStone, Inc., in cooperation with the NICE$^3$ Program, has demonstrated a cooking aid that reduces the amount of virgin wood feedstock needed to process wood chips. It also increases pulp yield and quality. The cooking aid is a molecule that remains soluble in the highly alkaline and hot environment for cooking pulp. The molecules help pulp-cooking liquors penetrate the chips, resulting in more uniform cooking. The rate of penetration into the chips enables the mill to produce a more uniform fiber in less time and with less energy. This chemistry eliminates overcooking the external chip to effectively cook the internal chip and eliminates the need to reprocess the uncooked portion. The reduction in cooking time translates into an energy savings of 125 thousand Btu per ton of wood clips processed.

The process greatly reduces sulfur-based emissions, such as hydrogen sulfide and methyl mercaptans. Approximately 1-million tons of emission gases are eliminated. Eleven United States mills are currently using this novel chemistry either full time or for part of their production. ChemStone is establishing a distribution network in South Africa, Europe, Indonesia, Canada, and Mexico.

## Benefits

### Pollution Prevention

Reduces sulfur-based emissions such as hydrogen sulfide and methyl mercaptans.

### Product Quality

Produces better-quality pulp through less harsh cooking of the wood chips and less refining of the pulp, reducing rejects.

### Use of Raw Materials/Feedstocks

Reduces consumption of raw wood for required production. Uses less bleaching chemicals to reach the required brightness.

## Overview

- Developed by ChemStone, Inc.
- 11 pulp mills currently using the technology

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 8.08 | 1.09 |

## Emissions Reductions

*(Thousand Tons, 2004)*

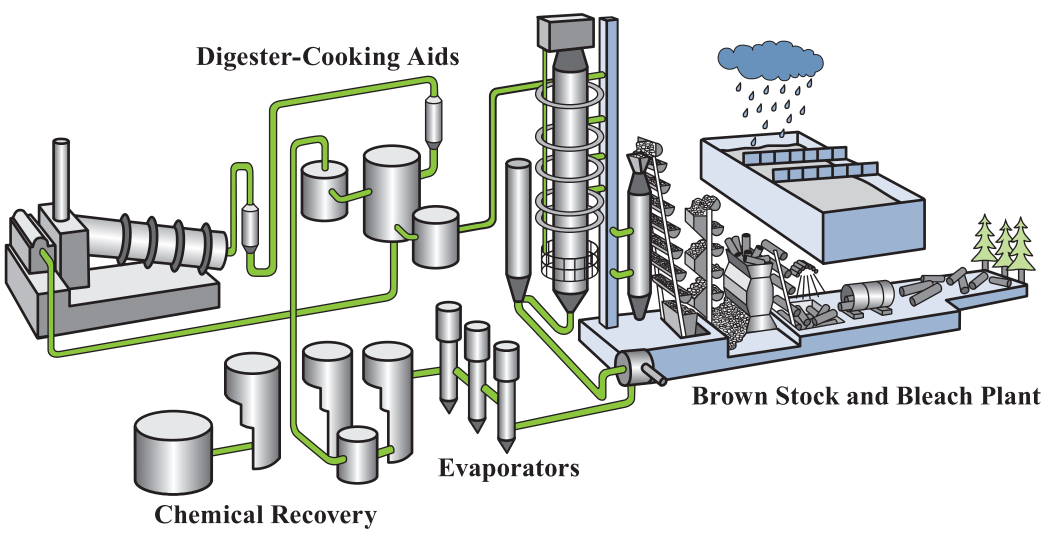
| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.0 | 0.0 | 0.128 | 17.3 |

## Applications

All pulping processes

## Capabilities

- Results in 2% to 5% increase in yield per ton of wood.
- Rejected pulp is reduced by 2% to 50%.
- Reduces the amount of fiber required for paper quality.




*ChemStone Programs for Mill Optimization*

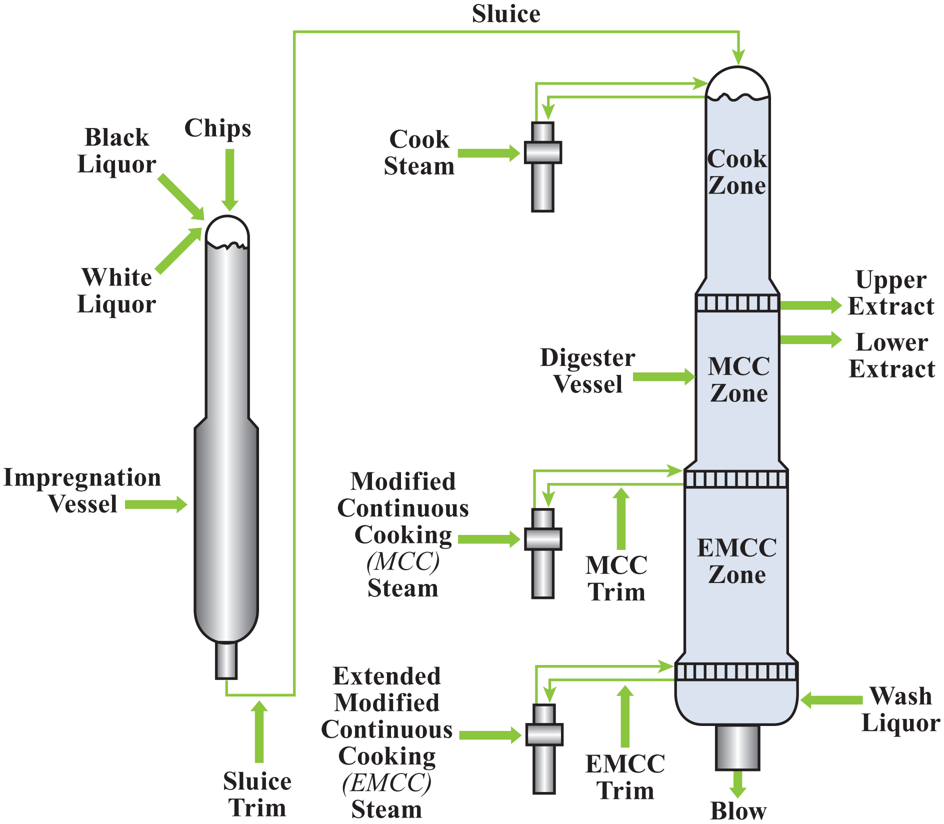
IMPACTS

## Pulp Process Model Identifies Improvements that Save Energy and Improve Productivity

The pulp digester is known as the bottleneck unit in the pulp mill flow sheet because it can require 5 to 50% of typical on-line operation time, making this component of the pulping process very capital intensive. Improving digester performance can significantly reduce production losses, operating costs, and negative environmental effects while increasing paper quantity and quality. Using a computer-based model and control system for continuous digesters could regulate the pulping process, thereby minimizing mill downtime caused by digester problems and fostering continuous operation and pulp production.

Previous work conducted at the University of Delaware (UD) indicated that fundamental computer models could manage the internal conditions within the digester. The UD resolved the major challenge to designing such a model by developing a fundamental digester model that manages production rate changes and grade swings between hardwood and softwood feedstocks.

The digester's fundamental process model integrates physical and chemical properties as system "states" (i.e., points in the digester process) to track grade transitions. This model allows appropriate material, energy balance, and diffusion simulations to be calculated as various-origin chips pass through the digester. The observation and tracking of these data help identify process improvements. The model's first commercial application in a Texas mill allowed the temperature to be reduced in part of the pulping process, thereby saving 1% of the process energy.




*Dual Vessel EMCC Continuous Digester*

## Overview

- Developed at the University of Delaware
- Commercialized in 2003
- Being marketed by IETEK

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 8.00 | 4.00 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.0 | 0.0 | 0.468 | 63.5 |

## Applications

All types of pulp digesters and provides the basis for developing more model-based methods of soft sensing, diagnostics, and control

## Capabilities

- Uses a computer model to evaluate the pulping process.
- Provides operational data through the model to identify process improvements.

## Benefits

### Environmental Impact

Minimizes the amount of chemicals used.

### Productivity

Improves operator control, thus raising productivity and process reliability. Also improves system operability through rate and grade transitions.

### Product Quality

Reduces pulp and paper quality variations.

# Detection and Control of Deposition on Pendant Tubes in Kraft Chemical Recovery Boilers

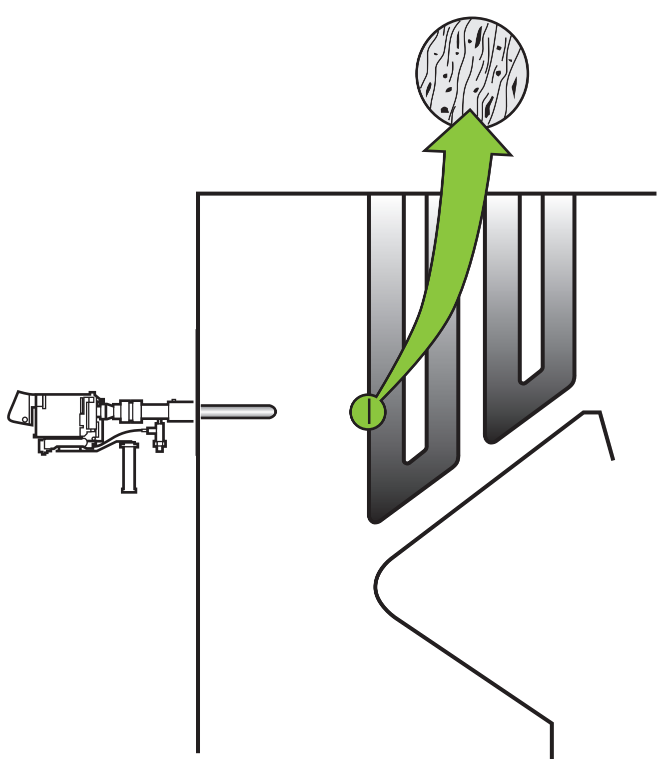


## Advanced Imaging System Improves Boiler Efficiency, Reduces Sootblowing Costs, and Improves Operational Safety

The kraft chemical recovery boilers used for pulp processing are large and expensive and can be the limiting factor for mill capacity. Improvements in boiler efficiency with better control of deposits on heat transfer surfaces (e.g. pendant tubes) and reductions in boiler downtime (due to pluggage or slag impact) can improve boiler capacity and reduce operating costs.

With assistance from DOE's Inventions and Innovation Program, Enertechnix, Inc., has developed a hand-held infrared inspection system. Using the inspection system technology, they have also established the feasibility of and are developing a continuous integrated monitoring sootblower control system to detect and control buildup of deposits. The early detection of deposits can extend the intervals between boiler shutdowns. The resulting improved boiler operation and reduced maintenance provide energy savings and productivity improvements to the pulp processing industry.

The hand-held inspection system has demonstrated reductions in sootblower steam use of up to 20%. This steam improvement is achieved because the frequency of sootblower operation is reduced, sootblowers can be repositioned based on data obtained from the inspection, and sootblower malfunction can be detected. Reduced pluggage and deposition in the boiler have also led to improved heat transfer rates. The integrated observation camera and soot-blower control system (under development) are expected to reduce sootblower steam usage by 30-35% and improve heat transfer efficiency by 20%.



*Hand-held Inspection System on a Kraft Recovery Boiler*

## Overview

- Developed by Enertechnix, Inc.
- Commercialized a hand-held device in 2002
- 44 units in use in 2004

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 0.660 | 0.484 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.004 | 0.281 | 0.075 | 10.5 |

## Applications

Kraft recovery boilers in the pulp and paper industry and in the coal, cement, steel, and glass manufacturing industries

## Capabilities

- Produces clear images and videos of boiler interiors despite highly particle-laden environments.
- Produces images at distances up to 100 feet, enabling inspection anywhere in the combustion chamber including the convection pass and economizer.

## Benefits

### Productivity

The hand-held inspection system reduces boiler downtime through early detection of defective fixtures (tube leaks or damaged sootblower). Without shutting down the boiler, the system also detects slag formation at an early stage, preventing impact damage and enabling cleaning before deposits harden.

### Safety

The impact of sizable slag deposits on boiler internals can lead to severe damage and potential injury. The hand-held inspection system has enabled early detection and elimination of such deposits.

# Improved Composite Tubes for Kraft Recovery Boilers

IMPACTS

## New Alloys Improve Performance and Safety

Black liquor recovery boilers are critical components of kraft pulp and paper mills. These boilers burn organic waste to generate steam and electric power for the mill and allow the sodium hydroxide and sodium sulfide used in the pulping process to be recovered. The boilers are constructed with floors and walls of tube panels, and these tubes circulate pressurized water to permit generation of steam. Originally, carbon steel tubes were used for these tube panels, but severe corrosion thinning and occasional tube failure led boiler manufacturers to search for materials that could better survive in the recovery boiler environment.

As a result of this search, new weld overlay and co-extruded tubing alloys were developed and are now being used in United States kraft recovery boilers and foreign installations. These materials are currently produced by Welding Services Inc., Sandvik Materials Technology, and Sumitomo Metals for application in recovery boilers. Boiler manufacturers are using the technology in designing and fabricating new and rebuilt kraft recovery boilers

A series of alloy studies, conducted by Oak Ridge National Laboratory, Pulp and Paper Research Institute of Canada, and the Institute of Pulp and Paper Science and Technology showed that Alloys 825 and 625 are more resistant than 304L stainless steel to cracking. Sandvik Materials Technology produces Sanicro 38 (modified 825) composite tubes for the world's largest manufacturers of black liquor recovery boilers. The boilers have been delivered to plants in the US, Australia, Belgium, Brazil, Canada, China, France, Finland, Sweden, Germany, Spain and Norway.

## Benefits

### Environmental
The change in operating conditions resulting from the improved materials will reduce gaseous emissions.

### Productivity
Improved materials enable the use of black liquor with higher dry solids content, thus increasing the thermal efficiency. The improved materials decrease the number of shutdowns and improve the overall boiler efficiency and productivity.

### Safety
In recovery boilers, tube leaks can result in serious explosions if the pressurized liquid contacts the molten salt on the floor and walls of the boiler. The use of improved materials significantly reduces the cracking of the floor and wall tubes, thus reducing the likelihood of a boiler tube leak.

## Overview

- Currently produced by Welding Services Inc., Sandvik Materials Technology, and Sumitomo Metals for application in recovery boilers
- Commercialized in 1996 and installed in over 17 kraft recovery boilers in the United States

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 0.038 | 0.007 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.0 | 0.002 | 0.001 | 0.128 |

## Applications

Being used in constructing new and rebuilt kraft recovery boiler floors

## Capabilities

The new materials can operate in the aggressive environments that can cause stress corrosion cracking of 304L stainless steel.

# METHANE de-NOX® Reburn Process

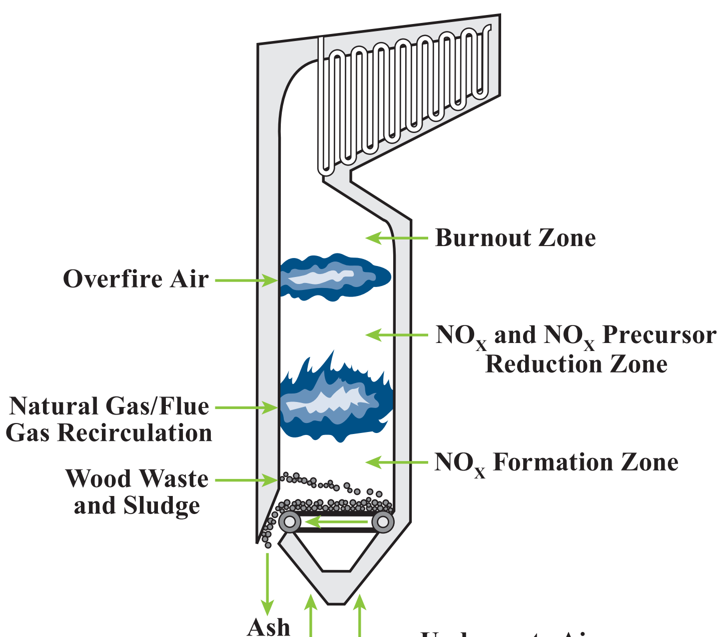


## METHANE de-NOX Reburn Process Uses Waste Wood for Biomass-Fired Stoker Boilers

The METHANE de-NOX process is a reburn technology using 5% to 25% natural gas heat input for improving combustion of solid waste fuels and for controlling emissions of $NO_X$ and CO. The METHANE de-NOX process injects natural gas above the grate and uses flue gas recirculation to enhance mixing and create an oxygen-deficient atmosphere that retards $NO_X$ formation. Overfire air is injected higher in the furnace to burn out the combustibles. The technology has been successfully demonstrated in commercial power plants using municipal solid waste and coal as fuel. In these demonstrations, the combustion systems operated more efficiently; required less maintenance; and reduced emissions of $NO_X$, CO, and VOCs.

With assistance from ITP, the Gas Technology Institute (formerly the Institute of Gas Technology) demonstrated the METHANE de-NOX reburn technology in the forest products industry. The project involved a field demonstration on a 300 million Btu/hr stoker-fired boiler fueled with waste wood and paper sludge at Boise Paper Solutions' paper mill in International Falls, MN. After the boiler was retrofitted, performance tests confirmed that the added heat released from natural gas combustion above the stoker grate stabilized the firing of solid fuel, permitted uniform heat release, reduced localized peak temperature, and permitted greater load flexibility including low load operation, thus improving combustion of difficult-to-burn waste fuels.

Commercial implementation of the technology provides the forest products industry with a means to use (rather than landfill) more waste wood solids and sludges, reduce natural gas consumption and $NO_X$ emissions, and improve boiler thermal efficiency.




*METHANE de-NOX Process*

## Overview

- Developed by the Gas Technology Institute
- Commercialized in 1998
- Two units operating at paper mills and 26 units on coal-fired cogeneration boilers

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 1.16 | 0.218 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.001 | 0.031 | 0.034 | 4.06 |

## Applications

A wide range of wastewood and sludge-fired stoker boilers in the forest products industry and coal-fired boilers

## Capabilities

- Improves grate combustion of difficult-to-burn fuel such as high-moisture-content waste wood.
- Substantially reduces $NO_X$ emissions and natural gas input while increasing sludge firing rates and thermal efficiency.
- Provides a cost-effective means to use abundant waste wood solids and sludges for energy generation rather than land-filling them.

## Benefits

### Ease of Operation

Cleaner gas passes through the furnace with less fouling and unburned carbon and fly ash at the bottom.

### Productivity

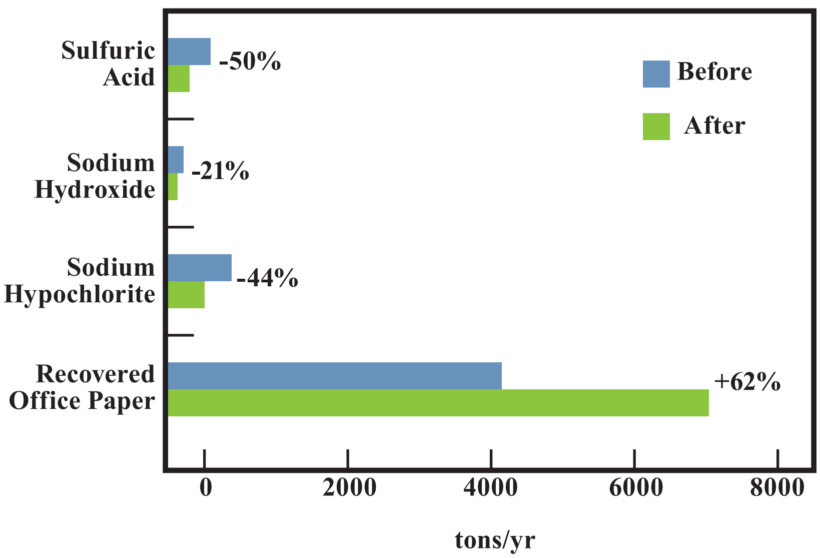
Sludge firing increases from 1.2 up to 5 tons/hour and boiler thermal efficiency increases by 1% to 2% resulting in greater steam production capacity.

IMPACTS

## Optimizing Tissue Paper Manufacturing Increases Paper Recycling

Government standards and customer requests led Erving Paper Mills Inc. to modernize its de-inking process to increase the amount of recovered office paper used in producing paper napkins and tissue. De-inking is the process of removing inks, dirt, and other contaminants from the fibers used in making paper products. Waste paper is made into a slurry, and the contaminants are removed mechanically by size.

Using a NICE³ grant, Erving Paper Mills demonstrated changes to its process, which included de-ink equipment upgrades, on-line image analysis, alternative chemistry trials, and other energy-conservation projects. These improvements reduced energy and toxic chemical usage and increased the amount of recovered office paper in the feedstock. The improvements in de-inking equipment included system reconfiguration, new high-efficiency cleaners, a new high-efficiency flotation cell, and a new high-efficiency washer. These improvements resulted in higher efficiencies for removing dirt, better washing, improved clarification for process water, and lower bleaching requirements.




*Process Improvement Results*

## Overview

- Developed by Erving Paper Mills, Inc.
- System modifications began in late 1996

## Applications

- Production of tissue and napkin products
- Pulp and paper mills

## Capabilities

Increased use of recovered office papers-from 10.5% to 17% of total feedstock.

## Benefits

### Energy Savings

Lower pulping temperatures decrease fuel oil usage. Conservation projects resulted in reduced electrical energy.

### Emissions Reductions

Lower pulping temperature and new continuous-belt washer decreases solvent usage, resulting in reduced emissions of volatile organic compounds.

### Use of Raw Materials/Feedstocks

Increasing amount of recovered office paper decreases amount of direct-entry recycled fiber used. Changes to de-inking process decreases use of several controlled chemicals

# Pressurized Ozone/Ultrafiltration Membrane System



## Novel Process Dramatically Reduces Energy Use, Improves Process Water Quality, and Reduces Effluent Discharge

With the support of a NICE$^3$ grant, LINPAC, Inc., demonstrated a novel technology for closed-loop systems that uses pressurized ozone with dissolved air flotation and an ultrafiltration membrane in series. This system allows total dissolved solids in process water to be readily converted to total suspended solids for efficient removal. Contaminated mill process water thereby can be continually and cost effectively cleaned to the high-quality process water standards required for reuse in the mill. After passing through the new system, process water is far cleaner and of higher quality than water from other processes and requires far less energy for reheating than fresh water. The system reduces the production problems associated with buildup of total dissolved solids (TDS) in paper mill operations and provides operational benefits such as reduced energy needs and fewer chemicals and additives. The system also results in production and quality gains because of the higher-quality process water. Because the environmentally friendly system allows paper mills (and other water-intensive manufacturing mills) to operate in a closed loop, effluent discharge to rivers and waterways is eliminated or drastically reduced. This new system substantially reduces both effluent discharge and the need for fresh water.

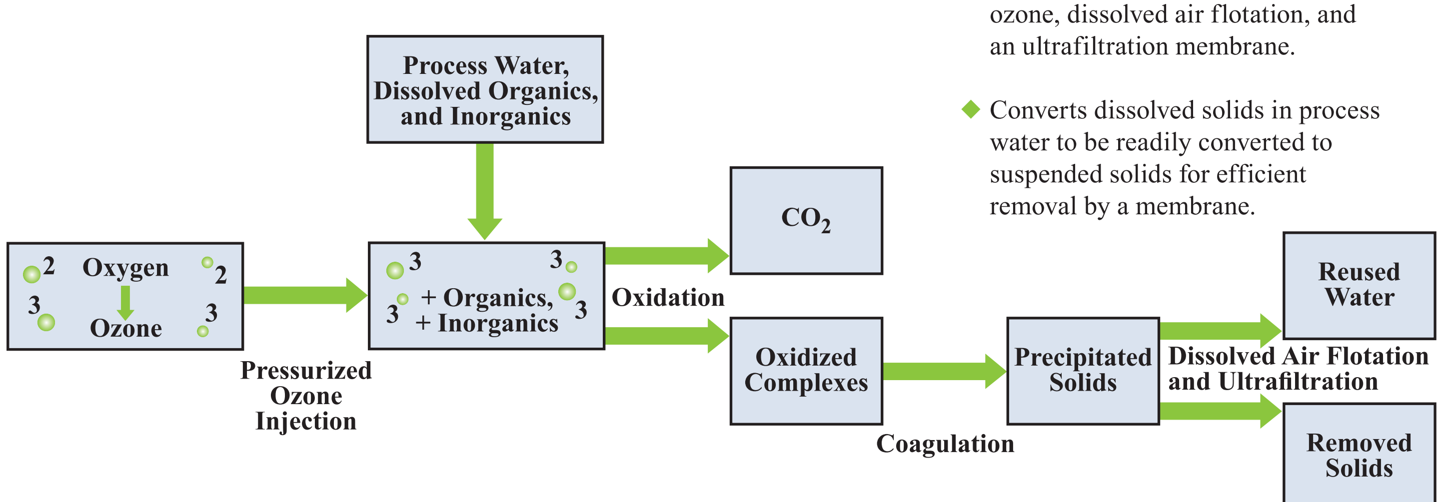
## Benefits

### Environmental

Removes TDS in mill process water, thereby allowing mills to eliminate or reduce effluent discharge. Eliminates $CO_2$ discharges of up to 815 tons a year for a typical plant operation. Potentially reduces landfill waste by 50% and use of processing chemicals by $5/ton of paper produced.

### Productivity

Clean process water allows production gains of 5% to 15%. Saves energy costs due to heating and drying. Reduces chemical additive use. Potentially reduces downtime in mill process water treatment systems.




*Pressurized Ozone/Ultrafiltration Membrane System*

## Overview

- Developed by LINPAC, Inc., and Cellulose Products and Services LLC
- Commercialized in 2004 and marketed by Cellulose Products and Services LLC
- Currently installed and operating in a LINPAC paper plant

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 0.315 | 0.315 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.0 | 0.0 | 0.037 | 5.0 |

## Applications

Can be used in the pulp and paper industry and in other processes such as the food industry, which require filtration technology

## Capabilities

- Uses a series combination of pressurized ozone, dissolved air flotation, and an ultrafiltration membrane.
- Converts dissolved solids in process water to be readily converted to suspended solids for efficient removal by a membrane.

# Thermodyne™ Evaporator – A Molded Pulp Products Dryer

**IMPACTS**

## Thermodyne Evaporator–A Substantially Improved Molded Pulp Products Dryer

With assistance from DOE's Inventions and Innovation Program, Merrill Air Engineers demonstrated that its Thermodyne dryer outperforms conventional molded pulp dryers. Unlike other dryers, the Thermodyne dryer reheats water vapor released from the product being dried to create superheated steam that is directed onto the material being dried. Conventional paper dryers exhaust this liberated water outdoors, causing a large visible plume and dumping valuable heat. The Thermodyne dryer is sealed so internal vapor (moisture) cannot escape into the insulated dryer walls. The retained water vapor passes through indirect integral heaters to raise its temperature to a level that allows for substantially faster drying rates than if drying in relatively dry air. An absence of oxygen in the dryer also means the drying temperature can be higher and the retained water vapor can help protect and evenly dry the material. The released water vapor also helps control internal temperatures by mixing with the superheated steam, dropping its temperature to a more desirable level. Finally, the system recovers heat and harmful volatile organic compounds (VOCs) from the dryer's condensate, substantially reducing the amount released into the atmosphere.

## Benefits

### Energy Savings and Emissions Reductions

Substantially reduces energy requirements by eliminating the thermal energy needed to make up air exhausted from conventional dryers. Uses up to 50% less energy than a conventional dryer with the potential of saving up to 5 million Btu/ton of pulp. Captures volatile organic carbon (VOC) emissions by containing condensable gases.

### Productivity

Process promotes easier stacking and wrapping.

### Product Quality

The superheated steam-drying environment suppresses oxygen, reducing the chance of scorching or burning the product under higher and faster drying temperatures. Other quality enhancements include less warping, reduced case hardening, and no discoloration.

### Profitability

Process promotes lower shipping costs and lowers product losses.

## Overview

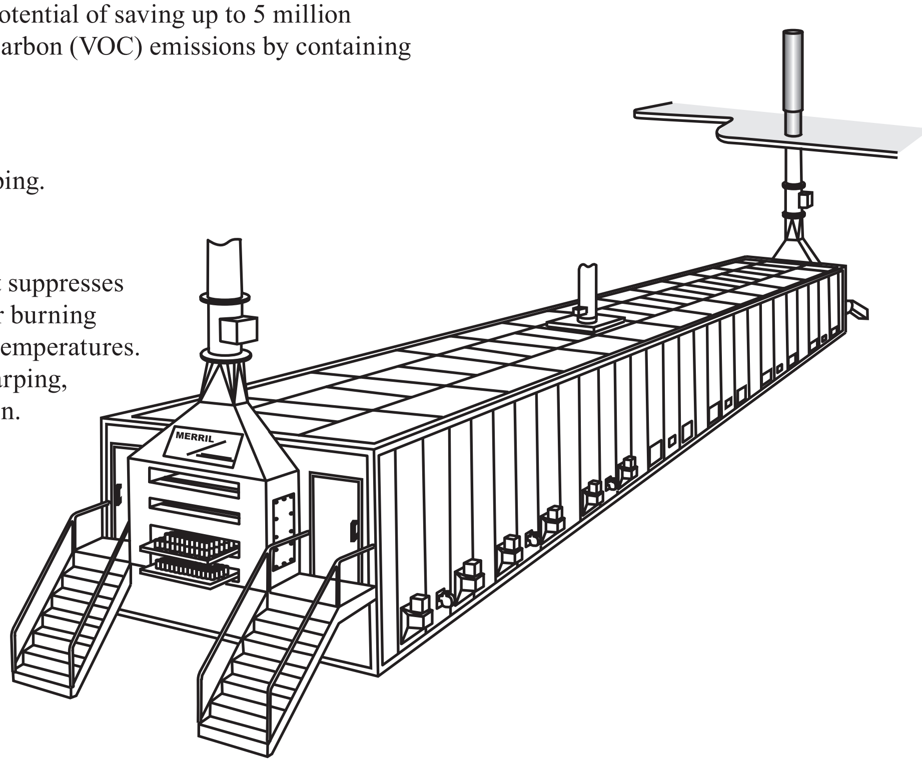
- Developed by MBA Polymers in 1995
- Developed by Merrill Air Engineers
- Commercialized in 1997
- 1 unit operating in Yakima, WA and 1 in Ireland

## Applications

Forest products industry for manufacturing molded fiber articles and for drying pulp, wood, cotton, cellulose, or torrefied wood and wood veneers

## Capabilities

- Fully capable of replacing conventional drying systems in the forest products industry.
- Handles a wide variety of forest products and can be applied to agricultural applications.




*Thermodyne Evaporator–A Molded Pulp Products Dryer*

# XTREME Cleaner™ – Removal of Light and Sticky Contaminants



## Centrifugal Cleaner Removes Light and Sticky Contaminants from Waste Paper

Americans now recover 45% of all paper used in the United States. Some brown paper grades, wax curtain-coated board, polyethylene-laminated paper, glue-containing magazine backs, and other secondary fiber sources contain contaminants like "stickies," wax, polyethylene, and binding glue that either make recycling impossible or cause an array of operating or product-related problems. Until recently, the technology for removing the contaminants was not completely effective. The development of the XTREME Cleaner, a centrifugal cleaner that replaces conventional dispersion systems in paper mills using waste paper, was a major breakthrough.

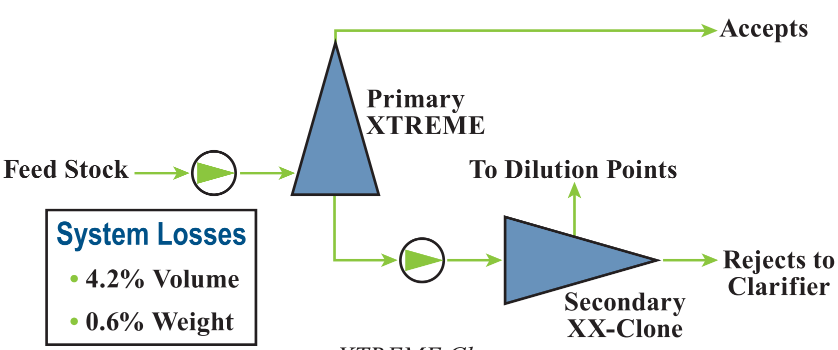
The XTREME Cleaner removes lightweight debris in all types of pulp slurries. It uses long residence times in a small-diameter cleaner to maximize separating very small contaminants that are close to the specific gravity of the fiber itself. Coupled with an advanced design through-flow cleaner such as the XX-Clone™, in the tailing position, only two stages are needed to minimize fiber loss and maximize contaminant removal efficiency. The XTREME Cleaner uses 50% less energy than conventional dispersion systems, resulting in significant cost savings to paper mills. The cleaner allows paper mills to use lower-grade, lower-cost furnish without compromising the quality of the final paper product. Paper mills using the cleaner system have reported savings of $3,500 to $11,000 per day just by using the lower-grade furnish.

## Benefits

### Environmental
Greatly reduces the amount of waste paper being landfilled. Uses fewer chemicals and less energy to process recycled paper than does producing paper from raw wood material.

### Productivity
Produces a 40% to 60% reduction in machine breaks or paper breaks, which are costly to paper mills due to downtime. Eliminates downtime to clean sticky contaminant buildup from processing machinery.

### Product Quality
Allows paper mills to use a lower-grade, lower-cost furnish while still producing the same or higher-quality end product. Removes contaminants so they do not contaminate the final product and cause product rejects.



*XTREME Cleaner*

## Overview
- Developed by Thermo Black Clawson
- Commercialized in 1997
- 11 systems operating in the United States

## Energy Savings
*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 1.19 | 0.183 |

## Emissions Reductions
*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.001 | 0.039 | 0.029 | 3.59 |

## Applications
Used in paper mills to recycle waste paper containing "stickies," wax, polyethylene, and binding glue

## Capabilities
- Effectively removes lightweight sticky contaminants from all types of pulp slurries.
- Improved kneading, or "liberation", unit better detaches and separates impurities from waste paper fibers.
- Improved vortex separation device allows greater unit capacity, longer treatment times, and more consistent operation.

# Glass

IMPACTS

# Advanced Temperature Measurement System



## New Material Leads to Development of Improved Monitoring Equipment

Self-validating sensor technology, developed by Accutru with support from ITP, is based on the ability to measure multiple, mutually exclusive thermoelectric properties of thermally sensitive materials contained in the tip of the sensor probe. The sensor probe is constructed like a thermocouple or RTD but is specially designed so that the thermal response of each element of the sensor can be monitored using independent combinations with multiple other elements. The signal conditioner/transmitter multiplexes these measurements and monitors the health of each individual thermo-element using at least two of its electrical properties.

This concept makes it possible to continuously monitor and "validate" each of the measuring elements inside the sensor while it is in service so that no element can drift without detection. If an individual element begins to drift or de-calibrate for any reason, the system eliminates the data for that element while still providing an accurate NIST traceable temperature with the remaining "healthy" elements. Using information about the number of "healthy" elements in the sensor, the transmitter then provides the operator or control system with sensor health status and notifies of impending loss of sensor validation before it occurs. Therefore an accurate and reliable temperature is reported for the life of the sensor.

Summarizing the features of this technology:

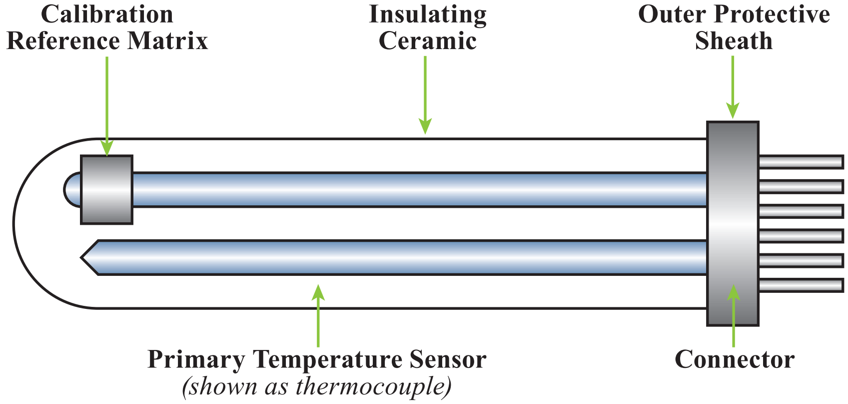
1) It uses a new concept of monitoring multiple independent measurements of the system temperature and individual element health,

2) it continuously validates and reports the system temperature,

3) it reports a temperature traceable to a NIST standard for the life of the sensor,

4) it reports the health of the sensor, and

5) it warns in advance of deterioration of any of the sensor elements.




*AccuTru Self-Verifying Temperature Sensor*

## Overview

- Developed by AccuTru International, Kingwood, Texas
- Commercialized and marketed by AccuTru
- 45 units currently operating in the United States

## Applications

Any thermochemical process where accurate and repeatable temperature read out is important:

- glass melters and delivery systems
- chemical reactors
- heat treating
- gas turbines

## Capabilities

- Separates as many as three different plastics at one time in a mixed waste stream.
- Reliable temperature range: -200ºC to 1750ºC
- Self-validating, while in service for the life of the sensor
- Warning on the onset of decalibration, predictive maintenance agricultural applications.

## Benefits

### Optimizing Process Yield

- Improved fuel efficiency
- Enhanced safety
- Extended equipment life

### Productivity

- 90% reduction in QC failures
- 10% increase in annual yields

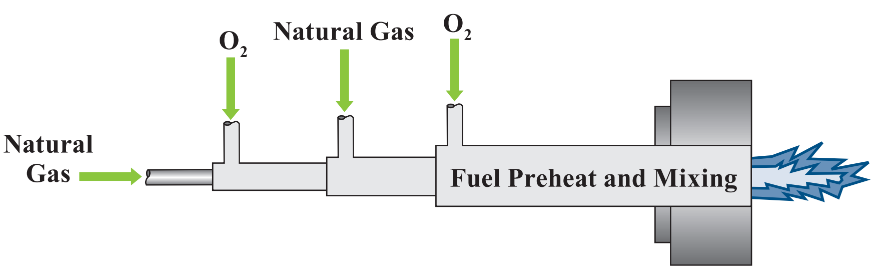
IMPACTS

## High-Efficiency Burner Lowers Costs and Emissions in Oxy-Fuel Glass Melters

Glass melters use combustion systems to produce molten glass. While significant progress has been made in developing oxy-fuel combustion systems, current technologies provide low flame luminosity and generate relatively high $NO_X$ emissions in the presence of even small mounts of nitrogen in the combustion process.

With the help of a grant from ITP, Combustion Tec Inc. has developed an innovative burner that increases luminosity and radiant heat transfer in high-temperature glass furnaces. The burner improves performance by modifying the fuel prior to combustion and then forming and burning soot in the flame. The burner increases heat transfer rates while decreasing flame temperatures to improve furnace production rates and thermal efficiency.

The high-luminosity, low-$NO_X$ burner combines a preheating zone with two combustion zones. First, a small fraction of the natural gas is burned. The products of this combustion are then mixed with the main supply of natural gas, resulting in hydrocarbon soot precursors generated in an oxygen-free heating environment. Next, the preheated natural gas enters the first, fuel-rich combustion zone in which soot forms in the flame. However most of the combustion occurs in the second, fuel-lean combustion zone. The burning soot particles create a highly luminous flame that is more thermally efficient and cooler than a typical oxy-fuel flame.




*High Luminosity, Low-$NO_X$ Burner Design*

## Overview

- Developed and marketed by Combustion Tec, Inc.
- Commercialized in 2002
- Operating in two U.S. plant in 2004

## Applications

Existing and new oxy-fuel glass melters. The largest demand currently exists in the container, fiber, and specialty glass sectors of the glass industry

## Capabilities

- Can clean tanks with capacities up to 2,300 gallons.
- Can be used on new furnaces or retrofit to older ones.
- Improves furnace production rates as a result of a more than 12% increase in heat transfer rates.

## Benefits

### Energy Saving and Pollution Reduction

The high luminosity burner technology reduces $NO_X$ emissions from glass melters up to 50% and improves thermal efficiency up to 20% over traditional oxygen fuel burners.

### Productivity

The improved burner allows cost-effective compliance with emissions regulations. The technology also provides flexibility for compliance in existing furnaces without major modifications.

### Reliability

The technology produces a lower flame temperature and lower exit temperatures, which could extend the furnace life.

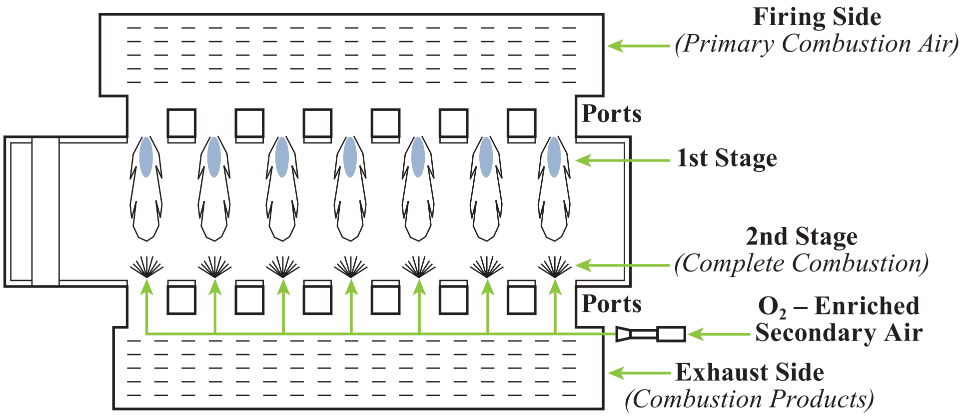
# Oxygen-Enriched Air-Staging (OEAS) Technology



## $NO_X$ Emissions Reduced for Glass Furnaces Using New Technology

Glass furnaces are facing very stringent environmental regulations with respect to $NO_X$ emissions. ITP has provided support to the Institute of Gas Technology and Combustion Tec to develop and commercialize the OEAS to help meet these new regulations. The OEAS system reduces the available oxygen in the flame's high-temperature zone and improves flame-temperature uniformity. This process controls $NO_X$ formation and improves heat transfer to the glass without interrupting furnace operation or adversely affecting product quality. The system stages combustion by holding back a portion of the combustion air normally provided during the earlier stages of combustion and flame development. This results in a minimum of excess air or even a fuel-rich operation that impedes $NO_X$ formation. The resulting flame is hotter and more luminous, resulting in higher flame luminosity, which translates to improved overall melting efficiency. By injecting air into the combustion space before the exhaust port, the CO formed earlier is burnt off. At this point, although the amount of free oxygen is higher, the lower flame temperature prevents $NO_X$ formation. The overall air-fuel ratio is similar to what is to be found in a conventionally fired furnace, and, therefore, glass redox is not affected.

The OEAS technology has been successfully retrofitted to endport furnaces in the United States and has achieved $NO_X$ levels below 2 lbs per ton (40% to 70% reduction). Efforts are currently underway to apply this technology to sideport furnaces that account for 65% of current glass production.




*Sideport Furnace Oxygen-Enriched Air-Staging System*

## Overview

- Developed by the Institute of Gas Technology
- Marketed by Eclipse, Inc.
- Commercialized in 1994
- 6 units operating in the United States

## Applications

Endport and sideport regenerative glass furnaces

## Capabilities

- Creation of oxygen-deficient primary flame inhibits $NO_X$ formation.
- Air or oxygen-enriched air is injected at strategic locations downstream to complete the combustion process.
- $NO_X$ is reduced from 40% to 75%.
- The process does not affect the furnace operation.

## Benefits

### Reduced Costs

Capital and operating costs are moderate for this process compared to competitive technologies, making it a cost-effective choice. Additionally, the technology will reduce the cost of producing oxygen.

### Reduced Emissions

NOX levels associated with the glass melting process will be reduced by 40% to 70%, enabling glass producers to meet more stringent environmental regulation.

### Reduced Waste

Total waste production is expected to be reduced by 10,000 tons per year, a 31% reduction.

# Metal Casting

## IMPACTS

# Ceramic Composite Die for Metal Casting



## New Ceramic Composite Materials to Produce Superior, Low Cost Dies

Metalcasting, a major U.S. industry, has long been hampered by the high cost and short life of casting dies. Steel dies often fail prematurely due to metal fatigue cracking, corrosion, erosion, oxidation, heat checking, and soldering when the dies are exposed to molten metals while operating under cyclic-mechanical and thermal loading.

For some applications, coatings are applied to protect the die from the damage inflicted by molten metals. However, these coatings can fail prematurely and tend to interfere with the welding and polishing operations needed during reworking and correcting damages in the die.

With assistance from DOE's Inventions and Innovation Program, the Materials and Electrochemical Research Corporation has developed ceramic composite materials as an alternative to conventional material used in forming casting dies. Ceramic composites can deliver proven stability to molten metals and are resistant to corrosion, erosion, oxidation, thermal fatigue, and cracking. In addition, lower-cost hybrid composites in the nitride/nitridecarbide family have the potential to last up to 10 times longer than coated steel dies with significantly lower weight. These new composites are expected to reduce the cost of many products fabricated in the United States and create stronger competitiveness in the domestic metalcasting industry.

## Benefits

### Productivity

The composite dies weigh approximately one-third less than traditional tool steel dies. The weight reduction saves time in production by eliminating some of the mechanical moving equipment.

### Waste Reduction

The longer life of ceramic dies reduces the amount of waste produced by failed tool steel casting dies. The ceramic dies also produce fewer casting rejections, reducing the energy needed to recycle the rejected castings.

## Overview

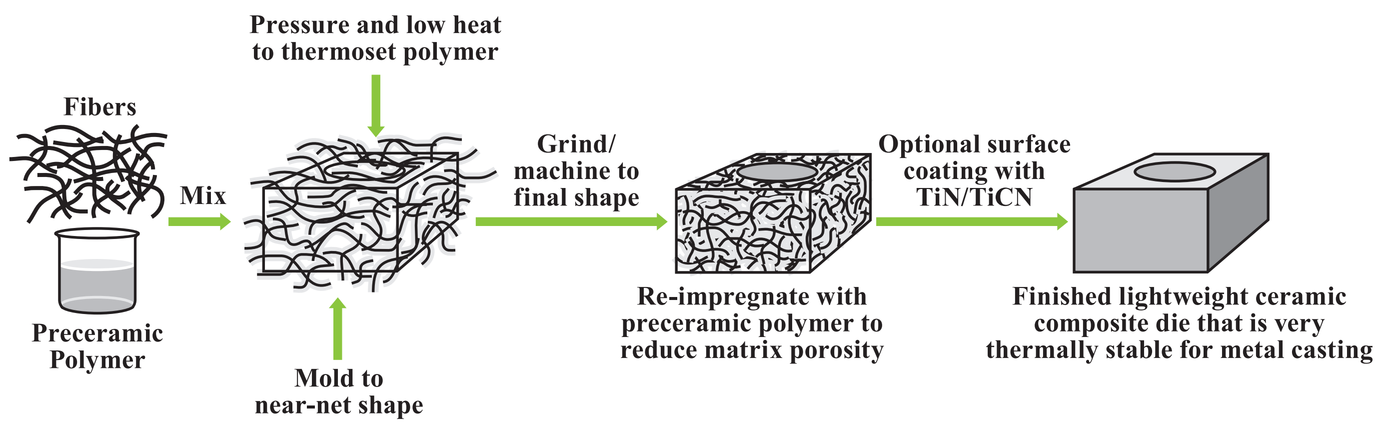
- Invented by the Materials and Electrochemical Research Corporation
- Commercialized in 2002
- Installed in several U.S. locations

## Applications

Dies for metal casting, including replacement dies that are currently tool steel

## Capabilities

- Offers resistance to corrosion, erosion, oxidation, thermal fatigue, and cracking.
- Provides stability when exposed to molten metals.
- 2 to 5 times harder than tool steels, resulting in 5 to 10 times longer useful die life.




*Ceramic Composite Die Forming Process*

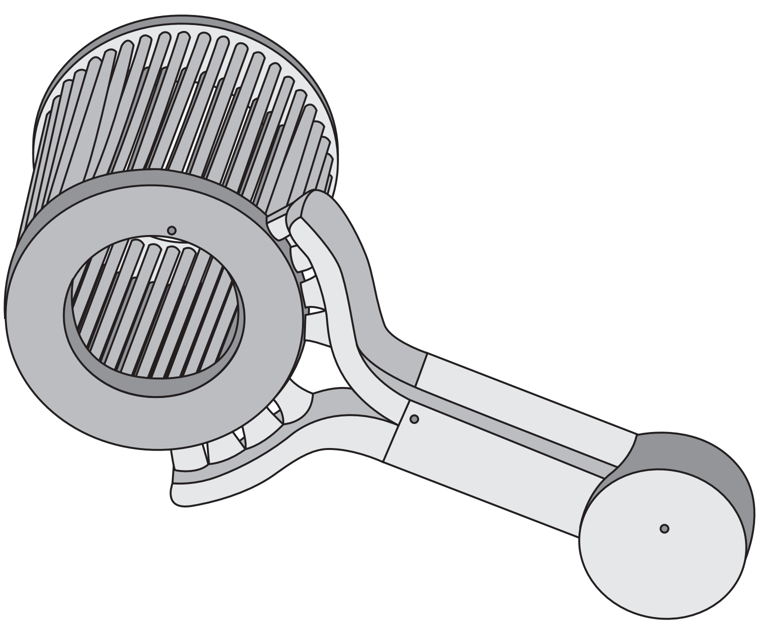
IMPACTS

## Die Casting Copper Technique Improves Energy Efficiency of Electric Motors

Though it conducts electricity less efficiently than copper, aluminum is the industry's preferred fabrication material in electric induction motor rotors. Traditional tool steel casting molds suffer thermal shock, shortening model life and increasing operating costs when used for die casting copper rotors. ThermoTrex Corporation, with the assistance of a NICE$^3$ grant, proposed a process for copper die casting using molds from high-temperature, thermal shock-resistant materials. The copper industry successfully tested these mold materials for copper die casting at higher temperatures (copper melts at 1083°C, aluminum at 660°C).

The copper die-casting technology developed by the copper industry is now in commercial use. The process replaces the tool steel molds used for the aluminum die casting with molds made from high-temperature die materials. In addition, the new process preheats the die inserts, reduces the temperature differential between the mold surface and the cooler interior, and avoids mold failure from thermal shock and thermal fatigue.

In 2003, SEW Eurodrive of Bruchsal, Germany, was the first company, worldwide, to bring the technology to market. A line of high-efficiency gear motors (1.1-5.5 kW) use copper rotors at a competitive price. Because traditional high-efficiency motors are larger than standard motors, gear boxes using copper rotor technology provide efficiency without increasing motor size. In 2004, FAVI S.A., a major French supplier of copper and copper alloy die castings, began offering custom-designed, copper-based rotors for squirrel-cage electric motors in sizes ranging from fractional to 100 hp.



*Squirrel-Cage Motor with Die Cast Copper Rotors*

## Overview

- Invented by the ThermoTrex Corporation and commercialized by the Copper Development Association
- Marketed by SEW Eurodrive and FAVI S.A.

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 0.091 | 0.085 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.0 | 0.018 | 0.014 | 1.68 |

## Applications

Electric motors are used throughout the United States industry and account for more than 60% of all electricity use in the nation. The annual market for electric motors totals about $35 billion internationally and about $10 billion in the United States.

## Capabilities

- Improves motor efficiency by 15% to 20%.
- Decreases operating costs compared with conventional motors.

## Benefits

### Productivity

The new technique reduces production time and hand labor compared with former methods of producing copper motor rotors.

### Profitability

Motors using copper rotors decrease operating costs compared with conventional motors.

# Simple Visualization Tools for Part and Die Design

IMPACTS

## New Software Program Helps Detect Potential Design Problems in Die Casting

With funding from DOE and the North American Die Casting Association (NADCA), a software program has been developed that offers a simple qualitative method to visualize potential design problems in diecasting. CastView™ is a PC-based modeling program for die casting flow simulation. It is based on a qualitative analysis of part geometry that yields extremely fast analysis times. The program uses imported STL files so a solid model does not have to be constructed. The user can select gate sizes and locations, and the program provides a visualization of how the die cavity fills. A typical analysis can be made in a matter of minutes, making multiple iterations quick and manageable. A "thickness" feature allows the user to find the thickest and thinnest sections of the casting geometry quickly and visualize the first and last area to solidify.

Using a standard computer interface and intuitive viewing controls, CastView points casting and die designers to the potential problem areas they may want to focus on using a more detailed, mathematically-based simulation program. CastView is an excellent front-end complement to the commercially available, mathematically-based computer modeling programs.

## Benefits

### Energy and Environmental Savings

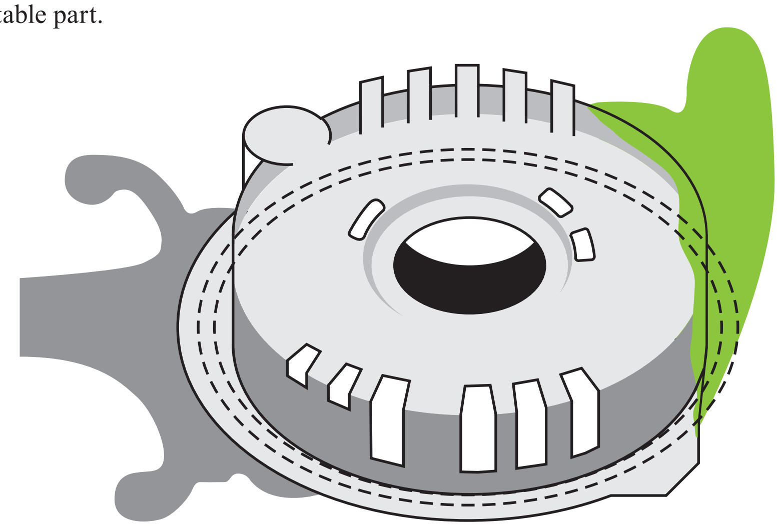
Process scrap can be reduced by 20% or more, resulting in increased yield and saving the energy formerly wasted producing defective parts.

### Productivity

By promoting compatibility between die casting part and die design, part development lead-time and tryout/setup time can be reduced significantly.

### Profitability

Detecting problems early in the process enables the die caster to negotiate a modification of the part geometry with the part designer to achieve a more castable part.



*CastView Pattern*

## Overview

- Commercialized by the North American Die Casting Association
- Commercialized in 1999
- 123 units sold to date

## Applications

CastView can be used in the die casting industry by both designers and die casters to visualize, identify, and resolve potential die casting design problems while still in the design stage

## Capabilities

- Improves communications between die casters and designers.
- Allows quick evaluations of a large number of design alternatives.
- Locates and displays thick and thin sections in the die.
- Minimizes flow-related filling problems.
- Minimizes thermal problems in the casting die.
- Minimizes solidification-related defects in the cast part.
- Allows more and easier to use controls for the rotation of the part for all views.
- Provides functions to test for bad STL files thus eliminating many problems associated with bad data.
- Includes print and save functions so that the analysis results can be recorded as bitmaps for use in other programs and documents.
- Includes an expanded animation function that includes slice mode animation allowing operator to automatically produce a sequence of slices through the part.

# Mining

## IMPACTS

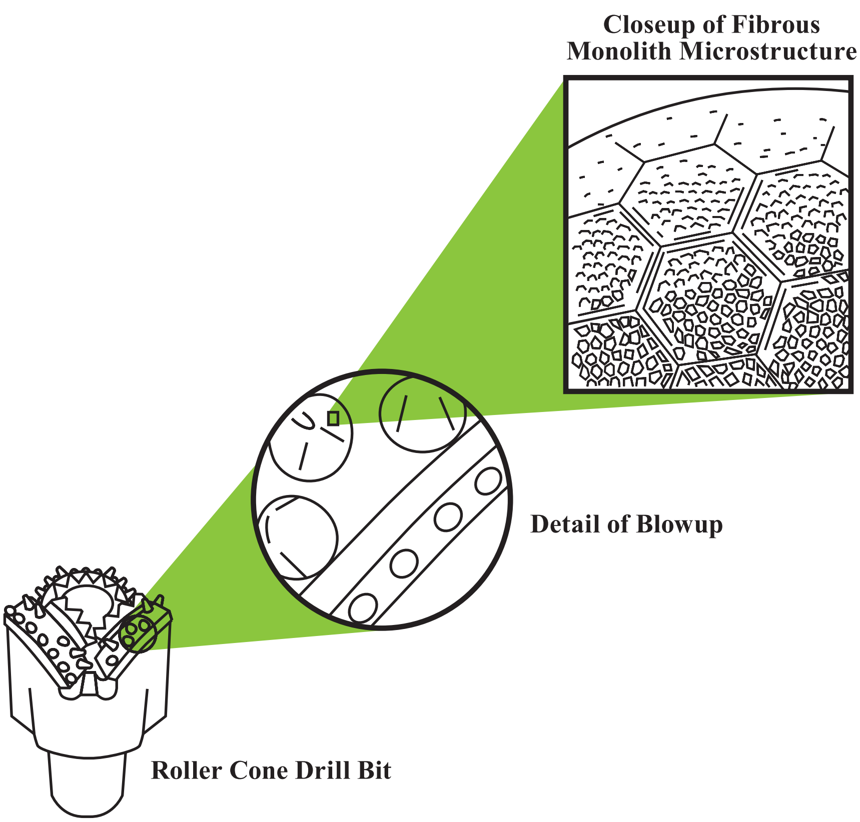
# Fibrous Monoliths as Wear-Resistant Components



## New Composite Material Improves the Cost/Performance Ratio of Drill Bits

Advanced Ceramics Research (ACR) led a collaborative effort of component manufacturers, end users, a national laboratory, and universities to develop fibrous monoliths (FMs) for mining applications. ACR licensed the technology to Smith Bits of Houston, Texas, one of the world's largest oil and drill bit manufacturers. Smith Bits demonstrated nearly a 3 to 1 oil drilling performance increase using FM technology compared with state-of-the-art diamond-coated drill bits. ACR also started a joint commercialization program with Kyocera Corporation to apply FM technology to industrial cutting tools.

Smith Bits uses the FM composites in Cellular Diamond™ inserts for drilling and high-impact applications. FMs are produced using a simple process in which sets of inexpensive, thermodynamically compatible ceramic and/or metal powders are blended with thermoplastic polymer binders and then co-extruded to form a green fiber. The green composite fiber is extruded and thermoformed into the shape of the desired component, pyrolyzed to remove the polymer binder, and consolidated at ultrahigh pressure and temperature to obtain the final FM product. The new FM manufacturing process produces ultra-hard inserts for roller cone bits.




*Roller Cone Drill Bit with Fibrous Monolith Inserts*

## Overview

- Collaboratively developed by a collaboration of a national laboratory, universities, and private companies led by Advanced Ceramics Research, Inc.
- Currently licensed to Smith Bits, a subsidiary of Smith International, Inc., for use on drill bits

## Applications

Wear-resistant components for drilling

## Capabilities

FM composites have very high fracture energies, damage tolerance, and graceful failure.

## Benefits

### Energy Savings

Reduces energy consumption by more efficient use of the drill machinery and less downtime.

### Productivity

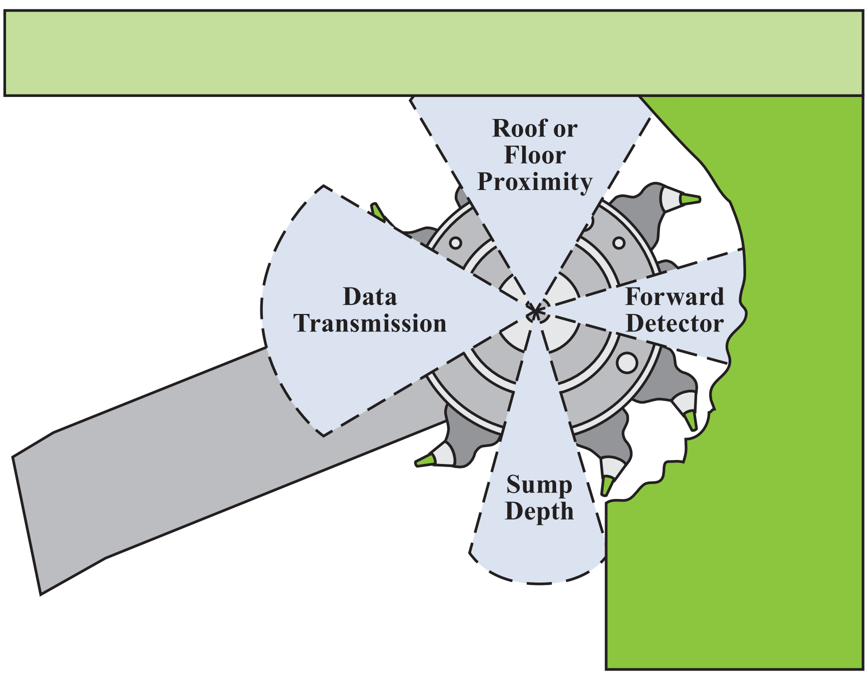
Increases the cost/performance ratio of wear materials and components and increases employee output.

IMPACTS

## Remote Sensing Cuts Coal and Other Minerals More Efficiently

Future mining will be from deeper and thinner seams; profiles of deep coal seams reveal multiple levels of coal and sediment strata or layers. Some of these layers contain greater levels of pollutants than others, which results in more effort to clean the coal once it is removed from the ground and more emissions when it is burned for fuel.

With the aid of a DOE grant, Stolar Horizon, Inc., developed the Horizon Sensor to distinguish between the different layers of coal. Miners can use this technology at remote locations to cut only the clean coal, resulting in a much more efficient overall process. The sensor, located inches from the cutting bits, is based on the physics principle of resonant microstrip patch antenna (RMPA). When it is in proximity of the rock-coal interface, the RMPA impedance varies depending on the thickness of uncut coal. The impedance is measured by the computer-controlled electronics and then is sent by radiowaves to the mining machine. The worker at the machine can read the data via a graphical user interface, which displays a color-coded image of the coal being cut, and direct the machine appropriately.




*Functions Performed by the Horizon Sensor Mounted on the Cutting Edge of a Continuous Mining Machine*

## Overview

- Developed by Stolar Horizon, Inc.
- Commercialized in 2002
- Used in 10 different mines within the United States

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 0.169 | 0.072 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.0 | 0.015 | 0.012 | 1.41 |

## Applications

Both underground and surface mining operations. This technology is primarily used in the coal industry but is also used to mine trona and potash.

## Capabilities

- Improves the quality of coal extracted from mines.
- Allows for deeper mining.
- Is used remotely for miner safety.

## Benefits

### Productivity

Extracting only desired material increases productivity by reducing or eliminating the cleaning step after extraction. This technology also allows for deeper mining, resulting in more material obtained from one location. Also, keeping the cutting bits out of rock results in longer bit life.

### Safety

The remote sensing tool allows workers to operate the machinery away from the hazards of cutting coal, including noise, dust and gases, and coal and rock splintering and outbursts.

# Imaging Ahead of Mining



## Radio-Imaging Method (RIM™) Improves Mine Planning and Products

Coal mining is becoming more difficult as machines must extract the coal from deeper, thinner, and more geologically complex coal beds. This type of mining also includes the need to reduce risk and costs.

To address these mining issues, Stolar Horizon, with support of a DOE grant, redesigned and improved a technology developed twenty years ago. The Radio-Imaging Method (RIM™) uses wireless synchronization between a transmitter and remote imaging receiver to detect geologic formations up to 1,800 feet ahead.

In layered sedimentary geology, a natural coal seam waveguide occurs because of the 10:1 contrast in conductivities between coal and surrounding materials. The electromagnetic wave sent by RIM through the rock reacts to these properties with a detectable change in magnitude because it is very sensitive to changes in the waveguide geology.

The information from RIM can be used to produce an image that maps out the dikes, faults, and paleochannels for more targeted mining. Areas of high signal loss represent geologic anomalies and can be imaged to high resolution using tomographic reconstructions similar to CAT scans.

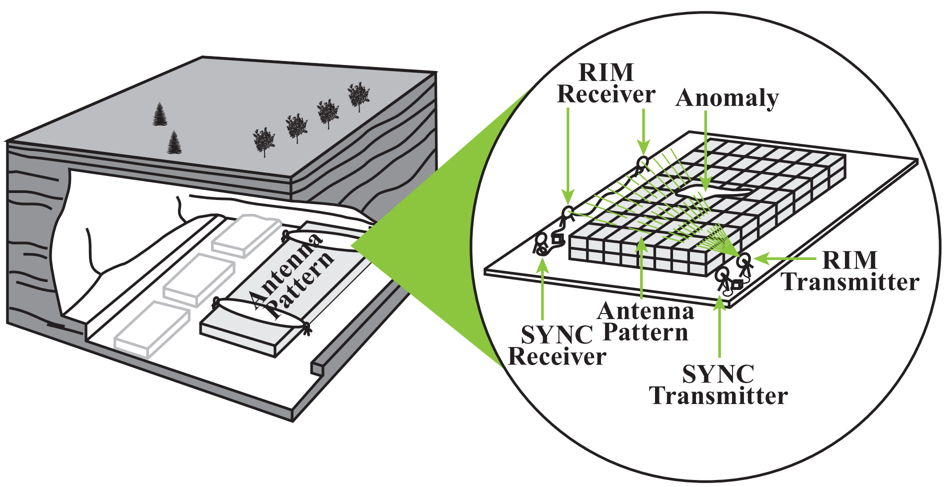
## Benefits

### Energy Savings

Being able to drill in targeted areas and to extract cleaner coal is expected to reduce energy use 2.7 trillion Btu/yr by 2020.

### Productivity and Profitability

In mining, forward imaging with confirmation will reduce the risk of interrupting production because of adverse geologic conditions. When RIM is integrated into the planning of underground mining, forecasting production can improve 10 percent, which in turn increases profits.




*In-Mine RIM Detection System*

## Overview

- Developed by Stolar Horizon, Inc.
- Commercialized in 2002
- Used in 6 different mines through 2004

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 4.10 | 1.64 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.007 | 0.354 | 0.264 | 32.2 |

## Applications

Both underground and surface mining operations. This technology is primarily used in the coal industry but has also been used for metalliferous mining, environmental research, and civil engineering applications. Additionally, it has been used to confirm the location of old and abandoned mine works and the integrity of barriers.

## Capabilities

- In-mine RIM detects ore seams and geologic anomalies.
- Crosswell RIM delineates ore bodies, monitors heap leaches, and detects voids in coal seams.
- Drillstring radar for navigation detects voids and confirms geologic anomalies.

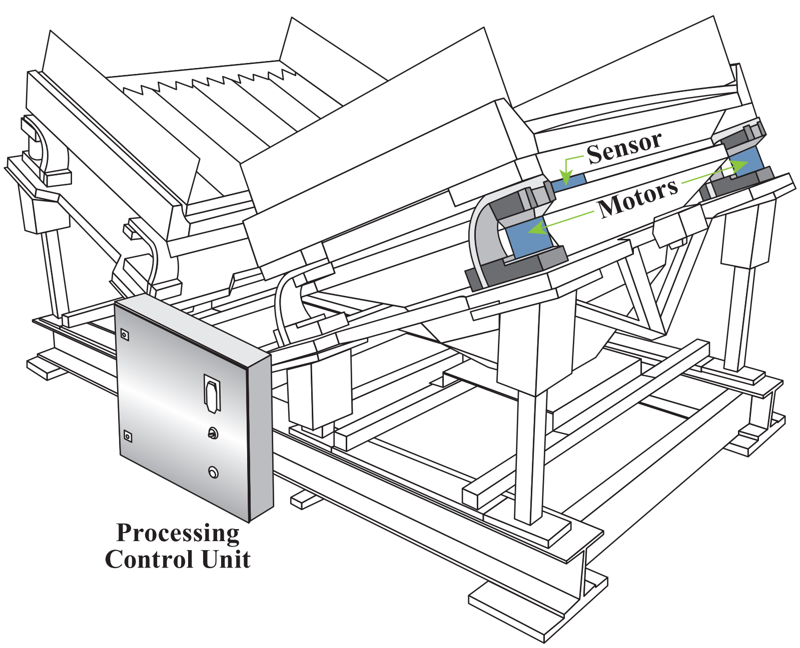
# Smart Screening Systems for Mining

IMPACTS

## Smart Screening Systems Will Increase Energy Efficiency And Throughput

In mining, contemporary vibrating screening machines use an electrical motor with an eccentric rotor that generates the shaking motion. These unbalanced electrical rotors are bulky and have high maintenance costs. They also waste significant energy through useless elastic deformation of heavy supporting structure and generate very loud noises and excess heat. Excess heat and mechanical vibration reduces the life of the moving components, such as bearings.

With assistance from ITP, Quality Research, Development, and Consulting (QRDC), Inc., developed a Smart Screening System that controls the flow of energy by directing and confining the energy to the screen rather than shaking the entire support structure. The systems saves energy by replacing the massive electrical motor and eccentric shaft, which typically weighs around 1,100 lbs, with miniaturized "smart" motors that weigh only 5 lbs in combination with multi-staged resonators. The processing control unit continuously receives screen panel deflection data taken from the sensor to control the electromagnetic motors. The motors are programmed to vibrate the screening panel at an optimal set rate, even as the material load varies over time, thus optimizing the throughput and energy savings of the screening system. Future designs may incorporate ceramic fibers in sieves so the shaking takes place at the mesh level, further focusing energy in such a way that particles will have a greater opportunity to pass through the openings.




*Smart Screening System Components*

## Overview

- Developed by QRDC and manufactured and sold by Smart Screening Systems, Inc.
- Commercialized in 2003
- 24 systems operating in the United States in 2004

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 0.002 | 0.001 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.029 |

## Applications

All mined materials that must pass through a positive size separation process using vibrating screens.

## Capabilities

- Vibrates only the "live" system components rather than the entire machine and supporting structure in the material separation process.
- Allows for a smaller physical structure to achieve a given process objective.

## Benefits

### Operation and Maintenance

Reduces maintenance costs in screening operations and eliminates the need for lubrication.

### Productivity

Improves screening efficiency and capacity as well as overall process throughput.

### Safety

Reduces noise and vibration levels increasing worker safety and health.

# Wireless Telemetry for Mine Monitoring and Emergency Communications

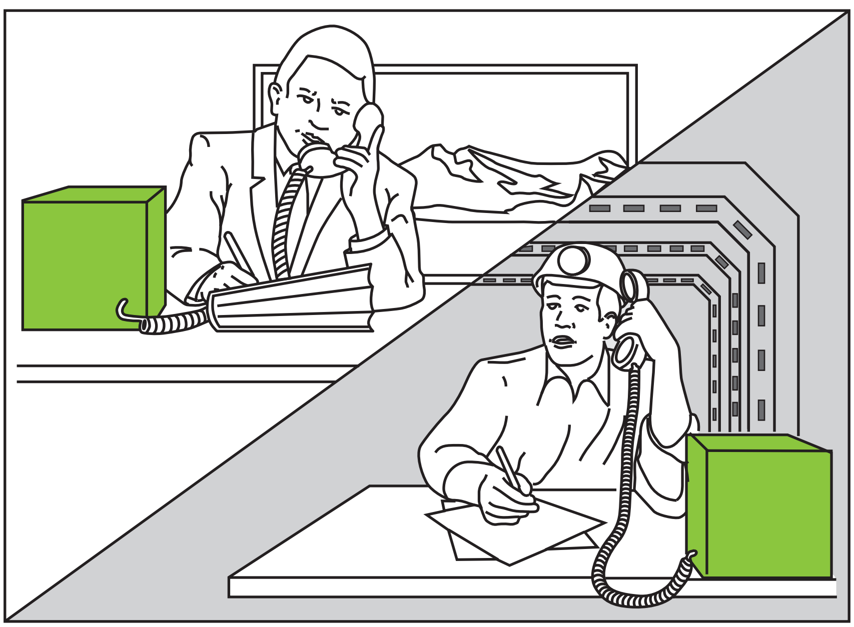


## Replacing Communication Cables Improves Safety, Efficiency, and Cost of Mining

The hard-wired systems currently used in mining to transmit production data, environmental monitoring data, and voice signals to the surface are not reliable in emergency situations because of shifting debris or other hazards. To solve these critical problems, a wireless, through-the-earth telemetry system has been developed with the assistance of DOE's Inventions and Innovation Program. The system eliminates the need for wire connections between the surface and mining sites underground.

In addition to improving safety for underground workers, such a system would be more reliable, useful, cost effective, and flexible. For example, if the new system is combined with a separate in-mine system, workers could communicate freely with other underground personnel as well as surface personnel. By using the wireless transmitters, mining operations would not need to invest in communications cables and their installation and maintenance.

Reports from installations in U.S. mines indicate that the technology is a significant source of cost and maintenance savings.



*Wireless Telemetry Communication System*

## Overview

- Invented by Transtek, Inc.
- Commercialized in 1998
- As of December 2004 there are 10 customers using 30 to 40 units in U.S. mines

## Applications

- All mining situations and other underground work
- Steel-reinforced buildings, tunnels and transit systems

## Capabilities

- Offers greater flexibility and mobility in communications.
- Allows for continued transmission of production data and environmental monitoring data.
- Increases communications capabilities both from the surface to the mining site and among personnel underground.

## Benefits

### Cost Savings

Costs are reduced by up to 25% by eliminating the need to purchase, install, and maintain communication cables. The new reliable system reduces unplanned downtime, thereby also saving costs.

### Worker Safety and Health

The new system increases the safety and acceptability of coal mining as an energy source, thereby augmenting the energy supply. Safety in the mine is improved by the system's ability to provide uninterrupted communications.

# Steel

## IMPACTS

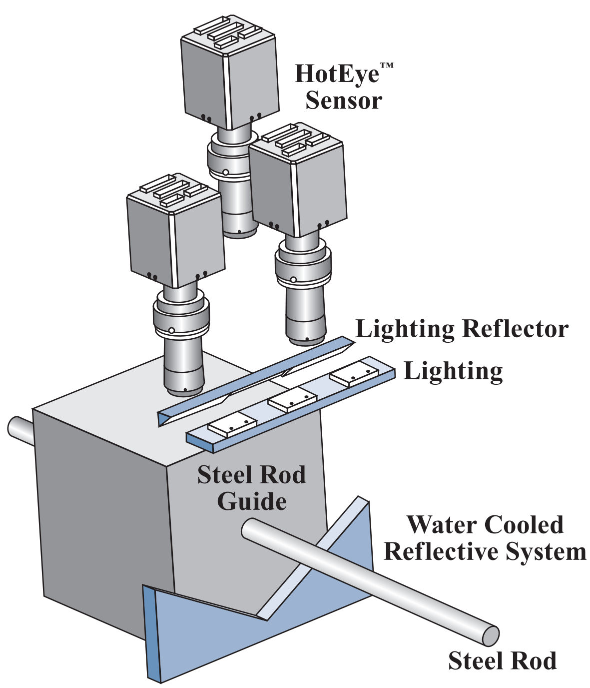
# Automatic High-Temperature Steel Inspection and Advice System



## Unique Measurement System Enhances Process Control, Reduces Scrap, and Saves Energy

A new measurement system, the HotEye™ Rolled Steel Bar (RSB) System, has been developed and demonstrated by OG Technologies (OGT) Inc., with the help of a NICE[3] grant. The HotEye RSB System is based on OGT's HotEye System and integrates it with a dynamic control plan (DCP) for hot steel processes. The HotEye System accurately and reliability measures a part's dimensions and detect its surface features, including defects, while it is still red hot, i.e. at temperatures of up to 1550°C. Current measurement systems cannot be used until the parts cool down, which results in higher scrap rates once defects are detected. The DCP classifies defects from production and identifies their root causes and corrective actions. The DCP's effectiveness depends on instruments that can detect quantitative quality information in real-time in a hostile operating environment. The HotEye RSB System provides real-time process control to increase yields 2.5% in continuous casting and hot rolling steel mills, saving energy, improving quality, and increasing productivity.

The HotEye RSB System consists of three HotEye imaging sensors, four powerful PC's, modulating devices for the lighting system, proprietary image processing software, the software version of the steel rolling DCP, and an enclosure to protect the hardware and software from the effects of the harsh operating environment in a steel mill. The HotEye RSB System will automatically (1) inspect 100% of the surface of the product in-line; (2) identify defects as small as 0.025 mm; (3) analyze and record the size, nature, and location of the defects; (4) measure 100% of the dimensions of the product; and (5) generate process correction advice based on the DCP, while the product is at a temperature up to 1550°C and moving at a speed up to 100 m/second.




*Design of the HotEye RSB Sensor System*

## Overview

- Developed by OG Technologies, Inc.
- Commercialized in 2004
- Operating in two U.S. steel mills in 2004

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 0.478 | 0.478 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.0 | 0.0 | 0.056 | 7.59 |

## Applications

The HotEye RSB System can be used in steel hot rolling mills and continued casting processes

## Capabilities

- Inspects 100% of product surface on-line.
- Identifies defects as small as 0.025 mm.
- Performs inspections while the product is at temperature of up to 1550°C and moving at 100 m/second.

## Benefits

### Employee Safety

Allows the measurement of parts at temperatures of up to 1550° C remotely, reducing employee burns.

### Profitability and Productivity

Detects and identifies production flaws quickly and reduces the scrap rate from the process by 50%.

IMPACTS

## Dilute Oxygen Combustion Improves Reheat Furnace Performance and Provides Very Low $NO_X$ Emissions

The Dilute Oxygen Combustion (DOC) system provides competitive rolling mill operators with higher productivity reheat furnaces without high capital and operating costs or increased $NO_X$ emissions. By replacing combustion air with oxygen, DOC needs less fuel to heat steel and also gives lower flue gas temperatures. These features allow a reheat furnace to operate economically at higher production rates. The DOC system injects the fuel gas and oxygen into the furnace as distinct, high-velocity jets through separate lances rather than through a single burner. The jets mix with the hot furnace gases before reacting with each other. This dilution effect prevents the high peak flame temperatures that are responsible for $NO_X$ generation, providing low $NO_X$ levels even with high nitrogen levels for the furnace. Because the flue gas is recirculated aerodynamically within the furnace, the DOC system is simpler and less expensive to install compared with conventional flue gas recirculation systems. In addition, the wide, diffuse flame from the DOC system provides exceptionally uniform heating of the steel, leading to better rolling mill performance and lower reject rates.

## Benefits

### Energy Savings

Results in fuel savings of up to 50% over air-fuel combustion for reheat furnaces.

### Productivity and Profitability

Increases productivity 10% to 30% over air-fuel combustion with the simple, low-maintenance combustion system. Improves heating uniformity, giving better quality and fewer rejects in rolled products.

## Overview

- Commercialized by Praxair, Inc.
- Installed in 1999 at Nucor Steel in Auburn, NY

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 0.042 | 0.007 |

## Emissions Reductions

*(Thousand Tons, 2004)*

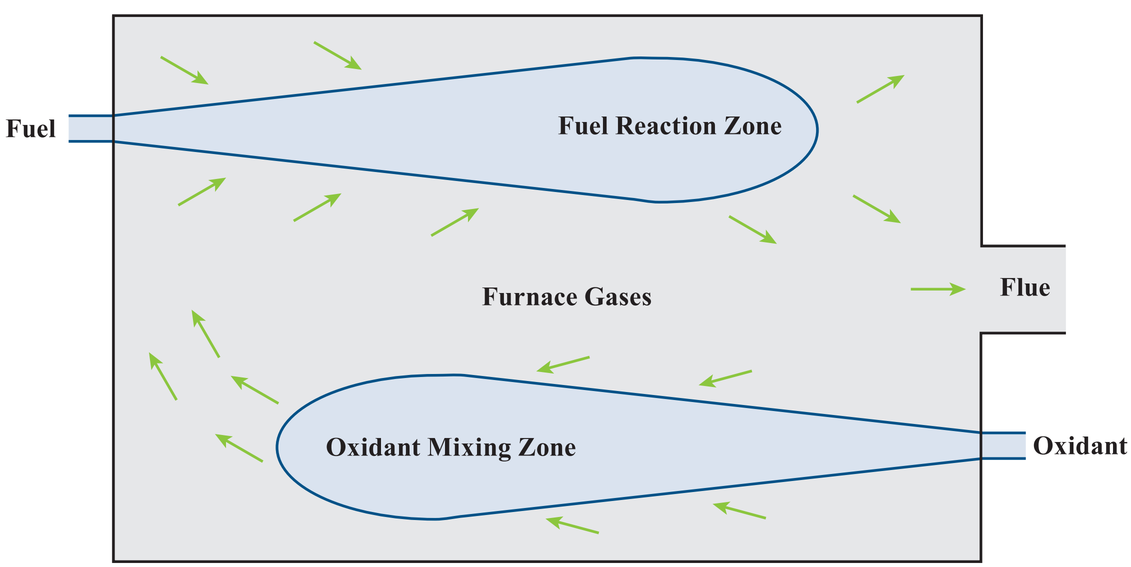
| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.0 | 0.0 | 0.001 | 0.111 |

## Applications

- Steel and glass industry
- Any combustion system

## Capabilities

- Up to 30% increase in furnace capacity.
- Can be used on continuous or batch reheat furnaces.




*Dilute Oxygen Combustion*

# Electrochemical Dezincing of Steel Scrap



## Dezincing of Steel Scrap Reduces Concerns of Recyclability and Waste Streams

Half of the steel produced in the United States is derived from scrap. With the use of zinc-coated prompt scrap increasing fivefold since 1980, steelmakers are feeling the effect of increased contaminant loads on their operations. The greatest concerns are the cost of treatment before disposal of waste dusts and the water associated with remelting zinc-coated scrap.

With financial assistance from ITP, Argonne National Laboratory with Metal Recovery Technologies, Inc., and Meretec Corporation have developed a technology that separates steel scrap into dezinced steel scrap and metallic zinc. The removal of zinc from steel scrap increases the recyclability of the underlying steel, decreases steelmaking dust, and decreases zinc in wastewater streams.

The process consists of two stages: dissolving the zinc coating from scrap in a hot, caustic solution and recovering the zinc from the solution electrolytically. Through a galvanic process, the zinc is removed from the steel and is in solution as sodium zincate ions rather than zinc dust. The steel is then rinsed with water and ready for reuse. Impurities are removed from the zinc solution, and then a voltage is applied in order to grow metallic zinc via an oxidation-reduction reaction. All waste streams in this process are reused.

## Benefits

### Pollution Reduction

Removal of zinc decreases steelmaking dust released to the air as well as pollutants in wastewater streams. The process itself does not consume any chemicals, other than drag-out losses, and produces only a small amount of waste.

### Productivity

Removing zinc prior to processing of scrap saves time and money in disposal of waste dusts and water. Without the zinc, this high-quality scrap does not require extra handling, blending, or sorting for remelting in steelmaking furnaces.

## Overview

- Developed by Argonne National Laboratory
- Commercialized in 2003
- Steel scrap sold to several dealers, steelmakers, and foundries after dezincing

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 0.030 | 0.017 |

## Emissions Reductions

*(Thousand Tons, 2004)*

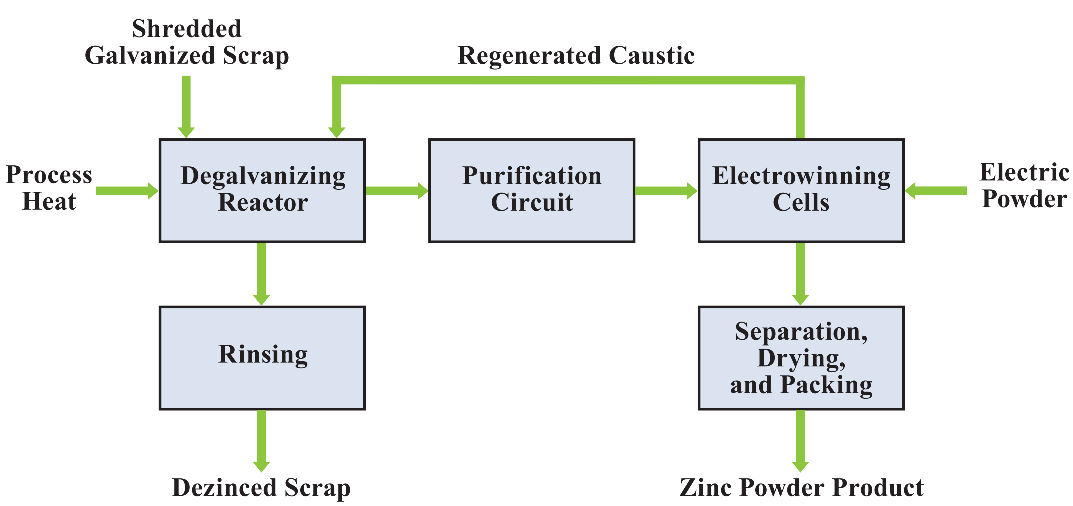
| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.0 | 0.010 | 0.005 | 0.0462 |

## Applications

Primarily the steel and foundry industries.

## Capabilities

- Improves quality of steel scrap that steelmakers can use.
- Produces 99.8% pure zinc for resale.




*Electrochemical Dezincing of Galvanized Steel Scrap*

# Laser Contouring System for Refractory Lining Measurements

IMPACTS

## Optical Sensor Provides Real-Time Process Control Resulting in Reduced Costs and Improved Performance

A suite of new robust sensors and control systems for base oxygen furnace (BOF) and other steelmaking operations makes possible dynamic process control and rapid assessment of the effectiveness of operations. With ITP support, Sandia National Laboratories and the American Iron and Steel Institute developed the Laser Contouring System (LCS) now being sold by Process Metrix. The LCS rapidly measures refractory lining thickness and incorporates high-speed, laser-based distance measuring equipment with a robust mechanical platform and easy-to-use software. With a laser scan rate of over 8,000 points per second, a single vessel scan can include over 500,000 individual contour measurements, providing incredibly detailed contour resolution and accurate bath height determination.

Contour maps of both vessel wall and bottom clearly illustrate lining thickness over the entire vessel interior. Thickness values are displayed both numerically and by color key, immediately revealing regions that might require attention. The report generator automatically prints all of the views and screens needed by the mill to make informed process decisions. New software releases, that include upgrades and feature requests from customers, are made twice annually.

Two principle objectives are emphasized in the mobile platform design: speed and simplicity. Fast measurement times are achieved using a laser-based navigation system. Working from three reflectors mounted on the building structure behind the cart, this system automatically measures the cart position relative to the BOF and reports position information directly to the LCS computer. The navigation system is completely automatic and updates 8 times per second. Process Metrix has also implemented a radio frequency (RF) link that continuously broadcasts the vessel tilt to a receiver located in the cart. The RF-link incorporates 2.4 GigaHertz spread-spectrum technology for interference-free transmission. During the measurement, the RF receiver automatically reports the vessel tilt to the LCS computer. Together, the laser navigation system and RF link enable fast, error-free measurement of the vessel lining thickness. Single measurements can be made in 20-30 seconds. An entire map of the vessel interior, consisting of 4-6 measurements and 500,000+ data points, can be completed in less than 10 minutes.

Fixed position installation is available for converter and ladle applications. This type of installation coupled with the high measurement speed of the LCS enables measurements after every heat with little or no loss of process time.

## Overview

- Commercialized in 2001 by Process Metrix
- 4 units in operation at three United States installations in 2004 and additional units in use overseas

## Applications

Rapid measurements of vessel wall and bottom lining thickness in the steel furnace or ladle environments

## Capabilities

- Available as a mobile platform or a fixed position installation.
- Maps the entire vessel interior in less than 10 minutes.
- Provides detailed contour resolution and vessel lining thickness with over 500,000 individual contour measurements.

## Benefits

### Energy Savings

Reduces energy usage via rapid real-time measurements and no loss of process time.

### Productivity

Reduces maintenance on BOF refractory via automated furnace inspection.

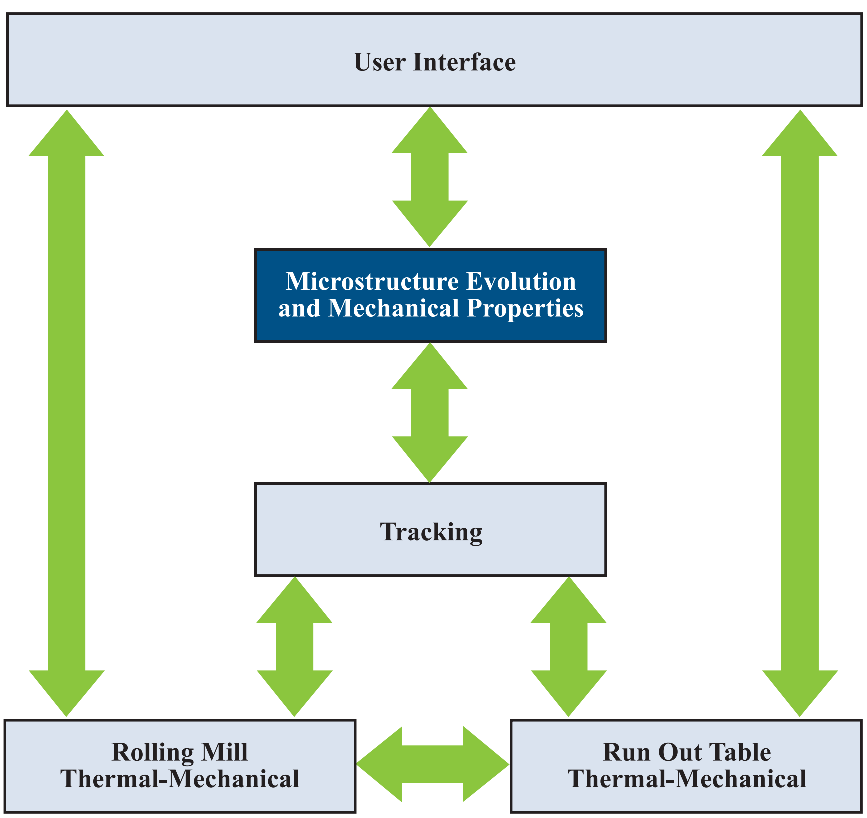
# Microstructure Engineering for Hot Strip Mills



## Innovative Model Provides a More Detailed Insight into Mill Operations to Reduce Costs and Improve Quality

Many hot rolled products must achieve strict strength and toughness requirements making control of the microstructure critical. This causes these products to be difficult to make and requires many costly full production trials before the range of both chemical composition and hot strip mill processing parameters can be defined. The Hot Strip Mill Model (HSMM) is an invaluable tool to cost effectively assist in determining the optimum processing conditions to achieve the desired product properties. This model runs in an off-line mode, thereby saving many tons of wasted product that might be scrapped in trying to identify the proper mill set-up.

The HSMM also provides additional savings in grade consolidation, control optimization of new grades, and improvement of mechanical and microstructure properties for downstream processing. The model can consolidate grades by allowing the user to develop different processing setups for the same steel grade that will then achieve the various mechanical properties needed for the different finished products. The HSMM can improve on-line control optimization for new grades by using what is learned from the HSMM to help setup the on-line models so they learn faster how to optimize the processing of the new grade. And finally, processing the steel to achieve the optimum or specific microstructure attributes further improves processing of the product in downstream operations.




*Components of the HSMM*

## Overview

- Developed by The American Iron and Steel Institute as part of its Advanced Process Control Program and being marketed by INTEG Process Group, Inc.
- Being used by US Steel, Weirton Steel, IPSCO Steel, Nucor Steel, Saldanha Steel (ISCOR Steel South Africa), Lloyds Steel (India), St. Petersburg Technical University (Russia) and Algoma Steel (Canada).

## Applications

The HSMM is applicable to any hot rolling mill that produces sheet or plate products (flat rolled material). The model can handle a variety of rolling mill configurations, including roughing mills, coil boxes, finishing mills, run out tables, and coilers.

## Capabilities

- Allows the user to easily modify the mill configuration or processing parameters to see its impact on the end results of the product being rolled (simulated).
- Can also be used as a training tool, allowing operators to see the end result for different processing conditions or grades of steel.

## Benefits

### Competitiveness

Improves industrial competitiveness through product optimization and cost savings.

### Productivity

Decreases product variability through the development of a predictive tool, which can quantatively link the properties of hot rolled product to the operating parameters of the hot strip mills.

# Recovery of Acids and Metal Salts from Pickling Liquors

**IMPACTS**

## Acid and Salt Recovery Now Cost-Effective for Smaller Manufacturers

Steel fabrication processes often use pickling (immersing steel in acid) to remove oxide layers from recently heated steel. Technology for recycling the sulfuric acid has been available for large installations for some time. The Green Technology Group, in collaboration with DOE's Inventions and Innovation Program, developed the Pickliq® process to make sulfuric acid recovery cost-effective for smaller facilities.

The Pickliq process combines diffusion dialysis, energy transfer, and low-temperature crystallization technologies to efficiently recover acids and metal salts. It has demonstrated significant gains in production capacity, quality control, and productivity by maintaining pickling tank acid and iron concentrations at preset levels. Bath uniformity and predictable performance raises output and minimizes rejects and rework. To manufacturers, these benefits are even more important than the simple cost savings from eliminating waste. Additional benefits include reduced demand for virgin acids and elimination of chemicals to neutralize waste acid, as well as energy and cost savings associated with acid transportation and disposal.

The Green Technology Group has recently improved the technology, and the new system called Pickliq Hydrochloric Acid Regeneration (PHAR®) will soon be commercially available.

## Benefits

### Productivity
Significantly improves process uniformity and product quality, reduces downtime associated with acid revitalization, improves overall process effectiveness and throughput, and reduces rework. Optimal pickling bath acid concentrations are continuously maintained.

### Profitability
Costs less than transporting and disposing of waste acid. Eliminates long-term liabilities of waste disposal. Generates a saleable by-product (metal salts) that can be used in a variety of applications. Results in rapid payback estimated at 6 months to 2 years.

### Waste Reduction
Recycles acid for reuse, eliminating disposal of spent acid and neutralized sludge. Reduces the demand for virgin acids, conserving petroleum feedstock.

## Overview

- Developed by Green Technology Group
- First commercial unit installed in 1995
- 2 units operating in the United States

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 0.011 | 0.001 |

## Emissions Reductions

*(Thousand Tons, 2004)*

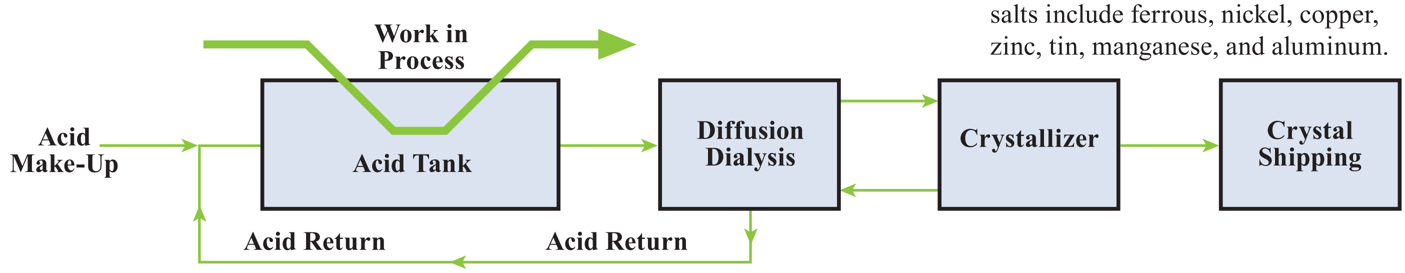
| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.026 |

## Applications

To be used primarily in the primary metal industry but could be used in the metal finishing and circuit board industries for recovering acids and metal salts from etching and metal stripping

## Capabilities

- Provides better process control and product quality.
- Maintains acid baths at optimum concentration.
- Permits continuous operation.
- Can recover hydrochloric, sulfuric, nitric, hydrofluoric, and other acids (including nonmineral acids).
- Recovers metal salts into a saleable by-product. Metals with recoverable salts include ferrous, nickel, copper, zinc, tin, manganese, and aluminum.




*Recovery of Acids and Metal Salts from Pickling Liquors*

# Shorter Spherodizing Annealing Time for Tube/Pipe Manufacturing

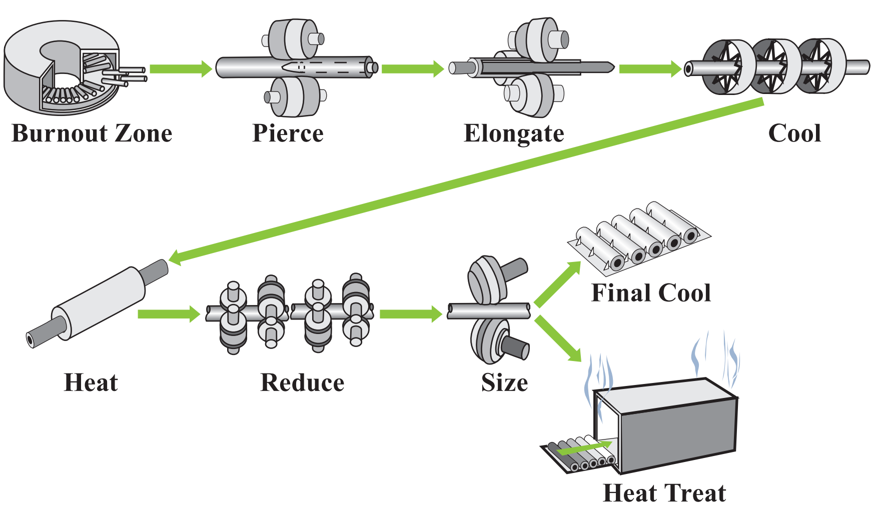
IMPACTS

## New Process Results in Productivity Improvements and Energy Savings

The steel industry is working to improve the manufacturing of tubes and pipes while maintaining key steel parameters and reducing the amount of energy used in the process. The Timken Company developed an enhanced spherodized annealing cycle for through-hardened steel. This technology is a by-product of a larger ITP sponsored project, the "Controlled Thermo-Mechanical Processing (CTMP) of Tubes and Pipes for Enhanced Manufacturing and Performance."

The spherodized annealing process changes the hard, elongated carbide particles in the steel to be spherical in shape with a preferred diameter. The size and shape of the original elongated carbides produced by the previous hotworking process influence the ability to spherodize the carbides. The spherodized annealing process consists of heating the carbide particles to temperatures at which they form spherical shapes. This entire heating and holding cycle takes 20 to 50 hours. Various combinations of temperatures and times can be used to achieve the desired shape and distribution of the carbide spheres. In this ITP sponsored project, experimentation was conducted to characterize the effect of the original elongated carbides and the annealing times and temperatures on the resulting spheroid size and distribution.

The experimental results helped The Timken Company shorten the annealing cycle time by 20% and condense the number of plant trials to achieve that. The result was an optimized cycle that reduced energy consumption and improved productivity while generating a quality product with the desirable metallurgical properties for forming and machining.




*Tube Making Process*

## Overview

- Developed by The Timken Company
- Process being used at two facilities in 2004

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 0.084 | 0.017 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.0 | 0.0 | 0.002 | 0.266 |

## Applications

- Steel tube and pipe manufacturers
- Specialty metal manufacturers

## Capabilities

Shortens annealing cycles and saves energy.

## Benefits

### Energy Savings

Reduces fuel requirements by reducing annealing cycle time by 20%.

### Productivity

Increases productivity approximately 10% due to the reduced cycle time.

### Product Quality

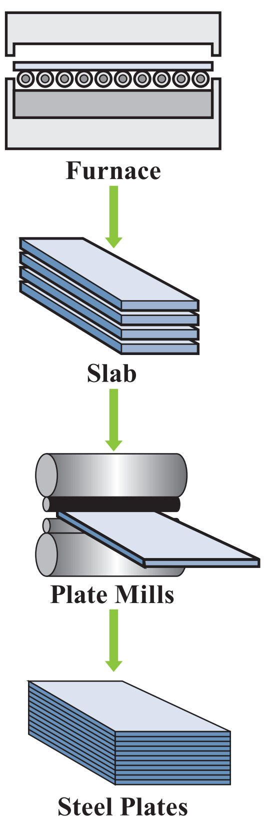
Provides the end user with steel that is easily formed and machined with the same desirable metallurgical properties.

IMPACTS

## New Oxy-Fuel Burners Reduce Energy Use While Reducing Emissions and Increasing Productivity

Steel reheating is an energy-intensive process. Historically, "recuperators" have been used to preheat combustion air, thereby conserving energy. Innovations that are more recent include oxygen enrichment and the use of regenerative burners, which provide higher preheat air temperatures than recuperators. These processes increase $NO_X$ emissions with increased air preheat temperature, unless special equipment is used. $NO_X$ is an industrial pollutant whose emissions are being increasingly restricted.

With assistance from a NICE$^3$ grant, Praxair developed and demonstrated a low $NO_X$, oxygen-burner retrofit using 100% oxygen. The burners require less fuel to heat steel and promote lower overall heat content in the waste gases. Energy use was reduced by 60% from five to two million Btu per ton of steel processed. Air burners can be retrofitted or new burners can be installed where the fuel and oxygen are injected through separate ports rather than through a single burner. The low $NO_X$ feature of this system is expected to be a general requirement of the steel industry of the future. The Praxair technology provides exceptionally uniform heating of the steel. This results in better rolling-mill performance and allows a reheat furnace to economically operate at higher production rates. Successful implementation of this technology eliminates the need to periodically replace recuperators and install $NO_X$ removal equipment.




*Production of Steel Plates Using Reheat Furnace*

## Overview

- Burners are available from Praxair, Inc.
- 4 burners retrofitted on No. 6 furnace at ISG/Bethlehem Steel's Burns Harbor Plant

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 1.00 | 0.154 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.0 | 0.0 | 0.018 | 2.44 |

## Applications

- Steel reheating furnaces
- Burners can be retrofitted or added to new furnaces

## Capabilities

- Reduces $NO_X$ and particulate emissions from steel furnaces.
- Results in energy savings per ton of steel while increasing the quality of the metal.

## Benefits

### Emissions Reductions

Reduces $NO_X$ emissions and particulates by 60 to 90% per ton of steel.

### Productivity

Provides uniform heating of steel, resulting in better mill performance and an increase in productivity of 3%.

### Profitability

Eliminates the need for recuperators and $NO_X$ removal equipment.

# Transfer Rolls for Steel Production



## New Nickel Aluminum Transfer Rolls for High-Temperature Applications

A nickel aluminum alloy developed by Oak Ridge National Laboratory (ORNL), in conjunction with ITP, has transformed the steel heat-treating resists industry. Nickel aluminide is a strong, hard, inter-metallic material that resists wear, deformation, and fatigue from repeated stress or high temperatures. Because it becomes stronger and harder at high temperatures, nickel aluminide transfer rolls are well suited to replace steel transfer rolls in heat-treat roller hearth furnaces.

In the annealing furnace at Bethlehem Steel Burns Harbor Plate Division (now ISG Burns Harbor Plate Inc.), nickel aluminide inter-metallic alloy rolls provide greater high-temperature strength and wear resistance compared with the conventional H series cast austenitic alloys currently used in the industry. ORNL and Bethlehem (ISG) partnered under the U.S. Department of Energy's ITP Emerging Technology Deployment Program to demonstrate and evaluate the nickel aluminide inter-metallic alloy rolls as part of an updated, energy-efficient, large, commercial annealing furnace system.

The project involved developing welding procedures for joining nickel aluminide inter-metallic alloys with H-series austenitic alloys and developing commercial cast roll manufacturing specifications. Several commercial suppliers helped produce a quantity of high quality, reproducible nickel aluminide rolls for a large steel industrial annealing furnace. The capability of the rolls in this furnace were then demonstrated and trials were performed to evaluate the benefits of new equipment and processes.

Straight-through plate processing is now possible because of the nickel aluminide rolls, which also improved the quality of the plate product surface to allow the additional processing of surface critical material. Benefits also include associated large reductions in maintenance, reduction in spare rolls and associated component costs, and potential for greater throughput and productivity. Estimated project fuel cost reductions alone for processing 100,000 tons/yr through this furnace are $100,000/yr from straight through processing assuming natural gas prices of $6.00/MMBtu. The nickel aluminide rolls are competitively priced with conventional H series alloy rolls.

## Benefits

### Productivity

Increased roll life reduces furnace shutdowns to replace worn components, resulting in increased production. Maintenance and furnace shutdowns decreased from weekly to quarterly. Reduced damage to steel during heat-treating, resulting in less steel scrap.

### Product Quality

The new rolls are two to three times stronger than conventional steel roll assemblies. The strength increases at temperatures greater than 1475°F. The high aluminum content resists oxidation and carburization at high temperatures without adhering to steel.

### Profitability

Extends transfer roll life three to five times and reduces life cycle costs by 75% compared with steel rolls. Produces steel plates with greater, more consistent quality.

## Overview

- Nickel aluminide developed by Oak Ridge National Laboratory
- Being marketed by Duraloy Technologies, Inc.
- Nickel aluminide transfer rolls technology commercialized in 1993

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 0.033 | 0.017 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.0 | 0.0 | 0.002 | 0.265 |

## Applications

Heat-treat roller hearth furnaces to move high-temperature steel plates through the heat treatment process

## Capabilities

Can operate in temperatures as high as 2100°F.

# Crosscutting

**IMPACTS**

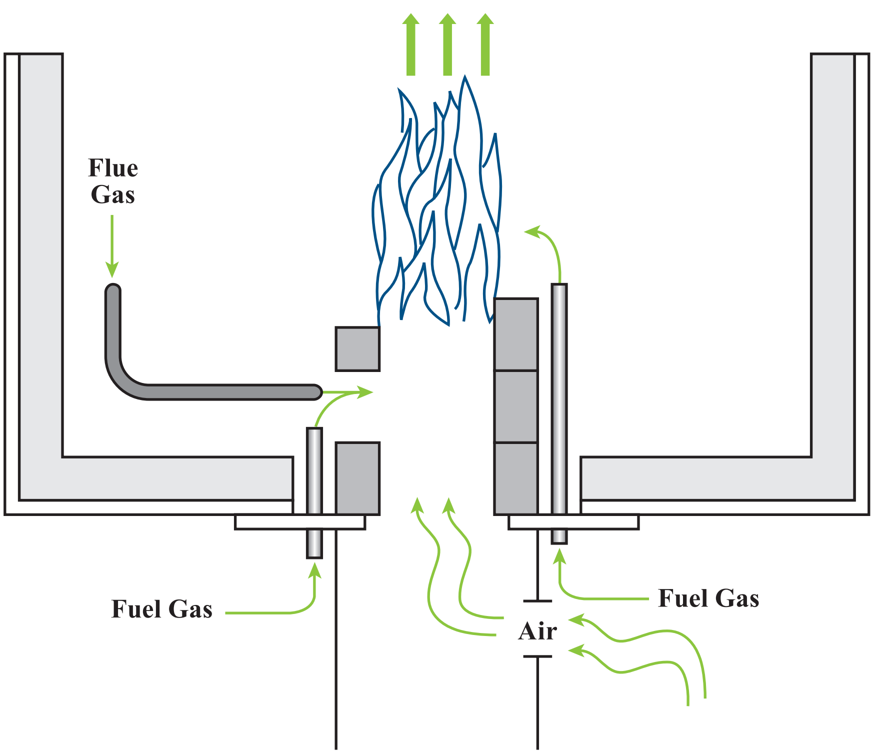
# Callidus Ultra-Blue (CUB) Burner



## A New Generation of Smart, Integrated Burner/Fired-Heater Systems

The refining and chemicals industries rely on process heaters to heat liquids and induce chemical reactions during production processing. Process heaters in these two industries generate over 235,000 tons of $NO_X$ emissions annually. The chemicals and refining industries are facing more stringent environmental regulations to reduce $NO_X$ emissions; for example, the state of Texas has ordered refiners in the Houston area to reduce $NO_X$ emissions by 80+%.

Callidus Technologies, along with funds and resources from ITP, Gas Research Institute (GRI), and Arthur D. Little Company, developed and demonstrated an ultra-low $NO_X$ emissions burner. The burner uses internal flue gas recirculation to reduce 80% of the $NO_X$ emissions, with many applications achieving reductions greater than 90%. Callidus Technologies, with licensing rights from GRI, is manufacturing and marketing the Callidus Ultra-Blue Burner to the chemicals and refining industries where potential $NO_X$ reductions of 200,000 tons/year are possible.




*Callidus Ultra-Blue Burner*

## Overview

- Developed by Callidus Technologies, Inc.
- Commercialized in 2000
- Over 2200 burner units installed by 2004

## Applications

High-temperature ultra-low $NO_X$ burner for the chemicals, petrochemicals, and refining industries

## Capabilities

The Callidus burner works with

- Natural or forced-draft operation
- Refinery fuel gas, natural gas, and high and low hydrogen content
- Ambient and preheated air.

## Benefits

### Emissions Reductions

Reduces thermal $NO_X$ in the combustion zone by 80% to 90%.

### Profitability

Eliminates or reduces the need for expensive post-combustion emission-altering equipment.

### Other

Is designed to be user-friendly.

IMPACTS

## Advanced Catalytic Combustion System Reduces $NO_X$ Emissions

Natural-gas-fired turbine systems currently require complex after-treatment systems to clean the exhaust of harmful emissions. Many of these emissions could be reduced by lower operating temperatures during the combustion process.

With the support and recognition from many organizations, including DOE, the California Air Resources Board, the California Energy Commission, and the U.S. Environmental Protection Agency, Catalytica Energy Systems, Inc., has developed an innovative system to reduce turbine emissions. The Xonon Cool Combustion® System uses a catalytic process instead of a flame to combust the fuel, thereby lowering the combustion temperature and significantly reducing the formation of $NO_X$.

While maintaining turbine efficiency, the technology has the potential to reduce the cost associated with achieving ultra-low emissions while generating electricity with gas turbines. With the growing need for electricity generation that produces less pollution, Catalytica Energy Systems' solution provides a cost-effective method to meet air pollution control standards through pollution prevention rather than cleanup.

## Benefits

### Emission Reductions

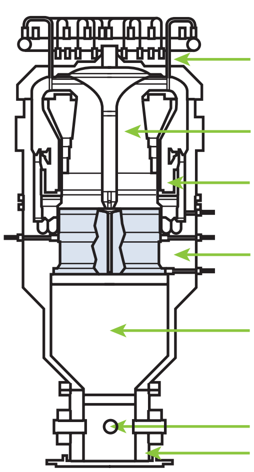
The system reduces air pollutant emissions from gas turbine energy generation systems. In its first commercial installation, the $NO_X$ output was reduced from approximately 20 ppm to well below 3 ppm.

### Pollution Reduction

The catalytic system avoids the need for costly or burdensome exhaust cleanup systems that use toxic reagents such as ammonia.

### Productivity

The $NO_X$ reduction process using catalytic combustion does not reduce the turbine efficiency. The system has demonstrated operating reliability greater than 98%.




*Catalytic Combustion*

## Overview

- Developed by Catalytica Energy Systems, Inc.
- Has accumulated over 18,000 hours of operation on the grid in field demonstrations
- First commercialized in 2002

## Applications

- Commercially available through Kawasaki Gas Turbines-America on its M1A-13X, a 1.4-MW gas turbine as part of the GPB 15X congeneration system
- For power generation turbine systems with low emission requirements or preferences, such as California installations, international systems, and systems with low pollution requirements
- Could also be applied to turbine generation systems with cogeneration to improve energy efficiency
- Being actively developed in partnership with GE Power Systems for its GE10, a 10-MW gas turbine, and with Solar Turbines for its Taurus 70, a 7.5-MW gas turbine

## Capabilities

- Can be used in a broad range of turbine sizes and will not reduce the turbine efficiency.
- Achieves emissions less than 3 ppm for $NO_X$ and less than 10 ppm for CO.
- Uses a catalyst rather than a flame to combust fuel.

# Chemical Vapor Deposition Optimization of Ceramic Matrix Composites

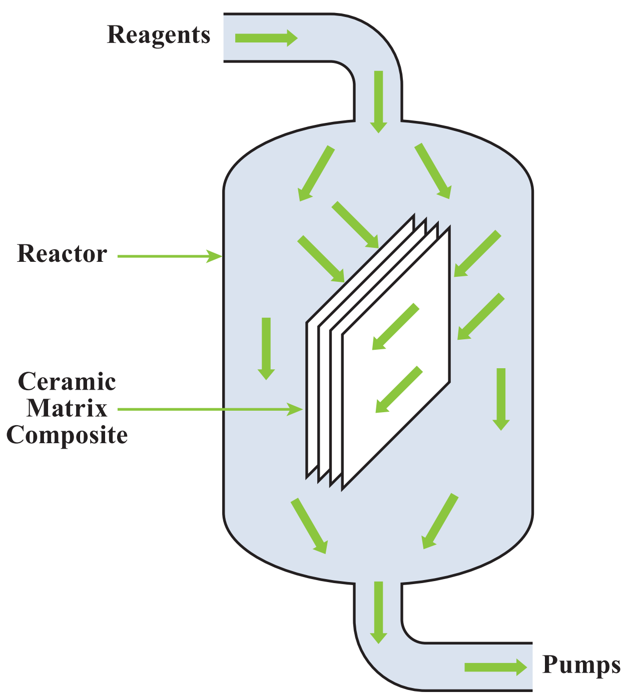


## Chemical Vapor Deposition Optimizes Industrial and Aerospace Ceramic Matrix Composites

Ceramic matrix composites comprise a new technology that is practical for a wide range of industrial and aerospace applications. Ceramic matrix composites are extremely heat-tolerant and corrosion-resistant, making them ideal for applications requiring lightweight materials capable of withstanding high temperatures.

Chemical vapor deposition (CVD) is used to enhance the physical characteristics of the ceramic matrix composites. Honeywell Advanced Composites, Inc. uses CVD to apply a thin, even interface coating to the surface of ceramic fibers. A coating of silicon carbide is then added to further strengthen the composite, making it stronger than conventional composites and shatterproof upon failure.

Sandia National Laboratory partnered with AlliedSignal Composites, a major producer of high-tech ceramic composites, to optimize the CVD process presently used by Honeywell Advanced Composites. Researchers used a Sandia research reactor, originally funded by ITP, to determine identities and amounts of gaseous-phase species present during CVD. Sandia researchers developed a computer model whose predictions are now being used to increase the throughput of two Honeywell coating reactors. The partnership saved Honeywell approximately $1 million in development time and expenses.




*CVD Process*

## Overview

- Developed by Sandia National Laboratory in cooperation with Honeywell Advanced Composites, Inc., formerly AlliedSignal Composites, Inc.
- Commercialized in 1997
- 2 CVD reactors presently use the optimized coating process to make ceramic matrix composites

## Applications

- Liners in jet engines
- Leading edges of jet turbine engine vanes
- Liquid oxygen thrusters in rockets
- Components for the reusable launch vehicle for space shuttles

## Capabilities

- CVD ceramic composites can replace superalloys in numerous aerospace and industry applications.
- Can withstand high-temperature, corrosive environments better than traditional superalloys.

## Benefits

### Energy Savings

In turbine engines, CVD ceramic composites allow higher operating temperatures that produce greater fuel efficiency.

### Productivity

Computer software operates CVD reactors at optimal conditions and reduces the time to process CVD ceramic composites. Reduces the number of reactor operations. Increases the number of parts processed per operation, resulting in greater productivity.

### Product Quality

CVD ceramic composites weigh about one-third less than superalloy counterparts, have greater strength and toughness than conventional alloys, and will not shatter when failed.

# Energy-Conserving Tool for Combustion-Dependent Industries

**IMPACTS**

## MultiGas™ Analyzer Provides On-Line Feedback Resulting in Lower Energy Use and Emissions

Using a NICE³ grant, Advanced Fuel Research (AFR), Inc., has developed and demonstrated a new system to improve continuous emissions monitoring (CEM) and on-line process tuning of combustion-dependent systems such as boilers and turbines.

Many existing combustion-monitoring techniques are unable to effectively and efficiently monitor all combustion gases, including difficult-to-separate hydrocarbons such as formaldehyde and emission control reactants such as ammonia. Typical CEM systems monitor a limited number of gases using an expensive collection of single-gas analyzers. These systems require a temperature-controlled room and a substantial ongoing investment to maintain operation and calibration of the facility.

The new multi-gas analyzer technology is portable, low-cost, and energy-efficient and combines advanced Fourier transform infrared spectroscopy with advanced electronics and software. This system provides CEM and on-line feedback for operational tuning of combustion-based industrial processes. The system allows for real-time measurement of criteria emissions and pollutants, including pollutants that are not usually monitored such as formaldehyde and ammonia. The improvements in dependability and efficiency and the lack of need for expansive temperature-controlled space result in lower operations, energy, and labor costs.

## Benefits

### Environmental

Measures criteria and hazardous air pollutants that are not typically monitored on-site in real-time, such as formaldehyde and ammonia.

### Productivity

Reduces maintenance and performance verification time, resulting in labor savings of up to 80%.

## Overview

- Developed by Advanced Fuel Research, Inc.
- Commercialized in 2001
- Manufactured and sold by MKS Instruments
- 20 units operating in the United States in 2004

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 0.004 | 0.002 |

## Emissions Reductions

*(Thousand Tons, 2004)*

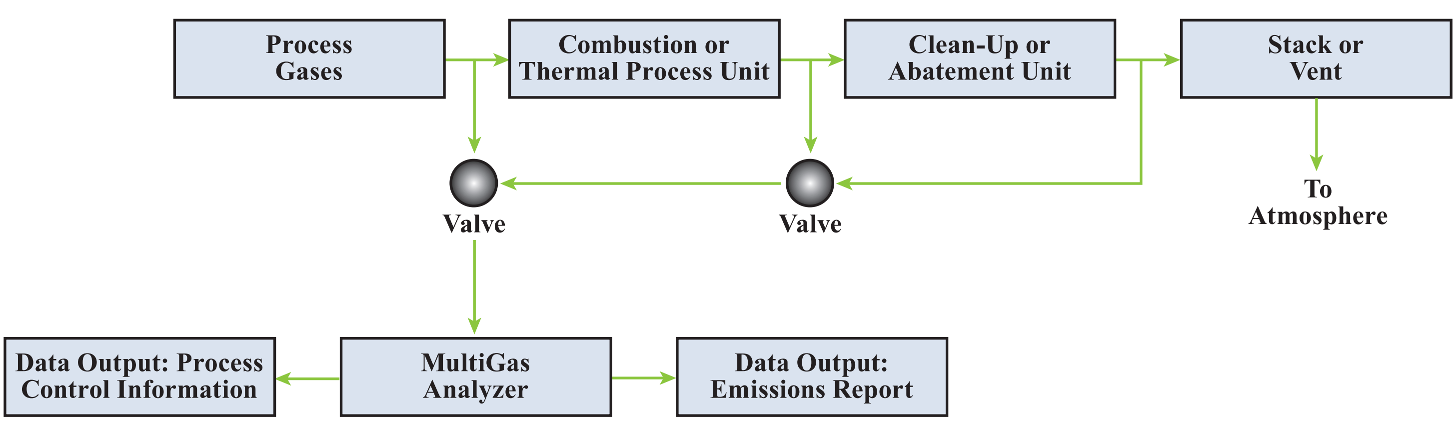
| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.031 |

## Applications

Systems and processes requiring combustion of fuels in engines, boilers, incinerators, and turbines

## Capabilities

- Achieves higher combustion efficiencies through closely monitored and controlled combustion.
- Reduces emissions through verified efficient operation.




*MultiGas Analyzer System*

# Evaporator Fan Controller for Medium-Temperature Walk-In Refrigerators



## Fan Controller Saves Energy in Two Ways

With assistance from DOE's Inventions and Innovation Program, Advanced Refrigeration Technologies (ART) commercialized an innovative control strategy for walk-in refrigeration systems. The ART Evaporator Fan Controller is inexpensive and easy to install.

The concept and operation of the ART controller is technically quite simple: refrigerant flow is sensed by temperature differential at the expansion valve within the evaporator. When refrigerant is not flowing through the evaporator/evaporators, voltage is dropped to the evaporator fans, saving energy in two ways. First and foremost, the evaporator fans consume less energy. Secondly, heat introduced to the refrigerated chamber from the evaporator fan motors is decreased. This decrease in heat, coupled with a decrease in thermal inversion, results in a decreased overall box load, thereby reducing the compressor/condenser on-duty cycle. The slow fan speed maintains air circulation to avoid temperature stratification. The lower air speed also maintains natural product moisture, thereby increasing shelf life.

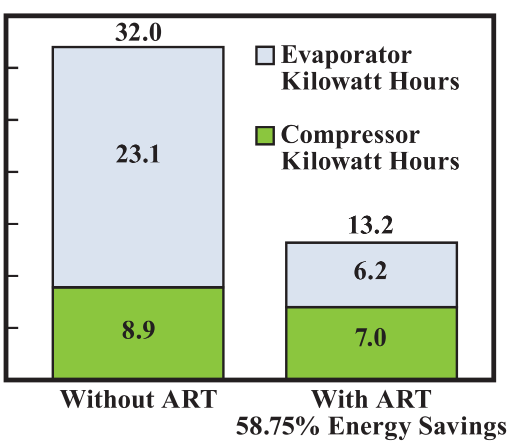
## Benefits

### Energy Savings
Reduces evaporator and compressor energy consumption by 30% to 50%.

### Productivity
Even temperature distribution and lower air velocity improve working conditions and result in workers keeping refrigerated spaces closed.

### Product Quality
Less air movement maintains the natural moisture in open product, so freshness and shelf life is increased without affecting overall relative humidity within the refrigerated chamber.

### Profitability
Lower running times increase equipment life span and cut maintenance and replacement costs.




*Average Daily Energy Consumption for a 29,200 Btu Evaporator*

## Overview

- Developed by Advanced Refrigeration Technologies, Inc.
- Commercialized in 1997
- Being sold by RS Services
- Over 1425 units operating in 2004

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 0.054 | 0.016 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.0 | 0.003 | 0.003 | 0.309 |

## Applications

Decrease in energy consumption in low- and medium-temperature walk-in refrigeration and freezer systems in restaurants, cafeterias, mess halls; grocery and convenience stores; hospitals; colleges and other educational facilities; naval vessels; and custom industrial and commercial applications

## Capabilities

- Control logic cuts evaporator and compressor energy consumption and lengthens component life.
- Controller can be retrofitted into existing refrigeration systems or incorporated into the design of new equipment.
- New models have the capability to monitor energy use and savings associated with the ART controller. Monitored information may be downloaded to a PC.

# Fiber-Optic Sensor for Industrial Process Measurement and Control

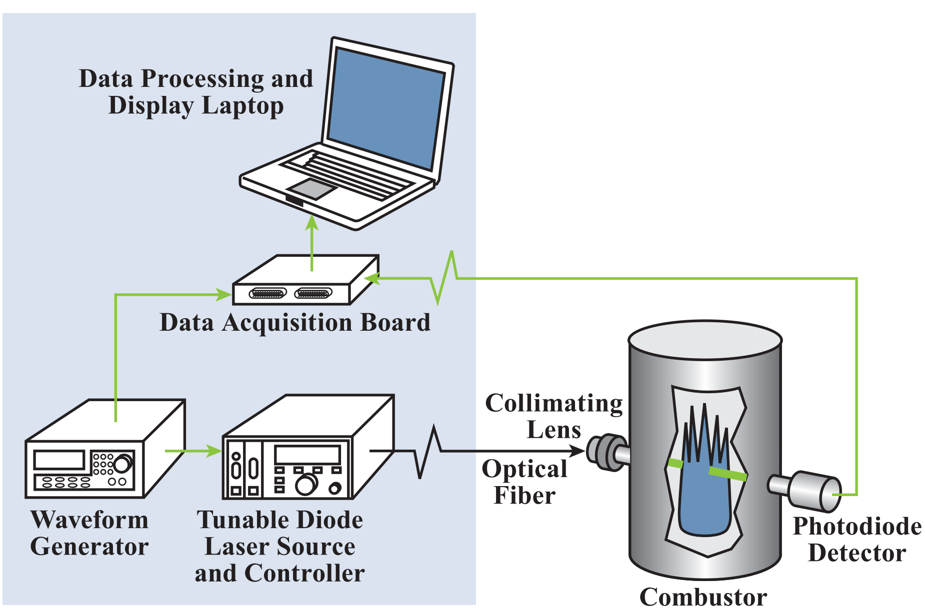
IMPACTS

## Reliable Advanced Laser Sensor Helps Control High Temperature Gas Combustion

Through a marketing agreement with MetroLaser, Inc., Bergmans Mechatronics LLC is offering the LTS-100 sensor to the aerospace and industrial markets. This new sensor will help reduce the cost and improve the performance of traditionally difficult temperature measurements.

Many existing industrial process sensors have limited accuracy in applications involving highly corrosive gases at elevated temperature and pressure because they require extractive sampling systems that introduce variations in the temperature, pressure, and composition of the probed gases. Moreover, sampling systems introduce a lag resulting in >1-10 second response times, require frequent servicing, and may be subject to unexpected failures because of their complexity. Using advanced tunable diode laser absorption spectroscopy (TDLAS) sensors for closed-loop process control affords a direct, quantitative measure of the species concentration in the probed region. In addition, by monitoring two or more transitions, the temperature along the optical path can also be determined.

Near-infrared diode lasers are attractive light sources for sensing applications because they are rapidly tunable, small and lightweight, low-cost, efficient, and robust. They operate at near-ambient temperatures and produce narrow bandwidth radiation over a broad wavelength range. These on-line sensors can be combined with process optimization control strategies to significantly improve plant throughput, increase product quality, and reduce energy consumption and waste.




*LTS-100 Processing Unit*

## Overview

- Developed by MetroLaser Inc., Irvine, CA
- Commercialized in 2003
- Being provided as a service in the United States by MetroLaser

## Applications

- Coal-fired power plants to achieve accurate real-time temperature measurements
- Solid propellant combustion to enhance the capabilities of the next generation of solid-fuel vehicles

## Capabilities

Monitors high-temperature gas combustion in process control applications.

## Benefits

### Reliability

Performs measurements regardless of vibration, flame luminosity, temperature, pressure extremes, and particle interferences.

### Profitability

Reduces maintenance costs and minimizes slag buildup heat-transfer losses in coal-fired power plants by precisely controlling furnace temperature and startups.

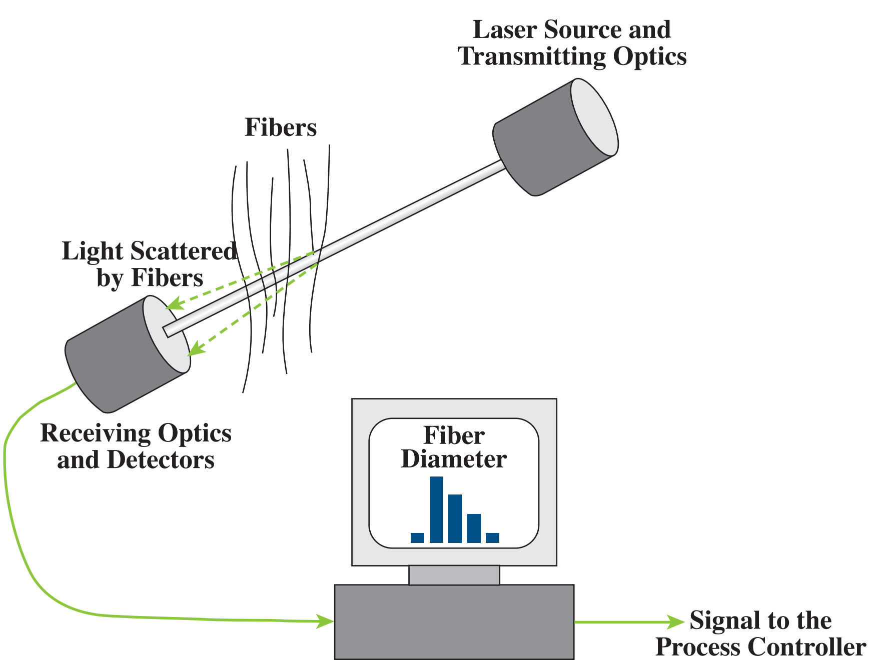
# Fiber Sizing Sensor and Controller



## Revolutionary Optical Technology Provides On-Line and Off-Line Measurement of Fiber Sizes

Fiber size (or denier) has a significant effect on the performance of fiber-based products, such as filters, insulation, and composites. Fiber samples are generally characterized by optical or electron microscopy. Flow resistance of a sample of fibers (e.g., by the Micronaire™ technique) is also used to estimate the mean fiber size. However, these methods require sampling and are time consuming, and microscopic measurements are usually based on a small number of fibers selected from an image of a collection of fibers and may not be statistically reliable. Rapid measurement of fiber size, based on a large sample, is desirable for quality control of fiber-based products, development of new fiberizing processes, and basic research on fiber generation. With assistance from DOE's Inventions and Innovation Program, Powerscope, Inc., developed FibrSizr,™ which provides such rapid measurements for both on-line and off-line fiber characterization. The sample size is large and usually consists of hundreds of fibers.

FibrSizr consists of a new laser instrument developed for the accurate real-time and in-situ determination of fiber diameter distributions. This device can be used to monitor nonwovens and glass fibers during production and to rapidly measure fiber size distribution in a web sample. This technique is applicable across a wide range of polymers, production methods, and fiber sizes.




*Fiber Sizing Sensor/Controller Using Ensemble Laser Diffraction*

## Overview

- Developed and commercialized by Powerscope, Inc., in 2004
- Sale, lease arrangements, and contract measurements completed for several major fiber manufacturers in the United States

## Applications

Can be used in off-line and on-line process control of fibers on a variety of production/treatment methods such as meltblown, spunbond, meltspun, carded, chemical bonded, needlepunched, spunlaced, stitchbonded, thermal bonded, and rotary fiberizing

## Capabilities

- Offers a new model that uses violet laser, instead of red laser, for better resolution of fine fibers as small as 0.7 micron in mean size.
- Provides a detachable transmitter and receiver for applications with limited physical access.
- Covers a wide range of fiber sizes (denier) and fiber densities using adjustable laser power and detector gain.

## Benefits

### Energy Savings

Eliminates events, such as sudden shutdowns, which result in waste of energy and material by close monitoring of the process.

### Pollution Reduction

Minimizes release of pollutants such as $CO_2$ from the pertinent combustion processes by operating the fiberizers at near optimal conditions.

### Product Quality

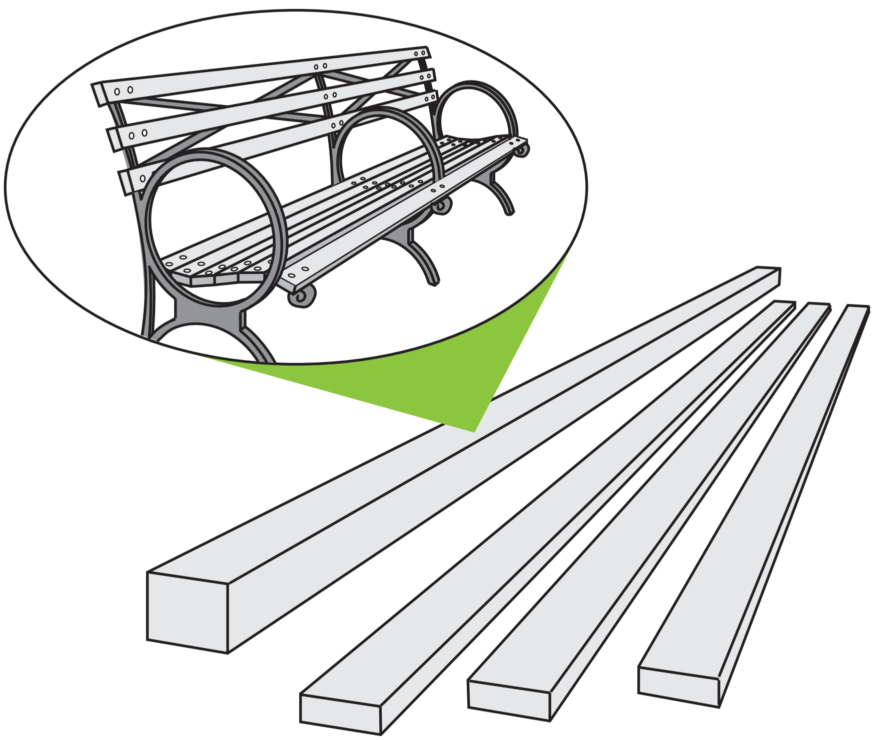
Measures and controls fiber size distribution, which is a critical element in producing nearly all value-added fiber products.

IMPACTS

## New Process Allows Coal Ash to be Made into Building Material Products

With a grant from DOE's Inventions and Innovation Program, Century-Board USA, a licensee of Ecomat, Inc., has a fully developed process to convert solid wastes into synthetic building materials.

The process consists of mixing up to 85% solid waste into a modified polyester polyurethane resin with special additives. This polymer system is a thick liquid that is poured into discrete molds or continuously cast, as is done with the 'plastic' lumber. This thick liquid then forms and fills all the crevices of the mold and produces a lightweight, hard, and tough product. The material does not contain thermoplastics such as polyethylene or PVC, wood or sawdust unless requested by the customer.



*Foamed Recyclable Building Material*

## Overview

- Developed by Century-Board USA
- One plant operating in the United States with the capacity to process 1 ton/hr of coal fly ash to make plastic lumber
- 1 pilot plant is making synthetic structural lumber using coal fly ash as the main ingredient

## Applications

Among the products made with the Century-Board process are roof tiles, artificial slate, siding, molding, doors, utility poles, marine and dimensional lumber, picture frames, office partitions, and wallboard

## Capabilities

Even though Century-Board will focus on the fly ash-based lumber, the following have been successfully tested in their process as the major ingredients: waste glass, sand, ashes from wood and municipal waste burning, wood flour, waste from metal smeltings, red mud from aluminum refining, mixed recycled plastics, coral dust, rice hulls and rice hull ash, agricultural plant ashes, waste cotton and polyester fibers, paper processing wastes, heavy metal contaminated waste, contaminated soil, foundry sand, sewage sludge, slate dust, and rubber tires.

## Benefits

### Productivity and Profitability

Below the cost of many competitive materials and can be reground and reused in the same process. It is lightweight and can be 1/10th the density of concrete.

### Product Quality

Their synthetic building material products are maintenance-free, fire and weather resistant, lightweight and tough.

### Waste Reduction

Reduces landfilling of coal ashes from utility power plants.

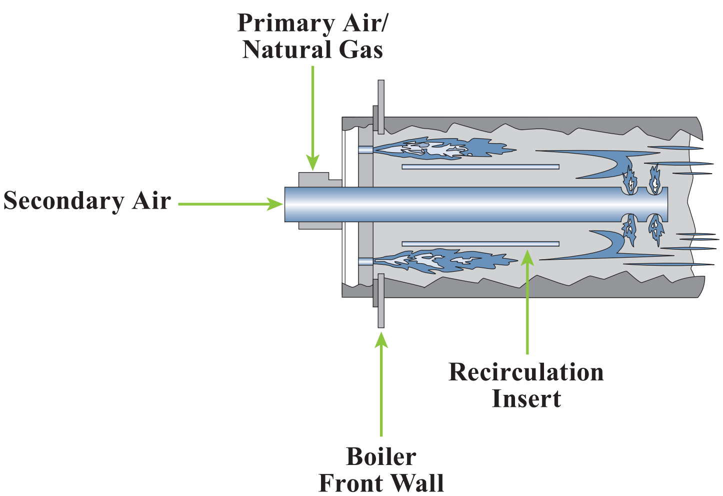
# Forced Internal Recirculation Burner

IMPACTS

## New Burner Significantly Reduces Emissions Compared with Conventional Technology

The forced internal recirculation (FIR) burner combines several techniques to dramatically reduce $NO_X$ and CO emissions from natural gas combustion without sacrificing boiler efficiency. One technique is premixed substoichiometric combustion and significant internal recirculation of partial combustion products in the first stage to achieve stable, uniform combustion that minimizes peak flame temperatures and high oxygen pockets. Other techniques include enhanced heat transfer from the first stage to reduce combustion temperatures in the second stage and controlled second-stage combustion to further minimize peak flame temperature. As a result, the burner minimizes overall NOX formed in the combustor.

The FIR burner was developed by GTI and several sponsors, including DOE. The FIR burner technology is licensed to Johnston Boiler Company (firetube boiler applications), Coen Company, Inc. (packaged watertube boiler applications), and Peabody Engineering Corporation (field-erected boilers in the steel industry). The burner is applicable to a wide range of fire tube boilers from 50 to 100 MMBtu/hr. The technology is currently being tested for applications in packaged water tube boilers and multi-fuel burners for the steel industry.




*Forced Internal Recirculation Burner*

## Overview

- Developed by the Gas Technology Institute
- Marketed by Johnson Boiler Company for fire tube boilers
- Operating on 17 boilers in 2004

## Applications

Currently used in fire tube boilers and being developed for water tube boilers and field-erected boilers for the chemicals, petroleum products, food, and steel industries

## Capabilities

Minimizes thermal and prompt $NO_X$ through staged combustion with internal recirculation of products of partial combustion. Burner design is suitable for new or retrofit applications on a wide range of combustion chamber configurations.

## Benefits

### Emissions Reductions

Results in very low $NO_X$ emissions, less than 9 ppm, without using diluents such as steam, water, or external flue gas recirculation.

### Productivity

Increases system efficiency, with operation at less than 15% excess air over the entire turndown range of four to one.

### Profitability

Reduces developmental, operating, maintenance, and capital costs compared with “current generation” low-$NO_X$ burner systems.

IMPACTS

## Innovative Aerodynamic Fairings Minimize Drag on Box Shaped Semi-Trailers

A great deal of scientific research has demonstrated that streamlining box-shaped semi-trailers can significantly reduce a truck's fuel consumption. However, significant design challenges have prevented past concepts from meeting industry needs. Freight Wing, Inc., was formed to improve fleet profitability through innovative aerodynamic devices. Freight Wing was initially funded through a grant from DOE's Inventions and Innovation Program to develop rear-fairing technology and has since expanded the company's products to a complete line of aerodynamic solutions. Their initial research focused on developing a practical rear fairing that would not interfere with the truck's operation and on investigating other means to reduce aerodynamic drag on box-shaped semi-trailers. Freight Wing market research soon revealed that the industry was not very interested in the rear fairing because that area is extremely prone to damage and durability is a primary concern.

Freight Wing also developed designs for front or gap fairings and undercarriage or belly fairings and made prototypes of all three fairing designs with their manufacturing partner, ASAP Metal Fabricators. In May 2004, Freight Wing tested all three fairing prototypes at the independently owned Transportation Research Center (TRC) in East Liberty, Ohio. TRC tested the fairings using the industry standard Society of Automotive Engineers/Technology & Maintenance Council (SAE/TMC) J1321 fuel consumption procedure Type II test. A 7% fuel savings was demonstrated on trailers equipped with all three fairings. Freight Wing arranged a testing partnership with Transport America to retrofit five of their trailers for an operational test. These tests enabled Freight Wing to identify some problems and finalize the designs. The product was marketed starting in the fall of 2004, and soon thereafter the company made its first sale of two belly fairings to a fleet called LVL, Inc., in Little Rock, Arkansas. Additional research is also underway to develop second-generation designs using different materials and aerodynamic concepts.

## Overview

- Developed and marketed by Freight Wing, Inc.
- Commercialized in 2004.

## Applications

The Freight Wing Fairings are used on semi-trailers to reduce the effects of aerodynamic drag.

## Capabilities

- Reduces aerodynamic drag on semi-trailers.
- Retrofits on existing semi-trailers.

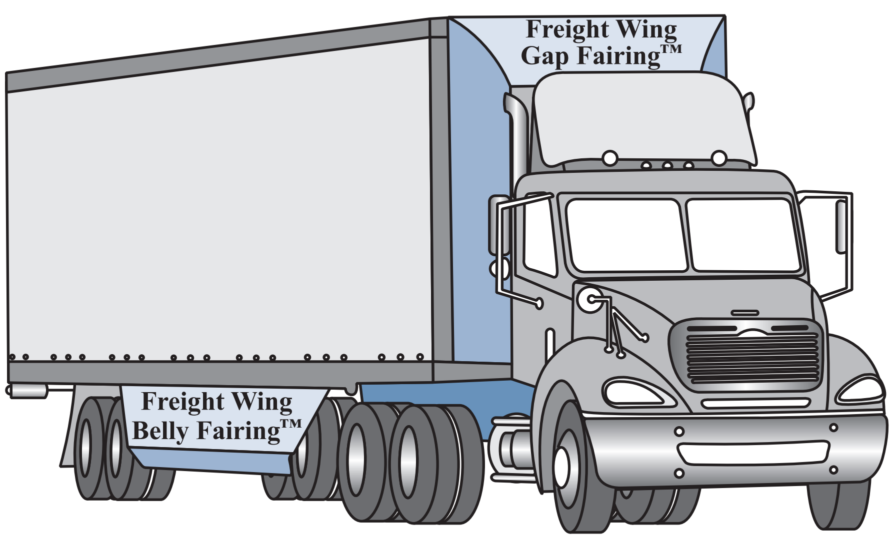
## Benefits

### Energy Savings

Reduces fuel usage by 7%.

### Emission Reduction

Reduces emissions of combustion products, including particulates, $SO_X$, $NO_X$, and $CO_2$.



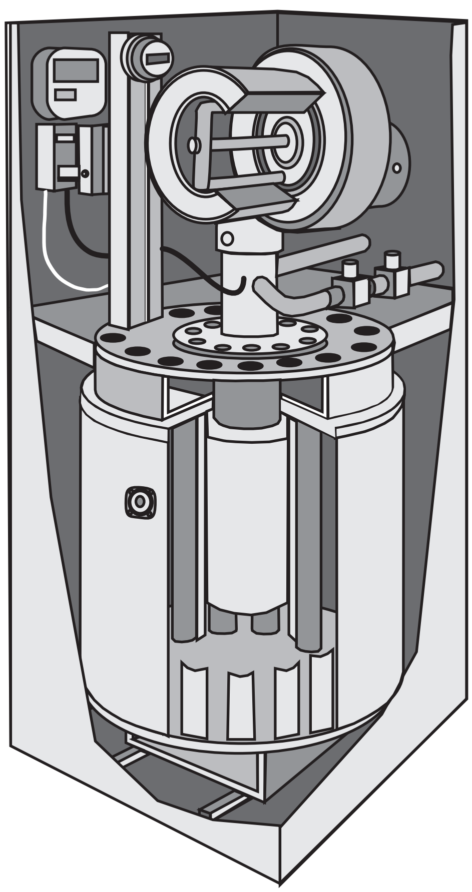

*Freight Wing Fairings Installed on a Semi-Trailer*

# High-Temperature Radiant Burner



## ITP Development Eliminates Global Warming Gas In Semiconductor Manufacturing

The high-temperature radiant burner developed by Alzeta with ITP assistance, forms the core of a thermal processing unit that destroys up to 99.9% of one of the most potent classes of global warming gases known – the perfluorocarbons (PFCs). PFCs, which include $C_2F_6$ and difficult-to-destroy $CF_4$, are generated during the semiconductor manufacturing process. PFCs are among the most potent greenhouse gases known, having high global warming potential and extremely long atmospheric lifetimes. For example, $C_2F_6$ has a warming potential 9,200 times that of $CO_2$ and an atmospheric lifetime of 10,000 years. The long lifetime means that even small emissions will contribute to the cumulative atmospheric global warming burden that will persist for thousands of years. The PFC destruction system, the TPU 4200, received a "best products" award from Semiconductor International magazine and is sold by Edwards High Vacuum International. Edwards selected the Alzeta burner for its ability to operate reliably at high process temperatures and provide uniform, well controlled heat. The TPU 4200 is placed downstream of semiconductor wafer etching "tools" made by Applied Materials and Novellus. Because plants have multiple tools to serve multiple production lines, several TPU 4200 units are generally installed in each plant. TPU 4200 customers include well known companies such as Advanced Micro Devices, Hewlett Packard, and Motorola, as well as several manufacturers in Japan.



*High-Temperature Radiant Burner*

## Overview

- Developed by Alzeta Corporation
- Commercialized in 1995
- Over 5,000 burners sold in the United States

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 9.47 | 2.19 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.0 | 0.0 | 0.256 | 34.8 |

## Applications

- Adiabatic thermal oxidizers for destroying hazardous volatile organic compounds
- Gas-fired boilers, paper dryers, refineries (asphalt heating), and plastics manufacturing (resin drying)
- Other boilers, furnaces, dryers, and combustion equipment applications

## Capabilities

- Can operate reliably with higher-than-normal process temperatures.
- Has uniform and well-controlled heat flux.

## Benefits

### Ease of Installation

Manufactured in standard-size cylindrical segments to facilitate shipping and installation.

### Pollution Control

Reduces $NO_X$ emissions by up to 80%.

### Productivity

Reduces maintenance and associated downtime in applications that require handling of hazardous gases. Increases productivity in paper drying by increasing energy delivered to drying drums.

IMPACTS

## Redesigned Diesel Engines Improve Heavy Truck Fuel Economy

The KIVA computer model resulted from the efforts of a diesel engine working group formed in 1979 as part of DOE's Energy Conservation and Utilization Technologies (ECUT) Division's Combustion Technology Program. The goal of this activity was to guide the development and application of diagnostic tools and computer models. Under the guidance of DOE and the Cummins Engine Company the multidimensional KIVA model was developed to help engine designers overcome some of the technical barriers to advanced, more fuel-efficient engines.

KIVA allows designers to see the effects of alterations to engine geometry without actually building the engine. Cummins Engine Company has used KIVA to make piston design modifications and other modifications to diesel engines for heavy trucks. In a cooperative effort with DOE, Cummins has also improved engine breathing, pulse-preserving manifolds, and turbocharger design. Cummins has improved the diesel engine sufficiently to increase the mileage by nearly one-half mile/gallon. With millions of trucks and buses currently on the road, this improvement in engine efficiency yields a significant savings in fuel.

Energy savings from this development are based on the number of trucks (class 7 and 8) powered by Cummins engines. This value, multiplied by the savings per mile and the number of miles driven per year, results in the estimated annual energy savings.

## Benefits

### Competitiveness
Helps the United States automotive industry strengthen its competitive position relative to Europe and Japan.

### Productivity
Reduces time required from engine design to production.

### Waste Reduction
Optimization in engine performance considerably reduces emissions, including unburned hydrocarbons.

## Overview

- KIVA computer model developed by Los Alamos National Laboratory, Sandia National Laboratories, Southwest Research Institute, and others
- Commercialized in 1991
- Cummins Engine Company is the first to use KIVA to redesign diesel engines for improved energy efficiency

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 932 | 82.2 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.617 | 47.8 | 12.7 | 1790 |

## Applications

- Visualizing effect of design changes on engine performance
- Assessing engine ability to use alternative fuels or reduce emissions
- Optimizing engine operation to reduce emissions

## Capabilities

- Simulates precombustion fluid motion, chemical kinetics, flame propagation, and combustion dynamics in engines.
- Investigates airflow and diesel spray characteristics nonintrusively.

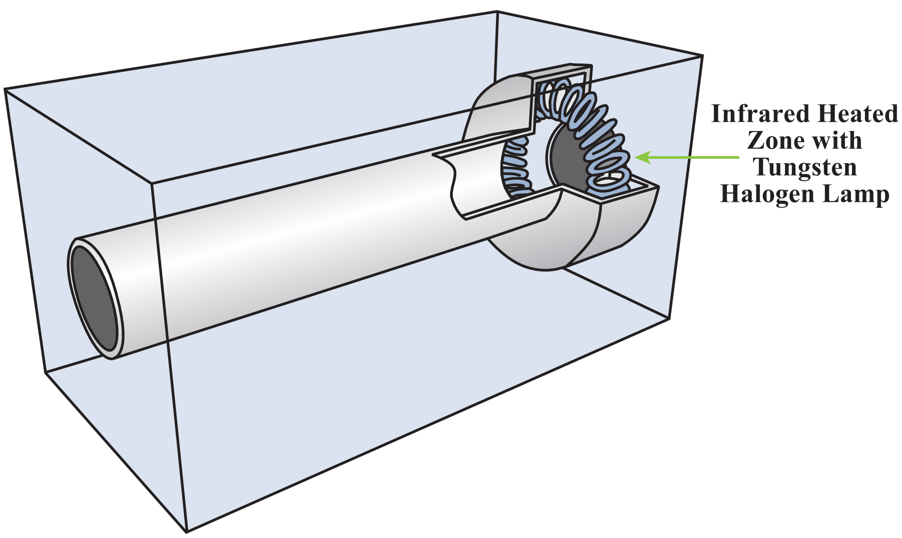
# Infrared Polymer Boot Heater



## New Heating System Results in Fewer Repetitive Stress Injuries While Saving Energy

Employees of General Motors, Delphi Automotive Steering Systems in Athens, Alabama, suffered repetitive stress injuries from placing protective polymer boots over car steering wheel assemblies. Delphi came to Oak Ridge National Laboratory (ORNL) requesting the development of a heating technology to heat and expand the lower 2 inches of a polymer boot without using hot fluids or heating the worker or surroundings. The infrared boot heater was developed from these requirements. A tungsten halogen lamp based infrared heater goes from cold to full power in 0.2 second and shuts down in less than a second.

The technology converts electrical energy to radiant energy at 90% efficiency. The heat can be delivered to only the areas needing to be heated, and the design can be cold walled. Because the polymer expands, the force required for installation is virtually eliminated, thus reducing repetitive stress injuries. The subsequent cooling also results in an improved seal. A single infrared boot heater saves 6.25 million Btu over conventional electrical rod type heating in one year.




*Infrared Polymer Boot Heater*

## Overview

- Developed by Oak Ridge National Laboratory
- Commercialized in 2000
- 5 units installed in the United States

## Applications

Designed to heat thermoplastic and polymer boots for applications that require placing boots on steel parts (steering assemblies, CV joints, etc.)

## Capabilities

- Capable of rapid heating (at 50-400°C/second) and cooling.
- Does not require any medium such as gas for transmission and is noncontact.
- The radiant energy couples only to the part of the polymer that requires it.

## Benefits

### Increased Productivity/Safety and Improved Product

The expansion of the polymer resulting from heating virtually eliminates the force required for installation. The subsequent cooling also results in an improved seal.

### Reduced Waste and Materials

Grease formerly used for installing polymer boots is eliminated.

# In-Situ, Real Time Measurement of Melt Constituents

IMPACTS

## New Laser System Provides Real-Time Measurements for Improved Product Quality Control

A new probe uses laser-induced breakdown spectroscopy (LIBS) to determine the elemental constituents in an aluminum, glass, and steel melt. This probe measures continuously and in-situ at any point in the melt, thus providing spatial and temporal real-time data. The probe uses a pulsed (5-10 ns duration) Nd:YAG laser at 1064 nm that is focused, through a fiber-optic cable, into a molten aluminum sample, generating high-temperature plasma consisting of excited neutral atoms, ions, and electrons. Any chemical compounds present in the sample are rapidly separated into their constituent elements. The laser-generated plasma is allowed to cool several microseconds after the laser pulse, and then a spectrometer collects and disperses optical emissions from neutral and ionized atoms. The line radiation signal provides the concentration of each element present.

In the glass industry, both the melt and raw ingredients can be monitored. The probe has several applications in the aluminum and steel industries. For example, the probe can be used for in-line alloying to measure chemical content during a pour and for continuous and semi-continuous furnace operations to minimize the current practice of off-line sampling and measurement. In other applications, the probe can perform in-line monitoring of impurity removal from the melt, such as removing magnesium from molten aluminum, and can provide real-time data to validate computer simulations and model furnaces.

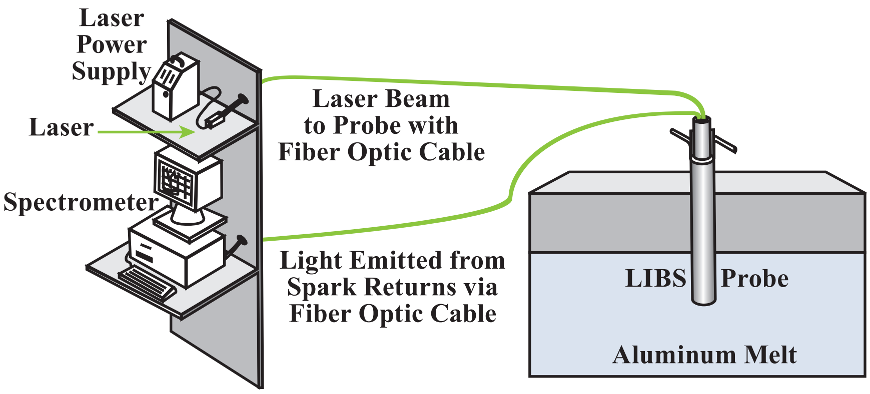
## Benefits

### Productivity and Profitability

Determining melt constituents and temperature in-situ, real-time, and simultaneously eliminates the aluminum and steel furnace idle time now required for off-line measurement of melt constituents. The payback has been shown to be less than one year.

### Product Quality

Providing data for use in a feedback control loop to control the furnace operation in real time increases product quality.




*Laser-Induced Breakdown Spectroscopy System*

## Overview

- Developed and marketed by Energy Research Company
- Installed on an aluminum melt furnace in 2003
- Installed in a glass plant in 2004

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 0.259 | 0.222 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.0 | 0.0 | 0.026 | 3.53 |

## Applications

Identifies elemental constituents in metal and glass melts during the alloying and fabrication process

## Capabilities

- Measures aluminum melt constituents with 5% accuracy and a 0.002% minimum detection limit.
- Monitors trace alkali metal content in electronic glass compositions.

# Materials and Process Design for High-Temperature Carburizing



## New Class of High-Performance Carburized Steels Saves Energy and Increases Productivity

Various project partners have integrated an optimization of process and materials that will enable a broad usage of high-temperature carburization. The unique capabilities of high-temperature carburizing were exploited to access new levels of steel performance, including the distortion-free, high-performance gear and bearing materials for the transportation sector. Emphasis was placed on creating a new class of thermally stable, ultra-durable, deep case-hardened steels that could ultimately extend case hardening to tool and die steels. Case hardening would enable major productivity gains in the forging, forming, and die casting of aluminum and steel.

With assistance from ITP, a consortium of project partners used their carburization simulation tools and fundamental calibration data to gain reliable control of high-temperature carburizing of their new class of high-performance gear steels. One of the partners, QuesTek, used the technology to successfully commercialize new gear steels by demonstrating both higher gear performance and acceptably reduced manufacturing variation.

## Benefits

### Energy Savings

Reduces the U.S. annual energy consumption for carburizing.

### Environmental

Reduces greenhouse gases compared with conventional gas carburizing technology.

### Productivity

Reduces scrap and eliminates the need for hard chromium plating in many applications; offers increased durability and higher performance when it replaces conventional steel.

## Overview

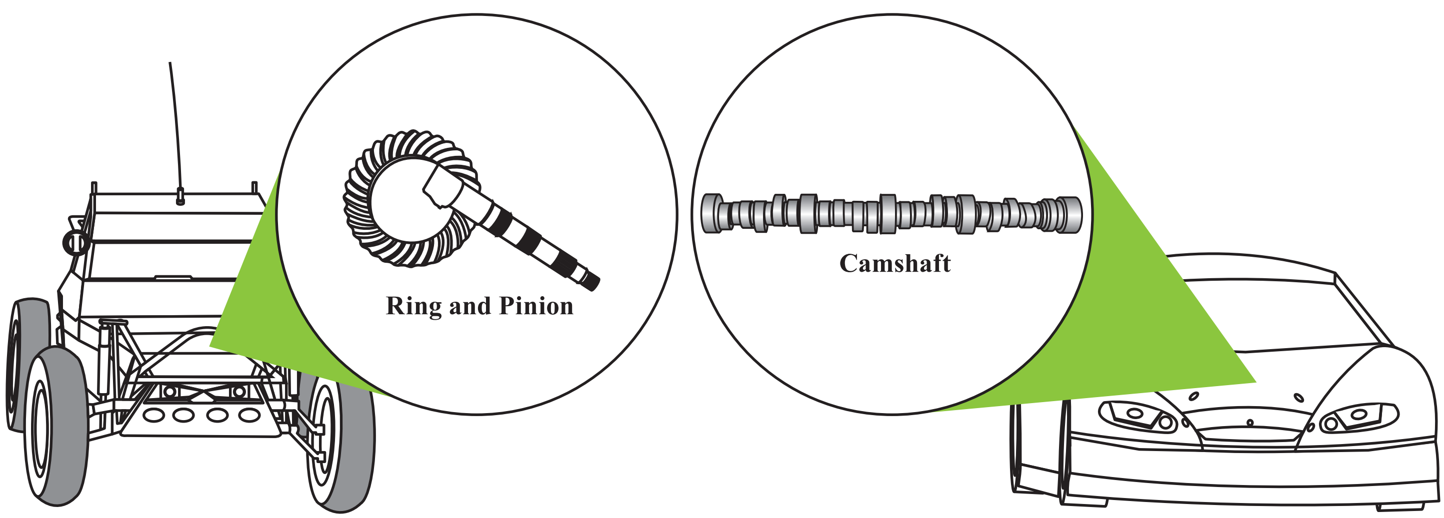
- Developed by a consortium of project partners including the Center for Heat Treating Excellence, Metal Processing Institute – Worcester Polytechnic Institute, Northwestern University, and QuesTek
- Commercialized by QuesTek in 2003

## Applications

High-performance gear and bearing applications for the transportation sector. New deep-case applications include ultra-durable die materials for forging and forming of steel and aluminum and for die casting of aluminum

## Capabilities

- Establishes sufficient control of high-temperature carburizing to greatly expand applications.
- Creates a new class of steels with particular emphasis on novel deep-case applications.
- Demonstrates accelerated materials and process development through the emerging technology of computational materials design.




*New Gear Steel Products Created Using High-Temperature Carburizing*

# Method of Constructing Insulated Foam Homes

IMPACTS

## An Innovative Building System That Is Energy Efficient, Structurally Sound, and Easily Constructed

The concerns of the home building industry center around increasing productivity in the construction process, improving the quality of American homes, expanding opportunities for affordable home ownership, enhancing the U.S.'s competitive position relative to global markets, and ensuring the cost-effective and energy-efficient operation and maintenance of homes.

With the help of a grant from DOE's Inventions & Innovation Program, Amhome USA, Inc., developed a method of constructing buildings that are both energy efficient and structurally sound. The new home consists of an exterior patented wall system made of expanded polystyrene (EPS) foam insulation panels with an internal steel-reinforced concrete post and beam design. This wall has an R-40 insulation panel with an internal steel-reinforced concrete post and beam design. The roof is insulated by EPS slabs sandwiched between the rafters and has an R-50 insulation value. The primary innovation of this system is the way the walls are constructed, which requires less labor compared with traditional wood-frame houses.

## Benefits

### Environmental

The Amhome method saves timber by using 35% less wood than frame homes and saves insulation by using recycled insulation in the roof.

### Productivity/Quality

Homes using the innovative EPS foam can be built faster than traditional wood-frame homes. The homes' superstructure is reinforced with concrete and steel for more stability, and the entire house is united into one solid piece.

*Concrete Being Pumped into the Wall Cavity of an Insulated Foam Home*

## Overview

- Commercialized by Amhome USA, Inc., in 1996
- 316 homes constructed through 2004
- Marketed by Home Corporation International, Inc.

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 0.033 | 0.005 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.0 | 0.0 | 0.001 | 0.093 |

## Applications

- New single-family residences.
- New multifamily dwellings.
- Small commercial buildings.

## Capabilities

- Provides an R-40 wall using EPS foam insulation panels to form the exterior walls.
- Provides an R-50 roof/ceiling using EPS foam between the rafters.

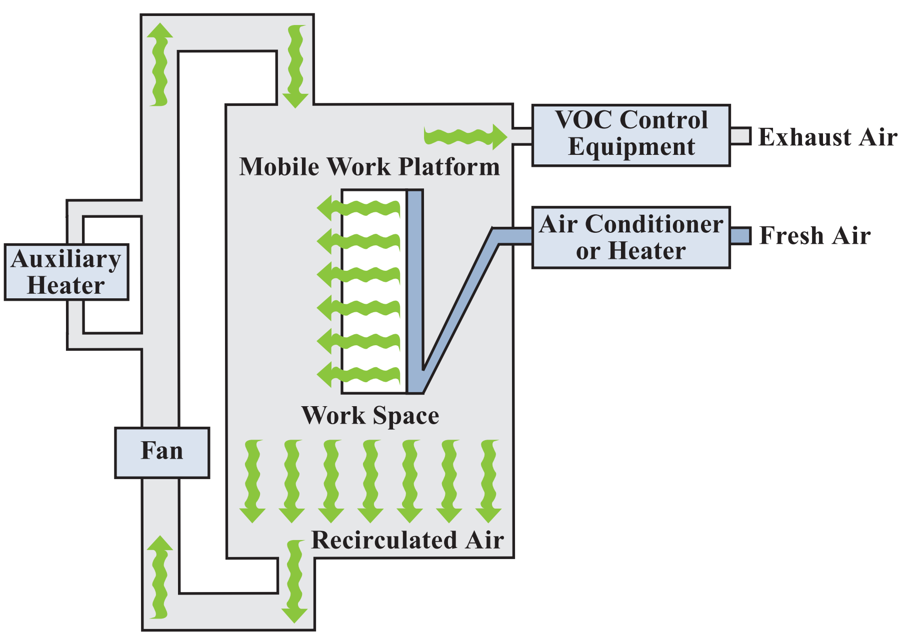
# Mobile Zone Optimized Control System for Ultra-Efficient Surface-Coating Operations



## New Surface-Coating Technique Reduces Air Pollution and Energy Use

Volatile organic compounds (VOCs) are released during the application of spray coatings in paint enclosures, which expose workers to toxins, create air pollution emissions, and create fire or explosion hazards. To meet safety and environmental regulations, paint booths are usually ventilated with 100% outside air, which is then heated or cooled to maintain comfortable temperatures and control pollution emissions.

A new spray booth technology developed by Mobile Zone Associates with the help of a grant from the Inventions and Innovation Program greatly reduces the amount of energy needed to heat and cool ventilation air during surface coating operations. The Mobile Zone system separates the human painter from the contaminated air of the spray booth by providing the painter with a separate, mobile work platform or cab during spray coating operations. The cab is flushed with fresh air, while the rest of the spray booth uses recirculated air. The design meets OSHA regulations and National Fire Protection Association guidelines. The technology is currently being used by the US Army at Fort Hood, Texas for consideration of system wide use.




*Air Flow in Paint Spray Booth with Mobile Zone System*

## Overview

- Developed by Mr. Clyde Smith and Mr. William Brown of Mobile Zone Associates
- 1 installation operating in the United States in 2004

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 0.024 | 0.007 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.0 | 0.001 | 0.001 | 0.120 |

## Applications

Applying sprayed surface coatings to chairs, tables, motorcycles, tractors, railroad cars, aircraft, and other painted products in either side-draft or down-draft booths

## Capabilities

Reduces the ventilation, heating and cooling requirements by directing a sufficient, but small, amount of fresh air to the painter and recirculated air to the remaining unoccupied space within the spray booth. Meets existing OHSA, EPA and NFPA standards for worker conditions.

## Benefits

### Profitability

The technology reduces the size of heating, cooling, and pollution control equipment between 60% and 98%, which offers significant savings in associated capital and energy costs.

### Productivity/Product Quality

Testing has shown the technology is able to maintain or improve production speed and quality.

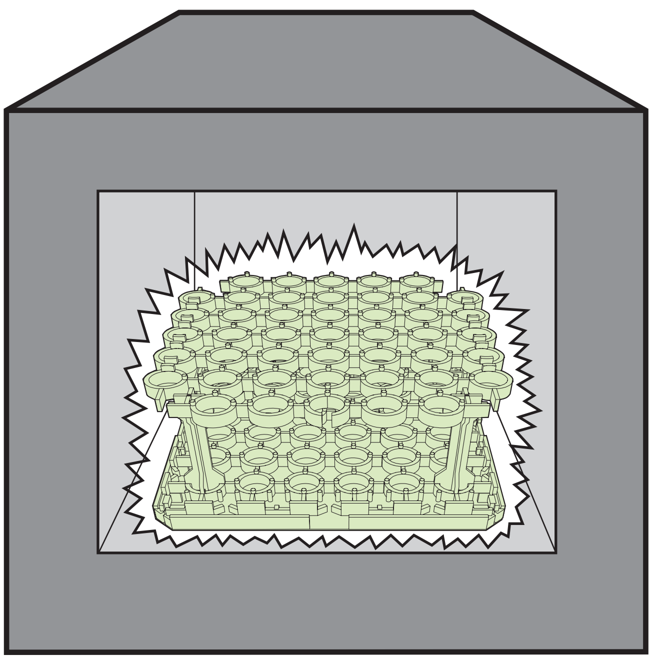
# Nickel Aluminide Trays and Fixtures Used in Carburizing Heat Treating Furnaces



## Advanced Material Use Results in Decreases in Energy and Operating Costs

Typically, 90% of all heat treating furnace problems are caused by alloy issues such as failure of assemblies at high heat and short life of the assembly racks. Since 1992 Delphi Corporation, Oak Ridge National Laboratory, and DOE have been working together on nickel aluminide ($Ni_3Al$) fixtures for furnaces. The research and development has focused on nickel aluminide alloys (including alloy development) and the welding, melting and casting technologies associated with $Ni_3Al$.

Delphi installed 500 $Ni_3Al$ base trays as part of their carburizing furnaces, which are very large gas-fired systems (up to 150 ft long) and heat treat hundreds of tons of steel per day. The $Ni_3Al$ fixtures last 3 to 5 times longer than current high-performance steel alloys and are at least 3 times stronger at operating temperature than conventional alloys. These properties result in improved energy and production efficiencies. Using the stronger $Ni_3Al$ fixtures enabled Delphi to meet production goals with only two new furnaces instead of the three that would have been required with the current technology fixtures.



*Heat Treating Furnace Containing Nickel Aluminide Trays*

## Overview

- Developed by Delphi Corporation and Oak Ridge National Laboratory
- Commercialized in 2001 by Alcon Industries, Inc.

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 0.034 | 0.0 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.0 |

## Applications

Nickel aluminide can be used in the heat treat industry for trays, fixtures, radiant tubes, cast link belts, rollers, fans, and miscellaneous furnace parts.

## Capabilities

Nickel aluminide alloy is a high-strength heat-resistant alloy that is very resistant to carburization. The $Ni_3Al$ fixtures last 3 to 5 times longer than current high-performance steel alloys and are at least 3 times stronger at operating temperature than conventional alloys.

## Benefits

### Profitability

The ability to meet production requirements in two furnaces instead of three has increased profitability by avoiding capital expenditure and reducing maintenance, energy, and alloy costs.

### Reliability

The high strength and lower carburization of the trays and fixtures increase the life of the trays and has significantly decreased furnace problems.

# PowerGuard® Photovoltaic Roofing System



## Photovoltaic (PV) Roof Tile Assembly Delivers Clean Solar Electricity to Buildings

With the help of a grant from the Inventions and Innovation Program, PowerLight Corporation has developed the PowerGuard roofing system that offers building insulation, shading, roof protection, and solar power generation encompassed in a single roofing panel. The roofing panel includes a photovoltaic module mounted on a 3-inch-thick styrofoam board coated with a proprietary, cementitious coating. Designed specifically for flat or slightly sloped commercial and industrial building roofs, the panel works as a retrofit over existing roofs, as a new roof with new construction, and for re-roofing. The system can be tailored to capacities of 1 kW or greater and allows easy expansion.

PowerGuard installations are saving energy and money from New York to Hawaii as well as overseas. A 540-kW system installed at the Santa Rita Jail in Dublin, California reduces the jail's annual energy load by over 800,000 kWh. On the opposite coast, a 186-kW system installed atop Tompkins County Public Library in Ithaca, New York generates 200,000 kWh per year despite the fact that Ithaca receives only 60% of the solar radiation compared with Southern California. Electricity demand is reduced when it is most expensive, such as during peak demand periods on hot summer days. Reducing the load during peak demand periods also decreases the threat of blackouts and other problems associated with overloading the utility grid.

## Benefits

### Ease of Installation

PowerGuard can tailor systems from 1 kW up to the building's peak load and offers easy expansion. The panels use a tongue-and-groove design to interlock adjacent panels for fast installation without penetrating existing roofing material.

### Product Life

The lightweight PowerGuard system is designed to survive severe weather conditions and protects the roof membrane from harsh UV rays and thermal degradation for up to 30 years, approximately doubling the life of the roof.

## Overview

- Developed by PowerLight Corporation
- Commercialized in 1998
- Installations from New York to Hawaii and overseas.

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 0.247 | 0.097 |

## Emissions Reductions

*(Thousand Tons, 2004)*

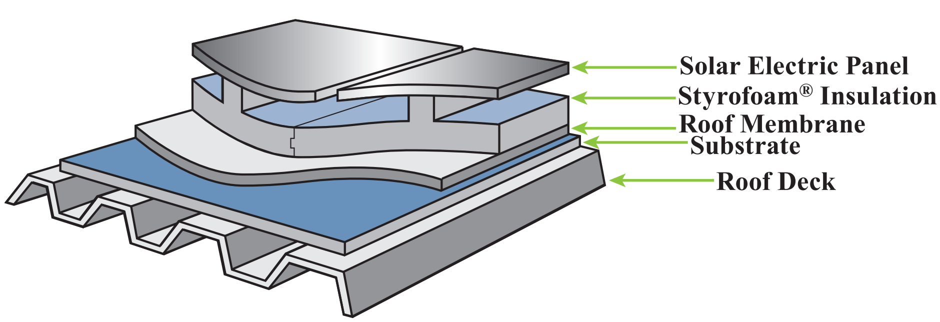
| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.0 | 0.021 | 0.016 | 1.91 |

## Applications

- Installed on commercial or residential buildings that have flat or low-slope roofs
- Economical for building owners and utilities located in summer-peaking service areas where utilities offer time-of-use rates

## Capabilities

- PowerGuard is a photovoltaic power system in which the photovoltaic modules are integrated with the materials used for a building's roof.
- Feeds clean AC power into the building, displacing high daytime utility rates.




*PowerGuard System Cutaway View*

IMPACTS

## New Particle-Size and Concentration Monitor Leads to Efficient Use of Lower-Quality Fuels

While both gas turbines and power-recovery expanders used in petroleum power generation are efficient energy-conversion devices, fuel quality limits the application of these technologies. Widely available low-cost fuels generally contain more contaminants, which can lead to system fouling and wear as well as downtime for repair and cleaning. Without continuous monitoring for particulate contamination and feedback control, systems must be set for unknown conditions, so the more-efficient gas turbines and power-recovery expanders are not installed or, if installed, operate at lower efficiency.

With assistance from ITP and a grant from DOE's Inventions and Innovation program, Process Metrix LLC developed a real-time laser-optical process particle counter/sizer (PPC). The PPC can be used as a short-term or automated long-term sensor and control system for dust monitoring of expanders/gas turbines and process stacks. The PPC uses optical technology with fixed alignment to provide a continuous, real-time, robust, standalone particulate monitor that allows expanders and gas turbines to operate closer to optimum conditions. Such conditions improve efficiency while protecting turbines, allowing use of lower-quality fuels.

## Benefits

### Durability

Protects turbines from high particulate concentrations that lead to blade wear.

### Emissions Reductions

Decreases emissions by improving power-generation efficiency.

### Energy Savings

Could save 20 billion Btu of Natural gas per installation annually.

### Productivity

Allows high-efficiency turbines to be installed in more applications and reduces production downtime from failures caused by particulate contamination.

## Overview

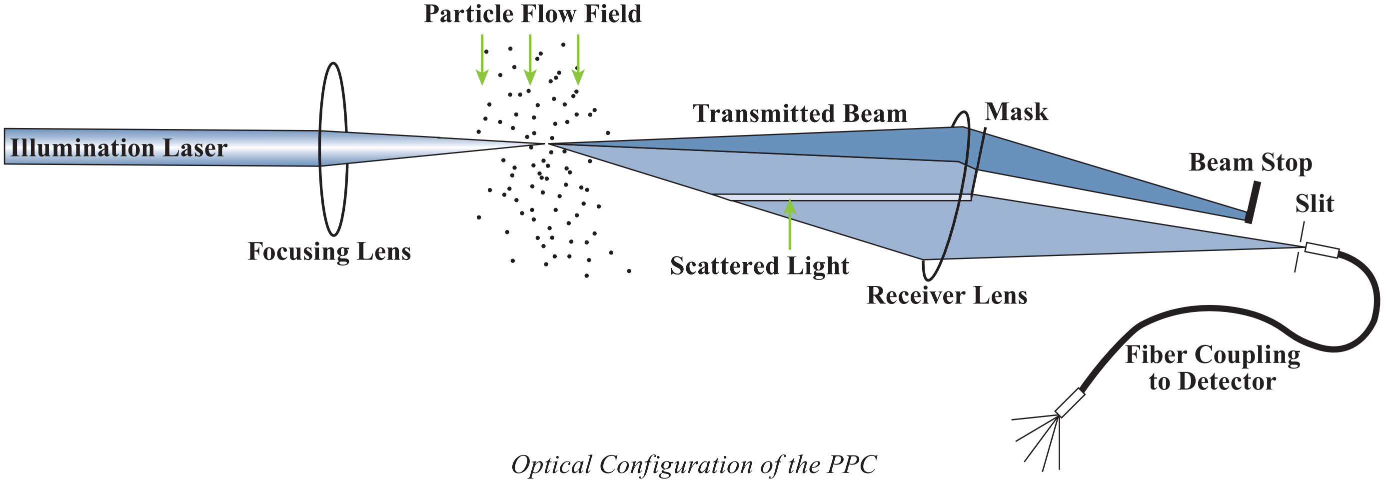
- Developed and being marketed by Process Metrix, LLC (formerly Insitec)
- Commercialized in 2004 with one unit being used for emission control by a U.S. utility

## Applications

Process particle counters are applicable in petroleum power generation both for existing power recovery expanders and in situations where power recovery expanders have not been used because of unreliable fuel quality and return on investment concerns.

## Capabilities

- Monitors gas-phase particle contamination at low concentration using single particle counting.
- Measures size, concentration, and velocity of gas particles in real-time.
- Operates in-situ at industrial high temperatures/pressures.
- Uses diffraction light scattering with minimum shape and refractive index sensitivity.




*Optical Configuration of the PPC*

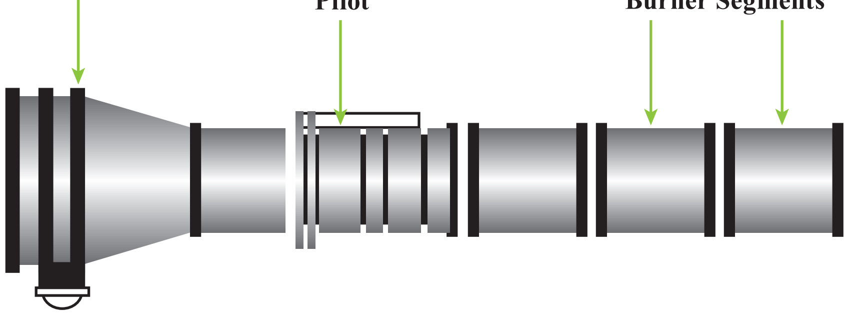
# Radiation-Stabilized Burner



## New Burner will Deliver High Efficiency and Low Emissions in Industrial Boilers and Process Heaters

ITP and Alzeta Corporation have developed the Radiation-Stabilized Burner (RSB), an ultra-low $NO_X$ and CO burner for applications in industrial boilers and process heaters. Characteristics of the RSB that improve performance relative to conventional burners include (1) full premixing of fuel and air to the greatest extent possible prior to combustion, (2) surface stabilization through the use of radiant zones and high flux zones on the burner surface, and (3) controlled flame shape above the burner surface. This results in low $NO_X$ and CO emissions without sacrificing thermal efficiency or boiler reliability.

Premixing of the fuel and air before combustion provides a simple method of combusting all fuel at the desired fuel-air ratio and has been demonstrated to be an effective method of providing simultaneous low $NO_X$ and low CO emissions. Excellent flame stability is needed to achieve low emission levels over the broad range in which industrial boilers operate. High-surface heat flux and controlled-flame shape above the burner surface allow for more compact boiler designs and for more rapid cooling of the flame to further reduce $NO_X$ emissions.




*Radiation-Stabilized Burner*

## Overview

- Developed by Alzeta Corporation
- Commercialized in 1999
- Since 1999, over 150 burners have been installed

## Applications

Industrial boilers and process heaters with capacity ranging from 2 MMBtu/hr to 150 MMBtu/hr, which are used in refineries, pulp and paper plants, and chemical manufacturing facilities

## Capabilities

- Ultra-low $NO_X$ and CO industrial burner capable of achieving sub-9 ppm $NO_X$ and sub-50 ppm CO emissions.
- No loss in thermal efficiency relative to current 30 ppm burner designs with high efficiency controls option.
- Stable operation over a broad range of emission levels, from sub-7.5 ppm $NO_X$ to sub-30 ppm $NO_X$ , with one burner design.

## Benefits

### Emissions Reductions

Simultaneously achieves low $NO_X$ , CO, and unburned hydrocarbon emissions due to the fully premixed burner design.

### Productivity

This simple technology approach to low $NO_X$ emissions results in little downtime; any problems are easily repaired.

### Profitability

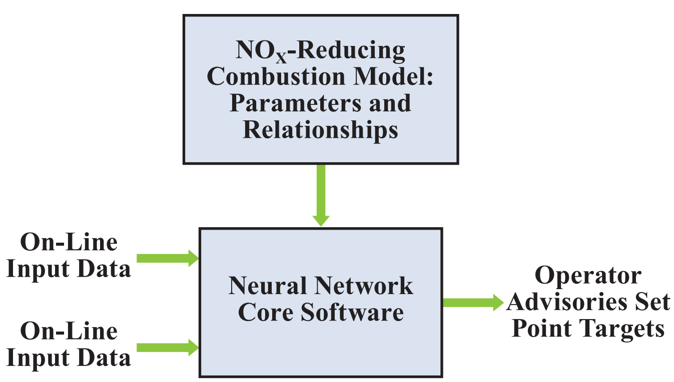
Eliminates the need for "post-combustion" pollution-control devices to reduce the cost of $NO_X$ compliance. Allows for more compact boiler designs due to the uniformly distributed heat flux from the RSB surface.

## Real-Time Neural Networks for Combustion Optimization of Utility Boilers Reduce Emissions

Nitrogen oxides ($NO_X$) resulting from the combustion of fossil fuels are damaging to the environment. $NO_X$ emissions from coal-fired boilers, such as those used by industry and electric utilities, can be reduced through the appropriate manipulation of combustion process set points. However, it is beyond the capability of existing plant control systems to optimize these set points during actual plant operation. Using a NICE³ grant, Pegasus Technologies developed and demonstrated the NeuSIGHT® system to optimize combustion control settings for minimal $NO_X$ emissions while maintaining the required exit gas temperatures, levels of unburned carbon, and flue gas corrosives. The NeuSIGHT system, part of the Delta E³™ portfolio of optimization strategies, is an on-line system that adapts dynamically to changes in plant operating conditions and accommodates equipment performance variations throughout typical maintenance cycles. In many cases, this approach can eliminate the need to install low-$NO_X$ burners to meet regulatory requirements.

The computer model, which uses an advanced form of artificial intelligence known as a neural networks, has been shown to be capable of improving boiler efficiency by as much as 5% and reducing $NO_X$ emissions by 20% to 60%. Emissions of $CO_2$ and $SO_X$ would also be reduced in direct proportion to the amount of fuel saved. The cost of reducing $NO_X$ emissions using the model is much lower than the cost of installing low-$NO_X$ burners or catalytic converters. Pegasus Technologies forecasts that 37% of the United States pulverized coal plants and 25% of plants worldwide will use neural network systems by 2010.

Pegasus is also investigating the capability of using sophisticated control processes and advanced sensor technologies to optimize mercury speciation in order to meet new requirements coming in 2018.




*Real-Time Neural Networks for Combustion Optimization – Process Flow Diagram*

## Overview

- Developed by Pegasus Technologies
- Commercialized in 1995
- 56 units currently operating

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 57.8 | 11.2 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.143 | 6.99 | 3.07 | 310 |

## Applications

Coal-fired boilers, particularly those with capacities of 25MW or greater

## Capabilities

- Reduces $NO_X$ emissions by 20% to 60% while maintaining or improving plant thermal efficiency and reducing $SO_X$ and $CO_2$ emission levels.
- Generates set point targets that are optimized to dynamically balance the trade-offs between $NO_X$ emissions, heat rate, and unburned carbon.

## Benefits

### Natural Resources

Reduces the need for new power plants for utility expansion projects, thus reducing associated impacts on land and water.

### Profitability

Improved heat rate means that more electricity is produced per unit of $CO_2$ and $SO_X$ emitted.

### Waste Reduction

Reduces emissions of combustion products, including $NO_X$ , $SO_X$, and $CO_2$.

# RR-1 Insulating Screw Cap



## New Fastening System Reduces Energy Use of Buildings

Roofing systems for industrial and commercial buildings continue to make significant strides in their performance and durability. Fasteners are essential to keeping many of these roofs intact by joining of pieces or multiple layers. However, the combination of newer roofing materials, known as singly-ply membranes, with conventional metal fasteners leads to increased heat loss. This loss occurs because the metal screw and plate of the fastener are only minimally insulated from the surroundings and conductive heat flow occurs through the thermal bridge created by the metal fastener.

The RR-1 Insulated Screw Cap Assembly, developed by The Romine Company of Newark, Ohio, with the aid of a grant from the DOE's Inventions and Innovation Program, is a simple but effective solution to heat loss and back-out problems found with many conventional fasteners. This improved fastener consists of an injection-molded fiberglass-reinforced nylon anchor, soft insulating plug, and optional grappel washer. The system is simple to install and extremely strong.

The energy advantage of the RR-1 results from the fastener depth and insulation value. The metal screw portion of the fastener is embedded at least one inch into the insulation board, reducing the heat transfer through the fastener. A foam plug is inserted in the cavity created and acts as an insulator. The new fastener design is more resistant to condensation and corrosion, which makes the fastener less likely to corrode and lose holding strength over time.

## Benefits

### Productivity

The simple flush mount requires less torque and time to screw in (no predrilling required) and provides a smoother finish than conventional fasteners. The RR-1 is also produced from less costly materials, so it is a more economical choice than other all-plastic fasteners.

### Durability

In tests conducted on wind uplift, the strength of the RR-1 insulating fastener proved to be greater than the holding power of the metal decking. The RR-1 fastener also resists back-out. These features, and fastener tear-out, are particularly critical with the newer flexible membrane roofing materials.

## Overview

- Developed and marketed by The Romine Company
- Commercialized in 1997
- 275,200 units sold through 2004

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 0.008 | 0.002 |

## Emissions Reductions

*(Thousand Tons, 2004)*

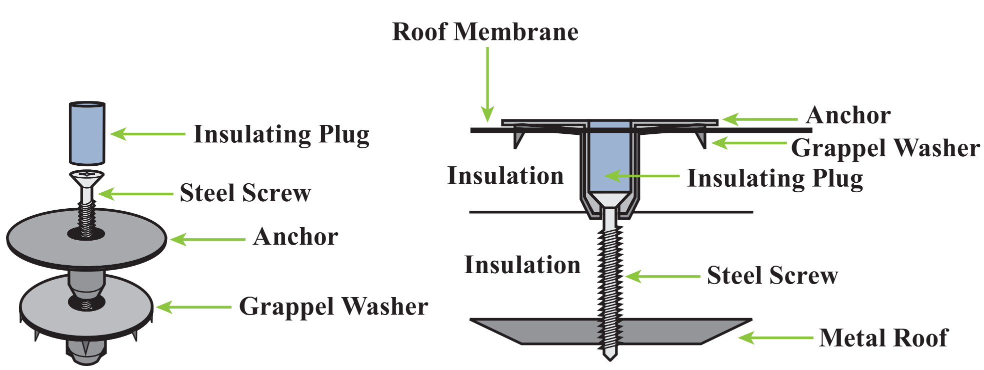
| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.034 |

## Applications

The technology may be used on commercial and industrial buildings with membrane roofs and metal roofs. The screw caps may also be applied as a retrofit to older roofs.

## Capabilities

- Replaces conventional metal or plastic fasteners to improve the energy performance in building roofs.
- Optimized for fastening single-ply roofing or rigid insulation to metal decking.
- Resists typical problems for fasteners including back-out and corrosion.




*The RR-1 Insulated Screw Cap Assembly*

# Solid-State Sensors for Monitoring Hydrogen

IMPACTS

## New Sensors Rapidly and Accurately Detect Hydrogen, Improving Industrial Safety and Efficiency

Molecular hydrogen, $H_2$, is a combustible gas that is produced in large quantities by many industries and has a broad range of applications. When $H_2$ is an undesirable contaminant, a monitor must be able to detect concentrations on the order of parts per million (ppm). In other cases a monitor must be usable in nearly pure hydrogen. Although gas chromatography and mass spectrometry are widely used for detecting $H_2$, these methods require bulky, expensive equipment.

Using solid-state technology developed at the U.S. Department of Energy's Sandia National Laboratory, H2scan LLC is now commercializing hydrogen-specific sensing systems that can detect hydrogen against virtually any background gases. These hydrogen-sensing devices can detect hydrogen in 1 to 10 seconds, thus allowing the devices to be used in control systems. Currently, H2scan offers three hydrogen-sensing system configurations: a hand-held portable leak detector, a fixed-area monitoring system, and an in-line real-time concentration analyzer.

The advantages of the H2scan hydrogen sensors are in their operating parameters. The sensors have a low hydrogen sensitivity of about 5 ppm in air and less than 1 ppm in nitrogen. They are hydrogen specific with no cross-sensitivity to other gases. The upper range of the sensor is 100% with an extremely fast speed of response. They operate between -40°C to 150°C, making them attractive for virtually all sensor applications.

## Benefits

### Energy Savings

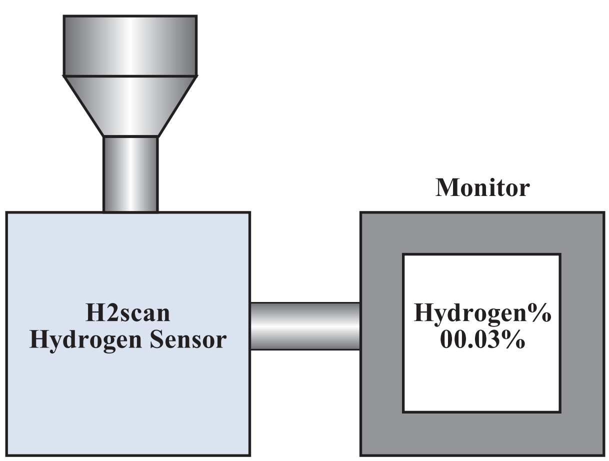
Hydrogen plays a critical role in float-glass manufacturing, an energy-intensive industry that produces 2.6 million tons of glass per year. Improper monitoring can substantially increase defects and waste energy.

### Productivity

The solid-state devices can detect hydrogen in 1 to 10 seconds, which is suitable for interfacing to control systems. Using the device to monitor hydrogen in feedstock of a refinery feed hydrogen/carbon monoxide facility could improve overall performance by up to $250,000 per year per plant.

### Profitability

Solid-state sensors can be mass-produced, making them much less expensive than competing sensors. Small sensor dye produces a system that is much smaller than traditional sensors.




*H2scan Hydrogen Monitoring System*

## Overview

- Developed by Sandia National Laboratory and H2scan LLC
- Commercialized in 2004
- Over 300 units sold in 2004

## Applications

- Monitoring trace levels of $H_2$ in high-purity feed gases for chemical processes
- Monitoring hydrogen production from methane and refinery offgases, where the hydrogen is often mixed with carbon monoxide
- Monitoring hydrogen levels in transformer oil to detect when the oil starts breaking down
- Measuring the hydrogen given off from lead acid batteries due to overcharging to stop a buildup of hydrogen and reduce the threat of either a fire or explosion
- Monitoring and control of hydrogen, which are crucial to obtain the correct molecular-weight distributions in the gas-phase polymerization of polyethylene and polypropylene
- Analyzing fugitive hydrogen emissions in ambient plant environments or in materials subjected to high-energy radiolysis, which is crucial for safety in those environments
- Measuring hydrogen levels to control the efficiency of fuel cell reformers

## Capabilities

- Can be used over a wide range of hydrogen concentrations with minimal interference from other gases.
- Provides rapid response time of 1 to 10 seconds, allowing them to be used for process control.

# SpyroCor™ Radiant Tube Heater Inserts



## Unique Twisted Design of Ceramic Insert Saves Energy for Metal Heat-Treating Furnaces

Radiant tube heaters are typically used in metal heat-treating furnaces. The heaters are long tubes, often in a U shape, which have natural-gas fired burners at one end of the tube (the burner leg) to produce a flame and heated gas that flows through the tube to produce heat for conditioning metals (e.g., strengthening them or otherwise changing some of their properties). In a traditional radiant tube, the burner leg releases 30% more energy than the exhaust leg because of convection and radiation heat transfer in the burner leg.

With the help of a grant from DOE's Inventions and Innovation Program, STORM Development LLC and Sycore, Inc., optimized the SpyroCor, a ceramic (silicon-carbide) insert for the exhaust leg of the tube heater. The patented twisted design of the SpyroCor produces nonturbulent, high convection flow that produces the highest possible rate of uniform heat transfer. As a result, the SpyroCor reduces heat loss and the energy demands of the process by 15% to 20%. A typical furnace contains 10 radiant tubes, which use an average of 3 SpyroCors per tube. Through 2004, 77 furnaces have been equipped with SpyroCors for a savings of 300 billion Btu.

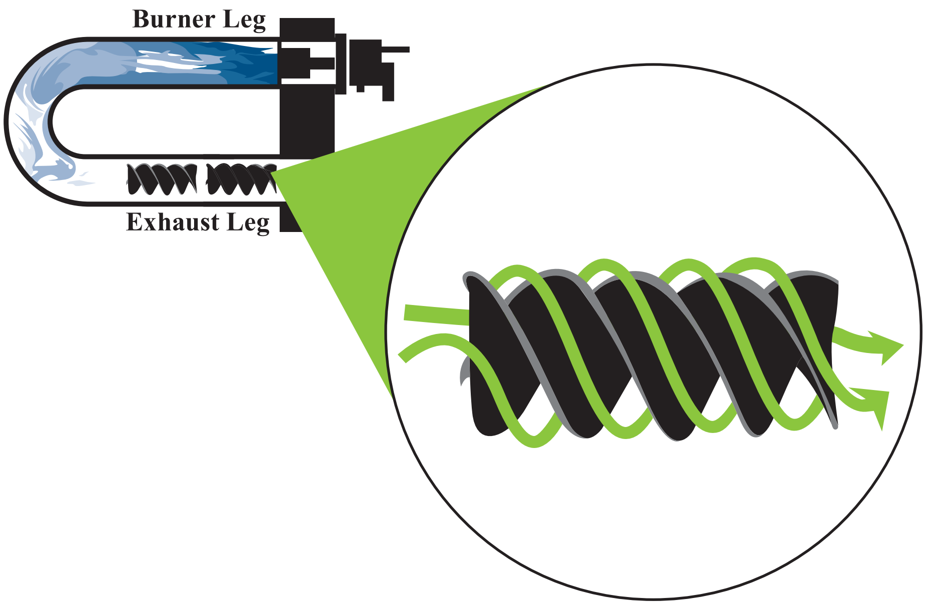
## Benefits

### Ease of Installation

Can be quickly and easily inserted into existing heater tubes without overhauling the entire furnace.

### Productivity

Allows the furnace user to increase the amount of metal treated for the same amount of energy used or to reduce the amount of energy used for the same output.




*SpyroCor Installed in a Radiant U-Tube Heater*

## Overview

- Developed by STORM Development LLC and SyCore, Inc.
- Commercialized and being marketed by Spinworks LLC
- More than 2300 units sold through 2004

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 0.300 | 0.300 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.0 | 0.0 | 0.035 | 4.77 |

## Applications

To be inserted into radiant tube heaters typically used in metal heat-treating furnaces that use natural gas burners.

## Capabilities

- Produces nonturbulent, high convection flow in the radiant tube.
- Doubles the amount of surface area available for heat transfer.
- Balances the heat transfer throughout the radiant tube, allowing more energy to be available to the load.

# SuperDrive – A Hydrostatic Continuously Variable Transmission *(CVT)*

**IMPACTS**

## Unique Measurement System Enhances Process Control, Reduces Scrap, and Saves Energy

The heavy-duty truck (class 7 and 8) market is dominated by standard-geared transmissions. Standard transmissions are so efficient that little interest has been shown in exploring even greater efficiencies using other types of transmissions. With assistance from the DOE's Inventions and Innovation Program, SuperDrive, Inc., addressed increased efficiency by developing a hydraulic transmission system to uncouple engine rpm from wheel speed. This design allows the electronic control module to seek the lowest rpm at which sufficient torque is available to maintain the desired speed.

The patented SuperDrive system uses an axial piston, variable hydraulic pump that is coupled to the crankshaft at the rear of the engine. The pump drives axial-piston variable motors connected to the drive shaft. With an electronic control module, SuperDrive maintains the lowest rpm possible to produce sufficient torque to maintain required pump output. If demand increases, the fuel flow to the engine increases to meet demand, but engine speed is increased only as a last resort. This method allows the vehicle to maintain a constant speed over varying terrain with little or no increase in engine rpm. Because this is a closed-loop hydraulic system incorporating variable pumps and motors, it has the capacity for hydraulic braking by activating a flow control valve. The improved fuel efficiency, an average of 25% to 40%, more than offsets the reduction in transmission efficiency for heavy-duty trucks.

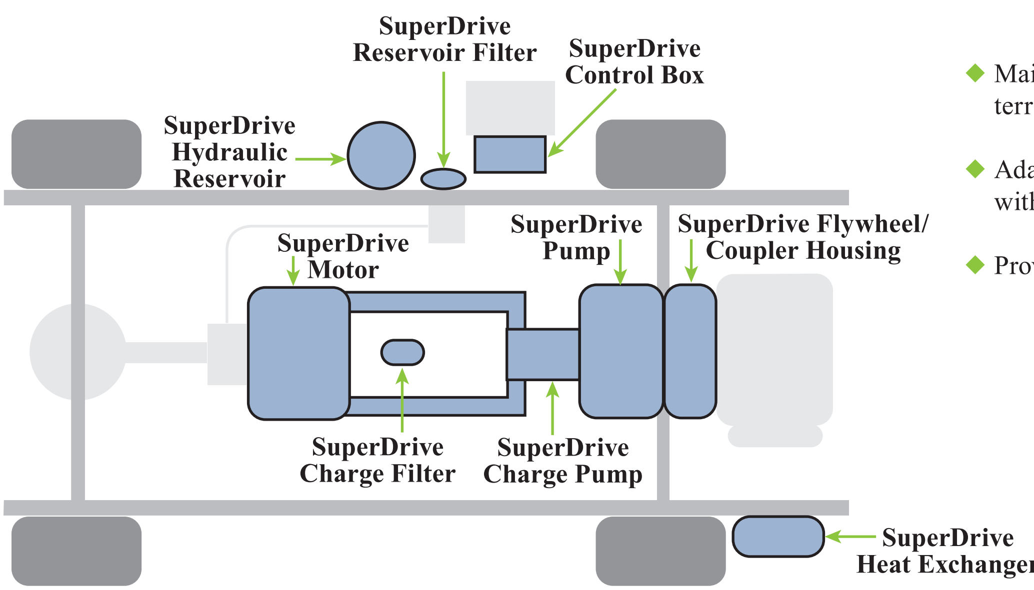
## Benefits

### Environmental

Reduces emissions by up to 35% over conventional long haul operations.

### Productivity

Reduces driver fatigue and the need for drivers skilled in using multi-gear standard transmissions.




*SuperDrive Components*

## Overview

- Developed and marketed by SuperDrive, Inc.
- Commercialized in 2004
- Currently installed on three transit buses in Paducah, KY

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 0.001 | 0.001 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.0 | 0.001 | 0.0 | 0.024 |

## Applications

The SuperDrive system can be used in heavy-duty truck and bus engines in long-haul and fleet applications.

## Capabilities

- Maintains constant speed over varying terrain with minimal increase in rpm.
- Adapts to unique characteristics or trucks with different engines and transmissions.
- Provides hydraulic braking.

# Thin Wall Casting of Stainless Steel



## New Alloy Allows Use of Improved Casting Method

A new alloy of cast stainless steel composition was developed at the Oak Ridge National Laboratory in conjunction with GM-Powertrain and Alloy Engineering and Casting. The new stainless steel composition is optimized for its liquid metal fluidity, high-temperature creep strength, thermal fatigue resistance, and higher-temperature oxidation resistance. The alloy fluidity allows it to be cast by the Hitchiner process – a process also known as counter-gravity casting – in which ceramic molds are manufactured from wax patterns, inverted, and then filled with molten metal (via pressure) from the bottom to the top. Using the Hitchiner process allows components to be cast with wall thickness of less than 3 mm – nearly two to three times less than conventional sand casting. The process also allows automation and high product quality and yield. The optimized alloy improved component life nearly five-fold. The current commercial application is the production of exhaust manifolds for GM.

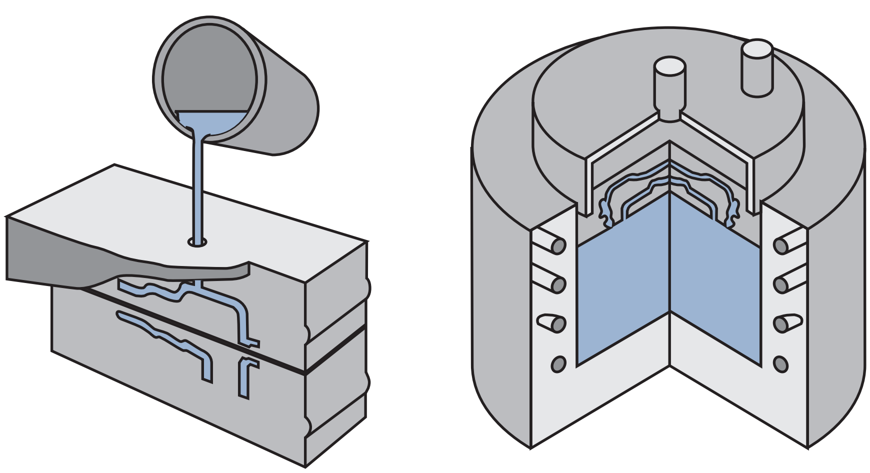
## Benefits

### Productivity

The Hitchiner process increases automation, increases throughput by a factor of two to three compared with the conventional process, and produces a significantly higher yield with very low defect rates.

### Product Quality

The fluidity of the optimized alloy composition permits it to be cast into complex shapes by the counter-gravity Hitchiner process. This process enables higher metalcasting process yield than conventional sand casting.



*Traditional Casting vs. Counter-Gravity Casting*

## Overview

- Developed by Oak Ridge National Laboratory in conjunction with GM-Powertrain and Alloy Engineering and Casting
- Commercialized in 2000 with more than 100,000 parts cast in 2004

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 0.461 | 0.061 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.0 | 0.013 | 0.010 | 1.20 |

## Applications

New alloy allows the use of the Hitchiner counter-gravity casting process for stainless steel parts rather than conventional sand casting

## Capabilities

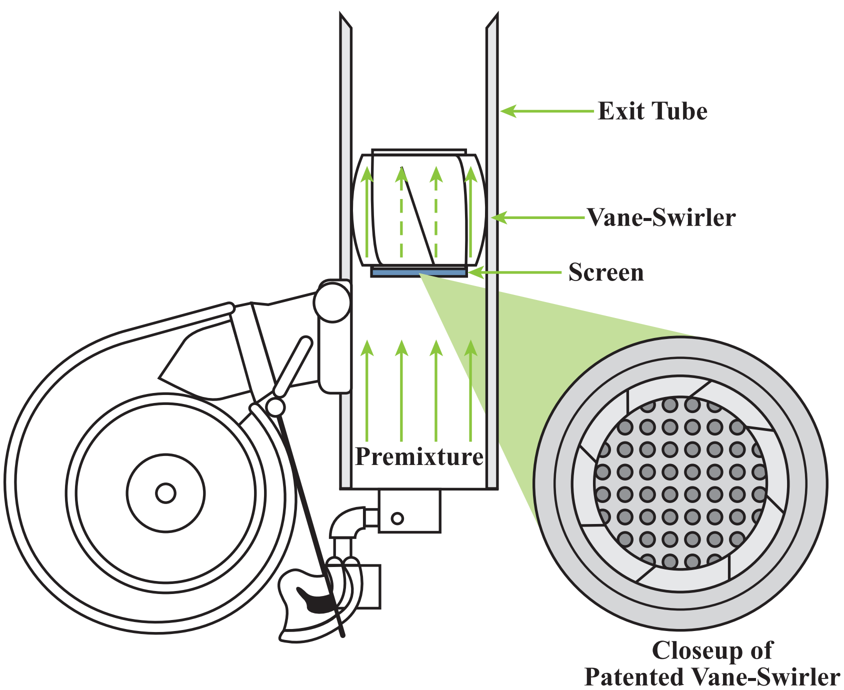
- Easy-to-install modular system.
- Specifically optimized for the Hitchiner metal-casting process.
- Excellent oxidation resistance (i.e., resistant to exhaust gases at temperatures exceeding 1000°C) and thermal and fabrication properties.

IMPACTS

## Reduction of Burner NOx Production with Premixed Combustion

Industries that are dependant on combustion processes are faced with more stringent environmental regulations to reduce NOx emissions. Some states require NOx emissions reductions as great as 90% for chemical and refining industries. The recently developed M-PAKT™ Ultra-Low NOx Burner uses lean premixed combustion gases and low swirl flow of combustion gases to achieve NOx emissions levels <10 ppm (an NOx reduction of 80% to 90%).

The research for this technology originated at Lawrence Berkeley National Laboratory with funding from the DOE Office of Science Experimental Program and Industrial Technologies Program. This new burner's distinct characteristic is a detached flame that is lifted above the burner, providing the capability for more complete combustion with less emissions. This burner concept can be applied to a wide range of combustion systems including furnace and boiler applications, gas turbines, and liquid process heaters for the chemical and refining industries. The burner can be operated with natural gas, biomass gas, and pre-vaporized liquid fuels. The burner is scalable and simple in design with no need for costly materials for manufacturing and installation. Maxon Corporation has licensed the technology for industrial process heaters used in many industrial baking and drying ovens. Applications have also been successfully tested in smaller-diameter domestic heater units.




*M-PAKT Ultra-Low NOx Burner Installation*

## Overview

- Developed by LBNL with two patents issued.
- Installed in the U.S. and overseas.
- Technology licensed to Maxon Corporation and sold as the M-PAKT burner.
- Estimated to reduce NOx by almost 38,000 pounds for 2004.

## Applications

The novel ultra-low NOx burner concept can be used on a wide range of combustion systems:

- Furnaces and boilers
- Chemical and refining industry process heaters
- Gas turbines.

## Capabilities

Reduces thermal NOx in the combustion zone.

## Benefits

### Adaptability

Burns different gaseous fuel types and blends. Can be scaled to different sizes of units and adapted to different orientations and sizes of various flue configurations.

### Low Cost

Offers low cost for manufacturing compared with traditional low NOx solutions because the components are simple and are made from conventional materials.

### Pollution Reduction and Energy Efficiency

Typically reduces NOx to less than 10 ppm without compromising energy efficiency.

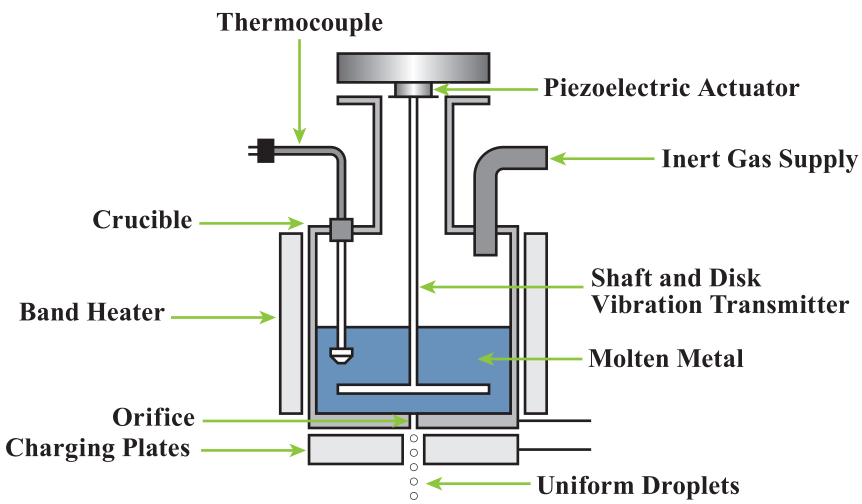
# Uniform Droplet Process for Production of Alloy Spheres



## New Process Allows High-Quality Production of Uniform Alloy Droplets

The Uniform Droplet Spray (UDS) process is a nongas atomization process that uses the concept of controlled breakup of a laminar jet to produce uniform alloy droplets with identical thermal histories. This controlled breakup is similar to that used in ink-jet printing technology and produces monosized droplets. The droplets are solidified along a path that produces a desired microstructure. Unlike other methods for producing thermal sprays, the spray parameters in this process are fully decoupled and, therefore, permit materials processing under conditions inaccessible by conventional thermal spray processes.

With support from ITP, Oak Ridge National Laboratory, the Massachusetts Institute of Technology, and Northeastern University have developed this process that is now being commercialized for various applications. With appropriate engineering, novel particulate materials can be produced at reasonably high production rates and low capital and operating costs. Currently, the major commercial use is to produce micro-solder balls for Ball-Grid Array electronics packaging, which are used for manufacturing and assembling electronic products.




*Uniform Droplet Spray Process*

## Overview

- Developed by Oak Ridge National Laboratory, the Massachusetts Institute of Technology, and Northeastern University
- Currently licensed to three United States and three Japanese firms who are exploring the Ball Grid Array application

## Applications

Directly benefits the integrated circuit packaging industry with potential applications for use as a filtering media in the chemicals and petroleum industries

## Capabilities

- Offers high quality production of uniform alloy droplets.
- Saves significant time and energy over traditional methods relying on cutting and milling operations.

## Benefits

### Product Quality

Produces uniform alloy droplets.

### Profitability

Reduces labor costs compared with traditional cutting and milling operations.

### Quality Control

Increases quality control because of the consistency of solder ball production.

# Uniformly Drying Materials Using Microwave Energy

IMPACTS

## New System Uses Microwave Energy to Dry Materials Uniformly at Half the Cost

Industrial Microwave Systems LLC with assistance from a Department of Energy NICE$^3$ grant, successfully demonstrated and is commercializing an innovative system that uses microwave energy to dry materials. Traditionally, microwave-drying systems have scorched the portions of materials that were close to the radiation source while materials further from the source remained moist. This result is due to a primary characteristic of microwave energy—it attenuates as it leaves its point of origin, creating hot spots across the materials being dried. This characteristic has kept microwave drying from becoming the drying technology of choice.

This new technology addresses these traditional problems by using a rectangular wave-guide. This guide is slotted and serpentined to maximize the exposure area of materials as they pass through the system. A number of wave-guides can be cascaded to form a system that dries an entire piece of fabric or other material. Leakage of microwave energy is greatly reduced by using choke flanges to limit the amount of radiation reaching outside openings.

## Benefits

### Energy Savings

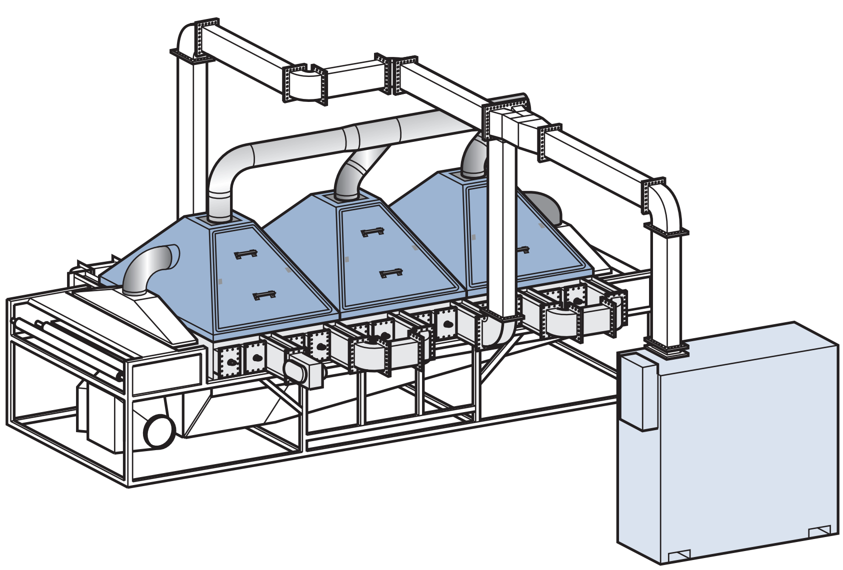
Reduces natural gas heating requirements by 20% to 50% saving up to 12 billion Btu/year for a typical plant.

### Pollution Control

Reduces greenhouse gas emissions by approximately 50% with 68% of particulates eliminated.

### Productivity and Profitability

Reduces drying stress because of no contact drying, lower maintenance costs because of fewer movable parts.



*Microwave-Drying System*

## Overview

- Developed by Industrial Microwave Systems LLC
- Commercialized in 2000
- Currently operating at 5 facilities in the United States and 1 in Germany
- Two demonstration units being tested in Georgia and North Carolina

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 0.107 | 0.030 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.0 | 0.001 | 0.004 | 0.493 |

## Applications

- Fabrics, leather-good linings, and shoes
- Cleaning cloths
- Industrial filters and insulation
- Medical adhesives, dressings, and gowns
- Paper products
- Geotextiles, carpeting, and roofing materials
- Personal hygiene products such as diapers

## Capabilities

- Provides efficient and uniform drying of materials continuously fed through the drying system.
- Works with existing systems to reduce conventional natural gas or electric drying needs.
- Reduces microwave leakage with the use of choke flanges.

# Variable-Frequency Microwave Furnace



## New Microwave Furnace Shows Promise in a Variety of Materials Applications

Microwave heating can speed the curing of thermo-setting resins and polymer-matrix composites. Conventional microwave furnaces use standing waves that create a non-uniform energy distribution in the working cavity. Lambda Technologies and ITP have developed MicroCure™, a variable-frequency microwave furnace that eliminates non-uniform energy distribution and provides reproducible heating with every batch. By sweeping the frequency over a range, the power distribution becomes uniform because of the superposition of thousands of individual microwave modes.

Various types of polymer products can be uniformly cured, often in 5% of the time of conventional processing. For example, the new furnace has reduced the curing time of net-shaped polymer matrix composites from 10 hours to 30 minutes. The new furnaces have been scaled up to hold large volumes of materials in the microwave cavity while still producing high-quality products and maintaining excellent process control.

MicroCure furnaces are being used in the electronics industry to manufacture circuit boards. Because the MicroCure furnace operates at lower temperatures than conventional furnaces, the stress on circuit board components such as silicon chips is reduced. In addition, circuit board manufacturers using the MicroCure furnace can replace conventional adhesives with solventless adhesives requiring lower curing temperatures, reducing emissions caused by conventional solvents.

## Benefits

### Competitiveness

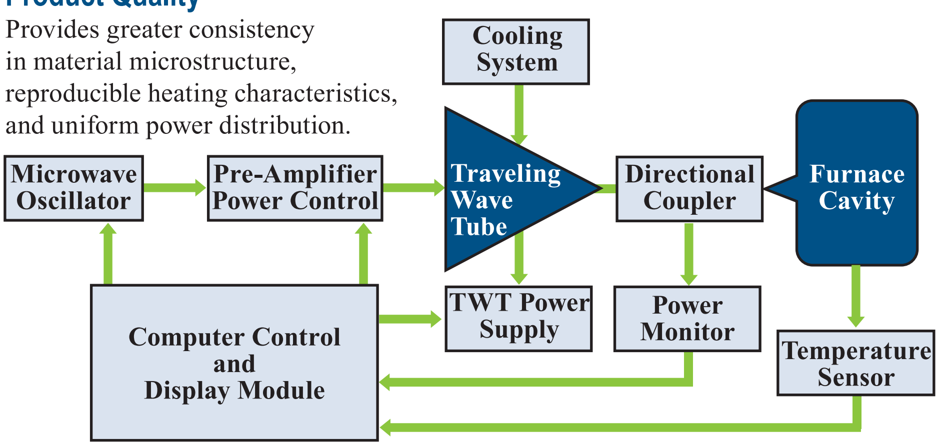
Control of the reaction rate by coupling microwave energy at the molecular level allows new material structures not possible with conventional heating techniques.

### Productivity

Reduces the time required for heat treatment by up to 95% over conventional furnaces.

### Product Quality

Provides greater consistency in material microstructure, reproducible heating characteristics, and uniform power distribution.




*Variable Frequency Microwave Furnace System Block Diagram*

## Overview

- Developed by Lambda Technologies
- Commercialized in 1994
- 80 units installed, 47 in the United States

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 0.047 | 0.009 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.0 | 0.002 | 0.002 | 0.186 |

## Applications

- Developing new materials and materials processes, including epoxy curing, ceramic sintering, polymer matrix composite processing, composite joining and/or fusing and surface treatments
- Plasma processing, including chemical vapor deposition, chemical vapor infiltration, and surface cleaning and modification
- Drying large volumes of textiles, ceramics, and rubber products
- Biomedical processing, including sterilization and uniform thawing

## Capabilities

- Can operate at a fixed, preset frequency over a range of 1 to 18 GHz or in controlled swept frequency mode.
- Has power levels ranging from 700 W to 2 kW.

IMPACTS

## Heat Recovery System Extracts Energy From Waste Fluids

With assistance from DOE's Inventions and Innovation Program, WaterFilm Energy, Inc. developed a new coil and tube design for heat exchangers that increases heat transfer coefficients two to four times higher than conventional designs. Named the GFX system, the unit is a double-walled, self-vented, copper heat exchanger that forces fluid to flow as a film. Gray water or waste streams flow through the inner drain section, while makeup or incoming water supply flows through the outer coiled jacket. The design, IAMPO- and UL-approved, incorporates equal flow rates on both sides of the heat exchanger for optimum efficiency. GFX's lack of internal welds eliminates cross-contamination problems caused by weld failures and tube leaks common to shell and tube heat exchangers. A common industrial application is to cool effluent to meet environmental or waste treatment regulations. Eliminating the potential for cross-contamination, ensures low maintenance costs and guarantees consistent energy savings.

## Benefits

### Energy Savings

Reduces energy consumption by recovering heat usually lost through disposal of waste. Can recover up to 70% of the heat carried to settling ponds or sewers. Hospitality industry installations have demonstrated a simple payback of 1.7 years.

### Other

Preheating potable water for dairy cattle increases fluid intake and boosts milk production. Cooling wastewater sent to settling or holding ponds reduces the evaporation rate, cutting down the release of foul aromatics.

### Productivity

Reduces scale formation and maintenance required to maintain boiler peak efficiency.

### Profitability

Has lower first costs and operating costs than buying and maintaining larger or multiple-process heating units or systems.

## Overview

- Invented and developed by WaterFilm Energy, Inc.
- Commercialized in 1997
- Over 2250 units installed in the United States

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 0.088 | 0.025 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.0 | 0.003 | 0.003 | 0.440 |

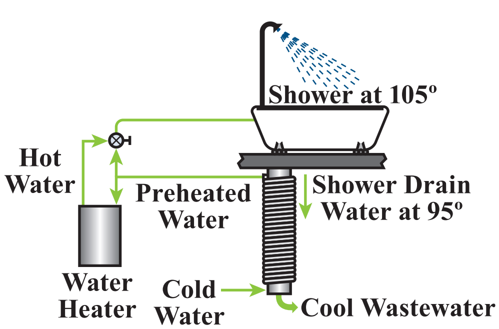
## Applications

- Agricultural, chemical, refining, textile, food preparation, and other processing industries requiring heated supply water for processing
- Commercial buildings, heat recovery to complement electric and boiler water-heating systems
- Single and multifamily residential building water-heating systems

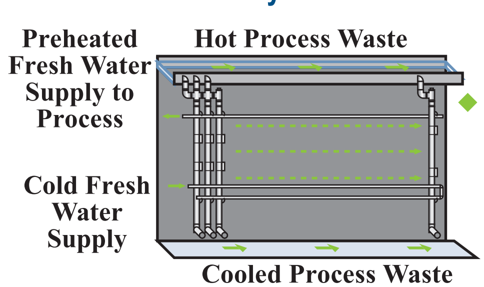
## Capabilities

- Can be installed on nearly any system between the drain and sewer or holding pond.
- Units come in several sizes and can be clustered to create an "energy recovery wall" for larger facilities.
- Design promotes self-cleaning, and low residence time prevents unwanted biological growth or fouling.

### Building Application




### Industrial Application Water Preheating Application – from Dye Waste




*Waste Fluid Heat Recovery System*

# Waste-Minimizing Plating Barrel

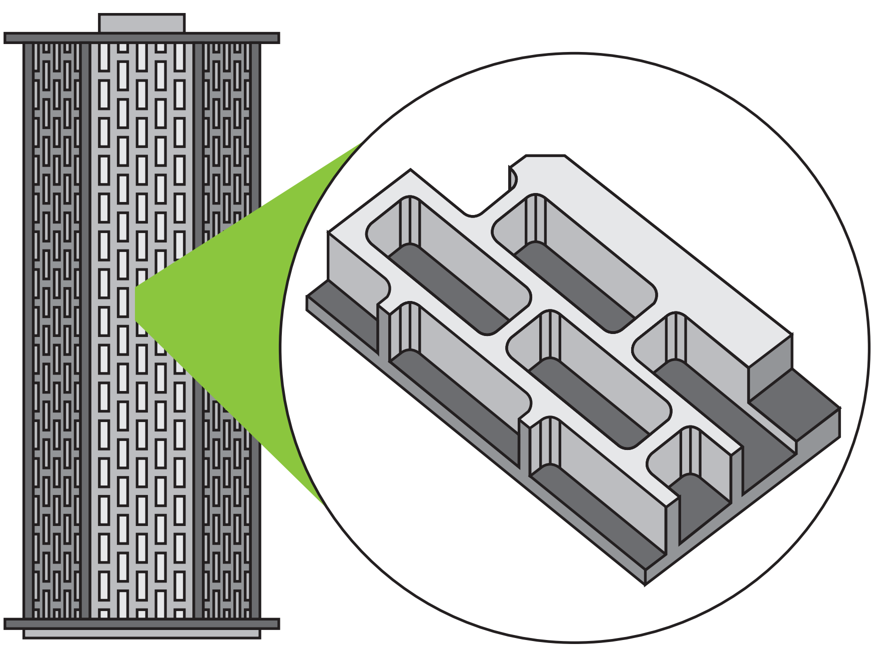


## Waste-Minimizing Plating Barrel Increases Productivity

Plating barrels are used in metal plating operations to hold the parts to be plated. Traditional barrel designs have a wall thickness ranging from 1/2 to 1 inch, with thousands of holes drilled into the walls to allow electrical current and plating solution into the vessel. The wall thickness is required to provide adequate structural integrity. However, it lowers the efficiency of transferring plating solution into and out of the barrel and diminishes the ability to push electrical current through the holes and onto the parts being plated.

The Whyco barrel, developed by Whyco Technologies, Inc. and demonstrated using a NICE$^3$ grant, is constructed by machining a staggered pattern of rectangular-shaped pockets into the traditional thick-walled polypropylene barrel. After machining, the barrel's structure resembles a honeycomb formation into which thousands of small, now shorter, holes are drilled. This patented staggered-cell design allows for the greatest number of holes per open area while maintaining structural integrity. This thin-walled honeycomb structure increases the hydrodynamic pumping action during barrel rotation, creating greater solution transfer than the traditional barrel design. The Whyco barrel also has higher current density plating leading to faster plating cycles, reduced bath concentration due to higher mass transfer rates, and better plating of difficult chemistries such as alloy plating.

To date, more than 1000 of these innovative barrels are in use at Whyco and other plating companies.



*Whyco's Staggered-Cell Design*

## Overview

- Developed by Whyco Technologies, Inc.
- Commercialized in 1997
- Currently 1097 plating barrels in use

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 3.01 | 0.524 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.002 | 0.078 | 0.077 | 9.69 |

## Applications

Metal-plating operations; metal finishing and electroplating

## Capabilities

Increases process efficiency of metal plating operations.

## Benefits

### Energy Savings

Energy savings from reduced process time and better plating efficiency.

### Productivity

Reduces process time and increases productivity by more than 22%.

### Use of Raw Materials

Due to better plating efficiency, product yields have improved by up to 40% while cycle times have decreased by up to 25%.

### Waste Reduction

Because this process reduces drag-out (drag-out refers to the chemical solution held in barrel holes by capillary action) barrel users have reported up to a 60% decrease in plating solution loss.

# Other Industries

IMPACTS

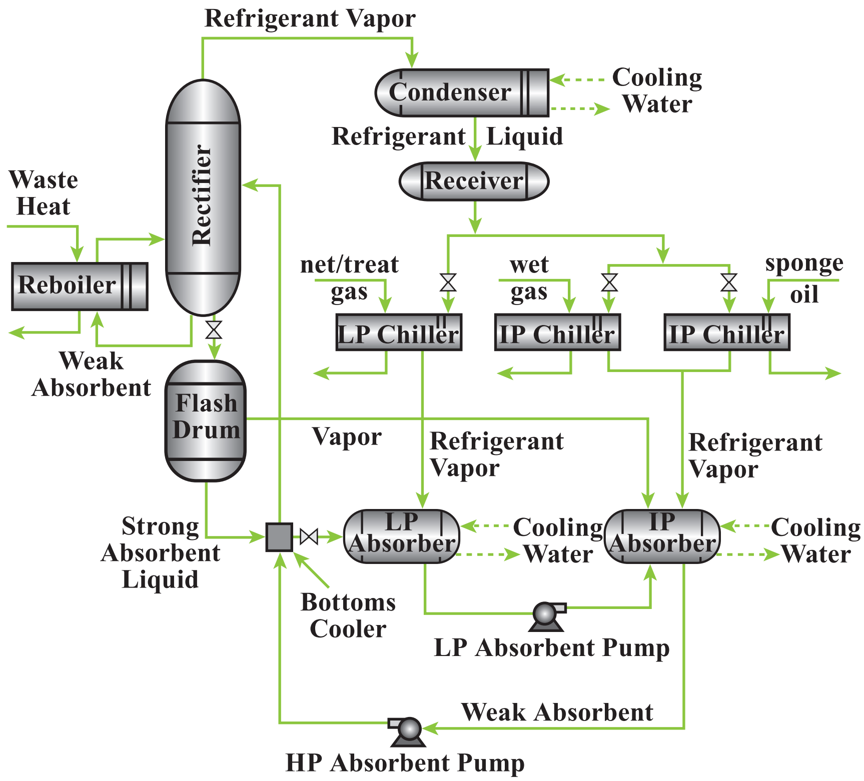
# Absorption Heat Pump/Refrigeration Unit



## Advanced Water Ammonia Absorption Cooling Finds Profitable Application in Refinery Operations

Refineries usually prefer ambient cooling with cooling towers because refrigeration systems cost more initially, create headaches in operating and maintaining compressors, and significantly increase the demand for electricity. With assistance from ITP and a grant from the Inventions and Innovation Program, the Energy Concepts Company developed an advanced ammonia refrigeration unit powered by waste heat. It overcomes the disadvantages of a refrigeration system. It recovers fuel from reformer waste gas and raises the capacity of a catalytic cracker. The unit debottlenecks the net gas compressors in a cracker. The inlet vapors are cooled, which increases the compressor capacity.

A commercial unit operating in Commerce City, Colorado, is providing up to 265 tons of refrigeration capacity to refrigerate the reformer plant net gas/treat gas stream and is recovering a net 45,000 barrels/year of gasoline and LPG. The 290°F waste heat content of the reformer reactor effluent powers the unit. The absorption cooling system is directly integrated into the refinery processes and uses enhanced, highly compact heat and mass transfer components. The refinery's investment was paid back in less than 2 years as a result of increased recovery of salable product, which was formerly flared. It is important to note that the recent increase in fuel prices has lowered this system's payback considerably.




*Absorption Heat Pump/Refrigeration Unit*

## Overview

- Developed by Energy Concepts Company
- One commercial unit installed at a refinery in 1997

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 2.23 | 0.306 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.002 | 0.178 | 0.047 | 6.66 |

## Applications

- Resource recovery in the petroleum refining and chemical industries
- Refrigeration and space conditioning for commercial and industrial facilities

## Capabilities

- Water/ammonia absorption cycle can be powered from any heat source.
- Can deliver temperatures as low as -50°F.

## Benefits

### Profitability

Reduces energy intensity for a refinery and increases throughput for fluid catalytic crackers that have a bottleneck due to an overloaded wet-gas compressor. Applying refrigeration to refinery fuel gas header streams can recover millions of dollars worth of gasoline and liquefied petroleum gas (LPG) annually.

# Advanced Membrane Devices for Natural Gas Cleaning

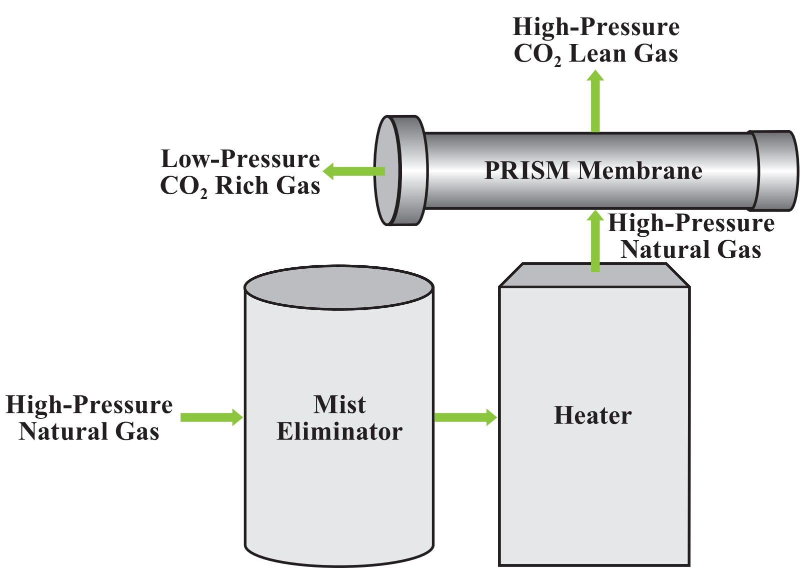
**IMPACTS**

## New Membrane Cost Effectively Upgrades Sub-Quality Natural Gas

Carbon dioxide ($CO_2$) is a common impurity that must be removed in natural gas to improve the gas's heating value or to meet pipeline specifications. Hydrogen sulfide ($H_2S$) often prohibits natural gas from being used to generate power and drive compressors at remote locations such as oil and gas production sites. Production companies are faced with choosing among shutting in a well, overhauling engines frequently, or dealing with logistical challenges associated with routing other fuels to the site.

With DOE support, Air Products & Chemicals, Inc., through its Advanced Membrane Devices project, developed and successfully commercialized PRISM® membranes for upgrading sub-quality natural gas. These semi-permeable polymeric membranes can be used as gas scrubbers for natural gas, removing $CO_2$ and $H_2S$ from natural gas.

PRISM membranes, based on simple process designs, provide a low-cost alternative to traditional amine systems that are used to upgrade natural gas. The membranes can also be used as a bulk-removal device to minimize the size of an amine system. The benefits become even more pronounced as the industry produces natural gas from very remote locations. Fuel-gas conditioning systems that incorporate PRISM membranes provide oil and gas production companies with an economical solution to an otherwise often enormous problem. The membrane device can be used to make low-grade natural gas with high $CO_2$ and $H_2S$ content into a pipeline-grade gas for domestic and industrial consumption.




*$CO_2$ Removal Process Using the PRISM Membrane System*

## Overview

- Developed by Air Products & Chemicals
- Commercialized in 2001
- 98 $CO_2$-removal units operating in the United States in 2004

## Applications

- Recovers $CO_2$ from associated gas in enhanced oil recovery programs
- Removes acid gas from natural gas

## Capabilities

Can reduce impurities to allow natural gas to meet pipeline specifications.

## Benefits

### Environmental Quality

The PRISM membranes do not use any hazardous chemicals such as amines, which can cause environmental complications.

### Ease of Installation

Units are lightweight and compact, thus facilitating their transportation and installation.

### Profitability

The membranes are ideal for remote locations with limited utilities and sour natural gas.

### Reliability

No moving parts mean minimal maintenance costs.

# Brick Kiln Design Using Low Thermal Mass Technology



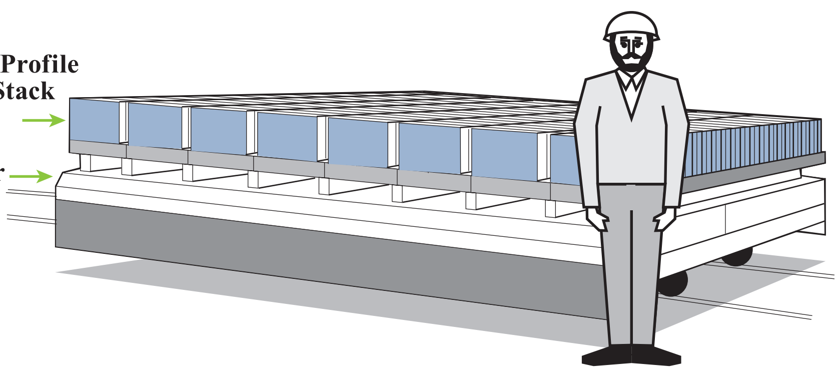
## Innovative Brick Kiln Using Low Thermal Mass and Low-$NO_X$ Technologies

Swindell Dressler and Pacific Clay Brick have successfully developed and demonstrated, using a NICE[3] grant, a tunnel-kiln design with a low thermal mass. This new brick kiln uses three technical innovations: ceramic-fiber insulation in lieu of traditional refractory brick, a lower profile stack design for brick kiln cars, and more but smaller low-$NO_X$ gas burners. These innovations result in a reduction in natural gas usage of 35% compared to a conventional kiln.

Replacing traditional refractory brick with ceramic fiber insulation allows the new design to reach operating temperature in about 1 hour compared to 24 hours for traditional designs. Additionally, the ceramic-fiber bricks with a low thermal mass absorb less heat, so more heat is available to fire the bricks.

A lower profile stack design for the bricks on the kiln cars means that bricks are placed 4 to 5 layers high instead of 15 layers high with traditional kilns. This lower profile stack design allows for better heat penetration into the bricks and better process control.

Several process changes reduce $NO_X$ emissions: lower kiln firing temperatures (2100°F versus 2250°F), newer high-velocity burners, and a fully automated Process Management System that will maintain set points, including furnace-zone and rapid-cool zone temperatures.




*New Low Profile Brick Kiln Car*

## Overview

- Developed by Swindell Dressler
- Commercialized in 1996
- 2 units now operating

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 0.248 | 0.032 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.0 | 0.0 | 0.004 | 0.508 |

## Applications

Brick and ceramic material kilns

## Capabilities

- Uses low thermal mass kiln design to reduce energy consumption and increase throughput.
- Has better process control with better placement of more but smaller burners.
- Employs low-$NO_X$ burners.

## Benefits

### Productivity

Reduces time to preheat kiln to operating temperature from 24 hours to 1 hour.

### Waste Reduction

Reduces rejection rate due to better process control and even heat distribution.

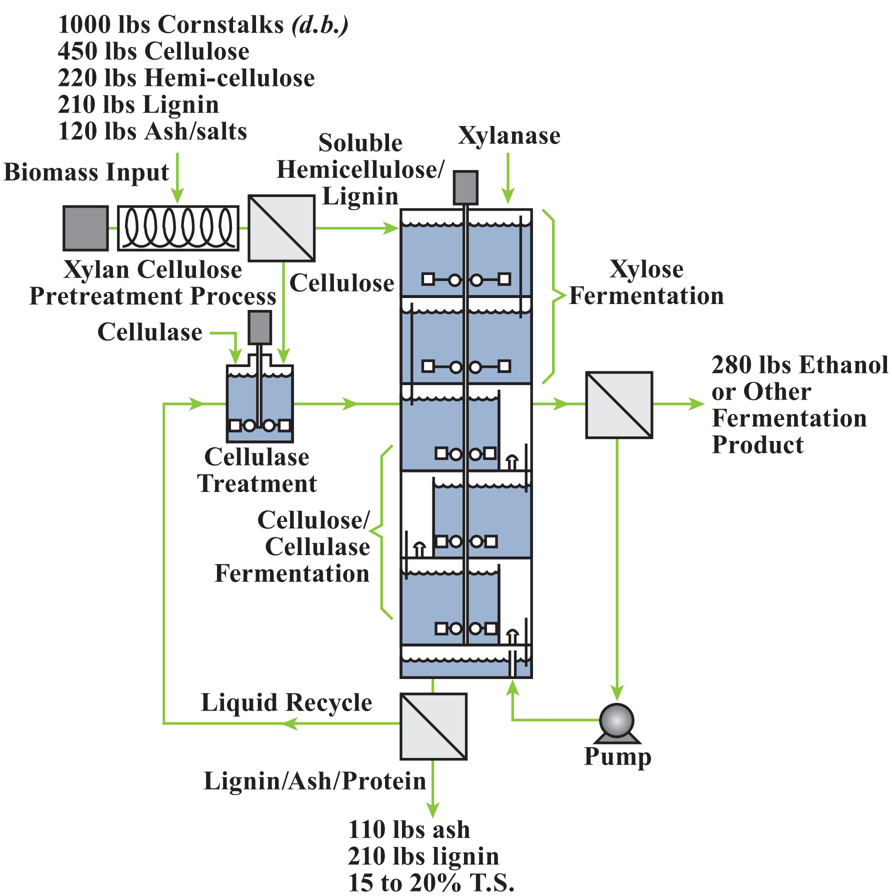
# Continuous Cascade Fermentation System for Chemical Precursors

IMPACTS

## Continuous Cascade Fermentation System Increases Yields and Cuts Process Time for Converting Carbohydrates to Ethanol and other Chemical Precursors

With assistance from DOE's Inventions and Innovation Program, Bio-Process Innovation (BPI), Inc., developed a proprietary cascade reactor for ethanol production from carbohydrate feedstocks that eliminates the need to fill, empty, and wash a fermenter as part of a batch operation. Feed is introduced continuously into the first of three to five stirred reactors placed in series, with the outflow of one reactor flowing into the next reactor. The effluent from the reactor is then taken to a low-energy solvent absorption/extractive distillation system for separating and purifying ethanol. Separating the ethanol as it is produced increases the rate of ethanol production. BPI, Inc., also developed a highly flocculent yeast that further speeds the reaction of sugar to ethanol by maintaining cell densities of over 30 grams/liter. Continuous operations can more than double the fermentation capacity of a batch ethanol facility.

A five-stage unit of 40,000 gallons reactor volume operated at an Iowa site from 1996 to 2004 on waste starches/sugars. It produced about 1 million gallons of ethanol per year. Two small plants in Wisconsin and Minnesota were using this technology to convert permeate mother liquor to ethanol.




*Commercialized Fermentation Technology Applied to Emerging Concept of Biomass Fermentation*

## Overview

- Commercialized by Bio-Process Innovation (BPI), Inc. in 1996
- Over 8 years operational experience
- 1 United States installation operated in 2004

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 0.814 | 0.037 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.0 | 0.0 | 0.0 | .782 |

## Applications

Converting carbohydrate feed stocks, which comprise 65% of municipal solid waste, to ethanol or other chemical precursors

## Capabilities

- Continuous rather than batch system allows quick and complete saccharification and fermentation of feedstocks and removal of ethanol into a gas phase as it is produced.
- Uses abundant cellulosics as a feedstock for alternative chemical precursors.

## Benefits

### Productivity

Conventional reactor processing time of 36 to 48 hours is reduced to 24 hours or less. Dramatically improves throughput by maintaining a high cell density in the reactors and operating continuously.

### Profitability

Lowers the cost of producing ethanol or other fermentation chemicals from carbohydrates by cutting production labor. Can be retrofitted on fermenters currently in use in batch-process ethanol production facilities.

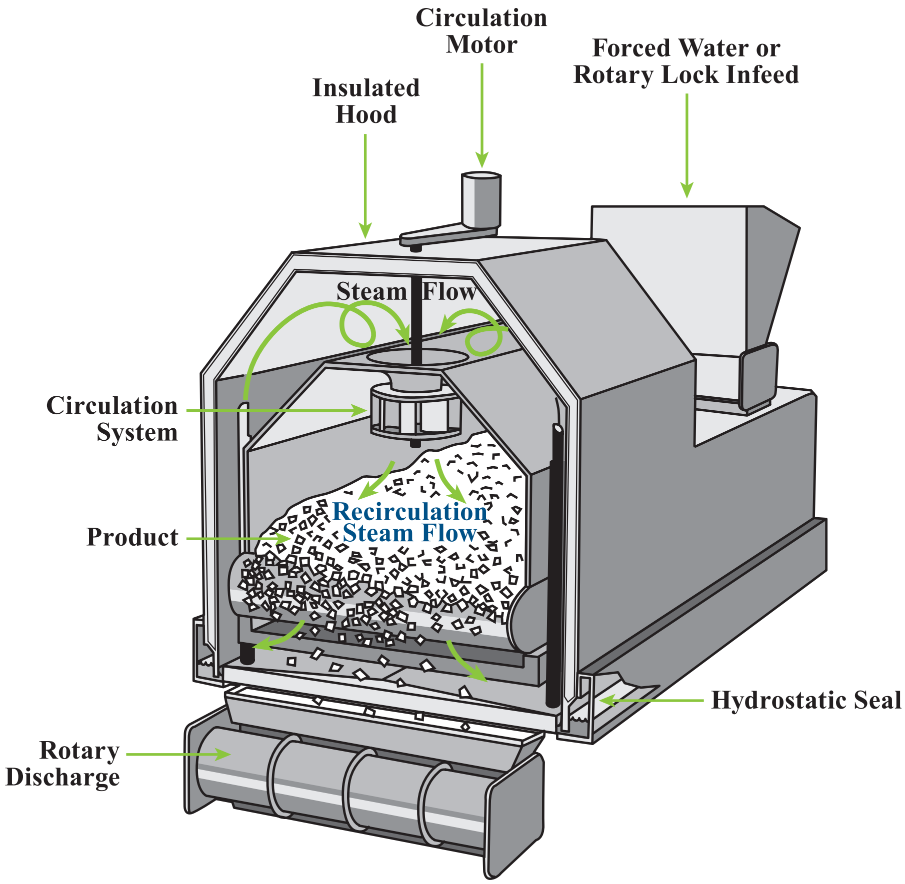
# Energy-Efficient Food Blanching



## New Blanching System Increases Productivity While Saving Energy

This innovative blanching technology recirculates and reuses steam, dramatically reducing water and energy use, and wastewater production. Key Technology, Inc., using a NICE³ grant, developed and demonstrated the energy-saving and waste-reducing Turbo-Flo® Blancher/Cooker System. The Turbo-Flo system is a revolutionary advance in blanching and cooking technology. Traditional blanchers use a tremendous amount of steam or hot water (200-212°F) that is energy intensive, often overcooking the product being blanched. There are currently more than 60 Turbo-Flo units operating with energy savings of more than 70% and improved product quality.

In addition to the blancher innovations, Key Technology also collaborated with Washington State University to develop a lipoxygenase enzyme sensor that is capable of reducing blanch times in several types of vegetables. While the sensor was demonstrated in bench-scale tests, it is still in a developmental stage and not yet available commercially. When the development is complete, the new sensor will provide even more energy savings by further optimizing the blanching process.




*Cut-Away of the Turbo-Flo Blancher*

## Overview

- Developed by Key Technology, Inc.
- More than 62 units operating in the food processing industry

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 0.007 | 0.001 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.026 |

## Applications

Processing of fruits, vegetables, and potatoes for shelf-life protection

## Capabilities

- Reduces product-to-steam ratio.
- Saves approximately 70% of energy use.
- Eliminates process wastewater.

## Benefits

### Environmental

Wastewater is virtually eliminated with the Turbo-Flo. Estimated water savings from the use of this system are over 3.8 million gallons of water per year per unit.

### Productivity

With efficiency gains, shorter cook and blanch times increase yields by 2% to 5% over conventional water blanchers.

### Quality/Process Improvement

The Turbo-Flo system improves nutrient retention, taste, and appearance through shorter cook cycles and takes up only about 60% as much floor space as conventional blanching/cooking equipment. The Turbo-Flo system ensures more even cooking temperatures, and provides consistent product definition and quality.

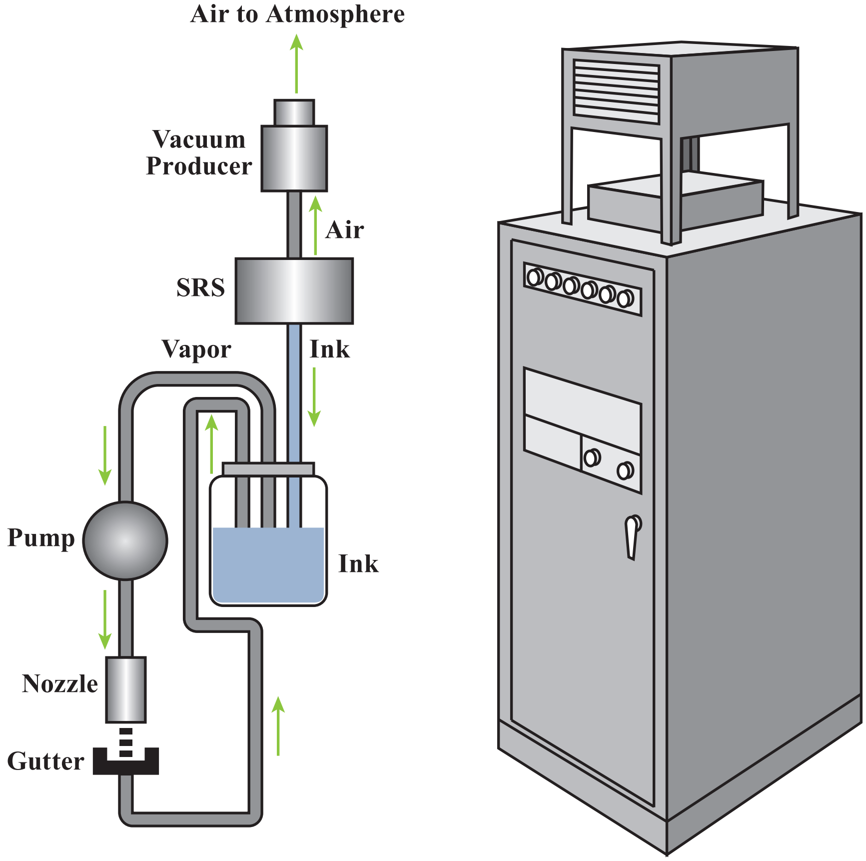
IMPACTS

## Ink Jet Printer Solvent Recovery System for Commercial Printing Applications Reduces Emissions

Quad/Tech International (QTI) developed a new solvent recovery system (SRS) for commercial printers. This system was demonstrated using a NICE[3] grant. The SRS captures and reuses 60% to 70% of the volatile organic compounds (VOCs) associated with the printing process. The SRS can also reduce the amount of ink and solvent that would be lost as vapor by up to 50% on average, resulting in a significant reduction in emissions. Additionally, because less fluid is used, the fluid containers do not have to be changed as often, resulting in labor savings and less downtime on the production line. Lastly, reduced VOC and acetone emissions make the work environment healthier for employees.

The SRS consists of a closed-loop ink supply tank that directs solvent vapors discharged from the tank through a vent tube. The vent tube is connected to a condenser that cools the vapors, condensing nearly all the solvent. The vapors are then returned via the vent to the ink supply tank.

QTI has over 625 of these units currently in operation. Energy savings result from the reduced need to manufacture the solvent, manufacture the plastic containers that the solvent is shipped in, and transport the solvent.




*The Quad/Tech Solvent Recovery System (SRS)*

## Overview

- Developed by Quad/Tech International (QTI)
- Commercialized in 1997
- 637 units operating

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 0.345 | 0.051 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.021 | 1.03 | 0.769 | 93.9 |

## Applications

Capturing and reusing VOCs in commercial printing processes

## Capabilities

- Recovers 60% to 70% of VOCs.
- Reduces ink and solvent loss by vapor capture.
- Increases compliance capability with environmental regulations governing VOC release.

## Benefits

### Productivity

Recovers ink and solvent lost as vapor, resulting in less downtime to replace depleted fluid reservoirs.

### Use of Raw Materials/Feedstocks

Recovery of ink and solvent reduces make-up streams, saving ink and solvent feedstocks.

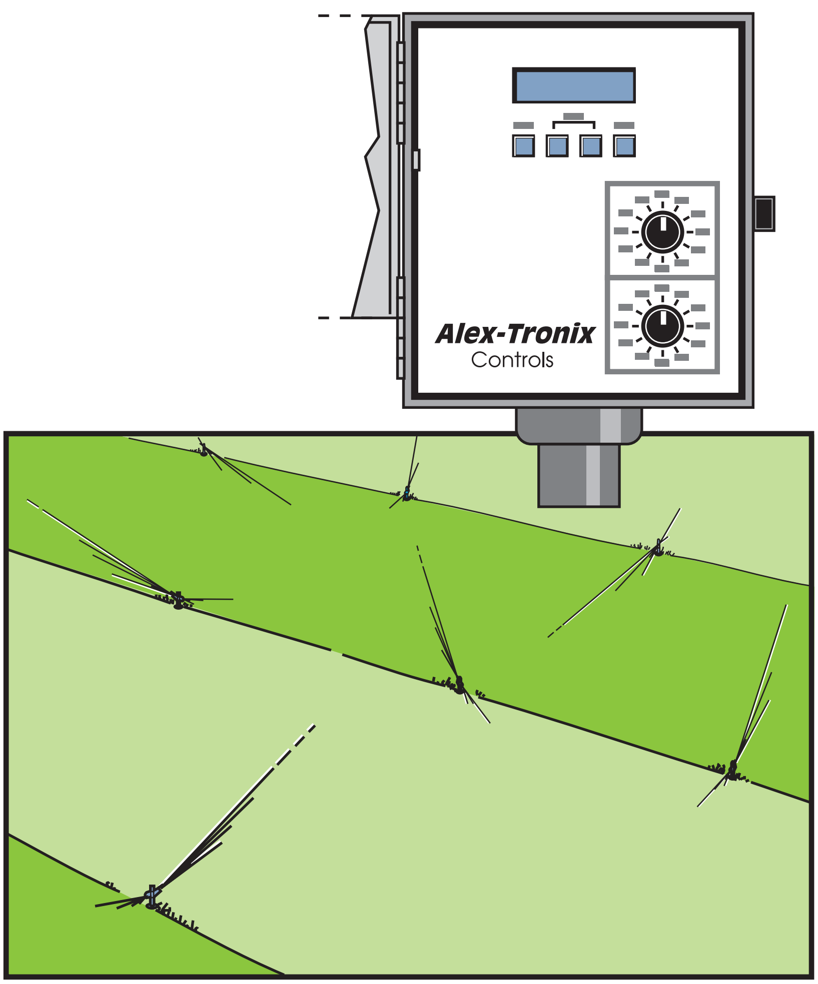
# Irrigation Valve Solenoid Energy Saver



## New Solenoid Controller for Irrigation Valves Saves Energy

A battery operated, multi-station, irrigation valve control unit was developed with funding from DOE's Inventions and Innovation Program. The Battery Control System (BCS) uses low-powered, latching solenoid controllers with internal batteries that last for a minimum of 5 years.

Automated irrigation systems with latching solenoid controllers require a constant flow of electricity to keep the valves operating. A battery sends power surges to the solenoid as needed to open and close the valves. The BCS available from Alex-Tronix Controls uses the SWELL solenoid power saver. With the SWELL unit, the inrush and holding current requirements are only about 10% that of most other solenoids. The SWELL's greatly reduced inrush and holding current requirements allows valves to be operated at much longer distances. The BCS can operate valves reliably out to a distance of almost 20 miles. Other battery-powered controllers are limited in distance to about 1000 feet. Up to five valves can be operated simultaneously with a single irrigation controller. The solenoid coil never burns out because there is no power in the coil.




*Battery Control System for Irrigation Valves*

## Overview

- Developed and being marketed by Alex-Tronix Controls
- Commercialized in 1999 with over 2700 units in the field
- Proven operation in laboratory and field tests

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 0.014 | 0.003 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.0 | 0.001 | 0.0 | 0.056 |

## Applications

For sprinkler systems in medians, schools, shopping malls, golf courses, parks, agricultural and industrial applications

## Capabilities

- Operates valves out to about 20 miles.
- Eliminates the energy and primary wiring needed to operate an irrigation system.
- Technology has 10 times the battery life and 100 times the operating distance of any other controller.

## Benefits

### Ease of Installation

Controllers can be installed anywhere. There is no need to install electrical meters or to use licensed electricians for installation.

### Safety

There are no electrical safety concerns. Power surge and lightning-related problems associated with primary power leads are eliminated because there is no need for primary wiring.

# Restaurant Exhaust Ventilation Monitor/Controller

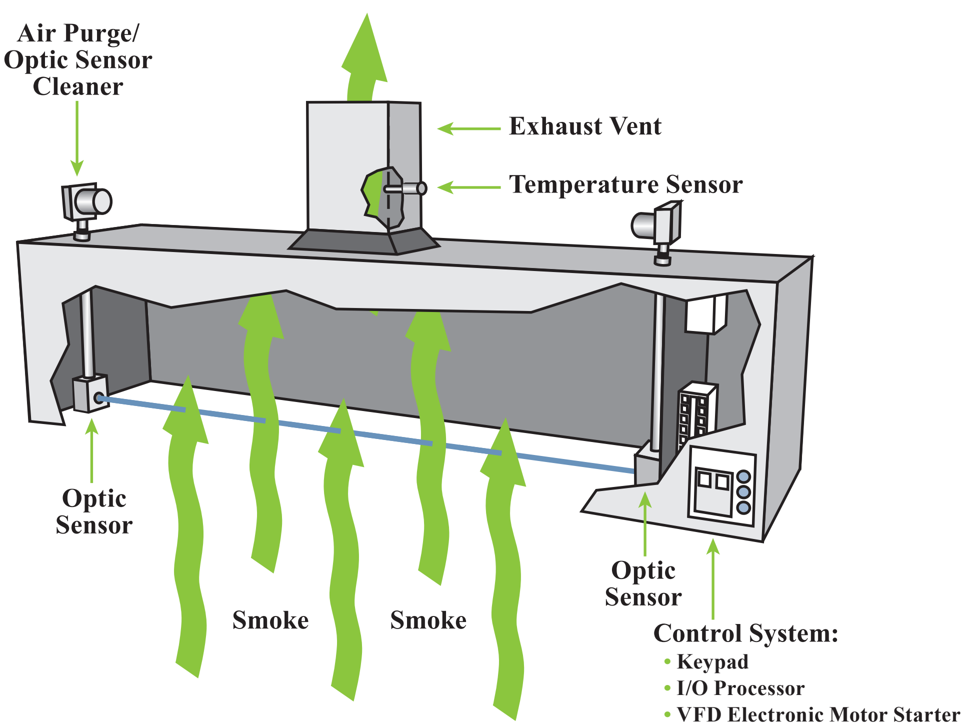
IMPACTS

## New Kitchen Exhaust System Uses Variable Speed Controls to Save Energy

Typical exhaust hoods in restaurants operate at full speed all day long and sometimes all night long even when cooking is not taking place. With assistance from DOE's Inventions and Innovation Program, Melink Corporation developed a microprocessor-based controller for commercial kitchen ventilation systems. The controller optimizes system performance for four key parameters: kitchen comfort, fire safety, occupant health, and energy efficiency. The controller uses an intelligent code that continually analyzes an array of operational inputs and provides an output signal to variable-frequency speed drive (VFD) electronic motor starters, which then vary the speed of the exhaust and makeup fans.

The main control system includes a keypad that provides bypass capability and preset functions such as minimum fan speed, temperature span, and monitoring. The input/output (I/O) processor continuously reads inputs from the optic and temperature sensors that monitor heat and smoke levels from cooking activity. The air purge units prevent grease vapors from collecting on the optic sensor lenses to ensure trouble-free operation.

When cooking needs are low, the sensors prompt the processor to maintain low preset fan speeds, which provides fan motor energy savings. When the sensors identify smoke or temperature levels above preset limits, the processor prompts the electronic motor starter to increase the exhaust fan speed to accommodate increased ventilation needs. When cooking needs are reduced, the sensors prompt the processor to again reduce fan speeds to energy-saving levels.




*The Melink Restaurant Exhaust Ventilation System*

## Overview

- Developed by Melink Corporation
- Commercialized in 1994
- Over 2700 units sold

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 0.605 | 0.236 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.001 | 0.051 | 0.038 | 4.64 |

## Applications

Commercial kitchen ventilation systems for restaurants, schools, hospitals, hotels, and other institutions

## Capabilities

- Monitors and reduces the fan speed during idle periods of kitchen activity to save energy.
- Provides sensors that monitor heat and smoke levels for safety.

## Benefits

The main benefit of upgrading the hood system with variable-speed controls is energy savings. Other benefits include improved kitchen comfort, occupant health, and fire safety.

# Stalk and Root Embedding Plow

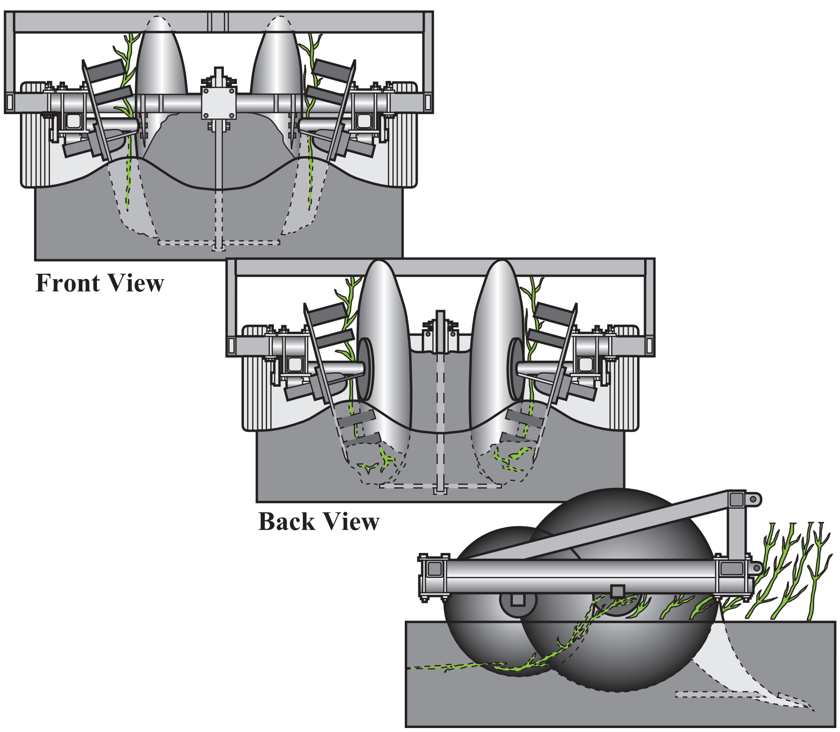


## New Stalk and Root Embedding Plow Prevents Post Damage and Saves Time in Preparing Fields

Disposing of cotton stalks and roots in the field after harvest is an energy-intensive operation. Nationwide, many cotton farmers use conventional tillage practices that involve shredding the stalks and making several tillage passes over the field to prepare a new seedbed. These tillage operations consume over one-half of farmers' annual fuel budget, and most farmers are frustrated with the high costs and time requirements. Over the last 50 years, farmers have tried several alternative tillage systems, all of which involve uprooting the cotton plants and mixing the crop residue into the soil. All uprooters have shortcomings, and none have gained wide acceptance across the Cotton Belt.

With assistance from DOE's Inventions and Innovation Program, the University of Arizona invented the Pegasus system—a stalk, root, and agricultural debris-burying tillage machine suited for burying row crops, especially cotton, to prevent pest damage and prepare fields for crops. The rapid plow-down design is a breakthrough in cotton tillage. A narrow moldboard plow opens a deep trench in the soil next to the crop row. Then a "stuffer disk" inserts the roots and stalks into the deep trench. The whole stalks are buried in a "rope" bundle under the bed where they decompose. The machine also forms new beds, leaving the field ready for the next crop.

Rigorous research by the United States Department of Agriculture indicates dramatic savings in cost, time, and energy. There are no adverse effects. Yields with the Pegasus have ranged from the same as conventional methods to 12% greater than conventional methods.




*Stalk and Root Embedding Plow*

## Overview

- Invented by the University of Arizona and being sold by the Rome Plow Company
- Commercialized in 1996
- 73 units operating in 2004

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 0.102 | 0.020 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.421 |

## Applications

- Breakthrough tillage technology for agriculture
- Cotton and other row-crop tillage

## Capabilities

- Operates valves out to about 20 miles.
- Deeply entrenches whole stalks and roots into soil in one pass, eliminating need to shred stalks.
- Plows 7 acres/hour at 4.0 to 4.5 mph.

## Benefits

### Air Emissions Reductions

Eliminates stalk shredding, a large contributor to dust emissions, and cuts engine air emissions by 70% compared with conventional tillage practices.

### Productivity

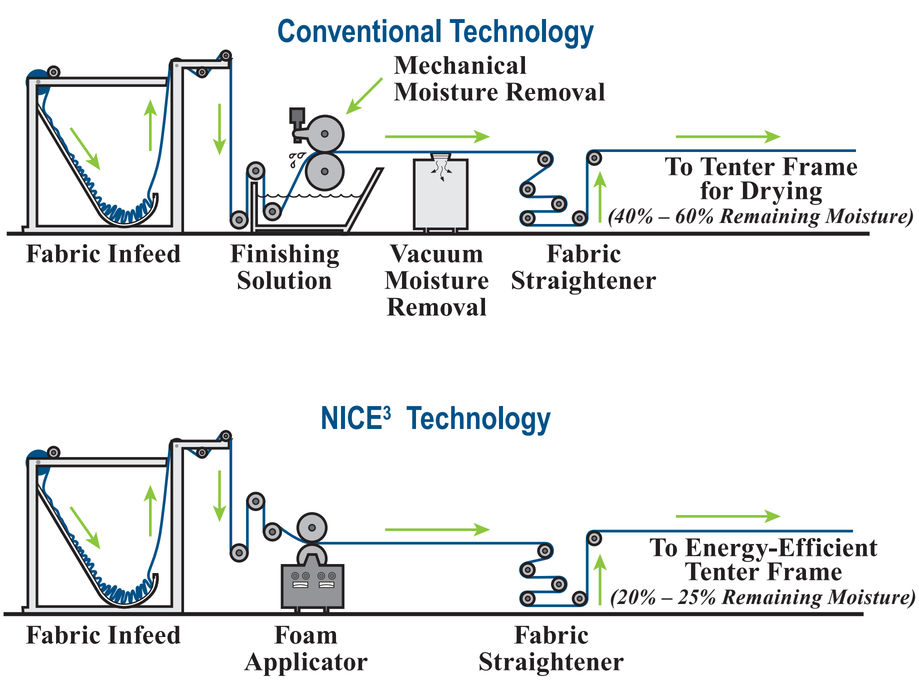
Requires 75% to 80% less time to dispose of crop residue and prepare a new seedbed compared with conventional tillage practices. Saves 4 to 7 repeat passes of tillage machinery to work and prepare fields. Results in cost savings of $50/acre compared with conventional tillage practices.

IMPACTS

## New Process Increases Productivity and Energy Efficiency in Fabric Finishing

The United States textile industry consumes large amounts of energy and water in finishing fabrics. The finishing operation is the final step in producing fabrics and typically imparts the aesthetic and physical properties required for various fabric uses. Using conventional technology, fabric finishers immerse fabric in a solution of finishing chemicals diluted in water. Once saturated, the fabric is removed, and excess moisture is squeezed out mechanically. The moisture is further reduced by a vacuum system before the fabric is directed to fabric drying equipment called the "tenter frame." The tenter frame removes the remaining moisture by processing the fabric through a series of nozzles that expose it to hot air. Because of the relatively high moisture content, the fabric finishing process has been very energy intensive.

With assistance from a NICE$^3$ grant, Brittany Dyeing and Printing demonstrated a new process for finishing textiles. In the new process the finishing chemicals are diluted with air instead of water and applied to the fabric as foam. No additional mechanical or vacuum moisture removal is necessary; thus, saving energy and water. The moisture content of the fabric is cut in half, allowing a new energy-efficient, high-speed tenter frame to be used. This new process increases the productivity of the finishing line by more than 100%.




*Textile Finishing Operations*

## Overview

- Commercialized in 1999
- Demonstrated savings continue at Brittany Dyeing and Printing Corporation

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 0.136 | 0.023 |

## Emissions Reductions

*(Thousand Tons, 2004)*

| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.0 | 0.002 | 0.003 | 0.397 |

## Applications

Process applies to the textile finishing industry

## Capabilities

- Replaces traditional water-based textile finishing applications.
- Reduces the moisture content of fabric from finishing by more than 50%.
- Increases production capability by over 100% through higher production speeds.

## Benefits

### Energy Savings

Energy savings result from application of chemicals in a foam media rather than liquid – this reduces the moisture content; thus, less energy is needed to dry fabric.

### Environmental

In the new system, finishing chemicals are diluted with air instead of water; thus, less water is used and less wastewater discharged.

### Productivity

Reduced moisture content allows for higher production rates (over 100% increase in production capability).

# Utilization of Corn-Based Polymers



## Plastics from Renewable Resources Offer Significant Commercial and Environmental Benefits

Each year, 60 billion pounds of thermoplastics are produced from imported and domestic oil to make industrial and consumer products. Because oil is an increasingly limited resource with negative impacts on the environment, reducing dependence on oil in all areas is important, including product manufacturing.

Polylactide (PLA), derived from annually renewable corn, can be used in place of petroleum-based thermoplastics in many applications such as compostable packaging, film, and fibers for apparel, carpeting, and other fabrics. With financial assistance from DOE, the National Renewable Energy Laboratory along with Cargill Dow LLC and the Colorado School of Mines developed and refined a process to use PLA in manufacturing. Substituting PLA for petroleum-derived polymers reduces fossil energy use by 20% to 50%. The PLA plastics also result in reduced emissions of $CO_2$ compared with the petroleum-based thermoplastics. Projections are that 10% of the U.S. nonrenewable plastics packaging can be replaced with polylactide polymer.

This project assisted in expanding the PLA market by developing two new processing technologies. Both technologies yield semi-crystalline PLA articles that have improved physical properties. Other project tasks helped to better understand the relationship between polymer molecular structure and physical properties, which is useful information for improving process control.

## Benefits

### Energy Savings and Pollution Reduction

Compared with producing products from petroleum, corn-based PLA consumes 20% to 50% less energy in the form of fossil resources. Additionally, the carbon comes from plants that extracted $CO_2$ from the atmosphere, thereby emitting less $CO_2$ than petroleum-based products.

### National Security

Using U.S.-grown corn instead of oil reduces the nation's dependence on foreign resources and oil to produce necessary products such as clothing and food packaging.

## Overview

- Research being led by NREL with Cargill Dow LLC and Colorado School of Mines
- Commercialized in 2003
- Produced at Cargill Dow's Blair, Nebraska, facility with a capacity of 300 million pounds per year

## Energy Savings

*(Trillion Btu)*

| Cumulative through 2004 | 2004 |
|---|---|
| 0.033 | 0.018 |

## Emissions Reductions

*(Thousand Tons, 2004)*

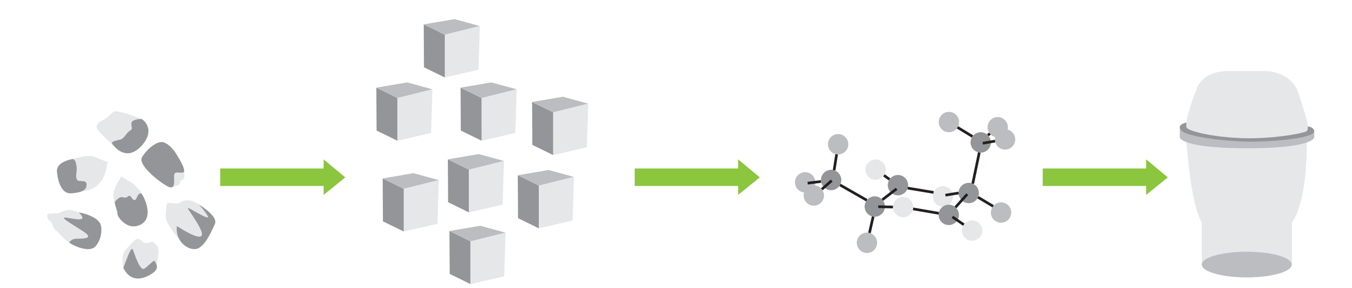
| Particulates | $SO_x$ | $NO_x$ | Carbon |
|---|---|---|---|
| 0.0 | 0.011 | 0.003 | 0.394 |

## Applications

Plastics and textile industries, replacing certain packaging, films, and fibers used for apparel, carpeting, and other fabrics

## Capabilities

- Competes in a market based on price and performance, with a better environmental profile than today's plastics.
- Currently can replace 10% of packaging with PLA, with more research being conducted to infiltrate the market further.



**Renewable Resource** **Fermentation Products** **Lactide Formation** **Plastic Products**

*Process for Producing Plastic Using Renewable Resources*

# Appendix 2:
## ITP Emerging Technologies

# ITP Emerging Technologies

IMPACTS

## IMPACTS

## Aluminum

### Aluminum Salt Cake: Electrodialysis Processing of Brine

The project goal was to eliminate landfilling of aluminum salt cake by developing technologies that would separate salt cake into constituents (aluminum, salt, and nonmetallic products). Salt recovery consumes more energy and incurs more costs than any other unit operation in the recovery of salt cake constituents. A salt-recovery process based on electrodialysis is more cost-effective than currently proposed technology (evaporation with vapor recompression) for recovering salt.

### Converting Spent Potliner to Products

A new technology, the cyclone melting system, is being developed that will convert spent potliner from aluminum smelting plants into commercial-quality glass fiber and aluminum fluoride products. Spent potliner contains many of the chemical oxides typically used to manufacture glass products. The benefits of this new technology are the ability to produce a value-added product from the waste, to recover fluoride from the waste in a form that can be recycled back into the aluminum production process, and to reduce waste disposal costs.

### Inert Metal Anode Life in Low Temperature Aluminum Reduction Process

The energy intensive Hall-Héroult electrolytic cell, developed over 100 years ago, is the primary process used to produce aluminum. This technology would provide a carbon-free, energy saving alternative to the traditional aluminum production method by using a wetted cathode, a non-consumable metal alloy anode, and a low-temperature electrolytic bath. This smelting process could cut the energy need for aluminum production by 25% to 30%.

## Aluminum

*(continued)*

### Intelligent Potroom Operation

The Intelligent Potroom Operation project focuses on developing components of an intelligent manufacturing system to recognize and correct suboptimal performance of an aluminum reduction cell. System components include: 1) a finite element cell state estimator that is model based to estimate alumina concentration, an indicator of cell health; 2) an Intelligent Potroom Advisor (IPA) to recommend optimum corrective actions when predefined abnormal temporal process data patterns are detected; and 3) a method to identify statistically significant yet unknown complex behaviors that occur before suboptimal behavior to predict and avoid such behavior. The IPA will increase the current efficiency of the reduction cells and reduce average cell voltage, thus saving energy and reducing emissions.

### Semi-Solid Forming of Aluminum Alloys

Semi-solid rheocasting is a simple and efficient technique for converting molten aluminum into semi-solid aluminum; it is less expensive than conventional techniques and can work with existing manufacturing equipment. With this technology, die-casting machines will produce large volumes of aluminum castings with high mechanical performance. Rheocasting will save energy by reducing furnace holding temperatures, reducing die casting energy usage, increasing tool life, and providing wider aluminum usage, primarily in the transportation industry.

### Vertical Flotation Melter

The Vertical Flotation Melter (VFM) is an advanced remelting process that is energy efficient and environmentally friendly. It will help the aluminum industry meet energy and environmental performance targets. The technology also applies to other industries, such as the glass container, fiberglass and steel industries.

IMPACTS

## Chemicals

**Affinity Ceramic Membranes with $CO_2$ Transport Channels**

Compared with more conventional separation processes, membrane separation processes offer several advantages, including increased energy efficiency, compact design, and operational flexibility. Numerous unexploited applications exist for advanced separations in aggressive environments that rely on a membrane's affinity to a specific chemical as opposed to traditional molecular sieving. Highly selective thermally/hydrothermally stable inorganic membranes offer a solution to these difficult industrial separation applications.

**Alloys for Ethylene Production**

New intermetallic or metallic alloys are being developed for manufacturing ethylene production tubes that are resistant to coking and carburization. Traditionally, ethylene furnace tubes have been fabricated from cast or wrought high stainless steel alloys. Coke and metal carbide layers form on the inside surfaces of the tubes, reducing the mass flow and heat transfer of the tubes and resulting in significant downtimes. The new material will reduce these problems as well as increase the structural life of the tubes.

**Catalytic Hydrogenation Retrofit Reactor**

A new monolith loop reactor, a compact fixed-bed catalyst system, is being developed for use in a variety of hydrogenation chemical processes. This technology integrates new catalyst chemistry with advances in reaction engineering and can be retrofitted onto existing slurry tank reactor systems. The technology replaces slurry catalysts and their associated problems. Target markets include the commodity chemical, specialty chemical, fine chemical, and pharmaceutical intermediates. This new technology provides a number of benefits to these industries: reduced energy consumption because of higher productivity, improved yields, reduced waste, and elimination of the catalyst slurry filtration step and its associated operational costs.

## Chemicals

*(continued)*

**Concurrent Distillation**

This project aims to improve the performance of distillation and absorption trays by using a co-current flow design and to establish the economics of the new process. Compared with the conventional sieve tray, the co-current tray demonstrated a more than 100% increase in production capacity without sacrificing separation efficiency. The research will provide the design information and performance correlations necessary to manufacture the "Trutna Tray" (Co-Flo Tray). Three tray variations have been pilot tested using an industrial-scale distillation column.

**Electrodeionization for Product Purification**

This technology combines the advantages of ion exchange (an adsorption technology) and electrodialysis (a membrane separation) for a wide range of potential applications in the chemical industry, including direct production and separation of products, product purification and desalination, salt waste recovery, and water recycling. Targeted applications include organic acid production, dextrose desalination, ultrapure water production, product polishing, and waste salt recovery.

**High Octane Fuel-Stocks via Reactive Distillation**

High octane alkylate, an ideal clean fuel component for reformulated gasoline, is currently made using toxic liquid acid catalysts such as hydrofluoric or sulfuric acid. A commercially viable and environmentally superior alternative to conventional liquid-acid alkylation processes is being developed called the ExSact process. This process uses benign, engineered, solid-acid catalysts coupled with an innovative but practical, fixed-bed reactor to produce high-octane alkylate. The new process lowers utility consumption and produces fewer by-products compared to existing technologies, which result in significant savings in operating expenses.

## Chemicals
*(continued)*

### ◆ Hollow-Fiber Membrane Compressed Air Drying System

Compressed air is widely used as a utility in many industries and typically must be dried to avoid condensation or freezing in lines and to meet the needs of many processes. For compressed air drying, a new hollow-fiber membrane has been developed and demonstrated that is durable, resilient, and amenable for scale-up. This new membrane system increases productivity and lowers energy consumption compared with refrigerant or desiccant compressed air dryers. In addition, the system is compact and lighter weight, has no valves or moving parts, and requires no electrical wiring or power.

### ◆ Improved Methods for Producing Polyurethane Foam

This project seeks to commercialize new silicone surfactant products that will enable flexible foam manufacturers to use environmentally benign liquid $CO_2$ as a blowing agent. Using $CO_2$ to manufacture polyurethane foams would replace methylene chloride, a toxic chemical that contributes to air pollution; would provide cleaner production that uses less energy; and would reduce the net release of $CO_2$, which is implicated in global warming. To validate the technology's performance, several companies will conduct full-scale production runs in their facilities.

### ◆ Low-Cost, Robust Ceramic Membranes for Gas Separation

Ceramic membranes offer great potential for industrial gas separation. While ceramic membranes can improve the productivity for many reactions and separations in the chemicals and refining industries, they are costly. A low-cost, robust ceramic membrane has overcome the cost barrier and targets applications involving hydrogen production, water and energy recovery from fuel, and $CO_2$ removal in natural gas processing. Significant energy savings are possible because the new membrane eliminates cooling prior to gas separation. In addition, this low-cost membrane is currently under consideration as substrate for a wide range of thin films that can be used in industrial gas separations; and without the gas separating layer, the membrane has been used commercially for a wide range of liquid-phase separations.

## Chemicals
*(continued)*

### ◆ Low Emission Diesel Engines

Diesel engine exhaust is a major source of $NO_X$ pollution. The formation of $NO_X$ in diesel engines is dependent on the combustion temperature, which can be affected by the engine cylinder charge. An innovative membrane is being developed to adjust the cylinder charge and reduce the $NO_X$ emissions by delivering nitrogen-enriched air to the system. The system may reduce $NO_X$ formation in diesel engines by 50%.

### ◆ Low-Frequency Sonic Mixing Technology

This technology is an energy-efficient, electromechanical system that effectively substitutes low-frequency sonic energy for chemical and mechanical mixing, significantly improving the manufacture of a broad range of industrial products. This simple yet effective technology transfers acoustic energy into liquid, liquid-gas, and liquid-solid systems, inducing acoustic streaming. The result is improved mass transport and micromixing.

### ◆ Membrane for Olefin Recovery

Selective polymer membranes are being developed to allow recovery of olefins (compounds with carbon-carbon double bonds such as ethylene and propylene) from petrochemical by-product and vent streams. These streams are often flared or used as a fuel even though the olefin is more valuable as a chemical feedstock. This new separation technology will allow olefin separation and recycling within the process.

### ◆ Membranes for Reverse-Organic Air Separations

Underground storage tanks for gasoline traditionally vent vapors that contribute to ground-level ozone and smog. An innovative membrane system is being developed to discharge air from tanks while retaining VOCs. The membrane system has the potential to dramatically reduce gasoline loss and VOC emissions from underground storage tanks.

IMPACTS

## Chemicals
*(continued)*

### Nylon Carpet Recycling
This new chemical process provides recycled materials for manufacturing carpet products. The process can be used to recycle the used nylon carpet currently sent to landfills each year. The technology allows nylon manufacturers to recover and reuse caprolactam, the raw material used to make nylon 6 for carpets. A fully operating recycling plant is expected to keep more than 200 million pounds of post-consumer carpet waste out of U.S. landfills and produce approximately 100 million pounds of new caprolactam each year.

### Process Heater Ultra-Low Excess Air Control
A fully automated damper and air register damper control use a CO light-beam analyzer to control combustion in process heaters. The device enhances existing technology that requires air register controls to be manually adjusted. By analyzing for CO, the device can minimize excess air effectively to provide the most efficient combustion possible. The result is lower fuel use and reduced emissions of $NO_X$ and $CO_2$, which is considered a greenhouse gas. The technology is being installed on three heaters at a refinery in Corpus Christi, Texas.

### P-Xylene Production with Waste-Heat-Powered Ammonia Absorption Refrigeration
About 60% of the total electricity consumed in producing p-Xylene by crystallization is used to run the refrigeration compressors. Ammonia absorption refrigeration (AAR) can replace the standard ethylene or propylene refrigeration loop, saving about 37% of the total electricity use, depending on the feedstock and recovery process. Applying AAR in the p-Xylene production process will also lower indirect $CO_2$ emissions associated with electricity generation.

## Chemicals
*(continued)*

### Recovery of Thermoplastics via Froth Flotation
A process for the economical separation of high-value plastics from plastics waste streams derived from home appliances and electronics scrap has been developed and is ready for licensing. Current methods for separating plastics cannot economically separate plastics of similar density from each other. The process was demonstrated at a private company site involved in the recycling business. The design capacity of the demonstration plant was 1000 pounds per hour. About 20,000 pounds of ABS and HIPS plastics were recovered with a purity of more than 98% and a yield of higher than 80%. Recovered plastics via this process were successfully used by car-part manufacturers in making automotive parts. There are significant benefits due to lower energy use and resource conservation in the reuse of plastics for industrial manufacturing.

### Sonic Assisted Membrane
Membrane filtration systems are used to separate and recover products in a wide variety of applications. One of the main impediments to the broader use of micro and ultrafiltration membrane filters in biological applications is the occurrence of a layer of gel on the membrane surface, resulting in significant reduction in flux. A sonic device produces low frequency, high intensity, acoustic vibrations, which induce micro turbulence in the fluid near the membrane surface minimizing gel layer formation. This technology reduces maintenance costs and increases the number of biological applications for membranes.

### Sorbents for Gas Separation
A new technology based on oxygen-selective sorbent materials and pressure swing adsorption (PSA) could cost-effectively produce industrial gases, such as oxygen and nitrogen. Purification applications where oxygen is removed from argon, helium, and nitrogen streams offer early potential commercial opportunities. This technology potentially requires less energy for gas separation compared to conventional techniques and can provide high-purity gases at lower cost.

## Chemicals

*(continued)*

### Total Cost Assessment Tool

The Total Cost Assessment (TCA) methodology was developed to enable the chemical industry to include all environmental, health, and safety costs in decision-making. In particular, TCA includes contingent liabilities such as fines and cleanup costs and intangible costs such as damage to corporate or brand image and reduced employee morale. External costs, such as costs to society, can also be included in the TCA methodology. The Total Cost Assessment Tool (TCAce) builds on this methodology by enabling the company to use sliding ranges and probabilities to reflect the true nature of contingencies. TCAce integrates scenario case studies and sensitivity/uncertainty/risk analysis into a company's existing economic evaluation framework to enable sound decisions.

## Forest Products

### Biological Air Emissions Control

An innovative, biological sequential treatment system that integrates two types of biological oxidation offers an attractive alternative to conventional, thermal oxidizer emissions control techniques. This two-stage system uses microorganisms to degrade (bio-oxidize) air toxins and other volatile organic compounds without using natural gas as fuel or creating secondary pollutants. The system combines a biofilter for removing low concentrations of pollutants and polishing the air stream with a biotrickling filter system for removing high concentrations of hydrophilic compounds. The system will conserve water through "in-vessel" treatment and recycling of the scrubbing liquid.

### Black Liquor Steam Reforming/Pulsed Combustion

Black liquor is a liquid containing both pulping chemicals and tree organics. Historically, it was combusted to recover chemicals but this combustion is thermally inefficient and supplies about 50% of the energy needed in an integrated pulp and paper mill. A new process that gasifies the black liquor to recover chemicals and significantly more of the energy is being commercialized in two U.S. plants and a third plant in Canada. This gasification process could be further developed to produce power or transportation fuel and high performance chemicals. It also operates at significantly lower emission levels and eliminates the possibility of explosions.

### Borate Autocausticizing

Boron-based autocausticizing is a new, cost-effective technology to recover Kraft pulping chemicals. This technology can be used to recover either part or all of the sodium hydroxide requirements of the Kraft process through de-carbonation of sodium carbonate, supplementing or replacing the lime cycle. Because the de-carbonation reactions take place directly in the recovery boiler, instead of the lime kiln, this process reduces energy consumption and provides either increased causticizing capacity or reduced calcining requirement.

IMPACTS

## Forest Products

*(continued)*

### Decontamination of Process Streams through Electrohydraulic Discharge

In recycling paper, "stickies" cause considerable downtime and require costly minerals and polymers to be added for handling and detackifying them during the recycling process. A new mechanical method - pulsed power technology - is being demonstrated at several recycling mills to replace these costly chemicals. This technology uses a shock wave, developed from a spark discharging under water, to diffuse the stickies and create hydroxyl radicals from water, which oxidizes the stickies. This oxidation causes the stickies to lose their tack and become benign, thus allowing recycling to continue unimpeded.

### Directed Green Liquor Utilization (D-Glu) Pulping

Advances in the rate and selectivity of Kraft pulping without incurring major capital costs will increase the economic return of the pulp and paper industry. A high sulfidity pretreatment of wood chips is one of the most promising ways to achieve these advances. Green liquor is easily accessible in a mill and naturally rich in hydrosulfide ions, which are critical for accelerating pulping and providing a high value product. Researchers have discovered ways to reduce pulping time and energy requirements through the intelligent application of green liquor in the digester.

### Fibrous Fillers to Manufacture Ultra-High Ash/Performance Paper

Mineral fillers that increase paper brightness and opacity and improve paper print quality have reduced costs by replacing wood fiber. However, filler loading has been limited to 15% to 20% because higher loading levels cause a loss of sheet strength and bulk as well as "dusting" during printing. A new fibrous filler technology has been developed that may overcome these problems and replace high-cost wood fiber. The new fillers will ultimately produce a composite paper containing up to 50% ash, with equal or better performance characteristics than conventionally attainable paper. The new technology will also lead to better retention of fillers, additives, and pulp fines, significantly reducing biological and chemical oxygen demands in the mill process water.

## Forest Products

*(continued)*

### Gas-Fired Paper Dryer

A new paper dryer is being developed and tested to significantly increase the efficiency of papermaking. The Gas-Fired Paper Dryer (GFPD) is a natural gas-fired system that uses a combination of a flame sheet and dimpled pattern on the drum's inner surface, improving combustion stability, reducing pollutant emissions, and enhancing heat transfer from combustion products to the paper web. This patented approach could be implemented into new or existing equipment. The GFPD will ultimately help the paper industry reduce its energy use and increase the production rate of paper machines by 10% to 20%.

### Laser-Ultrasonic Web Stiffness Sensor

This technology uses noncontact laser ultrasonics to monitor paper mechanical properties (e.g., bending, stiffness, and rigidity) in real-time during the papermaking process. In the past, paper mechanical properties were probed with transducers in direct contact with the web. This approach is no longer used because contact transducers can damage the web, leading to costly production losses. Noncontact monitoring of paper stiffness during manufacture will reduce waste and energy use by using less refining and remanufacturing, make optimal use of pulp feedstock, and reduce production of offgrade paper.

### Low Temperature Plasma Technology for Treating VOC Emissions

Pulp mills and wood product plants are under increasing pressure to control the emissions of volatile organic compounds (VOCs) generated during their operations. The present-day control technology – regenerative thermal oxidizers – is energy-intensive and depends on combustion technologies that heat the entire waste stream. An emerging technology using nonthermal plasmas can selectively and cost effectively destroy VOCs by producing excited species (free radicals and ions) that oxidize, reduce, or decompose pollutant molecules.

## Forest Products

*(continued)*

### Materials for High-Temperature Black Liquor Gasification

New black liquor gasification technology with combined-cycle cogeneration of steam and electricity can increase energy output for the forest products industry. However, high inorganic salt concentrations and high temperatures significantly degrade refractory materials and metallic components. Improved refractories and wear-resistant nozzle materials are being developed to enable high-temperature black liquor gasification units to attain a longer service life. These improvements will reduce operating downtime and increase energy production capability.

### Novel Isocyanate-Reactive Adhesives for Structural Wood-Based Composites

Laminated veneer lumber (LVL) is a wood composite that is produced by bonding thin wood veneers together and is used for various wood construction applications. The current LVL manufacturing process is energy intensive, using adhesives that require extensive wood drying (to moisture contents of 6% to 8%) and high-temperature hot-pressing (~200°C). An alternative isocyanate-reactive that cures at room temperature (cold-setting) and is optimized for higher veneer moisture content promises significant energy savings. This new technology will also sharply reduce volatile organic compound emissions and improve product appearance and durability.

### Online Fluidics Controlled Headbox

This technology allows for more complete control of fiber alignment on the paper machine, which allows a machine making high performance products (e.g. containerboard, shipping sacks, etc.) to optimize sheet directional properties related to fiber orientation. In many cases, the optimization results in up to 10% reduction in fiber usage for the same product. Also, jet turbulence can be adjusted to optimize formation, thereby affecting not only strength but also properties such as smoothness, appearance, printability and coatability.

## Forest Products

*(continued)*

### Residual Solids From Pulp and Paper Mills for Ready-Mixed Concrete

The fibrous residuals from mill processing are typically sent to landfills. These residuals can be incorporated into ready-mixed concrete to improve the strength, durability, and lifespan of concrete structures, especially those exposed to weather. Adding residuals to concrete could increase the lifespan of high-performance concrete from the normal 30 years to up to 100 years. The new technology offers the pulp and paper industry a practical and economical solution for residuals solids disposal and provides the concrete industry with a low-cost source of fibers to produce a better product for its customers.

### Screenable Pressure Sensitive Adhesives

The presence of pressure-sensitive adhesives (PSAs) in recycled paper creates a number of problems for the recycling process, including lost production and diminished product quality. New adhesive materials are being developed that are more effectively removed from the papermaking process during furnish screening. These new adhesives should possess properties that enhance their removal without impacting their performance in PSA products.

### Steam Cycle Washer for Unbleached Pulp

A new commercial-scale Steam Cycle (SC) Washer is being developed. This steam-pressurized, high-consistency pulp washer will enable pulp mills to increase profitability by substantially reducing energy consumption, improving fiber and product quality, and ensuring that environmental compliance exceeds current regulations. The SC Washer will enhance pulp industry profitability by allowing most pulp mills to reduce electrical power consumption for unbleached pulp production by 21%, evaporator load by 50%, and plant effluent and fresh-water usage by 45%.

### Surfactant Spray To Improve Flotation Deinking Performance

This new technology uses an atomizer to spray frother at the top of the flotation column in the wastepaper flotation deinking process to significantly reduce the loss of fiber and water and the use of chemicals in the process. Frother spray technology will provide on-line control for the frother agent distribution in the flotation slurry. This technology will be easily retrofitted to industrial flotation equipment without significant modifications to existing systems.

IMPACTS

## Glass

**Advanced Combustion Space Model for Glass Melting**

Improved understanding and modeling of the combustion process in glass melting will result in innovative furnace designs that will have higher combustion and furnace efficiencies, minimized pollutant formation (primarily $NO_X$ reduction), and improved glass quality.

**Advanced Oxy-Fuel-Fired Front-End System**

A consortium of companies involved in the glass industry has developed the Advanced Oxy-Fuel-Fired Front-End System. A combination of burner modeling and bench trials was used to develop a burner and block that generate the appropriate size and shape of flame for optimal heat transfer distribution. This will result in reduced energy use and decreased $CO_2$ emissions. The new burner system can be integrated into a front-end system with capital costs that are competitive with a conventional air/gas system. Full-scale installation and testing are under way in a Tennessee glass plant.

**Electrostatic Batch Preheater System**

The electrostatic batch preheater system is a single-box solution that directs glass furnace exhaust gases through open-bottomed tubes running through a batch/cullet hopper. Direct contact with the hot exhaust gases preheats the batch and cullet before they enter the furnace and cleans $SO_X$ from the exhaust gas stream. A proprietary electrostatic mechanism captures entrained dust and returns it to the batch. The technology reduces furnace fuel requirements by 10% to 15% and cleans the exhaust gas stream of $SO_X$ and dust in accordance with the most stringent regulatory standards.

**Enabling Tool for Innovative Glass Applications**

Flat architectural and automotive glasses have traditionally been fabricated using technologies that have inherent cutting limitations because they are generally incapable of fabricating glass products with small radii, concave edges, or pierced holes. A new technology uses waste glass as a low-cost media for abrasive water-jet cutting of glass and other materials. This technology can refine and automate the glass manufacturing process while reducing the number of stages and equipment required to produce intricate glass products.

## Glass
*(continued)*

**High Throughput Vacuum Processing for Innovative Uses of Glass**

This project is developing a manufacturing process for cadmium telluride photovoltaic solar cells fabricated on glass substrates. The innovative process uses a proprietary air-to-vacuum-to-air system that allows continuous production of cadmium telluride cells rather than the slower batch process. In addition, maintenance and labor costs are lower and occupational safety is improved.

**Manufacturing Ceramic Products from Waste Glass**

Ceramic products have traditionally been processed from raw materials that require high firing temperatures and energy-intensive processing steps. A new technology lowers energy costs by substituting raw materials with recycled waste glass. Products manufactured by this new method are less sensitive to contaminants in the glass and can be made from difficult-to-recycle green or mixed-color container glass waste. Firing temperatures can be reduced by as much as 37%, lowering energy costs and $CO_2$ emissions. The technology has been used to design a low-cost highly-automated manufacturing process for producing ceramic tile from large volumes of waste glass. High-quality ceramic tile has been processed from 92% to 100% recycled glass with a wide range of colors and surface textures. The technology has been applied to several types of glass, including post-consumer container, flat and lamp glass, and industrial fiber-glass waste streams.

**On-Line Molecular Analysis for Improved Industrial Efficiency**

Research is ongoing to develop an on-line, real-time process analyzer that can monitor or control production on a wide variety of materials. The purpose of the analyzer is to improve product quality, increase manufacturing efficiency, and reduce waste. This analyzer uses transient infrared spectroscopy (TIRS) to determine chemical and physical properties of the material being produced as it moves past the TIRS sensor.

## Metal Casting

### ◆ CFD Modeling for Lost Foam White Side

One challenge in lost foam casting is maintaining a uniform density and fusion throughout the patterns. Non-uniform pattern density is thought to be responsible for approximately 80% of all casting defects. The metal casting industry has successfully utilized advanced Computational Fluid Dynamics (CFD) tools to enable foundry process improvements. This research has developed a new flow and particle modeling software to simulate the air-driven blowing of pre-expanded beads into a mold, and the subsequent steaming (expansion) of beads as they form a lost foam pattern. This technology is already providing cost savings and improvements in the lost foam casting process, and will enable new energy-efficient engine designs utilizing the unique advantages of lost foam.

### ◆ Cupola Furnace Process Model

A comprehensive mathematical model of the cupola furnace, a type of furnace used to melt iron that is subsequently cast into a variety of products, is being enhanced and updated. The model was incorporated into a user-friendly artificial-intelligence program that can help optimize the temperature, processing time, and other key variables of furnace operation. This improved operation results in energy savings, product quality enhancement, and waste reduction.

### ◆ Integrating Rapid Solidification Process Tooling and Rapid Prototyping in Die Casting

In this project, a new and unique Rapid Solidification Process (RSP) technology will be introduced to the die casting industry to reduce lead time for prototyping and producing die casting tooling. In addition to increased productivity, the RSP tooling technology also substantially reduces energy use and scrap compared with conventional machining practices.

### ◆ Lost Foam Casting Quantifier Program

Several process variables specifically related to pattern quality can result in scrap rates and defects that could be significantly reduced by properly quantifying and subsequently controlling the pattern in lost foam casting. A new program determines the detailed structure of foam and coating using x-ray imaging methods, measures intra-bead fusion by polymer chain entanglement characterization, and measures foam and coating permeability using gas flow measurement methods.

## Metal Casting

*(continued)*

### ◆ Lost Foam Casting Technology

Lost foam casting is a highly flexible process suitable for casting metal components with complex geometries. Research supported by ITP has led to a greater understanding of the process and to new control measures. These will increase foundry energy efficiency and reduce scrap. Emerging technologies from the ITP-supported research include: in-plant quality assurance procedures to measure casting parameters; a sand-density gauge to measure the rate of sand compaction; and real-time x-ray apparatus which allows visualization of the metal/pattern replacement process and an apparatus for measuring pattern permeability (fusion) which is a major factor in the replacement process.

### ◆ Process to Recover and Reuse Sulfur Dioxide in Metal Casting Operations

Sulfur dioxide ($SO_2$) is used as a catalyst in forming cold-box molds and cores in the metalcasting industry. The $SO_2$ is typically used once, scrubbed with a caustic solution, and then discarded (flushed to sewer or sent to a waste treatment facility). This new process recovers the $SO_2$ for reuse by processing it through a pressure-swing adsorption system that is expected to recover at least 95% of the $SO_2$. Using this process will reduce energy consumption, eliminate the need for caustic effluent, and pay back costs in less than 1 year.

### ◆ Rapid Heat Treatment of Cast Aluminum Parts

A system that reduces 80% of the time and energy required to heat-treat cast aluminum components is now being demonstrated. Unlike existing technologies where components are stacked in baskets and placed in a convection or vacuum furnace, this new process uses a fluidized bed in a continuous process mode. The fluidized bed is coupled to an automated production line that moves the components through the process. Pulse-fired microprocessor-controlled burners inject heat directly into submerged radiant burner tubes, ensuring precise, even, and rapid heat transfer.

IMPACTS

## Metal Casting

*(continued)*

### Titanium Matrix Composite Tooling Material for Aluminum Die Castings

CermeTi® is a titanium-alloy composite material developed to partially line an existing H-13 shot sleeve or to make a complete shot sleeve for aluminum die casting. H-13 shot sleeves frequently must be replaced because of H-13's poor resistance to heat checking, thermal fatigue, erosion, aluminum soldering, and distortion. A significant portion of the energy used in aluminum die casting is wasted because metal must be kept molten during the tooling replacement and the dies must be reheated before casting can resume. Compared with conventional technology, this new technology is more resistant to aluminum soldering and erosion, extends the shot sleeve's life, reduces downtime, and improves product quality.

## Mining

### Dense-Medium Cyclone Optimization

Dense-medium cyclones are used to separate coal or other minerals from waste rock in most modern coal plants and in a variety of mineral plants, including iron ore, diamonds, and potash. A set of engineering tools to improve the efficiency of dense-medium cyclones is being developed and demonstrated. These tools include low-cost density tracers to rapidly assess cyclone performance, mathematical process models to predict the effects of operating and design variables, and a model-based expert system for trouble-shooting cyclone circuits. These tools will successfully improve plant productivity, reduce energy costs, and minimize waste rock generation.

### Drill-String Radar Navigation for Horizontal Directional Drilling

Horizontal drilling in a coal seam can relieve methane gas trapped in a coal bed, increasing the safety of coal miners and supplying methane, a desirable resource. Gamma sensors, currently used for horizontal drilling, cannot withstand the vibration of the drill and require additional costly drilling steps. Instead of gamma sensors, drill-string radar transmits radio waves and measures their reflection to identify boundary rocks, reducing vibration sensitivity and allowing real-time measurement while drilling. This technology will reduce the risk, cost, and time required for extraction.

### GranuFlow™ Process in Coal Preparation Plants

The GranuFlow technology involves adding a binding agent such as an asphalt emulsion to a slurry of coal and water prior to mechanical dewatering. The binding agent agglomerates the fine-sized coal, increasing its capture during mechanical dewatering, thereby reducing coal loss to impoundments. The GranuFlow treatment also reduces moisture content, alleviating downstream handling, dusting, and freezing problems.

### Grinding-Mill Optimization Software

Millsoft 3D is a simulation software for visualizing the charge motion in semi-autogenous mills and ball mills used in the mining industry. The software provides various quantitative information, such as power, forces on the mill lifters, and wear. The three-dimensional code uses the discrete element method to model the individual collisions of ball and rock particles. The software handles mills of all sizes, saves energy, and increases productivity.

## Mining
*(continued)*

### High-Temperature Superconductors in Underground Communications

Underground communications are important for the mining industry, urban first-responders, and others who frequently work underground. The through-the-earth radio system can increase underground mining production by improving communication and eventually allowing orientation and position information, which can benefit both an individual miner and a mining machine. Most importantly, fast wireless communication improves underground mining safety through early response to problems. A new system has been built using conventional copper and semiconductor designs and higher-performance superconducting designs. Using superconducting materials in underground communications equipment increases the range and clarity of through-the-earth wireless networks.

### Lower-pH Copper Flotation Reagent System

In the mining industry, flotation is a process that concentrates minerals from their ores prior to metal recovery. Current practice uses slurry pHs in excess of 10, achieved by adding burnt lime (CaO). However, lime production is an energy-intensive process that releases large quantities of carbon dioxide into the atmosphere. A new reagent system recovers copper minerals at much lower pHs than conventional reagents while not floating pyrite. The process reduces or even eliminates both the lime used in copper flotation and the accompanying carbon dioxide. The result is immediate cost and energy savings along with improved recovery of copper and other minerals.

### Magnetic Elutriation Technology for Processing Iron Ore

Magnetic elutriation improves the quality of low-grade domestic iron ore by using an alternating-current pulsed-magnetic field to clean iron ore into a highly refined product. This new continuous countercurrent system is being demonstrated in the field. The technology efficiently separates the tailings and middling particles out of the iron ore without using harmful chemicals.

## Mining
*(continued)*

### Mapping with Natural Induced Polarization

The mining industry uses induced polarization (IP) surveys to locate and characterize mineral resources. Conventional surveys use high-power motor-generator sets to transmit electrical current in the earth through grounded electrodes that are slow and laborious to install. This new natural field polarization survey eliminates the need for these cumbersome transmitters by using the natural electromagnetic fields as the source to collect induced polarization data. The natural fields also provide the benefit of greater depth of exploration than conventional IP surveys. Other benefits of using the natural fields survey induced polarization technique include reduced environmental impact, energy and drilling requirements.

### Real-Time Coal/Ore Grade Sensor

Various project partners worked on developing a real-time coal content/ore grade sensor that will increase selectivity as well as decrease environmental impacts and energy requirements during exploration, mining, and processing operations. The unique spectral characteristics of coal and ore were used to quantify coal content and ore grade in real time. The sensor will be suitable for both surface and underground mining operations either at the working face or where mined material is being processed.

### Soft (Unfired) Ceramic Particles via Dynamic Cyclone Classification

Many industrial processes involve the separation of particles from an airstream. The mining industry, in particular, has indicated a need for improved separation methods and reduced waste. In this technology, the particles are separated and transported by boundary layers and induced airflow vorticity near a stack of rotating (slightly separated) disks, which minimizes particle impact and attrition, as well as component wear. The dynamic cyclone classifier offers substantial potential for indirect energy savings by reducing the amount of off-spec product processed to achieve the same amount of product output. Smaller scale devices, operating under the same separation principles, can generate sharp particle classification cuts below 10 microns and are targeted for the pharmaceutical/neutriceutical, food/additives, cosmetic and specialty chemical markets.

IMPACTS

## Steel

◆ **Automated Steel Cleanliness Analysis Tool (ASCAT)**

The ASCAT provides steel producers with a rapid, near-real time analysis of inclusions in steel in order to correlate these inclusion measurements at various points in the process with the measured properties of the finished product. This will facilitate the determination of critical process parameters and will permit production of higher quality steel in a more cost effective manner. It has been estimated that the ASCAT has the potential to save the U.S. steel industry more than 2 trillion Btu of energy per year. In addition to energy savings, this technology has the potential to save the US steel industry about $100 million per year.

◆ **Cost-Effective, Energy-Efficient Steel Framing**

The construction industry has used steel framing in residential construction for several years. However, designs for minimal energy code compliance have not always been cost-effective or practical. This project focuses on overcoming the major performance and cost barriers that prevent many builders from using steel framing. The project considers thermal performance and installed cost to determine designs for steel-framed residential and light commercial construction that are energy-efficient and meet applicable building codes.

◆ **High Quality Iron Nuggets Using a Rotary Hearth Furnace**

A new process, now being demonstrated in a pilot plant, is an iron making technology that uses a rotary hearth furnace to turn iron ore fines and pulverized coal into iron nuggets of similar quality as blast furnace pig iron. The new technology will be able to effect reduction, melting, and slag removal in only about 10 minutes. The process is a simple one-step furnace operation that requires less energy, capital, and operating costs than existing pig iron technology. Consequently, high-quality iron product can be produced at a substantially lower cost.

## Steel

*(continued)*

◆ **Hot Oxygen Injection into the Blast Furnace**

A new injection system has been developed to directly inject hot oxygen in blast furnace tuyeres. Material and energy balances on the blowpipe/raceway zone of the blast furnace have shown that injecting ambient temperature oxygen offers little overall benefit, whereas injecting hot oxygen offers several mechanisms for improving burnout. This process increases coal injection rates and reduces coke consumption. Consequently, direct injection of hot oxygen into blast furnace tuyeres improves operating cost, energy consumption, and emissions.

◆ **Laser-Assisted Arc Welding**

Applying this new process to steel welding will meet the needs for a new joining technology. The benefits of combining laser- and arc-welding processes will ease the current requirement for precise fit when laser welding alone. Using filler metals in the arc-welding component of the process will result in greater flexibility in the choice of materials that are joined. The process could easily be applied to nonlinear joint geometries. This process will increase the welding throughput and productivity over either laser or arc welding alone.

◆ **Life Improvement of Pot Hardware in Continuous Hot Dipping Processes**

Coating steel sheets by continuous hot dipping in a molten metal bath of zinc or a Zn/Al melt is an efficient and economical method of protecting most steel sheet compositions from corrosion. Performance problems with galvanizing bath hardware can strongly influence the downtimes experienced by a production line and the coating quality. A new generation of bath hardware materials was developed to provide ten times the corrosion resistance in the zinc bath compared with currently available materials. This new generation of bath hardware includes several entirely new materials, such as an iron-aluminum-cobalt alloy, which can form a very tough and protective oxide film, and several industrially available materials that have been processed in novel ways to give the desired properties.

## Steel
*(continued)*

### ◆ Magnetic Gate System for Molten Metal Flow Control

This project is developing an electromagnetic flow control unit that improves the quality and productivity of the continuous casting process. The dc axisymmetric flow control device has the potential to overcome the disadvantages of high-frequency, high-power electric currents that have been tried previously. The device's configuration allows it to be used around conventional ceramic pouring tubes.

### ◆ Method of Making Steel Strapping and Strip

A new continuous process has been developed that produces high quality steel strapping and strip from rod stock produced from scrap steel. The process yields a higher quality, less expensive, product while increasing the amount of recycled steel in the finished product. The continuous process has lower processing and capital costs than the conventional production method while increasing the strength of the final product.

### ◆ Modeling of Post Combustion in Steelmaking

Currently, many furnaces used for molten steel production employ post-combustion technology to transfer heat to the molten steel bath. For typical electric arc furnaces and basic oxygen steelmaking furnaces, a significant amount of CO is available during the steelmaking process. Combustion of the available CO to $CO_2$ (post-combustion) can release heat energy above the molten steel bath. Efficient transfer of the heat energy from the post combustion gases to the molten steel bath can reduce steel production costs and improve productivity. To optimally design the injection parameters for post combustion, modeling the injector location, geometry, and oxygen flow rates before plant trials is more efficient, thereby minimizing operational problems associated with high temperatures (e.g., failed lances and burned hoods). The technology developed from this project enables a modeling program to be conducted in a fraction of the time it would take to start the program from scratch.

## Steel
*(continued)*

### ◆ Optical Sensor for Post-Combustion Control in Electric Arc Furnace Steelmaking

This project is developing an optical sensor for electric arc furnace steelmaking based on measuring off-gas temperature and carbon monoxide, carbon dioxide, and water vapor concentrations. The remote-sensing optical instrument is based on tunable infrared-laser technology and will provide input signals for control and optimization of oxygen use and post-combustion emissions. This new technology will also address needs for improving energy use and developing automated process controls.

### ◆ Oscillating Combustion

Oscillating combustion creates successive fuel-rich and fuel-lean zones within the flame. This technology reduces the formation of $NO_X$ and increases the heat transfer from the flame to the load. Oscillating combustion is easily retrofitted to existing burners since no modifications to the burner or the furnace are necessary. Only the addition of oscillating valves, a valve controller, and assoicated piping changes are required.

### ◆ Plant Trial of Non-Chromium Passivation Techniques for Electrolytic Tin Plate

Two previously identified nonchromium passivation treatments for electrolytic tin plate are being compared in a plant trial to determine their commercial viability. These new techniques will replace the existing cathodic dichromate treatment method that is facing environmental use restrictions. In addition, continued use of chromate treating solutions will result in ever-increasing operating costs.

### ◆ Processing Electric Arc Furnace (EAF) Dust into Salable Chemical Products

This unique technology will hydro-metallurgically process EAF dust into saleable products. EAF dust is oxidized and digested in acid and then treated by a series of individual steps to isolate and retrieve individual components of the dust.

IMPACTS

## Steel

*(continued)*

### Regeneration of Hydrochloric Acid Pickling Liquors

The PHAR® hydrochloric acid regeneration system is an innovative method of regenerating spent hydrochloric acid from steel pickling. Conventional pickling technology generates 1.5 billion gallons of spent pickle liquor nationwide each year, resulting in costly and energy-intensive handling, treatment, and disposal. This new technology eliminates the disposal problem, significantly reducing operating, environmental, and capital costs. The process uses sulfuric acid to restore hydrochloric acid for reuse. Salable ferrous sulfate heptahydrate is a by-product.

### Single-Ended Infrared Emission Sensor

Newly developed laser-based sensors measure infrared emissions from the particles in the basic oxygen furnace offgas. These sensors will provide an early and direct indicator of when the steelmaking process is complete. The process uses an infrared laser beam fired across the mouth of the vessel to a spectrometer that detects molecular interference with the beam. The instantaneous analysis of CO, $CO_2$, and water in the gases indicates the carbon level of the bath with a high degree of accuracy, while reducing oxygen and improving furnace yield.

### Steel Foam Materials and Structures

Metal foams with high levels of controlled porosity are an emerging class of ultra-lightweight materials receiving increased attention for a broad range of applications. Steel foams produced via a powder metallurgy process are about 50% lighter than conventional steel materials and can be produced as monolithic foams, as foam-filled tubular structures, and in sandwich panel geometries. The efficient energy-absorption characteristics of steel foams can increase safety in commercial and military vehicles. The light weight can improve operational efficiency and competitiveness in shipbuilding and rail systems. These foams can also be recycled and reproduced, as well as produced from recycled metal scrap. Additional process scale-up development is required to position steel foams for production readiness and commercialization.

## Steel

*(continued)*

### Submerged Entry Nozzles That Resist Clogging

Clogged nozzles in the steelmaking industry slow production and must be frequently replaced to enable a consistent flow of molten metal. A comprehensive refractory research program is providing the data necessary to define the mechanisms controlling nozzle accretion, which will form the basis for developing new technologies for reducing or eliminating nozzle clogging.

### Vanadium Carbide Coating Process

Traditional methods of coating steel surfaces with a layer of hard metal carbide require large capital investment, produce toxic and hazardous gases, are costly to operate, and require multiple heat treatment steps during processing. Vanadium carbide coating technology provides a superior protective coating for steel surfaces and eliminates the need for multiple heat treatments processing, thereby eliminating harmful gas emissions.

## Crosscutting Technologies

### ◆ A Hybrid Integrated Model for Gas Metal Arc Welding

This project is attempting to completely optimize the welding process, the process parameters, and the welding consumable selections. A hybrid integrated model for Gas Metal Arc Welding (GMAW) is being developed to combine both the fundamental approaches based on physical science, where feasible, and the artificial neural networks based on industrial experimental data. The model will have direct immediate benefit in optimizing the welding processes using both solid- and cored-wire Fe-C-Mn-Si electrodes. The technology will minimize the extent of expensive trial-and-error experimentation typical of weld processes and consumables development for new steels and advanced materials.

### ◆ Advanced Weld Overlay Alloys

A new advanced weld overlay alloy uses pure aluminum wire to make welds on carbon steel or nickel-based alloy substrates. Welding with pure aluminum wire results in a weld overlay deposit with typical aluminum content from 8% to 10%. Such a weld overlay offers a unique combination of oxidation, carburization, and corrosion resistance. This technology can be used in weld overlays for corrosion resistance in basic oxygen furnace hoods used in steelmaking. Various types of alloys are also being considered for that application.

### ◆ Carbon Films for Next Generation Rotating Equipment Applications

A super-low-friction carbon film, Near Frictionless Carbon (NFC), and a carbon conversion film, Carbide Derived Carbon (CDC), have been combined to achieve extended wear life and higher energy savings in rotating-equipment applications, including mechanical seals, sliding bearings, and shafts. Adherent, low-friction, wear-resistant coatings for silicon carbide and other metal carbide ceramics for rotating seal applications have been developed.

## Crosscutting Technologies
*(continued)*

### ◆ Chromium Tungsten Alloys for Use as Reaction Vessels

Chromium-tungsten alloys are a new class of steels having the unique properties of strength, toughness, and stability when subjected to thermal cycling. These properties are a function of the alloy's microstructure, which results in highly favorable material properties. Chromium-tungsten applications include reaction vessels where significant reductions in plate thickness (by up to one-half) are expected and heat-transfer tubing applications where thinner-walled tubes will significantly improve heat transfer.

### ◆ Composite-Reinforced Aluminum Conductor

Composites are a proven and broadly accepted technology with a wide range of applications in the aerospace, energy, industrial, and transportation markets. All of these applications demand high-strength and cost-effective solutions that increase product performance, safety, and reliability. A new, advanced technology and manufacturing process harnesses the benefits of composites for the diverse needs of the energy marketplace. Strategic relationships have been established with existing cable manufacturers to rapidly expand production and assist utilities and governments in achieving immediate improvements in power grid capacity and reliability worldwide.

### ◆ Continuous Fiber Ceramic Composite (CFCC): Combustion Liner

Two classes of continuous fiber ceramic composite (CFCC) materials were developed for gas turbine combustors and other stationary hot section components (e.g., transition pieces, shrouds, and nozzles). One class of CFCCs consists of continuous silicon carbide fibers in a matrix of silicon carbide, and a second class consists of oxide fibers in an oxide-based matrix. The CFCCs provide oxidation resistance and thermal and mechanical properties in air. However, silicon carbide-based CFCCs suffer degradation from water vapor attack in the hot section of gas turbines operating at high firing temperatures and pressure ratios. To improve their environmental resistance, Environmental Barrier Coatings (EBCs) were applied to the silicon carbide-based CFCCs. While the oxide-based CFCCs do not require EBCs, their mechanical properties are improved by applying thermal protection coatings to the surface. Field testing of CFCC liners in gas turbines has been ongoing in California and Massachusetts since 1997.

IMPACTS

## Crosscutting Technologies
*(continued)*

### ◆ Cromer Cycle Air Conditioner

In many climates, especially where fresh air is introduced, air conditioners need to overcool to control moisture and maintain comfort. The Cromer cycle air conditioner increases the moisture-removal capacity of the air conditioner coil, reducing run time and saving energy. The cycle uses desiccant to transfer moisture from the supply air to the return air, which increases the air conditioner's efficiency.

### ◆ Diagnostics and Control of Natural Gas Fired Furnaces via Flame Image Analysis

A real-time multi-sensor expert system using vision technology and artificial intelligence techniques is being developed. This new system uses furnace video images to provide input to three independently operating sensors: 1) a flame sensor, which includes a flame detector and a flame analyzer; 2) a temperature profiler; and 3) a feed batch-line detector for glass melting furnaces. The expert system output can be integrated with a furnace control system in real time or used as a diagnostic tool for manual control adjustment by an operator. This technology can improve furnace thermal efficiency and product quality and lower $NO_x$ and CO emissions.

### ◆ Diode Laser Sensor for Combustion Control

A sensor system based on using tunable diode lasers will allow in-situ determination of the concentrations of CO, oxygen, and water vapor as well as gas temperature in harsh industrial furnaces. The chemical species targeted are key to controlling combustion for improved energy efficiency, reduced pollutants, and improved process quality.

## Crosscutting Technologies
*(continued)*

### ◆ Energy-Savings' Model for the Heat Treatment of Aluminum Castings

A research program is extending the understanding of the evolution of microstructures during the heat treatment of complex, multi-component alloys and will develop quantitative relations among process, microstructure, and properties applied to aluminum castings. The methodology developed, Integrated Heat Treatment Software (IHTS), will serve as a framework to develop quantitative process models for other alloy systems, including ferrous alloys. Compared with the current technology that specifies heat treatment cycle and furnace loadings based on prior specifications and historical "rules of thumb," IHTS is expected to reduce solutioninzing heat treatment times by 50% to 80%, leading to 25% to 50% reductions in cycle time and energy consumption and 50% indirect reduction in non-energy environmental impacts and variable costs.

### ◆ Enhancement of Aluminum Alloy Forgings

The forging process creates parts that are stronger than those manufactured by any other metalworking process. Unfortunately, the grain growth in the material prior to forging can be significant, which subsequently affects the fatigue properties of the final part. The infrared technology being developed uses tungsten-halogen lamps as the heating source for the heat flux used to preheat aluminum billets prior to forging into various shapes. The technology will result in higher-quality forgings, longer fatigue life, finer grain size, and less energy consumption.

### ◆ High-Density Infrared Transient Liquid Coatings

The high-density infrared (HDI) process provides a rapid, localized heating method that will allow the use of advanced cermet-fused coatings on many industrial products. This technology is currently being used to produce wear- and corrosive-resistant coatings on a variety of surfaces including current research into coatings for aluminum dies used in the automotive industry.

## Crosscutting Technologies
*(continued)*

### ◆ High-Temperature Coating for Gas Turbine Components

A new high-temperature coating material for gas turbines has been developed as a replacement for existing coating materials  Coatings made from this new material provide superior cracking resistance and enhanced oxidation protection to the hot-section components of gas turbines and better adhesion for thermal barrier coatings, while reducing manufacturing cycle time and cost.  In addition, the process for applying the new coating material is more environmentally friendly than some of the current techniques.

### ◆ High Temperature Refractory Ceramic

A new castable refractory liner material to be used in high temperatures has been developed. The capabilities of this new ceramic liner will be a 200°C improvement in maximum allowable operating temperatures, an operating life extension of five times, and additional cost savings in installation.

### ◆ Insert Drill Having Three or More Flutes

A newly developed, patented drill concept uses a three-fluted design to lower horsepower requirements by allowing smaller inserts and producing smaller metal chips.  For through-hole drilling, a metal slug is not ejected as the drill exits the drilled hole.  This design results in a smooth finished hole eliminating the need for two or more machining operations.

### ◆ Intelligent Extruder

Intelligent control of extruder operation is becoming critically important as plastic manufacturers face significant yield losses, up to 20%, from off-line and delayed lab measurement of key material property variables such as viscosity, color, and composition. A new model-based inferential diagnostic and control system uses commonly available process sensors and on-line diagnostic strategies to detect and classify common process upsets and then make corrective on-line adjustments or invoke operator intervention to quickly control production and keep it within tolerance limits. Not only does the software system reduce waste and recycle resin, but because it ensures tight specifications on attributes such as composition and viscosity, injection molders can achieve consistent mold filling and yields in their high-speed parts production systems.

## Crosscutting Technologies
*(continued)*

### ◆ Intensive Quenching Technology for Heat Treating and Forging Industries

Intensive quenching technology (IQT) for steel products was developed as an alternative way of quenching steel parts.  While conventional quenching is usually performed in environmentally unfriendly oil, the IQT process uses environmentally friendly water or low-concentration water/mineral salt solutions.  Complete development and commercialization of IQT in heat-treating, powder metal, and forging industries will significantly reduce energy consumption and environmental impacts, thus enhancing the economic competitiveness of the domestic steel, metal casting, and mining industries.

### ◆ Iron Chromium Alloys for Use in Corrosive Environments

A new alloy (Fe-35Cr-2.5%Si) has significant potential for applications in the glass and chemical industries.  The alloy is based on a sufficient level of chromium to resist aqueous corrosion and the required silicon content for the formation of $SiO_2$ on the surface for high-temperature oxidation resistance.  This alloy is castable by conventional commercially available processes; it can be hot-formed (forged, rolled, or extruded); has limited cold formability and can be welded in thin sections without pre- and post-weld heat treatments.  The alloy has been recently formed into a prototype for testing as a water cooler for refractories used in a glass-melting furnace.

### ◆ Miniature, Inexpensive, Amperometric Oxygen Sensor

A new sensor to measure oxygen partial pressure from parts-per-million levels to 100% oxygen has been developed. It has particularly good sensitivity in the combustion range of 0.1% to 5% oxygen partial pressure. The new amperometric sensor, which is a multi-layer ceramic capacitor, is ideal for inexpensive mass production. The large reduction in cost of the sensor will economically allow any combustion process, including industrial, commercial, and residential furnaces and boilers, to be more closely monitored and controlled, thus saving energy.

## Crosscutting Technologies
*(continued)*

### ◆ On-Line Laser-Ultrasonic Measurement System

An on-line laser-based ultrasonic measurement of thickness and eccentricity has been found to improve the productivity of seamless mechanic steel tube making by 30% to 50%. The system reduces setup time and out-of-specification product and improves material use. Such a gauge also would facilitate reductions in energy consumption and pollutant emissions. The developed gauge has been in service since March 2002 and an installation was tested. The test estimated annual savings of 5%, or 23 billion Btu, primarily from increased efficiency (target size is achieved faster) and quality (record low tube wall scrap rates were reached).

### ◆ Particulate Ejection Coal Fired Turbine

A sub-scale prototype of a medialess inertial rotary disk filter was successfully evaluated to operate at the high temperatures/pressures typically found in coal-fired gas turbine generators. This technology demonstrates 98% to 99% coal ash removal efficiency without fouling, thus reducing the need for conventional disposable porous ceramic candle filters for hot gas filtration. Constant filtration efficiency and non-varying pressure drop across the all-metal filter eliminates brittle ceramic failures and allows operation at higher gas temperatures, which eliminates gas reheating and improves energy efficiency. The continuously self-cleaning technology may also eliminate landfilling of spent/replaced ceramic candles.

### ◆ Portable Parallel Beam X-Ray Diffraction Systems

Real-time, nondestructive in-line measurements of material properties are needed for process control in metallurgical, thin film materials, and pharmaceutical manufacturing. By incorporating newly developed X-Beam®, x-ray diffraction systems can be used to identify structural phases, determine grain size, and measure stress and texture of materials in line. This parallel beam x-ray diffraction technology uses a polycapillary collimating optic to collect x-rays over a large solid angle from a low-power x-ray source to form an intense quasi-parallel beam. This technology reduces or eliminates errors from sample misalignment and surface roughness, reduces power consumption, and improves measurement efficiency.

## Crosscutting Technologies
*(continued)*

### ◆ Process Heater System

A new generation of process heaters is being developed and demonstrated that is both highly efficient and extremely low in emissions. This innovative system incorporates several advanced technologies: 1) ultra-low-emission (ULE) burners; 2) a specially designed fired heater with enhanced heat recovery, optimized for use with the ULE burner systems; and 3) on-line tube metal temperature sensors and burner control system to optimize heater operation, reduce maintenance costs, and increase run lengths. The technology will have applications for a broad range of refining and chemical processes. The advanced heater components will be developed for new design and retrofit applications.

### ◆ Radiation Barrier Heating Mantle for High-Temperature Furnaces

Retort furnaces, which consist of a heating-mantle jacket surrounding a retort vessel, are widely used to generate high temperatures for the metal-processing, chemical-processing, and heat-treating industries. A new porous wall radiation barrier (PWRB) heating mantle represents a breakthrough in heating mantles that significantly increases heat-transfer rates over both the existing gas-fired heating mantle and the electrically heated mantle. This unique development results in a heat-transfer rate in the 1,800°F to 2,400°F range that is 2 to 4 times greater than electric and conventional gas-fired mantles.

### ◆ Remote Automatic Material On-Line Sensor

A magnetic resonance system was designed to perform continuous measurements on materials as they pass through or over the sensor. The system will allow material properties such as hydrogen content and solid-to-liquid ratio to be measured. The technology is projected to be applicable for determining moisture content of wood chips, coal, food materials, and ores.

### ◆ Rotary Burner

A new rotary burner that provides ultra-low combustion emissions along with significant fuel and electricity savings has been developed and field-tested. The novel technology uses a process that allows for expansion of pressure energy in a rotary burner, meaning that combustion air needs can be satisfied and inherently coupled to match the fuel demand to ensure the desired air-to-fuel ratio. Its compact size ensures ease of retrofit to existing installations.

## Crosscutting Technologies
*(continued)*

### Self-Dressing Resistance Welding Electrode

The project is designed to produce an electrode from a unique metal-matrix composite material that employs a ceramic substrate, which enhances the themal resistance properties of the composite material, as the load-bearing element. The composite material also uses a metal matrix as the conduit for the electric current flow. The project will be carried out in four separate tasks, consisting of material selection, design development and optimization, fabrication and model verification, and performance test and evaluation.

### Sensing and Control of Cupola Furnaces

This project is developing an intelligent, integrated industrial process sensing and control system to optimize the performance of cupola furnaces. This system regulates the melt rate, temperature, and iron composition of the furnace. Successful control of furnace variables will increase energy efficiency, furnace yield, and productivity and will reduce environmental emissions.

### Simple Control for Single-Phase AC Induction Motors in HVAC Systems

A new approach to electric motor control removes the need for complex, high-frequency, high-voltage digital controllers that are motor and application specific. Using an optical programmable encoder offers continually variable speed, optimized commutation, dynamic vector control, real-time feedback, application tuning, and signal enhancement for operating AC and DC motors ranging in size from fractional horsepower to industrial motors. The application currently being developed is a drop-in unit for the residential HVAC retrofit market and provides continuous variable adaptability to air temperature, resulting in improved comfort, a cleaner environment, and energy savings.

## Crosscutting Technologies
*(continued)*

### Super Boiler

The Super Boiler concept using ultra-high-efficiency, ultra-low-emission steam generation technologies is targeted for broad industrial applications over the next 15 to 25 years. The concept combines a suite of enabling technologies such as a staged intercooled combustion system with forced internal recirculation, high-intensity heat transfer surfaces, an advanced transport membrane condenser, and a smart control system in an integrated package. The performance goals include 94% fuel efficiency, 5 vppm $NO_x$ and CO, and 50% size and weight reduction compared with a conventional firetube boiler.

### Thermal Imaging Control of High Temperature Furnaces

The near-infrared thermal imaging system fine-tunes the main furnace controller for improved combustion performance. The system uses multiple infrared wavelengths combined with a periscope probe to map the full field of combustion space during furnace operation. Control algorithms minimize differences between measured field temperatures and temperature set points and send output signals to the main furnace combustion control. Optimizing the combustion process has been shown to decrease the total fuel use by at least 5%, with a corresponding decrease in airborne emissions.

### Thermobarrier Coatings

Thermal barrier coatings for industrial gas-turbine components are critical for higher temperature operation and longer lifetimes. Current coatings do not last over 8,000 hours, and improvements are needed to achieve 25,000 hours in industrial applications and corrosion resistance. Coated components include combustor liners, blades, and vanes.

### Thermoelectric Generator for Diesel Engines

This new technology generates electric energy from waste heat and has many applications in the power industry, as well as in the chemical and petroleum industries. One possible application is as an array on the exhaust of the gas turbine to increase efficiency. Heavy earth moving equipment for mining presents another potential application. A prototype generator is being tested by a truck manufacturer and has been driven on their test track for 500,000 miles to demonstrate the ability to endure shock and vibration.

IMPACTS

## Crosscutting Technologies
*(continued)*

### Tough-Coated Hard Powders
Revolutionary tough-coated hard powder (TCHP) pseudoalloys combine the highest extremes of fracture toughness, hardness, wear resistance, light weight, low coefficient of friction, and thermal properties ever known. Designed nanostructures are created by encapsulating extremely hard core particles (e.g., diamond) with very tough materials (e.g., tungsten carbide and cobalt), which in the consolidation process become the contiguous matrix. As many unique properties can coexist in a TCHP variety as there are different core particle materials present in the uniform tough substrate. Extreme strength, double-digit component and tool life multiples, and reduced friction and thermal losses combine to enable tens of billions of dollars in annual cost, energy, and environmental impact improvements.

### Tube-Metal Temperature Sensor
A tube-metal temperature-sensing system has been developed for refinery and chemical plant process-fired heaters. The sensor monitors tube-metal temperature profiles and can guide adjustments to heater/burner operation to optimize radiant section heat transfer. This sensing system is being integrated into a low-emission, high-efficiency, advanced process heater system that will be the final product of a five-year, multi-partner R&D effort. The tube-metal temperature sensor was demonstrated at a refinery in 2005 and is being packaged for commercialization to fired heater manufacturers and operators. Other project technologies are being demonstrated in late 2005 and early 2006.

### Ultrananocrystalline Diamond Coatings
Ultrananocrystalline diamond (UNCD) coatings can be grown on various substrates by using emerging microwave plasma chemical vapor deposition technology. The coatings exhibit a unique microstructure that provides superior mechanical (high hardness), tribological (low coefficient of friction), chemical (inertness to chemical attack), and electronic (wide range of conductivity via doping) properties. Multipurpose mechanical pump seals will be the first to benefit from these coatings.

## Crosscutting Technologies
*(continued)*

### Variable Speed, Low Cost Motor for Residential HVAC Systems
Existing variable-speed motors cost at least four times as much as single-speed motors and thus are currently used in only 5% of residential HVAC systems. A revolutionary low-cost, brushless, variable-speed motor technology uses solid-state switches on the rotating armature to control motor torque and speed. It will shortly be tested by a dozen major HVAC suppliers. A variable-speed motor running continuously at half speed compared with a single-speed motor running at full speed but half the time uses 25% of the power to move the same amount of air in an HVAC blower, thus saving energy.

### Wear Resistant Composite Structure of Vitreous Carbon Containing Convoluted Fibers
A novel method makes a composite material consisting of a vitreous carbon matrix containing convoluted fibers. The resulting product has better wear resistance, lower coefficient of friction and higher electrical conductivity than competing materials. The material is being developed for use in cable and third rail electric transportation systems, such as light rail.

## Other Industries

### BEI Cellulose Hydrolysis Process

The BEI Cellulose Hydrolysis Process uses a double tubular reactor that is precisely controlled to convert cellulose into a high sugar content material. The second stage of the process also recovers heat and chemicals that can be reused in the first stage, thereby providing energy and economic savings. The process hydrolyzes cellulose to pentose, hexose, or glucose sugars at the point of use. These sugars may then be yeast-fermented to ethanol or other organic chemicals as commercial products.

### Biofine Technology

The Biofine technology can convert low-grade cellulose-containing wastes from paper mills, municipal solid waste plants, logging and agricultural operations, and other sources into levulinic acid, a versatile platform chemical that is an intermediate to several high-value chemical and oxygenated fuel products. Cellulose is converted to levulinic acid using a novel, high-temperature, dilute acid hydrolysis reaction system.

### Clean Energy from Biosolids

The innovative and unique SlurryCarb™ process receives waste as a slurry and then treats it in a heated pressure unit to rearrange the slurry molecularly. This step produces a homogeneous, clean fuel with an energy density significantly greater than untreated material. The high-energy renewable "E-Fuel" can be used efficiently in conventional combustion equipment as a substitute for fossil fuel.

### Deep-Discharge Zinc-Bromine Battery Module

A new zinc-bromine battery is being demonstrated that increases load-leveling efficiency and offers longer cycle life with less weight than conventional lead-acid batteries. This new battery is applicable to electric utilities and industrial companies. The modular construction allows for sizing and portability of the system to suit multiple applications and needs. This technology allows customers to purchase lower-cost power and then use it for reducing peak-power purchases.

## Other Industries

*(continued)*

### Distillation Column Flooding Predictor

A new control technology more accurately identifies incipient floods in petrochemical distillation and separation columns. The Flooding Predictor, a patented pattern recognition technology, allows a column to be operated at or near the incipient flood point. The technology identifies patterns of transient instabilities that occur just before flooding events. Identifying the incipient flood point allows the control objective to be shifted from delta-pressure to the actual flood point. Shifting the control objective virtually eliminates column flooding events, while increasing throughput.

### Distributed Optical Fiber Sensors for Continuous Liquid Level Tank Gauging

The Noverflo Multipoint Tank Gauging (NMTG) system is a family of fiber optic sensor arrays designed for the oil and gas, transportation, and food/beverage processing industries. Compared with similar products, the NMTG offers a simple design that allows both low and high accuracy measurements to be made at a very low cost. The system can make accurate measurements in liquids of shifting densities and performs continuous density measurements at any tank level. A new (patent pending) data acquisitions system allows the NMTG to monitor hundreds of sensors and numerous external-switching devices without any upgrades to existing systems.

### Float Zone Silicon Sheet Growth

This innovative technology consists of a process to develop crystalline silicon sheet from a polycrystalline silicon source. Its primary goal is the efficient, low-cost production of high-quality crystal silicon sheet for the solar and electronics industry. Development of this process will provide several important benefits, such as high production rates, low cost in terms of material and energy input, good dimensional control, improved crystal quality, and remarkable purity the same as the source material.

IMPACTS

## Other Industries
*(continued)*

### ◆ Forging Advisor
The forging advisor (also called the near net shape process selection advisor) is a manufacturing process selection system that allows engineers to rapidly analyze trade-offs with respect to geometry, performance, and cost among a series of manufacturing processes. The processes chosen for implementation in the advisor include three types of investment casting, rough machining, forging, and laser enabled net shaping. The system also provides input on best practices for the design of forgeable parts.

### ◆ Gas Imaging for Advanced Leak Detection
This project addresses the development and sufficient miniaturization of a gas-imaging system for increased transportability and usability by one person. The small size allows the use of newly developed laser materials and a high-power fiber amplifier. This improved technique can locate hydrocarbon leaks from process piping components by optical imaging of gas plumes.

### ◆ High-Intensity Silicon Vertical Multi-Junction Solar Cells
A new solar cell combines high voltage with low series resistance operation to create efficient concentrated solar power conversion at low cost. Output power densities exceeding 1000 times that of conventional solar cells have been demonstrated. The simple design of the new cell results in lower manufacturing costs and robust reliability compared with existing concentrator cells. Basically, the new solar cell technology enables high intensity photovoltaic concentrator systems that provide considerably lower $/watt cost than conventional photovoltaic modules. Immediate applications include large-scale electric power generation (>100 kW) in sunny regions of the world.

### ◆ Hydrodyne Process for Tenderizing Meat
The hydrodyne process offers a unique way of tenderizing meat, particularly tougher meat with less fat. The innovative new technology reduces beef tenderization time from weeks to a fraction of a second by using hydrodynamic shock waves. The process can increase beef tenderness in tougher meat cuts by as much as 72% without changing natural appearance, texture, or flavor.

## Other Industries
*(continued)*

### ◆ Long Wavelength Catalytic Infrared Drying System
A new drying system is being demonstrated that dehydrates wood chips and fines prior to oriented Strand board construction. This infrared technology reduces the moisture content by transferring energy directly to the moisture instead of heating the air and surrounding metal structure. The result is reduced energy and air emissions and improved productivity.

### ◆ Novel Membrane-Based Process for Producing Lactate Esters
This research aims to develop nontoxic replacements for halogenated and toxic solvents. The new method, called "Direct Process", uses proprietary advanced fermentation, membrane separation, and chemical conversion technologies to convert renewable carbohydrate feedstocks into lactate esters in an energy-efficient, waste-reducing, and cost-effective way.

### ◆ Petroleum Fouling Mitigation
Fouling is a deposit buildup in refinery process units that impedes heat transfer, increases pumping power, decreases equipment reliability, and is a leading cause of diminished efficiency and productivity in refineries. This project developed a threshold-fouling model and fouling test units for establishing operating procedures to allow refineries to operate heat-exchange equipment (heat exchangers and fired heaters) below threshold fouling conditions. The refinery industry will use these tools to determine the root cause of fouling and to evaluate cost-effective mitigation techniques. Fouling mitigation provides the basis for the condition-based maintenance of heat-exchange equipment.

### ◆ Plastics, Fibers, and Solvents from Biosynthetically Derived Organic Acids
Biologically-derived succinic acid is produced by fermenting sugar derived from grains and other biomass. After separation and purification, the succinic acid is used as a chemical intermediate that is converted into a wide assortment of products such as plastics for automobiles and household items, fibers for clothing, food additives, solvents, deicers, agricultural products, ink, and water treatment chemicals.

## Other Industries

*(continued)*

### ◆ Pulsed Laser Imager for Detecting Hydrocarbon and VOC Emissions

A new hydrocarbon detection device, the pulsed laser imager, uses the principles of infrared spectroscopy to locate and measure the extent of hydrocarbon leaks and emissions of volatile organic compounds (VOCs). The imager's main advantage over its competitors is its remote-sensing feature that does not require an air sample. The imager detects hydrocarbon leaks from a safe distance by analyzing the electromagnetic spectra of the compounds. Both the short- and long-range versions of the pulsed laser imager are flexible, sensitive, accurate, and intrinsically safe and provide a cost-effective solution to hydrocarbon detection.

### ◆ Soy-Based 2-Cycle Engine Oils

A new soy-based biodegradable lubricant called AquaLogic 460 has been developed to replace petroleum oils used in 2-cycle marine engines for outboard and personal watercraft. The new product is greater than 80% biodegradable, produces lower emissions, and extends engine life.

### ◆ $SO_3$ Cleaning Process in Semiconductor Manufacturing

A new process is being demonstrated that removes photoresist from semiconductor wafers by exposing the wafers to $SO_3$ gas followed by a deionized water rinse. Hardened photoresist must be thoroughly cleaned from very small crevices on the wafer at various stages in the manufacturing process. This process is anticipated to substantially replace damaging dry stripping and wet stripping that produces hazardous waste in the semiconductor manufacturing industry.

### ◆ Thermophotovoltaic Electric Power Generation Using Exhaust Heat

This new technology produces electricity directly from furnace exhaust waste heat by using infrared-sensitive photovoltaic cells. The cells are mounted inside ceramic tubes that are heated in the high-temperature exhaust stream from furnaces. This technology allows on-site generation of electricity from waste heat in industrial or residential applications.

# Appendix 3:
## Historical ITP Technology Successes

# Historical ITP Technology Successes

IMPACTS

## IMPACTS

### Advanced Turbine System

As part of the Industrial Power Generation Program, a new advanced metallic material, first-stage turbine vane was developed. This new vane allows turbines to operate at higher compression ratios and/or temperatures than conventional gas turbines resulting in an efficiency improvement of 15%, less down-time, and less maintenance. The use of these new vanes has resulted in an energy savings of 245 billion Btu.

### Aerocylinder Replacement for Single-Action Cylinders

The aerocylinder, a new machinery shock absorber, replaces conventional, single-action compressed-air cylinders in industrial forging, stamping, and welding applications. The aerocylinder has been installed on over 400 stamping and welding presses, primarily in the automotive industry. Using this new system reduces downtime, prolongs equipment life, improves final product quality, and has resulted in an energy savings of more than 340 billion Btu since 1988.

### Aluminum Roofing System

This new technology uses aluminum chips to reflect about 70% of the solar radiation received on asphalt roofs, which reduces building cooling needs. This invention has saved over 635 billion Btu since its introduction in 1984 and is now used on more than 35 million square feet of roofing.

### Arc Furnace Post-Combustion Lance

A new technology was developed that was applied in electric arc furnaces to increase productivity, reduce energy requirements, and improve control. The system consists of a water-cooled lance and controls to inject oxygen to combust the carbon monoxide in and above the furnace's foamy slag. The six installed systems have saved a total of 2.46 trillion Btu of energy.

### Auxiliary Air-Conditioning, Heating and Engine Warming System for Trucks

An auxiliary power unit was developed to maintain cab power in heavy-duty, long-haul trucks when the main engine is not operating. This unit takes fuel from the truck's fuel tanks to heat and air-condition the cab and sleeper, to generate electricity to keep the battery charged, and to furnish hot water to keep the truck's engine warm. Since 1988, more than 3000 units have been installed on trucks and have saved an estimated 19.9 trillion Btu in the form of diesel fuel.

### Biomass Grain Dryer

Originally developed for grain-drying processes, this heat exchanger system later expanded into the furniture industry. By burning husklage, wood waste, or other biomass fuels, the process quickly disposed of combustible waste, provided an alternative energy source, and saved landfilling fees. Used within both the corn and furniture manufacturing industries, this system resulted in a cumulative 1.35 trillion Btu in energy savings and reduced landfill scrap by thousands of tons since being commercialized.

### Biphase Rotary Separator Turbine

A new biphase turbine recovers waste energy from pressurized process streams that separate into liquid and gas when the streams are depressurized. Conventional turbines cannot be used efficiently with two-phase flows because they cannot withstand the forces released during the liquid's rapid evaporation to a vapor. This new turbine is being used by 125 large (500-ton) chillers and is saving 15 kW per chiller, for a cumulative savings of 107 billion Btu.

### Catalytic Distillation

Distillation is one of the most energy-intensive industrial processes, accounting for over 40% of the energy consumed by the chemicals industry each year. This single-stage catalytic reaction/distillation process has become a major commercial success and has improved the energy efficiency and productivity of certain chemical processes, including the production of methyltertiary- butyl-ether (MTBE) and tertiary-amyl-methyl-ether (TAME). Since its introduction in 1982, the 36 units installed in the United States have saved 43 trillion Btu.

### Cement Particle-Size Classifier

A system was developed to control the size distribution of cement particles and to help reduce the current energy-intensive regrinding process. Cement products produced from the improved particle distribution consumed less energy and were of better quality. This system yielded a total of approximately 9.5 trillion Btu in energy savings since its commercialization in 1984.

# Historical ITP Technology Successes



### ◆ Chemical Separation by Fluid Extraction

This technology removes hazardous organic compounds from contaminated solid or liquid waste streams. The technology is more energy efficient than conventional technical hazardous waste treatment methods. The use of this technology has resulted in energy savings of 440 trillion Btu since 1990.

### ◆ Cogeneration – Coal-Fired Steam Turbine

Using a coal-fired boiler and turbine exhaust steam system, a cogeneration process was developed for use primarily within the textile industry. The 16 systems installed saved more than 31 trillion Btu of energy/year and significantly reduced emissions due to lower demand for utility-generated electricity.

### ◆ Cogeneration – Slow-Speed Diesel Engine

This stationary internal combustion, slow-speed, two-stroke diesel engine was developed to accommodate limited space and/or varying load demands. The compact, slow-speed diesel engine has excellent efficiency, greater load flexibility, and lower fuel and maintenance costs than conventional cogeneration options. The three installed units have saved a total of approximately 17.7 trillion Btu of energy.

### ◆ Coil Coating Ovens

This system was developed to recover thermal energy previously lost in the solvent-based paint curing/incineration process. Heat, recovered from solvent vapor combustion in zone incinerators, was routed back into the curing oven to vaporize more solvent. The thermal incinerators normally used were replaced by afterburners and a waste heat boiler to produce process steam. A three-fourths reduction in natural gas requirements and a reduction in pollution control energy resulted in over 35 trillion Btu of cumulative energy savings since the system was commercialized. The savings were increased even further as a result of a technology upgrade that eliminated the zone-burning portion of the process.

### ◆ Combination Grain Drying

Designed to prevent spoilage during storage and reduce energy consumption, this system used a high-speed dryer and storage bin equipped with a drying fan. The grain was first dried by a high-speed, hot-air dryer, then transferred to a drying/storage bin that delivered ambient air to cool and further dry the grain to a moisture content of around 14%. This combination drying method improved grain quality, increased drying capacity, and reduced propane and natural gas consumption.

### ◆ Component Cleaning

A new chemical product for industrial cleaning was developed based on supercritical fluid technology. New equipment was developed that converted carbon dioxide ($CO_2$) into a fluid that was used to clean metal, plastics, printed wire boards, etc. This new technology takes the place of chloroflurocarbon (CFC) solvents in the cleaning process and has reduced the energy needed to evaporate the solvents during the drying process.

### ◆ Computer-Controlled Oven

To lower volatile organic compound (VOC) emissions, the computer-controlled oven technology was developed that permits operation at a higher percentage of lower explosive limits, reducing in dilution air requirements and the energy required to heat the high-temperature ovens. Optimizing airflows reduces VOC emissions that, in turn, reduces VOC incineration requirements. Fifteen installations saved a cumulative total of 27.75 trillion Btu of energy since being commercialized in 1982.

### ◆ Cupola Stack Air Injection

This process reduced the carbon monoxide (CO) content of the effluents from a cupola furnace and improved the efficiency of combustion in the furnace during production of gray iron. This process eliminated the need for afterburners and the large amounts of energy they used to reduce the CO content in the emissions. By injecting air into the exhaust gases below the furnace charging door, the CO was ignited at temperatures already existing in the stack, with the resulting final exhaust gas having a CO concentration of less than 1%. Cupola stack air injection saved a total of 80 billion Btu of energy before being superseded by more advanced technology.

## IMPACTS

### ◆ Delta T Dryer Control System

This dryer control system significantly improves control capability because it measures moisture content continuously in the dryer rather than only at the exit from the dryer. This more precise temperature control saves 10% to 20% more energy than conventional dryer control systems. Over 300 Delta T control systems have been installed and have saved more than 17 trillion Btu since 1985.

### ◆ Direct Source-to-Object Radiant Heating Panels

Radiant heating systems transfer heat directly to a person or object in a manner similar to sunlight, eliminating mechanical heat-delivery requirements. These systems can save up to 50% in heating costs compared with baseboard electric-resistance heating and up to 30% compared with heat pumps. Since 1981, more than 375,000 radiant heating panels have been sold, saving more than 1.45 trillion Btu.

### ◆ D'MAND® Hot Water Recirculating and Waste Prevention System

A new system was developed for water heaters to conserve water and energy while providing hot water on demand. The system recycles the hot water that would have remained in the pipes. The primary energy savings are from the reduced amount of energy needed to heat the water returned to the water heater tank. More than 33,000 units have been installed, primarily in residential applications, and have cumulatively saved 604 billion Btu.

### ◆ Dye Bath Reuse

To reduce the use of chemicals, water, and energy, two process modifications were developed for batch-dying textiles. These modified processes involved reconstituting and recycling the spent dye bath, eliminating the final rinse-water step. These modifications resulted in a cumulative energy savings of 2 trillion Btu prior to being replaced with advanced technologies.

### ◆ Electric Tundish

An enclosed and more efficient holding furnace or tundish was developed and demonstrated for the continuous casting of copper alloys. Switching to electricity to heat the tundish rather than gas or oil results in an energy efficiency increase from 20% to 98%. Four tundishes were installed in 1994 and operated until the manufacturing facility closed in 1996.

### ◆ Electronic Starter Device for Fluorescent Lamps

A quick and reliable electronic lamp starter was developed for small fluorescent applications. This technology was an important improvement for lower wattage fluorescent lamps which still use older preheat circuit designs. Use of the inexpensive and easily installed starter can double the life of a fluorescent lamp. More than 1.6 million units have cumulatively saved 3.1 trillion Btu.

### ◆ Energy-Efficient Canning

A thermal syphon recycle system using a recycling steam jet vacuum compressor and a recirculation pump and heat exchanger outside of the cooker were two methods developed to improve energy efficiency in the canning industry. From the installation of 100 new or retrofitted units, a cumulative energy savings of nearly 3 trillion Btu were realized.

### ◆ Energy-Efficient Fertilizer Production *(Pipe Cross Reactor)*

An ammonia granulation technology was developed to reduce moisture content and energy consumption in the production of pellet fertilizers. The process employed a pipe-cross configured reactor, mounted within a granulator, where liquid raw materials were mixed and then dried via heat from the chemical reaction. Seven reactors were constructed that produced a superior product with a 1% moisture content, reduced pollution, and contributed a cumulative energy savings of 2.6 trillion Btu.

### ◆ Energy-Efficient Process for Hot-Dip Batch Galvanizing

This new process combines a thermally stable flux solution and a preheat furnace to reduce energy use and increase batch galvanizing productivity while reducing waste generation. Hot-dip galvanizing is widely used to protect steel from corrosion. The new process was used at a Pennsylvania steel company and saved 4 billion Btu of energy.

### ◆ Fluidized-Bed Waste Heat Recovery System

A self-cleaning waste heat recovery system was developed to replace industrial furnace conventional recuperators. The new system employed finned heat exchange tubes submerged in a bed of spherical alumina particles that absorbed heat from the hot gas and transferred it to the finned tubes. The water flowing through the tubes was converted to steam for use elsewhere in the plants while the alumina particle agitation kept the tubing clean and distributed the heat evenly.

# Historical ITP Technology Successes

### ◆ Foam Processing
To replace the very energy-intensive wet processing of textiles, a process was developed to substitute medium-density foam for some of the water processing. A 50% to 70% moisture retention reduction was realized along with a significant decrease in energy previously required for drying, water usage, and pollution control. This technology, and several similar techniques, achieved a cumulative energy savings of more than 11 trillion Btu.

### ◆ Glass Feedstock Purification
A new optical sortation technology, which removes ceramic and other contaminants from glass cullet using optical sensors and computer-controlled jets of compressed air, was developed. This technology was used to recycle 50 tons/day of glass at one plant for two years thus resulting in a cumulative energy savings of 48 billion Btu.

### ◆ Guide for Window Routing Device
A tool guide to control the operation of a router was developed for converting single-glazed wooden-framed windows into double-glazed windows. Single-pane glass can thus be replaced with panes that are more energy-efficient without replacing the sash members or the entire window. This technology was used by licensees in the United States and England and has saved more than 520 billion Btu of energy.

### ◆ Heat Exchanger Dryer
This modified multideck dryer that incorporated a heat recovery system, was developed for the wood board products industry. Air-to-air, air-to-water, and air-to-liquid heat exchangers enabled the previously lost heat from exhaust gases to be reused throughout the plant. Three installations yielded nearly 800 billion Btu in cumulative energy savings.

### ◆ High-Effectiveness Plate-Fin Recuperator
New materials and fabrication techniques made the previously cost prohibitive plate-fin recuperators more economically feasible for a larger number of industrial applications. The recuperators can recover 90% of the energy from exhaust as hot as 1550°F, are more compact than conventional techniques, and use a flexible flow pattern. Further, the new technology provides more heat transfer surface per cubic foot of volume and is often used in nonfouling heat recovery applications. More than 100 units were installed with a cumulative energy savings of around 5 trillion Btu.

### ◆ High-Efficiency Dehumidifier
A new system was developed to recover reheat energy and to control the humidity in all types of buildings. This system uses heat pipe technology to increase the humidifying capacity of air-conditioning equipment and operates without any mechanical or electrical inputs. More than 12,000 units have been sold and have cumulatively 1.38 trillion Btu.

### ◆ High-Efficiency Direct-Contact Water Heater
This industrial/commercial water heating system uses a water-cooled burner sleeve and combustion zone to extract all possible energy from natural gas combustion by bringing water into direct contact with a submerged-flame jet-type burner. More than 3,000 units are in use throughout the United States, and have saved a cumulative total of more than 300 trillion Btu in natural gas.

### ◆ High-Efficiency Weld Unit
An inverter welding power source that included a multiprocess capability was developed for arc welding processes. Up to 75% smaller in size and weight than conventional units, this system's portability and improved weld quality also provided energy savings of up to 45% over conventional power sources. More than 75,000 units were sold, resulting in a cumulative energy savings of 21 trillion Btu before they were replaced by more advanced welding technology.

### ◆ High-Temperature Burner Duct Recuperators
Two ceramic tube recuperators, able to withstand 2000°F+ temperatures, were designed to recover heat from high-temperature industrial furnace exhausts. Used in iron forging and steel production, fuel consumption was reduced by approximately 50%.

## IMPACTS

### Hot Blast Stove Process Model and Model-Based Controller

A central control system was developed and installed on a blast furnace to optimize the thermal efficiency of the hot-blast stove system. The controller is linked to process optimization algorithms that determine heating fuel rates, thus minimizing fuel requirements and reducing the number of disruptions in iron production. This invention has saved more than 220 billion Btu since its installation in 1998.

### Humidity Sensor *(Optical)*

An optical humidity sensor (hygrometer) that determines humidity by measuring the absorption of ultraviolet light was developed for the pulp and paper industry. Replacing less reliable humidity sensors, the hygrometer maximizes drying efficiency by optimizing the balance of exhausted and makeup air. Multiple installations realized a cumulative energy savings of 20 billion Btu.

### Hydrochloric Acid Recovery System

An on-site, closed-loop HCl recovery system was developed for galvanizers and small- and medium-size steel manufacturers. Benefits of the new recovery system included reduced demand for virgin HCl, the elimination of the use of chemicals for neutralizing waste acid, and energy and cost savings associated with processing, transporting and disposing of the waste acid The use of this new system resulted in cumulative energy savings of 410 billion Btu.

### Hyperfiltration – Textiles

Hyperfiltration, a membrane-based separation technique, was adapted to treat textile industry wastewater. This process also found widespread use in the food-processing, biotechnology, pharmaceutical, pulp/paper, chemical, electronic, and nuclear industries. Allowing recovery of raw materials and minimizing waste, this process achieved a cumulative energy savings of nearly 1 trillion Btu.

### Hyperfiltration Process for Food

A membrane hyperfiltration process is being used to separate juice into pulp and liquid fractions. This process replaces the energy-intensive thermal evaporation step in the concentration process. This process has been installed in 17 locations and has saved more than 13 trillion Btu since 1989.

### Improved Poured Concrete Wall Forming System

A method for pouring concrete walls for building basements and crawlspaces was developed that uses lightweight, highly insulative extruded polystyrene forms. If left in place, these forms create walls that are both load-bearing and thermally insulating, up to R-22. Over 47 million square feet of walls have been installed that have cumulatively saved 978 billion Btu.

### Irrigation Systems

The design of efficient low-pressure impact sprinklers, low-pressure spray heads, and improved drop tubes upgraded center-pivot irrigation systems dramatically. Operating at lower pressures, these systems required 10% less water intake, reduced runoff, and yielded a cumulative energy savings of approximately 49 trillion Btu due to reduced pumping requirements.

### Lightweight Steel Containers

A new process for manufacturing lightweight steel containers uses the container's internal pressure for rigidity rather than a thick wall. The resulting container wall is substantially thinner, which reduces the container's metal content by 40% but provides equivalent or better strength. The process saves energy by using less material in the container, less material processing, and less transportation weight. Two container production lines have cumulatively saved 3 billion Btu.

### Membrane Filtration Technology to Process Black Olives

A zero discharge wastewater purification and reclamation system was installed at an olive production plant. This new system used a cyclone separation system followed by ultrafiltration and reverse osmosis to recycle wastewater back into the plant. Since its installation in 1997, it has saved 100 billion Btu.

### Membrane Separation of Sweeteners

A system to preconcentrate corn steep water was accomplished via a hollow-fiber membrane process. Resistant to fouling, this system extracted more than 50% of the water from the corn steep stream prior to evaporation, thus significantly reducing energy requirements. Additionally, a spin-off technology was commercialized for wastewater treatment.

# Historical ITP Technology Successes



### Meta-Lax Stress Relief Process

A new process applies subresonant vibrational energy to relieve stress in metal objects. The process replaces heat treating applications and reduces the energy and time needed to heat treat metal. The equipment is portable and treats a wide variety of work pieces in a pollution-free operation. More than 990 units have cumulatively saved 136 trillion Btu.

### Methanol Recovery from Hydrogen Peroxide Production

A new process was developed to recover and clean contaminated methanol for reuse in producing hydrogen peroxide. This process recovers more than 90% of the methanol needed to produce hydrogen peroxide, thereby saving the energy needed to produce virgin methanol. The process also saves energy by reducing the transportation of virgin methanol. The two units using this process have cumulatively saved 244 billion Btu.

### Night Sky – A New Roofing Technology

A natural evaporating roofing/cooling system was developed for flat or slope-roofed commercial buildings to increase the roof's life expectancy and reduce building cooling loads by 50%. This system spray-cools water on the roof at night and then applies the cooled water to reduce subsequent cooling loads. Systems involving more than 95,000 square feet have been installed and have cumulatively saved 2 billion Btu.

### Nitrogen-Methanol Carburization

A system was developed for steel manufacturers that replaced the conventional endothermic atmosphere process with a nitrogen-methanol carburization process. In addition to improving the strength, hardness, and wear resistance of the steel parts, the system proved more reliable and easier to operate. Significant reductions in carbon dioxide and other pollutants were noted along with a cumulative energy savings of 12 trillion Btu.

### No-Clean Soldering Process

After soldering, electronic equipment used to be cleaned using CFC solvents. Changing the soldering technique eliminated the need to use CFC solvents for cleaning, resulting in energy savings and reduced CFC waste. This process has cumulatively saved 3.9 trillion Btu.

### Onsite Process for Recovering Waste Aluminum

In the production of aluminum automobile wheels approximately 30% of the aluminum content is machined away as chips during the cutting and grinding steps. A new process for recycling the chips onsite rather than offsite improves the energy efficiency and productivity of chip recycling while simultaneously reducing airborne pollutants and other manufacturing wastes. This new process has resulted in cumulative energy savings of 139 billion Btu.

### Organic Rankine-Cycle Bottoming Unit

This organic Rankine-cycle system was developed to replace less-efficient, conventional steam Rankine-cycle systems in generating electricity from lower temperature waste-heat sources. It was found to be adaptable to a variety of solar and geo-thermal energy applications as well as suitable for many types of industrial waste-heat streams. The system consists of a standard Rankine-cycle engine, toluene as the working fluid, a waste-heat boiler, a waste-gas flow-control valve, system controls, and an electric generator. The installation of several units cumulatively saved 500 billion Btu of energy.

### Oxy-Fuel Firing

This oxygen-enriched combustion system for glass-melting furnaces significantly reduces energy requirements. About one-fourth of all glass-melting capacity in the United States has been converted to oxy-fuel firing. In addition to energy savings, this technology reduces $NO_x$ emissions by up to 90% and particulates by up to 30%. Since its commercialization in 1990, oxy-fuel firing technology has saved more than 25 trillion Btu.

### Paint Wastewater Recovery

A new system was developed to reclaim and reuse wastewater generated during equipment cleaning used in water-based paint-production operations. The system vastly reduces the volume of wastewater contaminated with metals and solvents that must be disposed of as hazardous waste. Energy savings resulted from the reduced fuel use for transporting and incinerating the waste. The process has cumulatively saved over 30 billion Btu of energy.

## IMPACTS

### ◆ Pallet Production Using Postconsumer Wastepaper

A new process produces paper pallets made of 40% postconsumer waste paper. Substituting virgin wood with this recycled product reduces by 60% the energy required to produce pallets, saves landfill space, and decreases air and water pollution. The process has cumulatively saved over 2 billion Btu.

### ◆ Pervaporation to Recover and Reuse Organic Compounds

A new membrane technology was developed which treats small-volume, less than 20 gallons per minute, waste streams contaminated with organic compounds. Small-volume wastewater streams are difficult and expensive to treat with most conventional organic-compounds control technologies. The three installed units cumulatively saved 57 billion Btu.

### ◆ PET Bottle Separator

Recycling certain plastics for conversion into fuel oil necessitated the development of a separation process that could sort containers of PET (polyethylene terephthalate), high-density polyethylene, and aluminum. One bottling plant using this process recycled 18 million pounds of PET and saved a total of 1.2 trillion Btu of energy.

### ◆ Pinch Analysis and Industrial Heat Pumps

Pinch analysis was used to locate the most productive process modifications and heat pump opportunities within a complex process to improve overall process efficiency. A pinch analysis of a wet-corn-milling plant showed that adding two new thermal vapor recompression heat pumps to existing evaporators could reduce overall process fuel use by 33%. These two heat pumps have cumulatively saved 917 billion Btu.

### ◆ Plating Waste Concentrator

A low-cost, vapor-recompression evaporation system was developed for the plating and surface-finishing industry to reduce water pollution and recover costly plating chemicals. The waste concentrator was designed with two evaporators, one to concentrate the wastewater and the other to use waste heat as an energy source. Recovery of plating metals, reduced hazardous material treatment costs, and energy recycling all contributed to improved operating costs and energy efficiencies. This technology was used in 62 applications and resulted in a cumulative energy savings of 3 trillion Btu.

### ◆ Recuperators

A cross-flow ceramic recuperator made of cordierite (a magnesium-aluminum silicate) was developed to recover heat from exhaust gases in high-temperature (up to 2600°F) furnaces. Corrosion and oxidation resistant, the compactly sized recuperator eliminated the need for a flue gas dilution system. These units cumulatively saved over 24 trillion Btu in energy and reduced both thermal and emissions pollution.

### ◆ Removal of Bark from Whole Logs

A machine, the Cradle Debarker™, was developed that removes bark from delimbed tree stems in a process that strips off less wood, allows for greater operator control, and improves the productivity of the debarking process. Unlike drum debarkers, which use a covered cylinder, the open top of this debarker lets the operator remove stems that have completed the debarking process and recycle others that require further processing. The four debarker units have cumulatively saved 132 billion Btu.

### ◆ Retractable® Labyrinth Packing Seals for Turbine Shafts

This invention is a redesigned shaft-sealing ring for utility and industrial steam turbines that self-adjusts from the gap required for start-up to that required for normal operation. The result is less wear damage and improved turbine efficiency. More than 500 of these new seals have been installed and have saved more than 74 trillion Btu.

### ◆ Reverse Brayton Cycle Solvent-Recovery Heat Pump

A reverse Brayton cycle heat pump was developed to economically and efficiently recover solvents from numerous industries. This heat pump reduces the demand for new solvents, saving petroleum feestock and the energy used to produce virgin solvents, and captures for reuse solvents that would have been released to the atmosphere. Ten heat pumps have been installed and have cumulatively saved 4.98 trillion Btu.

### ◆ Robotic Inspection System for Storage Tanks

This technology consists of a remotely operated robotic inspection vehicle that is submerged in bulk liquid storage tanks to gather input on structural and corrosion problems. This system replaces the time-consuming conventional inspection process of draining the tank, washing it out, inspecting it, and then refilling it. This technology has cumulatively saved 280 billion Btu.

# Historical ITP Technology Successes



### Scrap Tire Recycling

This new process converts scrap tires into high-value products, conserving energy and new materials while reducing the amount of scrap tires sent to landfills. This treatment process combines surface-treated rubber particles with other polymers such as polyurethane, epoxy, and polysulfide to form unique composites with improved strength, tear resistance, and resilience. This process has saved a cumulative 0.16 trillion Btu in natural gas.

### Selective Zone Isolation for HVAC Systems

A new method for selectively controlling air flow from a central HVAC system can now fit into ducts that cannot accept conventional dampers because of poor access. The flexible dampers can save 20% to 30% of a typical heating and cooling bill in a large house or commercial building by sealing off unoccupied rooms. More than 4000 systems have been sold and have cumulatively saved 305 billion Btu.

### SIDTEC™ Condenser Maintenance Program

A new on-line condenser tube cleaning system uses ultra-high molecular weight polyethylene tube cleaners to remove both soft and hard deposits. The system maintains system efficiency and keeps the thermal power plant operating. Twelve power plants have used the new system and have cumulatively saved 136 trillion Btu.

### Slot Forge Furnace/Recuperator

A high-performance slot forge furnace design that incorporated a ceramic shell-and-tube recuperator was developed to recover approximately half of the heat energy previously lost in the furnace exhaust gases. Additionally, modified recirculation burners, improved temperature and air/fuel ratio controls, and lightweight furnace wall insulation reduced energy requirements per pound of steel by approximately 4100 Btu. The use of this technology resulted in a cumulative energy savings of 13 trillion Btu.

### Solar Process Heat

This project was developed to expand the use of solar process heating systems primarily within the government and institutional sectors. Reducing the need for fossil fuels, solar heat supplies water preheating, process hot water, and steam as well as process hot air, cooling, and refrigeration.

### SolaRoll® Solar Collector System

A flexible rubber tubing solar collector system was developed to be used to heat hot water, swimming pools, and building heating systems. The collectors are an extrusion of ethylene-propylene-diamine rubber and are primarily used for heating swimming pools. The new systems replace conventional natural gas or electric heat pump systems. More than 35 million square feet of SolaRoll® have been sold and have saved more than a cumulative 25 trillion Btu of energy.

### SOLARWALL® Air Preheating System

A newly developed solar air heating system heats incoming ventilation and makeup air using a metal cladding system installed on the south-facing wall of a building. This system also reduces a buildings heat loss in the winter and lowers the cooling loads in the summer by preventing solar radiation from striking the south wall of the building. More than 40 systems with over 200,000 square feet of wall are operating in the United States and have cumulatively saved 76 billion Btu.

### Solvent Recovery from Effluent Streams

A membrane system was developed for recovering volatile organic compounds and chlorofluorocarbons from petrochemical waste streams. This new system allows solvents to be recovered from waste streams that are too diluted or too concentrated with solvents to use other methods. In addition to eliminating the environmental release of these solvents, the 27 units in operation in the United States have saved more than 15 trillion Btu since 1990.

### System 100® Compressor Controls

A compressor control system was developed that allows the operation of both pipeline and process compressors to operate efficiently without surge or recycle. The compressors are usually powered indirectly by natural gas (steam for process compressors and gas-powered turbines for pipeline compressors). Energy savings are typically in the 5% to 10% range. Total sales of the control systems were more than 3600 units and they have cumulatively saved more than 400 trillion Btu.

## IMPACTS

### The Solar SKYLITE Water Heater

A solar skylight water heater system was developed that uses lightweight, low-cost polymeric materials. A typical installation uses two solar collectors and the entire system can be installed in a few hours. The new system serves as a skylight and provides energy to the home's water heater. More than 1400 systems have been installed and these have cumulatively saved more than 75 billion Btu of energy.

### V-PLUS™ Refrigerant Oil Cooling System

The V-Plus system injects refrigerant liquid into the outlet stream of a screw-compressor for industrial refrigeration and cooling systems. The result is increased system capacity, extended system lifetime, and energy savings. Over 250 units have been installed and have saved more than 1 trillion Btu since 1982.

### Wallace Energy Systems Solar Assisted Heat Pump Water Heater

A new system was developed for extracting heat from a source (air or water) and applying this heat to water. The heat pump water heater provides both water heating and space cooling. The new systems can be used in applications that need large amounts of hot water and cooling, such as laundries and schools. More than 103 units are in use and have cumulatively saved 118 billion Btu.

### Waste Atactic Polypropylene to Fuel

This pyrolysis process converted a polypropylene plastic by-product, called atactic polypropylene, to fuel oil and gas. A total of 17 million pounds/year of atactic polypropylene was pyrolyzed into 2 million gallons/year of commercial-grade fuel oil that yielded a cumulative energy savings of 500 billion Btu.

### Waste Energy Recovery

Two waste-to-energy plants were constructed, one in Honolulu, Hawaii and one in Tacoma, Washington, that burn the combustible portion of municipal solid waste (MSW). The combustible MSW materials are burned to produce steam, which in turn, is used to power a conventional steam turbine/generator to produce electricity. These plants reduce the amount of electricity that must be produced by fossil fuels,as well as the amount of MSW that must be disposed of in landfills. These two installations have yielded more than 35 trillion Btu of energy since being commercialized.

# Appendix 4:
## Method of Calculating Results for the IAC Program

# Method of Calculating Results for the IAC Program



The Industrial Assessment Centers (IAC) within the Industrial Technologies Program (ITP) have been successfully generating energy savings for over 20 years. Twenty-six IACs located within engineering departments at top universities across the U.S. conduct comprehensive energy assessments for small- and medium-sized manufacturers and train the future workforce of energy engineers.

The following table presents energy savings calculated and summed from four sources associated with the IAC program: 1) IAC energy assessments, 2) assessments performed by IAC student alumni, 3) replication assessments within firms served by the IAC, and 4) IAC website-related energy savings. Output and savings estimates rely on information from the IAC assessment database (administered by Rutgers University), the IAC student registry, and evaluations conducted by Oak Ridge National Laboratory (ORNL). The IAC database documents savings recommendations and implementation history for plant assessments conducted over a 23-year period, covering more than 11,000 assessments and nearly 80,000 savings recommendations. The IAC student registry, established in FY 2001, tracks the progress of students from their starting date until their departure from the IAC. Finally, ORNL evaluations have studied the longer-term effects of plant assessments, career paths of IAC alumni, and the savings potential of web-based materials offered by the IAC.

Tabulations shown in the table are based on data collected by the IACs and studies done to estimate the nonassessment benefits. The first two lines of the table show the number of assessments conducted each year and the savings associated with each new assessment. The savings from each assessment are assumed to persist for seven years. Therefore, the energy saved in each year (shown in the third row) is the sum of energy savings from new assessment savings for that year plus the savings from measures implemented in the previous six years that continue to persist.

The contribution of assessments (or other, equivalent professional services) performed by IAC student alumni is estimated based on averaged student registry data and feedback from IAC alumni who are practicing energy engineers. In 2004, 168 fully trained students graduated from the IAC, and cumulatively over 2,300 IAC students graduated. According to ORNL research and alumni feedback, about 50% of the alumni have remained in the energy-efficiency business and each alumnus performs the equivalent of 4 assessments per year for 11 years after leaving the IAC program. The benefits of each energy assessment (or equivalent intervention) were assumed to persist for seven years, after which the aged energy assessment was “retired” for the purposes of this estimation. The annual energy savings from alumni assessments are shown in row four in the table.

The savings from replications from assessment activities are calculated as 25% of the energy saved in the prior year from all assessment activities. This calculation accounts for the ancillary effect of additional implementations that are initiated later but are the result of the IAC’s influence. These implementations may be accomplished at the same plant as the original implementations, or at other plants within the same company, or within other plants at other companies as plant managers/engineers/workers change jobs but take the energy efficiency know-how with them. The annual energy savings from replication activities are shown in row five in the table.

The IAC website maintained at Rutgers University was estimated to begin having an impact on energy savings in 1998. The methodology for determining the savings from web users relies on server data, IAC assessment savings, and data from the literature to approximate energy savings associated with the on-line, user-friendly version of the IAC database. While many centers host IAC-related websites, several of which contain useful software tools and publications developed by students and faculty, IAC savings estimates focus solely on the on-line version of the IAC database. The output estimate for the IAC website is based on the number of unique plants that used the on-line database. Server reports from Rutgers have identified about 51,600 annual visitors to the website, 6,100 of which were likely to represent unique U.S. plants. According to software use experience for similar programs, only 11% of those accessing the IAC database likely use it and only 20% of this number implement energy saving projects with the information provided. The estimates of energy savings are based on the savings generated by the unique plants that use the on-line database each year to implement energy-saving projects. Each unique plant that implements a project is assumed to save the equivalent of a single IAC assessment, or 5,053 MMBtu in FY2004. As with the other assessments, energy savings are assumed to persist for seven years.

The annual and cumulative energy savings from all IAC activities are shown in the table for each year. In 2004, the annual energy savings are 133 TBtu and the cumulative energy savings through 2004 are 1130 TBtu. Energy cost savings, carbon reduction, and other benefits are related to energy savings by projected fuel prices and emission coefficients. The cumulative energy cost savings and the cumulative carbon reduction are shown for the IAC program through 2004 in the last two rows of the table.

# Method of Calculating Results for the IAC Program

## IMPACTS

| Item | 1977 | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 |
|---|---|---|---|---|---|---|---|---|
| Number of Assessments | 82 | 70 | 636 | 224 | 359 | 253 | 211 | 248 |
| Annual Energy Saved Per New Assessment *(MBtu/Assessment-Year)* | 3,212 | 3,212 | 3,212 | 3,212 | 3,212 | 1,782 | 2,047 | 3,504 |
| Energy Saved From Assessments *(TBtu)* | 0.263 | 0.488 | 2.53 | 3.39 | 5.01 | 5.65 | 6.41 | 7.11 |
| Energy Saved From Alumni Assessments *(TBtu)* | – | – | 0.09 | 0.27 | 0.57 | 0.84 | 1.26 | 2.27 |
| Replication Energy Savings *(TBtu)* | 0.0 | 0.065 | 0.125 | 0.52 | 0.24 | 0.37 | 0.16 | 0.19 |
| Annual Energy Savings *(TBtu)* | 0.263 | 0.553 | 2.74 | 4.18 | 5.82 | 6.86 | 7.82 | 9.57 |
| Cumulative Energy Savings *(TBtu)* | 0.263 | 0.816 | 3.56 | 7.74 | 13.6 | 20.4 | 28.2 | 37.8 |
| Energy Cost Savings *(B$)* | 0.001 | 0.005 | 0.022 | 0.054 | 0.102 | 0.162 | 0.229 | 0.306 |
| Carbon Reduction *(MMTCE)* | 0.005 | 0.015 | 0.066 | 0.143 | 0.250 | 0.376 | 0.519 | 0.695 |

| Item | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 |
|---|---|---|---|---|---|---|---|---|
| Number of Assessments | 368 | 298 | 324 | 388 | 340 | 360 | 455 | 531 |
| Annual Energy Saved Per New Assessment *(MBtu/Assessment-Year)* | 4,208 | 4,520 | 3,898 | 3,842 | 4,724 | 3,821 | 3,207 | 3,942 |
| Energy Saved From Assessments *(TBtu)* | 8.49 | 7.92 | 8.40 | 8.87 | 10.0 | 11.2 | 12.2 | 12.8 |
| Energy Saved From Alumni Assessments *(TBtu)* | 3.96 | 6.27 | 8.79 | 11.8 | 16.0 | 19.9 | 23.3 | 27.1 |
| Replication Energy Savings *(TBtu)* | 0.44 | 0.80 | 0.84 | 0.88 | 1.09 | 1.39 | 1.19 | 1.26 |
| Annual Energy Savings *(TBtu)* | 12.9 | 15.0 | 18.0 | 21.5 | 27.1 | 32.5 | 36.7 | 41.2 |
| Cumulative Energy Savings *(TBtu)* | 50.7 | 65.7 | 83.7 | 105 | 132 | 165 | 202 | 243 |
| Energy Cost Savings *(B$)* | 0.406 | 0.507 | 0.619 | 0.743 | 0.896 | 1.08 | 1.28 | 1.50 |
| Carbon Reduction *(MMTCE)* | 0.932 | 1.21 | 1.54 | 1.93 | 2.43 | 3.02 | 3.68 | 4.42 |

| Item | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 |
|---|---|---|---|---|---|---|---|---|
| Number of Assessments | 585 | 776 | 879 | 867 | 720 | 723 | 755 | 705 |
| Annual Energy Saved Per New Assessment *(MBtu/Assessment-Year)* | 3,314 | 3,074 | 2,978 | 3,002 | 2,500 | 2,185 | 2,856 | 2,408 |
| Energy Saved From Assessments *(TBtu)* | 13.4 | 14.6 | 16.0 | 17.1 | 17.8 | 18.2 | 18.4 | 18.1 |
| Energy Saved From Alumni Assessments *(TBtu)* | 30.0 | 33.3 | 36.4 | 38.9 | 41.0 | 43.2 | 45.9 | 47.7 |
| Replication Energy Savings *(TBtu)* | 1.70 | 1.64 | 1.84 | 2.04 | 2.17 | 1.84 | 1.66 | 2.25 |
| Web Users Energy Savings *(TBtu)* | – | – | – | – | – | 0.06 | 0.17 | 0.29 |
| Annual Energy Savings *(TBtu)* | 45.1 | 49.6 | 54.2 | 58.1 | 61.0 | 63.3 | 66.1 | 68.3 |
| Cumulative Energy Savings *(TBtu)* | 288 | 337 | 392 | 450 | 511 | 574 | 640 | 709 |
| Energy Cost Savings *(B$)* | 1.73 | 1.99 | 2.25 | 2.56 | 2.87 | 3.16 | 3.48 | 3.88 |
| Carbon Reduction *(MMTCE)* | 5.24 | 6.13 | 7.10 | 8.14 | 9.24 | 10.4 | 11.6 | 12.8 |

| Item | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 |
|---|---|---|---|---|---|---|---|---|
| Number of Assessments | 639 | 649 | 696 | 724 | – | – | – | – |
| Annual Energy Saved Per New Assessment *(MBtu/Assessment-Year)* | 3,935 | 6,800 | 6,833 | 5,053 | – | – | – | – |
| Energy Saved From Assessments *(TBtu)* | 18.3 | 19.9 | 22.0 | 24.3 | – | – | – | – |
| Energy Saved FromAlumni Assessments *(TBtu)* | 54.3 | 69.4 | 85.8 | 100 | – | – | – | – |
| Replication Energy Savings *(TBtu)* | 1.97 | 3.33 | 6.14 | 6.42 | – | – | – | – |
| Web Users Energy Savings *(TBtu)* | 0.55 | 1.15 | 1.89 | 2.51 | – | – | – | – |
| Annual Energy Savings *(TBtu)* | 75.1 | 93.8 | 116 | 133 | – | – | – | – |
| Cumulative Energy Savings *(TBtu)* | 784 | 878 | 993 | 1130 | – | – | – | – |
| Energy Cost Savings *(B$)* | 4.32 | 4.83 | 5.55 | 6.38 | – | – | – | – |
| Carbon Reduction *(MMTCE)* | 14.1 | 15.8 | 17.9 | 20.3 | – | – | – | – |

# Appendix 5:
## Method of Calculating Results for the BestPractices Program

# Method of Calculating Results for the BestPractices Program



In support of the Industrial Technologies Program's (ITP's) mission to improve the energy intensity of the U.S. industrial sector, BestPractices is designed to provide industrial plant managers with information to evaluate opportunities and implement projects that improve the efficiency of energy systems within their production facilities. These process-supporting energy systems include those with motors and drives, pumps, air compressors, steam, and process heat. BestPractices relies on four main activities to deliver technical information to a target audience of medium- and large-size manufacturing establishments: 1) plant-wide assessments (PWA), 2) training, 3) software tool development, and 4) qualification of specialists by BestPractices to address industrial applications of energy-intensive pumping, compressed air, steam, and process heating systems. To a lesser extent, BestPractices also uses publications, direct technical assistance, and public-private partnerships to deliver information to targeted manufacturers.

Estimates of energy savings presented in this report are based on a methodology originally developed by Oak Ridge National Laboratory in 2002 and refined as the result of a peer review conducted in 2004. The impacts presented for FY 2004 BestPractices activities reflect the on-going efforts to implement recommendations from the peer review and improve the accuracy of savings estimates. Improvements include: 1) integration of results from a participant survey, 2) better understanding of energy characteristics of participating plants, 3) consistent registration information for software users, and 4) follow-up implementation information from plant-wide assessments. Savings estimates for years prior to FY 2004 have not been adjusted to reflect these most recent improvements.

The ITP Tracking Database provides data on participants in all activity areas and uses the data to estimate output and savings outcome performance of BestPractices. Participants include representatives from domestic or international manufacturing plants, corporations, research or educational institutions, state and local governments, and engineering or consulting organizations. Using information on participant affiliation, the tracking database provides estimates of the number of unique, domestic plants participating in each activity. The number of unique plants is then scaled back to estimate the number of unique, U.S. plants that are believed to take action to implement energy savings projects as a result of the dissemination of this information.

Estimates of energy savings from BestPractices' activities focus on the four core activities of PWAs, training, software, and qualified specialists. As a result of the peer review, estimates were constrained to these activities because of their significant savings potential and the higher quality of available data. The basic methodology for estimating the energy outcome of BestPractices is a combination of averaged energy savings reported by PWAs and calculated savings for training, software use, and qualified specialists. Energy benefits generated by PWAs are based on engineering estimates of savings identified in assessment reports and plant followup. Savings associated with unique U.S-based plants that implement projects following interaction with qualified specialists or by participating in training or use of software are estimated using historical assessment data from BestPractices and the Industrial Assessment Centers (IACs). Savings and descriptions for each of the four main delivery activities are summarized below.

## Plant-Wide Assessments

Plant-wide energy assessments identify overall energy use in manufacturing processes and highlight opportunities for best energy management practices for industry, including the adoption of new, efficient technologies. Plants are selected through a competitive solicitation process and agree to a minimum 50% cost-share for conducting the assessment. A PWA team conducts an on-site analysis of total energy use with plant personnel and identifies opportunities to reduce energy use and costs. BestPractices initially offered PWAs in FY 2000.

In FY 2004, 9 PWAs were completed and replication activities occurred at 5 additional plants. Original PWAs reported identified savings totaling 3.6 TBtu. Similarly, plants that replicated PWA results elsewhere identified savings totaling 3.3 TBtu. Previous year savings from PWAs are assumed to persist for seven years, which add 20.5 TBtu in savings for FY 2004. BestPractices PWAs saved 27.4 TBtu in FY 2004 and cumulatively saved 59.3 TBtu from FY 2000 through 2004.

## Training

Training activities continue to play a key role in the BestPractices' strategy. Participants who attend end-user training learn how to apply the software in their own plants to identify and implement savings in energy-intensive systems. The number of unique plants participating in a training activity is recorded in the ITP Tracking Database. From 1998 through 2004, representatives from nearly 3,000 unique plants attended BestPractices' training sessions. In 2004, of 693 plants attending training sessions, about 347 were estimated to actually take action to implement projects in their own energy-intensive systems, resulting in an estimated savings of 5.77 TBtu. Additionally, savings that persist from measures implemented as a result of training conducted in previous years contributed 44.0 TBtu in FY 2004. BestPractices' training saved 49.8 TBtu in FY 2004 and cumulatively saved 142 TBtu from FY 1998 through 2004.

## Software Tools Distribution

BestPractices has a variety of resources to help address a company's energy management needs and facilitate energy-efficiency decision-making. A range of software tools is available to help a plant manager perform a self-assessment of a plant's motor, pumping, compressed air, steam, or process heating systems. Software tools available in FY 2004 included AirMaster+, MotorMaster, Pumping System Assessment Tool (PSAT), Steam System Scoping Tool, Steam System Assessment Tool, Process Heating Assessment Tool (PHAST), and 3E Plus. Users may download the software from the BestPractices website or use the Decision Tools for Industry CD, which contains the entire suite of BestPractices' software tools.

Software is proving to be a powerful means of disseminating technical information for BestPractices. According to the tracking database, over 1,800 unique plants obtained BestPractices' software in FY 2004. Over 360 plants are estimated to have taken action to implement projects, saving an estimated 3.62 TBtu. Savings from measures implemented in previous years that persist in FY2004 contributed 32.4 TBtu. BestPractices' software saved 36.0 TBtu in FY 2004 and cumulatively saved 109 TBtu from FY 1998 through 2004.

## Qualified Specialists

Qualified specialists are industry professionals who have completed additional training and demonstrated proficiency in using BestPractices' software tools. Specialists apply these tools to help industrial customers identify ways to improve system efficiency. In FY 2004, BestPractices offered specialist qualifications in the following software tools: Steam Systems, PSAT, AirMaster+, and PHAST.

By the end of FY 2004, nearly 300 software specialists were qualified by BestPractices. That same year, an estimated 667 plants interacted with qualified specialists, resulting in implemented projects at 352 plants. Estimated savings from qualified specialists' activities in FY 2004 are 5.12 TBtu. Savings that persist in FY 2004 from measures implemented in FY 2001 through 2003 contributed 3.30 TBtu. Qualified specialists saved 8.42 TBtu in FY 2004 and cumulatively saved 12.7 TBtu from FY 2001 through 2004.

## Conclusion

The table below shows the total annual energy savings from ITP's BestPractices activities from 1998 through 2004. The subtotals from the four delivery activities are added together to calculate the total annual energy savings for FY 2004 of 122 TBtu and a cumulative energy savings of 322 TBtu. Fuel prices and emission coefficients for various fuels from Energy Information Administration publications were used to determine cumulative energy cost savings and carbon reduction.

# Method of Calculating Results for the BestPractices Program



| | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 |
|---|---|---|---|---|---|---|---|
| **Plant-Wide Assessments** | | | | | | | |
| Unique Plants Implementing Improvements Each Year | | | 2 | 14 | 17 | 8 | 9 |
| New Plant Replications | | | | 1 | 10 | 22 | 5 |
| Annual Energy Savings from Plant-Wide Assessments *(TBtu)* | | | 0.61 | 1.28 | 9.45 | 20.5 | 27.4 |
| Cumulative Energy Savings from Plant-Wide Assessments *(TBtu)* | | | 0.61 | 1.89 | 11.3 | 31.9 | 59.3 |
| **Training** | | | | | | | |
| Unique Plants Reached Each Year | 75 | 150 | 300 | 330 | 791 | 652 | 693 |
| Unique Plants Implementing Improvements Each Year | 38 | 75 | 150 | 165 | 396 | 326 | 347 |
| Annual Energy Savings from Training *(TBtu)* | 0.84 | 2.51 | 5.86 | 10.2 | 28.5 | 44.0 | 49.8 |
| Cumulative Energy Savings from Training *(TBtu)* | 0.84 | 3.35 | 9.21 | 19.4 | 47.9 | 91.9 | 142 |
| **Software Tools Distribution** | | | | | | | |
| Unique Plants Reached Each Year | 479 | 959 | 4,793 | 10,718 | 9,608 | 5,847 | 1,842 |
| Unique Plants Implementing Improvements Each Year | 96 | 192 | 959 | 2,143 | 1,922 | 1,169 | 368 |
| Annual Energy Savings from Software *(TBtu)* | 0.24 | 1.04 | 4.63 | 13.3 | 21.1 | 32.4 | 36.0 |
| Cumulative Energy Savings from Software *(TBtu)* | 0.24 | 1.28 | 5.91 | 19.2 | 40.3 | 72.7 | 109 |
| **Qualified Specialists** | | | | | | | |
| Number of Qualified Specialists | | | | 27 | 89 | 177 | 300 |
| Unique Plants Interacting Each Year with Qualified Specialists | | | | 13 | 43 | 85 | 667 |
| Unique Plants Implementing Improvements Each Year | | | | 7 | 22 | 43 | 352 |
| Annual Energy Savings from Qualified Specialists *(TBtu)* | | | | 0.17 | 0.77 | 3.30 | 8.42 |
| Cumulative Energy Savings from Qualified Specialists *(Tbtu)* | | | | 0.17 | 0.94 | 4.24 | 12.7 |
| **Sum of All BestPractices Areas** | | | | | | | |
| Unique Plants Reached Each Year | 554 | 1,109 | 5,095 | 11,076 | 10,469 | 6,614 | 3,216 |
| Unique Plants Implementing Improvements Each Year | 134 | 267 | 1,111 | 2,330 | 2,367 | 1,568 | 1,081 |
| Annual Energy Savings *(TBtu)* | 1.08 | 3.55 | 11.1 | 25.0 | 59.8 | 100 | 122 |
| Cumulative Energy Savings *(TBtu)* | 1.08 | 4.63 | 15.7 | 40.7 | 101 | 201 | 322 |
| Energy Cost Savings *(B$)* | 0.005 | 0.022 | 0.088 | 0.235 | 0.560 | 1.18 | 1.93 |
| Carbon Reduction *(MMTCE)* | 0.019 | 0.083 | 0.282 | 0.732 | 1.81 | 3.61 | 5.80 |

# Appendix 6:
## Methodology for Technology Tracking and Assessment of Benefits

# Methodology for Technology Tracking and Assessment of Benefits



## Technology Tracking

For over 27 years, the Industrial Technologies Program (ITP), previously the Office of Industrial Technologies (OIT), has been tracking and recording information on technologies developed through cost-shared R&D projects with industry. The tracking process considers technologies that can be classified as commercially successful, mature, or emerging.

When full-scale commercial units of a technology are operational in private industry, that technology is considered commercially successful and is on the active tracking list. When a commercially successful technology unit has been in operation for approximately 10 years, that particular unit is then considered a mature or historical technology and is usually no longer actively tracked.

Emerging technologies are those in the late development or early commercialization stage of the technology life cycle (roughly within one to two years of commercialization). While preliminary information is collected on emerging technologies, they are not placed on the active tracking list until they are commercially available to industry.

The active tracking process involves collecting technical and market data on each commercially successful technology, including details on the:

- Number of units sold, installed, and operating in the United States and abroad (including size and location)
- Units decommissioned since the previous year
- Energy saved by the technology
- Environmental benefits from the technology
- Improvements in quality and productivity achieved through use of the technology
- Any other impacts of the technology, such as employment, effects on health and safety, etc.
- Marketing issues and barriers

## Methods of Estimating Benefits

Information on technologies is gathered through direct contact with either vendors or end users of the technology. These contacts provide the data needed to calculate the unit energy savings associated with an individual technology, as well as the number of operating units.

Unit energy savings are unique to each individual technology. Technology manufacturers or end users usually provide unit energy savings, or at least enough data for a typical unit energy savings to be calculated. The total number of operating units is equal to the number of units installed minus the number of units decommissioned or classified as mature in a given year—information usually determined from sales data or end user input. Operating units and unit energy savings can then be used to calculate total annual energy savings for the technology.

The cumulative energy savings represents the accumulated energy saved for all units for the total time the technology has been in operation. This includes previous savings from now-mature units and decommissioned units, even though these units are not included in the current year's savings.

Once cumulative energy savings have been determined, long-term impacts on the environment are calculated by estimating the associated reduction of air pollutants. This calculation is straightforward, based on the type of fuel saved and the pollutants typically associated with combustion of that fuel. For example, for every million Btu of coal combusted, approximately 1.25 pounds of sulfur oxides (known acid raid precursors) are emitted to the atmosphere. Thus, every million-Btu reduction in coal use results in the elimination of 1.25 pounds of polluting sulfur oxides.

The results for annual and cumulative energy saving, as well as cumulative pollutant emission reductions for actively tracked technologies, are shown in Table 1 on pages 8 and 9.

## Deriving the ITP Cost/Benefit Curve

The approach to estimating the net benefits of ITP energy savings used here relied on the following methodology: First estimate the Cumulative Production Cost Savings which provides an estimate of the gross benefit of the ITP program since its inception. Next estimate the Cumulative Appropriations that were allocated by the government to support the development of these technologies that saved energy. Finally make adjustments to the gross energy savings to account for the cost to industry of adopting the new technologies. The method is based on the following sequence of steps:

- Cumulative energy savings – the accumulated energy savings (Btu) produced by ITP-supported technologies have been commercialized and tracked since the program began. As of 1997, this figure was 1662 trillion Btu and in 2004 it was 3,270 trillion Btu.

- ITP appropriations – cumulative funding provided for ITP programs. As of FY 2004, this number was $2.30 billion.

- Cost of industrial energy saved – the average fuel price (dollars/Btu) that would have been paid to purchase energy multiplied by annual savings. Average industrial energy prices since 1978 are constructed based on Bureau of Labor Statistics (BLS) fuel price indexes. The nominal prices (in dollars per million Btu) for various fuels are reported in the Energy Information Administration's Annual Energy Review; these are extended back in time by applying the BLS producer price index for number 2 fuel oil, natural gas, coal and electricity, normalized to a base year (currently 2000). These annual fuel prices are multiplied by the amount of energy saved per fuel type per year for each of the ITP commercialized and tracked technologies.

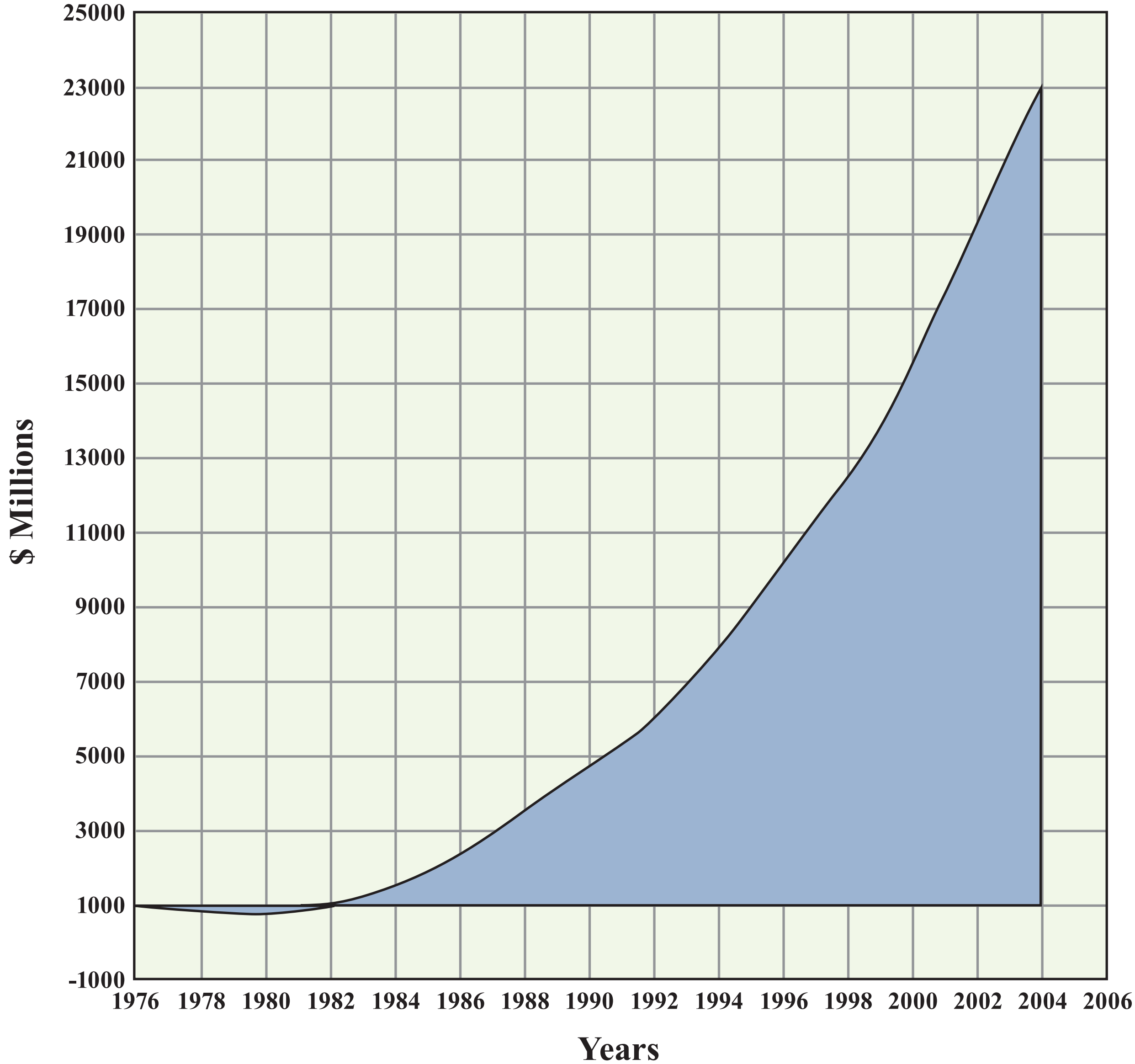
- Correct for Implementation Costs – Since we do not have reliable information about the incremental capital and operating and maintenance costs of these new technologies, an assumption must be made to adjust for these costs. The assumption we use is that industry demands at least a two-year payback period on all such investments, so we ignore the first two years of the cumulated energy savings for each of the technologies, arguing that these first two years savings are needed to recoup the life-cycle capital costs of adopting the new technology.

For each technology, the annual energy savings by fuel type is multiplied by the price of that fuel with price adjustments reflecting current costs of that fuel. The sum of all energy saved times the average energy price yields an estimate of the annual savings for all technologies in that particular year. In addition to technology energy savings, savings from the IAC and BestPractices Programs were also determined on an annual basis as described in Appendices 4 and 5, respectively. The net economic benefits are the accumulation of these savings over time with the net economic costs being ITP appropriations and the implementation costs reflected in the two-year payback period. These net benefits are then adjusted for inflation using the annual implicit price deflator for GDP, as published by the Bureau of Economic Analysis of the U.S. Department of Commerce, but renormalized to the current year so that all savings are reported in 2004 dollars.

Just as there may be benefits not accounted for by this method – spin offs, derivative technologies, etc. – there may be incremental costs not accounted for by this method. For example, there may be incremental capital costs associated with the use of a particular technology that are not currently captured in the tracking process, and thus are not included in the cost side of the equation.

The results of the application of this method are shown in the graph on page 162.

## Cumulative Production Cost Savings Minus Cumulative Program and Implementation Costs




*The cumulative Federal costs for the ITP Programs through fiscal year 2004 total $2.30 billion. Cumulative energy savings from completed and tracked ITP projects and programs add to approximately 4.72 quadrillion Btu in 2004, representing a net cumulative production cost savings of $23.1 billion after adjusting for inflation (using the implicit price deflator for GDP, renormalized to 2004). These production cost savings represent the net total value of all energy saved by technologies developed in ITP programs plus the energy cost savings from the IAC and BestPractices Programs, minus the cost to industry of using the technologies (estimated by assuming a two-year payback on investment) minus ITP Program costs. The graph shows that benefits substantially exceed costs.*

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