Final Project Report

Project Title: Energy Saving Method of Manufacturing Ceramic Products from Fiber Glass Waste

Project Period: April 15, 2003 to April 15, 2005

Date of Report: July 15, 2005

Recipient: Haun Labs, 122 Calistoga Rd., #116, Santa Rosa, CA, 95409

Award Number: DE-FG36-03GO13014

Working Partners: DOE, Haun Labs, and Fiber Glass Manufacturers

Cost-Sharing Partners: Haun Labs

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EXECUTIVE SUMMARY

The U.S. fiber glass industry disposes of more than 260,000 tons of industrial fiber glass waste in landfills annually. New technology is needed to reprocess this industrial waste into useful products.

A low-cost energy-saving method of manufacturing ceramic tile from fiber glass waste was developed. The technology is based on sintering fiber glass waste at 700-900°C to produce products which traditionally require firing temperatures of >1200°C, or glass-melting temperatures >1500°C. The process also eliminates other energy intensive processing steps, including mining and transportation of raw materials, spray-drying to produce granulated powder, drying pressed tile, and glazing. The technology completely transforms fiber glass waste into a dense ceramic product, so that all future environmental problems in the handling and disposal of the fibers is eliminated.

The processing steps were developed and optimized to produce glossy and matte surface finishes for wall and floor tile applications. High-quality prototype tile samples were processed for demonstration and tile standards testing. A Market Assessment confirmed the market potential for tile products produced by the technology. Manufacturing equipment trials were successfully conducted for each step of the process. An industrial demonstration plant was designed, including equipment and operating cost analysis.

A fiber glass manufacturer was selected as an industrial partner to commercialize the technology. A technology development and licensing agreement was completed with the industrial partner. Haun labs will continue working to transfer the technology and assist the industrial partner with commercialization beyond the DOE project.

PROJECT DESCRIPTION

I. Original Project Goals and Objectives

The overall objective of this project was to provide the basis for the design and construction of an energy-efficient manufacturing plant to convert large volumes of fiber glass waste into high-quality ceramic tile. The main objectives were to complete process development and optimization, construct and test prototype samples, conduct market analysis and commercialization planning, and to design an industrial demonstration plant. The specific milestones and tasks of the project are listed in Table I.

Table I - Project Milestones and Tasks

Milestone/ Task Number	Milestone/Task Title
Milestone 1	***Phase I Development and Testing***
Task 1.1	Optimization of Process Variables
Task 1.2	Glass Powder Characterization
Task 1.3	Phase I Prototype Fabrication
Task 1.4	Phase I Prototype ANSI Testing
Task 1.5	Phase I Demonstration Samples and Data
Milestone 2	***Phase II Development and Testing***
Task 2.1	Development of Product Formulations
Task 2.2	Formulation Characterization
Task 2.3	Phase II Prototype Fabrication
Task 2.4	Phase II Prototype ANSI Testing
Task 2.5	Phase II Demonstration Samples and Data
Milestone 3	***Plant Design/Cost Analysis***
Task 3.1	Initial Demonstration Plant Design
Task 3.2	Equipment Evaluations
Task 3.3	Final Demonstration Plant Design
Milestone 4	***Market Analysis/Commercialization Planning***
Task 4.1	Conduct Additional Market Analysis
Task 4.2	Determine Initial Product Focus
Task 4.3	Expand Commercialization Plan
Task 4.4	Investigate Potential Industrial Partners
Task 4.5	Attend Conferences and Trade Shows
Milestone 5	***Project Management and Reporting***
Task 5	Project Management and Reporting

II. Variance from Original Goals and Objectives

Overall the project goals were completed as planned, and on schedule or ahead of schedule. A significant variance resulted from the selection of an industrial partner much earlier than originally planned. The assistance from the industrial partner allowed most of the project to proceed ahead of schedule. This also allowed additional work to be completed towards commercialization of the technology, especially related to equipment and manufacturing trials, cost analysis, and establishing additional commercialization partners. Further details of are discussed in the following sections.

III. Discussion of Project Results

The project was divided into 19 tasks as listed in Table I. The project results are summarized in the following sections for each of these tasks.

A. Phase I Optimization of Process Variables and Glass Powder Characterization (Tasks 1.1 and 1.2)

Several types of fiber glass reinforcement and insulation waste samples from fiber glass manufacturers were investigated. The Phase I work was originally planned to focus on fiber glass reinforcement waste, but because of interest from insulation manufacturers, insulation waste was also included. The different as-received fiber glass wastes varied significantly, depending on the source of the waste and amount of previous processing. Variations occurred in the length of the fibers, moisture content, amount of binder (or sizing), and level of contamination.

Methods were developed to process all of the waste types into powder, which was then granulated with binder, pressed, and fired into dense ceramic samples. The process variables were optimized for both reinforcement and insulation types of fiber glass waste. Reinforcement waste requires firing temperatures of 850-950°C, while insulation waste only requires firing temperatures of 700-800°C, because of the differences in glass composition.

The main variables for each step of the process were investigated, including fiber glass waste type, fiber particle size, binder content, granulation conditions, pressing pressure, and firing temperature and time. Several properties were measured to optimize these variables. The green density and green strength were measured on pressed samples. The fired density and water absorption were measured on fired samples. The surface appearance was also used to optimize the variables. A wide range of colors and surface textures were produced, depending on the type of fiber glass waste and colorant and/or filler additions.

The glass powder particle size was varied by changing the milling conditions, and characterized by sieve analysis. The weight loss, and densification and crystallization behavior of granulated powders were characterized by Differential Thermal Analysis (DTA) and Thermo Gravimetric Analysis (TGA) at Orton Testing Services (Westerville, OH). The crystallization behavior was further investigated by x-ray diffraction on fired samples, which were crushed, ground into powder, and sent to the Mineral Lab (Lakewood, CO) for x-ray diffraction (XRD).

The glass powder characterization results were correlated with the initial powder processing, and also the subsequent processing steps of binder addition, granulation, pressing, and firing, as well as the resulting fired properties. The characterization results established an initial baseline of information for the next steps of the development work. This work completed Tasks 1.1 and 1.2, and provided optimized procedures for the remaining tasks of the project.

B. Phase I Prototype Fabrication, ANSI Testing, and Demonstration Samples (Tasks 1.3, 1.4, and 1.5)

The optimized procedures developed during Task 1.1 (Optimization of Process Variables) were used to fabricate over 600 prototype ceramic tile for ANSI Standards Testing and for demonstration samples. Tile with surface dimensions of 1” x 1”, 2” x 2”, and 1” x 4” were processed from both reinforcement and insulation types of fiber glass waste. The ANSI Ceramic Tile Standards Testing was conducted independently at the Tile Council of America on samples made from 100% fiber glass waste.

The results of the ANSI testing are listed in Table II. The testing was originally planned to be conducted on only reinforcement fiber glass waste samples, but was expanded to also include samples made from fiber glass insulation waste (discussed in previous reports). Because of this, a greater number of samples were tested, but less tests were run than originally planned. The seven most important tests were selected, as listed in Table II. The ASTM test procedures are also listed, along with the ANSI specifications.

The samples were sintered to almost the maximum theoretical density with very low porosity. This resulted in water absorptions of <0.04%, well below the porcelain tile specification of <0.5%. The porcelain tile water absorption specifications are the lowest of four tile categories, and represent the highest quality tile. The bond strengths of both types of fiber glass tile were >120 psi, significantly greater than the ANSI specification of >50 psi.

The abrasion resistance index of the reinforcement waste tile was >130, above the porcelain tile specification of >100. The insulation waste tile had an abrasion resistance of >60, above the clay-based tile specification of >50, but below the porcelain tile spec. The insulation waste tile had a more glossy surface finish compared to the reinforcement tile, and thus would probably be utilized more for wall tile applications

Table II - Property Data for Ceramic Tile made from 100% Fiber Glass Waste

(All testing conducted by the Tile Council of America)

Test Description	ANSI A137.1 Specification	Fiber Glass Reinforcement Waste	Fiber Glass Insulation Waste
Water Absorption (ASTM C373)	< 0.5% for Porcelain Tile	< 0.04%	< 0.04%
Bond Strength (ASTM C482)	> 50 psi	> 120 psi	> 120 psi
Abrasion Resistance (ASTM C501)	Clay-based: >50 Porcelain: >100	> 130	> 60
Breaking Strength (ASTM C648)	> 250 lbs	> 500 lbs	> 500 lbs
Chemical Resistance (ASTM C650)	No effect to a wide range of chemicals	Passed	Passed
Freeze-Thaw Cycling (ASTM C1026)	No cracking, etc.	Passed	Passed
Scratch Hardness (MOH's Scale)	No spec given	5	4

where abrasion resistance is not as important as in floor tile applications. These results were for 100% waste glass tile. The addition of crystalline fillers was utilized in the Phase II development work (discussed below) to further enhance properties, such as abrasion resistance.

Both the reinforcement and insulation waste glass tile had breaking strengths >500 lbs, well above the ANSI specification of >250 lbs. Both tile types also passed the chemical resistance testing, which involves exposure to fifteen different chemical including hydrochloric acid and potassium hydroxide. Passing the chemical resistance testing is very significant, because 100% waste glass tile were tested. This indicates that these glass compositions can be used to develop ceramic tile for a wide range of applications where chemical resistance is required.

Both types of tile also passed the freeze-thaw testing, which indicates that the tile can be used in outdoor applications in cold climates. The scratch hardness was tested using the MOH's scale with values of 5 for the reinforcement waste tile, and 4 for the insulation waste tile. These results are similar to those of commercial glass tile, however the hardness can be greatly increased with the addition of crystalline fillers (discussed below in Phase II development work).

The initial ANSI test results demonstrate that high quality tile for a wide variety of applications can be made from 100% reinforcement and insulation fiber glass waste. Demonstration samples were made from both types of waste with ceramic stains (colorants) added to demonstrate the range of colors possible.

C. Phase II Development of Product Formulations and Formulation Characterization (Tasks 2.1 and 2.2)

The Phase II development work involved development of product formulations and methods as originally planned, but was also expanded to include additional laboratory and manufacturing scale-up evaluations with the assistance of the industrial partner (discussed in Task 4.4). The work consisted of:

- Additional development of colors and surface appearance,
- Scale-up of laboratory mixing, granulating, and pressing equipment,
- Manufacturing-scale mixing, pressing, and firing trials, and
- Evaluation of carrier plates and release agents for firing.

Additional work to further develop colors and surface appearance of tile was conducted. The range of colors possible with different fiber glass waste streams were determined by preparing samples with a series of commercial ceramic stains. The range of colors possible was found to depend on the level of iron contamination present in the waste glass, with higher iron levels limiting the range of colors possible to only darker colors. This work demonstrated the need for reducing iron contamination during the initial waste glass processing steps.

The amount of ceramic stain was varied to determine the effect of stain level on the resulting color. Waste streams with low levels of iron contamination were found to produce a wide range of colors with only small amounts of stain required. The results indicate that the color saturates with only a small amount of stain addition (<1%). The amount of stain required is much less than needed in clay-based tile, which will result in a significant cost savings.

The method of stain addition was investigated by adding stain during different steps within the mixing and granulating process. Solid and multiple-color tile were obtained by different methods of stain addition and by controlling the granulated particle size. Combinations of different glass particle sizes were investigated to produce speckled colors, and to add a transparent appearance compared to the translucent appearance previously developed.

Methods of controlling the surface texture were further developed. Several types of surface textures or finishes were processed ranging from glossy to matte, and from smooth to rough. These surface textures were controlled by variations in glass type, glass-filler formulations, and firing conditions. Over 500 samples were prepared to demonstrate the wide range of colors and surface textures that were possible with the technology. These samples were used at the Coverings ceramic tile trade show as further discussed below (Task 4.5).

New laboratory equipment was purchased with assistance from the industrial partner, and set up at Haun Labs for processing larger batch sizes and tile samples. The mixing and granulating steps were previously conducted with manual processes. These steps were automated with three pieces of equipment, which increased the batch size possible, and ease and speed of processing. A larger press with 150,000 lbs of pressing capacity was also installed, six times greater than the previous press. A new 5” x 5” die was also machined for the press. Larger sized demonstration and test samples were processed with the new equipment.

Thirty-five batches of granulated powder were made from fiber glass waste with the lab-scale equipment, and shipped to a large U.S. ceramic tile company for manufacturing-scale pressing and firing trials. The Principal Investigator, along with engineers from the Industrial Partner, traveled to the tile company to observe and assist with the manufacturing evaluation. Tile with sizes of 2”x2”, 4”x4”, 6”x6”, and 12”x12” were successfully pressed with good green strength for handling and transport to the firing process. The pressed tile were then fired in a production scale roller kiln (~300’ long). The tile fired well, demonstrating that even large format 12”x12” tile can be processed by the technology. Tile with a textured surface, compared to a smooth surface, were also processed successfully.

A large-scale mixing and granulating evaluation was conducted in the test lab of a mixing equipment manufacturer. Over two tons of granulated fiber glass powder was prepared. The evaluation demonstrated that the mixing equipment will work well for the process, but also provided a large amount of powder for future pressing and firing trials. A second mixing evaluation was conducted at another company with a different type of mixer. This mixer also successfully granulated the powder, and thus provides an alternate mixing method for the technology.

The current process involves firing the pressed tile on refractory carrier plates for transport through a continuous kiln. The carriers provide support for the glass tile during sintering, and need to be coated with a release agent (or kiln wash) to prevent sticking with the glass. Work was conducted to evaluate various refractory carrier plates, and to develop improved release agents. Suitable carriers and release agents were identified.

Characterization of the product formulations and test samples was originally planned to be conducted by external labs (Task 2.2). However, this work was accomplished by Haun Labs and the Industrial Partner, and external labs were not needed. The costs for this work only involved Haun Labs labor, and thus were included within Task 2.1, and not charged to Task 2.2.

D. Phase II Prototype Fabrication, ANSI Testing, and Demonstration Samples and Data (Tasks 2.3, 2.4, and 2.5)

The Phase II prototype fabrication (Task 2.3) was originally planned to focus on processing samples for ANSI testing (Task 2.4) based on the improvements made from the Phase II development work. However, the extensive ANSI testing conducted during Phase I, separately with the Industrial Partner over the past year, and from previous work already provided enough data to complete the goals of the Phase II ANSI testing. Over 1000 prototype tile samples with twelve different types of glass formulations, surface appearances, and resulting properties were previously tested by the Tile Council of America. Because of the previous ANSI testing, work on Tasks 2.3 and 2.4 focused on additional process development and prototype fabrication to assist with the scale-up and commercialization activities of the industrial partner.

The work consisted of:

- Testing large lots of granulated fiber glass powder,
- Evaluation of carrier plates and release agents for firing,
- Development of methods to process shaped tile pieces,
- Evaluation of additional fiber glass waste streams,
- Additional development of colors and unique surface appearances, and
- Fabrication of demonstration samples.

A large-scale mixing and granulating evaluation was conducted in the test lab of a mixing equipment manufacturer, as previously discussed (Task 2.1). Over two tons of granulated fiberglass powder was prepared in eleven lots. These lots were evaluated by particle size analysis, binder content, green density and strength after pressing, and fired density and appearance. The particle size distribution of granulated glass powder was found to control the processing and properties.

Additional work was conducted to evaluate several types of refractory carrier plates, and to develop improved release agents for use during firing. Raw materials for possible use as release agents were investigated by studying the interactions during firing with various glass compositions and carrier plates. Suitable carriers and release agents were identified and further optimized.

Previously the prototype tile consisted of flat samples. Curved and shaped tile are also needed for trim pieces. Traditional tile manufacturing of trim pieces typically involves forming the shape during the pressing step. This method can also be used to process shaped pieces of glass tile. However, because of the softening behavior of the glass, curved and shaped pieces can be formed from flat pressed tile by slumping the glass into or around a mold during firing. Initial work was conducted to demonstrate the possibility of shaping the tile by slumping during firing. Curved pieces were processed from both unfired and pre-fired flat samples.

Additional work to further develop colors and unique surface appearances was conducted. Processing methods to produce several types of speckled color and transparent surface layer appearances were developed by combining different glass powder formulations and particle sizes. Four of the tile types were developed with a series of color combinations, and samples of each type prepared for display boards. Thirty color combinations were developed for two of the tile types, eighteen color combinations for the third type, and fourteen color combinations for the fourth type. The display samples demonstrate the unique glass tile appearances possible with the technology, and are currently were used by the industrial partner to help promote the commercialization activities.

Additional demonstration samples were fabricated from previous and new waste glass streams for the industrial partner and for prospective third party partners. Meetings with several tile and waste glass companies were held to establish additional partners to assist with commercialization of the technology. Business relationships with multiple companies were developed, with the goal to construct one or more initial manufacturing plants.

E. Initial Demonstration Plant Design (Task 3.1)

An initial design of a demonstration plant was completed. Potential equipment for the plant was identified, and plans were made for test trials at equipment manufacturers test labs. This work was conducted earlier than planned, because of the success of the Phase I development work, and interest from the industrial partner to move the project along quickly.

F. Equipment Evaluations (Task 3.2)

Equipment evaluations were conducted for the main steps of the process: mixing/granulating, pressing, and firing. The Principal Investigator, along with engineers from the Industrial Partner, traveled to four companies to observe and assist with the evaluations. Fiber glass waste from the industrial partner was shipped to a company which manufactures a special type of mixing equipment. Several formulations were prepared and processed in the mixers. The results were very promising, with the mixing and granulating completed in a single step as planned.

Granulated powders from the mixing/granulating trial were then shipped to a second company for pressing and firing evaluations. Production-scale equipment was used to press and fire tile samples. The granulated powder pressed well, and did not appear to have any significant problems during the pressing operation. The pressed tile had good green strength for transfer to the firing.

A production scale continuous furnace was used for the firing evaluation. Several firing profiles were investigated to optimize the process. Firing evaluations were also conducted at two additional furnace manufacturers by transporting pressed tile to these companies. Again, various firing profiles were investigated in continuous production-scale furnaces. Dense fired tile were produced in rapid firing times with several types of surface texture.

These initial equipment trials demonstrated that the process can be scaled up to production-scale equipment, and that the selected equipment was suitable for the process. By using production-scale equipment, compared to the previous lab-scale process, several improvements in the processing and properties of the tile were observed. These improvements include: enhanced mixing and granulating; higher green strength after pressing; and greater control over the surface appearance of fired tile.

Eleven additional equipment trials, beyond the initial four, were conducted over the course of the project as part of other tasks and as extensions to the project. This was made possible with the assistance from the industrial partner.

G. Final Demonstration Plant Design (Task 3.3)

A final demonstration plant design was developed based on the initial plant design and subsequent equipment trials. Three larger plant sizes were also investigated with the capability for full-scale glass tile manufacturing. The plant size required to produce a competitively priced product will depend on the waste glass sources uses, and initial product types targeted. Quotations for the manufacturing equipment were obtained, and process specifications developed. Additional equipment trials were also conducted to further evaluate the equipment, and to allow the proper designs to be specified.

H. Conduct Additional Market Analysis (Task 4.1)

Additional market analysis was conducted to determine the potential of selling recycled-glass tile processed from fiber glass waste. A ceramic tile market study was obtained, which provides extensive market data, and projects continued growth in the U.S. tile market. Information was also gathered on current glass tile products and companies, only a few of which utilize recycled glass as raw material. Additional market data was collected at the Coverings ceramic tile trade show, as discussed in Task 4.5 below. The market analysis was used to determine the initial product focus and market introduction strategy (Task 4.2). This information was also used as part of the commercialization plan, which was developed in Task 4.3.

A DOE Market Assessment of the technology was completed during the project by New Horizon Technologies. The report has been a very useful document in promoting the development and commercialization of the technology. The information collected greatly extends the results of an earlier assessment, which was conducted for a previous Container Glass Waste I&I Project. The new assessment provides useful additional information on the glass tile segment within the ceramic tile market.

Important conclusions from the report:

- "Several industry representatives believe that a high-quality glass tile produced domestically and priced comparably to existing ceramic tile could do very well in the market, particularly if it possesses the highly desirable aesthetic characteristics of existing glass tile."

- “Large glass tile would sell well if technical problems can be addressed.”

- “According to respondents interviewed for this assessment, large glass tile remains an unfilled niche. Several individuals predicted that if a manufacturer were to market a large tile, the market would embrace it immediately.”

The assessment confirms the market potential for the technology. The I&I project has demonstrated that high-quality glass tile can be produced and priced comparably to ceramic tile. The manufacturing trials indicate that large-sized 12”x12” tile can also be manufactured.

I. Determine Initial Product Focus (Task 4.2)

The ceramic tile market consists of a wide range of products and selling prices, and thus there are various approaches possible for introduction of a new recycled-glass tile product. The market analysis conducted as part of Task 4.1 was used to determine the initial product focus for the Phase II Development Work. This was based on analysis of the ceramic tile market, and in particular the glass tile segments of the market.

Two product types were chosen for development during Phase II; one with a glossy appearance for wall tile applications, and a second with a rougher matte surface for floor tile applications, where greater abrasion and slip resistances are needed. With this approach a set of matching colors for the glossy and matte tile can be designed, with color-coordinated combinations that can be used for complete wall and floor tile installations.

J. Expand Commercialization Plan (Task 4.3)

The commercialization plan for the technology was further developed based on the results of the Phase I work, market and product analysis, results of the equipment trials, and planning with the industrial partner. The early selection of an industrial partner and the activities of the partner advanced the commercialization process much faster than originally planned, as discussed in the next section.

K. Investigate Potential Industrial Partners (Task 4.4)

The goal of this task was to select an industrial fiber glass partner to work with to commercialize the technology following the project. This task was originally planned for the second year of the project, however because of strong interest from fiber glass manufacturers, work on this task was started during the first quarter of the project. In addition to obtaining fiber glass waste samples, extensive discussions about the technology and the project were conducted with the manufacturers.

An industrial partner was selected much earlier in the project than originally planned. A technology development and licensing agreement to commercialize the technology was completed with the partner. With the assistance of the industrial partner the project proceeded much fasted than planned, and was greatly expanded, especially with equipment and manufacturing trials, and cost analysis.

The industrial partner is actively continuing to commercialize the technology with a business development and engineering team. Agreements with equipment suppliers and additional commercialization partners (tile manufacturers and waste glass processors) have been established. Haun Labs will continue working to transfer the technology and assist the industrial partner with commercialization beyond the DOE project.

L. Attend Conferences & Trade Shows (Task 4.5)

The Principal Investigator attended the worlds largest international ceramic tile trade show, Coverings, in Orlando, FL in 2003, 2004, and 2005. Each year about 1,300 companies have exhibited with over 27,000 visitors from around the world. There has been considerable interest in glass-based tile. The number of companies exhibiting glass tile has increased dramatically in the past few years, however only a few of the companies use recycled glass. There is a large market for glass tile, especially made from recycled glass, if the sales price can be brought down from the very high current levels, often >$30/sq.ft. These high prices are required, because the current technologies are expensive. Glass products manufactured with the new technology will be very competitive with current glass tile, and even with low-priced ceramic tile, because of the substantial economic savings that are possible.

Employees from the industrial fiber glass partner also attended Coverings, and met with selected tile companies to show demonstration samples, and to explore possible collaboration. Partnering with a tile company offers several advantages to rapidly commercialize the technology, including the use of existing manufacturing facilities and established distribution channels. Positive feedback was received concerning the technology and demonstration samples, and agreements with tile companies have been established.

The Principal Investigator together with employees from the industrial partner attended two additional trade shows in 2004: Cersaie in Bologna, Italy and Technargilla in Rimini, Italy. Cersaie is one of the largest international ceramic tile trade shows in the world held each year. Over 500 ceramic tile companies had exhibits, with most of the companies from Italy. Technargilla is the most important trade show for ceramic equipment manufacturers, and is held every two years. This year there were over 30,000 attendees.

Italy leads the world in ceramic tile manufacturing, in terms of innovation and volume of exports. The U.S. imports 34% of ceramic tile from Italy, far more than from any other country, including domestically produced tile, which accounts for 22% of the market. Almost all ceramic tile manufacturing equipment is produced by Italian equipment manufacturers. Meetings were held with several ceramic tile companies from Italy and other countries from around the world to discuss possible collaboration in commercializing the technology. Meetings were also held with the major equipment manufacturers to obtain quotations for equipment, and to schedule equipment trials. The contacts developed at these meetings have led to additional commercialization partners and equipment suppliers.

M. Project Management and Reporting (Task 5)

Project management and reporting activities during the project consisted of all project planning, management, and reporting activities. The tables on the following pages summarize the work conducted and project costs according to task.

IV. Conclusions and Future Plans

A low-cost energy-saving method of manufacturing ceramic tile from fiber glass waste was developed. The processing steps were optimized to produce glossy and matte surface finishes for wall and floor tile applications. High-quality prototype tile samples were processed for demonstration and tile standards testing. A Market Assessment confirmed the market potential for tile products produced by the technology. Manufacturing equipment trials were successfully conducted for each step of the process. An industrial demonstration plant was designed, including equipment and operating cost analysis.

A fiber glass manufacturer was selected as an industrial partner to commercialize the technology. A technology development and licensing agreement was completed with the industrial partner. Haun labs will continue working to transfer the technology and assist the industrial partner with commercialization beyond the DOE project.

Appendix A - Final Task Schedule

Task Number	Task Description	Task Completion Date				Progress Notes
		Original Planned	Revised Planned	Actual	Percent Complete	
1.1	Optimization of Process Variables	10/15/03		9/30/03	100%	Competed
1.2	Glass Powder Characterization	10/15/03		9/30/03	100%	Competed
1.3	Phase I Prototype Fabrication	12/15/03		11/15/03	100%	Competed
1.4	Phase I Prototype ANSI Testing	01/15/04		11/30/03	100%	Competed
1.5	Phase I Demonstration Samples & Data	01/15/04		12/31/03	100%	Competed
2.1	Development of Product Formulations	07/15/04		6/30/04	100%	Competed
2.2	Formulation Characterization	07/15/04		6/30/04	100%	Competed
2.3	Phase II Prototype Fabrication	09/15/04		8/31/04	100%	Competed
2.4	Phase II Prototype ANSI Testing	10/15/04		8/31/04	100%	Competed
2.5	Phase II Demonstration Samples/Data	10/15/04		10/15/04	100%	Competed
3.1	Initial Demonstration Plant Design	11/15/04		1/31/04	100%	Competed
3.2	Equipment Evaluations	01/15/05		2/29/04	100%	Competed
3.3	Final Demonstration Plant Design	02/15/05		11/12/04	100%	Competed
4.1	Conduct Additional Market Analysis	08/15/03		06/30/03	100%	Competed
4.2	Determine Initial Product Focus	12/15/03		11/30/03	100%	Competed
4.3	Expand Commercialization Plan	04/15/04		2/29/04	100%	Competed
4.4	Investigate Potential Industrial Partners	10/15/04		11/30/03	100%	Competed
4.5	Attend Conferences & Trade Shows	04/15/05		10/2/04	100%	Competed
5	Project Management and Reporting	07/15/05		7/15/05	100%	Competed

Appendix B - Final Spending Schedule

Project Period: 04/15/03 to 04/15/05

Task		Approved Budget	Final Project Expenditures
1.1	Optimization of Process Variables	50,000	51,400
1.2	Glass Powder Characterization	2,000	1,885
1.3	Phase I Prototype Fabrication	15,000	14,600
1.4	Phase I Prototype ANSI Testing	6,000	4,235
1.5	Phase I Demonstration Samples & Data	7,500	7,000
2.1	Development of Product Formulations	50,000	55,900
2.2	Formulation Characterization	4,000	0
2.3	Phase II Prototype Fabrication	15,000	16,000
2.4	Phase II Prototype ANSI Testing	12,000	0
2.5	Phase II Demonstration Samples/Data	7,500	9,600
3.1	Initial Demonstration Plant Design	7,500	8,000
3.2	Equipment Evaluations	15,000	17,600
3.3	Final Demonstration Plant Design	7,500	13,200
4.1	Conduct Additional Market Analysis	6,000	6,300
4.2	Determine Initial Product Focus	6,000	8,800
4.3	Expand Commercialization Plan	6,000	5,000
4.4	Investigate Potential Industrial Partners	9,000	12,800
4.5	Attend Conferences & Trade Shows	9,000	10,400
5	Project Management and Reporting	15,000	13,000
	Total	250,000	255,720
	DOE Share	200,000	200,000.00
	Cost Share	50,000	55,720.00

Appendix C - Final Cost Share Contributions

Funding Source	Approved Cost Share		Final Contributions	
	Cash	In-Kind	Cash	In-Kind
Haun Labs		50,000		55,720.00
Total		50,000		55,720.00
Cumulative Cost Share Contributions				55,720.00

Appendix D - Energy Savings Metrics

One Unit of Proposed Technology:

One unit of the proposed technology consists of one million square feet of ceramic tile production from fiber glass waste.

One Unit of Current Technology:

One unit of the current technology consists of one million square feet of ceramic tile production from clay-based raw materials.

Discussion of Energy Savings:

The new technology requires substantially less energy compared to current clay-based tile production, because the firing temperatures are lowered, and the spray-drying and drying steps are eliminated. Data from the 1997 Economic Census on Ceramic Wall and Floor Tile Manufacturing from the U.S. Dept. of Commerce were used to determine the energy consumption of current ceramic tile manufacturing. These data indicate that for each installed unit of one million square feet of tile production 13.3 billion Btu are consumed from natural gas usage, and 7.1 billion Btu from electricity.

Data from ceramic tile manufacturing equipment suppliers indicate that 60% of the natural gas usage is from firing, 30% from spray drying, and 10% from drying. The firing temperatures are reduced from 1200C for the current technology to 900C for the new technology with fiber glass reinforcement waste. This is a 25% reduction of 60% of the natural gas usage, or 15% of the total. Combined with the 40% savings from eliminating the spray-drying and drying steps, results in an overall reduction of 55% of the natural gas used. Electricity usage is similar between the current and new technologies.

The new technology, with 55% savings in natural gas, requires only 6.0 billion Btu/unit of production, with a savings of 7.3 billion Btu/unit. These data are summarized in the following table. The energy savings are greater than originally proposed, because the savings from eliminating the spray-drying and drying steps were previously not included.

Fifty installed units are estimated by 2010, which will consist of 50 million square feet of production from 200 million pounds of fiber glass waste (4 lbs/sq.ft.). This represents 30% of the 660 million pounds of fiber glass waste estimated in 2010. 50 million square feet is only 1.2% of the total U.S. ceramic tile market estimated in 2010, and thus only a small market penetration will be required. An energy savings of 365 billion Btu will result from processing 30% of the fiber glass waste with the new technology. With 100% of the waste used, 1.2 trillion Btu of energy will be saved.

Energy Savings Metrics

	A	**B**	**C=A-B**	**D**	**E=CxD**
Type of Energy Used	**Current Technology (Btu / yr / unit)**	**Proposed Technology (Btu / yr / unit)**	**Energy Savings (Btu / yr / unit)**	**Estimated Number of Units in U.S. by 2010 (units)**	**Energy Savings by 2010 (Btu / yr)**
Natural Gas	13.3 Billion	6.0 Billion	7.3 Billion	50	365 Billion
Electricity (@ 10,500 Btu / kWh)	7.1 Billion	7.1 Billion	0	50	0
Total Per Unit	20.4 Billion	13.1 Billion	7.3 Billion	50	365 Billion