Pittsburgh
Mineral &
Environmental
Technology, Inc.

"Initial Commercial Application of Waste Coal Brixx"

Final Report for
Pennsylvania Energy Harvest Grant

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Pittsburgh Mineral & Environmental Technology demonstrated the commercial feasibility of its Brixx Technology on its pilot plant by producing 3000+ bricks. Using waste fly and bottom ash from power plants to produce ASTM compliant bricks, this process uses 70% less energy and produces 50% fewer emissions than current production methods.

Narrative Description of Project

Pittsburgh Mineral & Environmental Technology (PMET) was awarded an Energy Harvest Grant by the Pennsylvania Department of Environmental Protection (DEP) to demonstrate its Brixx Technology in a project entitled: "Initial Commercial Application of Waste Coal Brixx". PMET has developed this patented technology (U.S. Patent # 6,068,803) and planned to demonstrate it with this grant using existing pilot scale equipment that had been funded by the Beaver County Co-Op. This Brixx process produces building products by combining lime with fly and bottom ash from coal combustion by-products. The raw materials are blended in a high intensity mixer capable of handling 100-150 pound batches. The desired shapes are pressed using a 318-ton hydraulic press. The products are cured in a five-foot diameter autoclave heated using steam generated by an electrically powered boiler.

Figure 1 – PMET Brixx Pilot Plant

The goal of this project was to demonstrate the Brixx Technology on a pilot scale to validate its feasibility on a commercial scale. Issues that would affect commercial production were to be identified and resolved at this pilot scale. Key parameters for full-scale production, both technical and economic, were also to be identified. Finally, it was hoped to produce a large quantity of pavers, which could be used in a visible construction project. To accomplish these goals required a number of steps, including optimization on the laboratory scale of a Brixx mix to be used in this study on the pilot scale, procurement of raw materials, pilot-scale production, and evaluation of the products per ASTM standards.

The components required to produce Brixx include fly ash, bottom ash, lime and pigment for colored Brixx. Two fly ash samples were evaluated based on their performance in PMET Brixx lab-scale samples. Brixx made from either fly ash were expected to pass ASTM standards for compressive strength. However, those produced using fly ash from the Hatfield Ferry power Plant in Masontown, PA were 43% stronger, based on compressive strength, than Brixx using Cheswick Fly Ash. The Hatfield Ferry Fly Ash was chosen since it would produce the stronger product. Bottom ash from the Niles Power Plant in Niles, OH was selected due to PMET's familiarity and successful use of this material in the past. Two sources of lime were evaluated: a fine hydrated lime from Mercer Lime and a lime kiln dust by-product. When used to produce Brixx samples, the fine hydrated Mercer Lime produced Brixx that were 70% stronger those made with the lime kiln dust. Although the purchased Mercer Lime was selected for this project, the small Brixx samples again indicated that either sample would have successfully met the ASTM standards for compressive strength. Finally, a source of low cost pigment material was found. Iron oxide, a by-product of an acid recovery process, was used to give the Brixx a red tint. Table 1 shows the optimized Brixx mix. Approximately 25 tons each of the fly and bottom ashes were obtained from their respective plants, ¾ of a ton of pigment was purchased, and lime was purchased as needed from a local supplier in 50 pound bags. The 25 tons of fly ash was made available to PMET because its LOI exceeded 3% and could not be sold as concrete additive.

Table 1 – Optimized Brixx Mix

Component	Source	Gray Brixx	Red Brixx
Fly Ash	Hatfield Ferry Power Plant	44%	42%
Bottom Ash	Niles Power Plant	44%	42%
Hydrated Lime	Mercer Lime	12%	11%
Pigment	Iron Oxide from Amrox	-	5%

PMET chose to produce a paving stone in this project that could be utilized in a small sidewalk project. A review of available paving stones at local home improvement stores revealed that a common, inexpensive paving stone measured 8" x 4" x 2 ¼". Producing this shape required modification of the current 8" x 8" die. Producing the new shape using the current die was accomplished by modifying the upper and lower rams of the press to produce 8" x 2 ¼" shape inside the current 8" x 8" die. The distance traveled by the upper ram would set the 4" dimension of the shape.

Figure 2 – Brixx with (Red) and without (Gray) Pigment

Once the raw materials were obtained, production began at the end of June. A total of 3120 Brixx were produced and production is summarized below in Table 2. Production was accomplished by mixing the materials in 150 pound batches. After dry mixing, the operator trimmed the moisture content and further blended the material. The mix was transferred to a container for pressing. The mix for each Brixx paver was weighed (ranging from 2300 to 2600 grams depending on moisture content), placed in the die, and pressed to 8830 psi. The first set of Brixx from each batch were measured, and the mass used for each Brixx was adjusted by 40 grams for each 1/16" deviation from 4" in width. The Brixx were stacked on a metal pallet. Every second or third day, the pallet was placed in the autoclave, where the Brixx were cured for 6 hours with steam at 200 psi (370°F). After cooling, the Brixx were inspected, rejects were separated, and the acceptable Brixx were stacked on wooden pallets.

Table 2 – Summary of Brixx Production

Month	Brixx Produced	Reject Rate	Total Acceptable Brixx
June	Shakedown Period - Rejects Not Tracked		80
July	680	27%	496
August	1152	9%	1044
September	710	3%	690
October	515	18%	423
November	440	12%	387
Total	3577	13%*	3120

Die wear, measured at intervals during production, was found to range from 32 to 64 µm per 1000 presses on surfaces exposed to shear forces. Die wear also caused some cosmetically unappealing black streaks along the surfaces of the Brixx, which will be resolved by using harder tool steel. Energy requirements of the pilot plant were measured and averaged 461 kW*hr per ton of product.

It was hoped to produce more than 3000 Brixx. However, a number of production steps took longer than initially anticipated. Weighing the material required for each piece and filling the die manually was very slow. The hydraulic press, selected for its flexibility in multiple die configurations, was also much slower than a commercial scale mechanical press would have been.

Aside from the production of 3,000+ Brixx pavers, the project also experienced a number of other successes. On the whole, scrap rate decreased from July to September due to operator experience and improving procedures. Once a new operator was put in place in October, scrap rate again dropped the following month.

Key issues were identified and resolved that will affect commercial scale production. A minimum amount of moisture is required to hold the Brixx together while "green" after pressing and before curing. Excessive mixing heated the material and could evaporate much of the moisture. However, to find the correct moisture balance and successfully press Brixx, the fly ash was dried prior to blending, mixing times were limited to three minutes, and operator discretion was used to determine water addition.

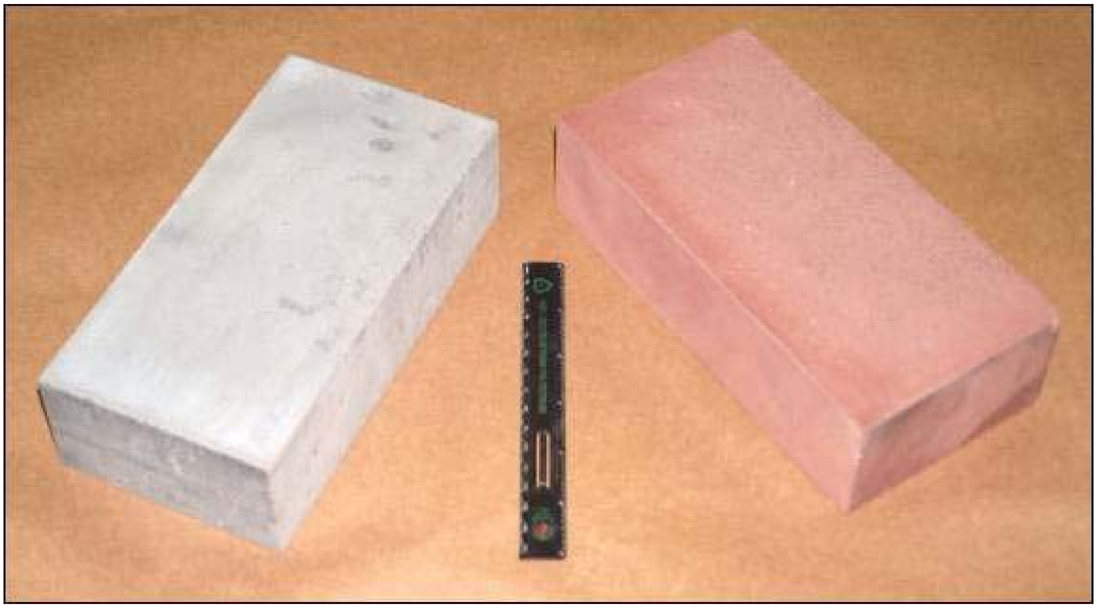
While pressing the Brixx on their side allowed two to be pressed per press stroke, this decreased the area of the mold to be filled, which increased the time to fill the mold. While a funnel was designed and constructed, a practiced operator could fill the mold more quickly with only a scoop. The hydraulic press used in the PMET pilot plant was not configured to press to a certain distance, but rather a specific pressure. This necessitated weighing the mix needed for each individual Brixx paver to ensure the 4" dimension was consistent. A defect named 'delamination' was observed on the PMET hydraulic press when the outer layer of the Brixx could be peeled away. Caused by air in the mix that could not escape, this defect was avoided by holding the pressure for 5-10 additional seconds after a press stroke. After curing, Brixx that did not meet ASTM standards for chips or exhibited cracking or delamination, were separated. However, 95% of the defects were due to chips. Rather than disposing these reject Brixx, they were crushed and were added to make up as much as 10% of subsequent mixes, taking the place of fly and bottom ash. A mechanical press will most likely be used for a commercial scale operation and can press to a more consistent volume eliminating the need to weigh each individual Brixx mix. The commercial die will be filled using an automatic shuttle device. However, during trials on a mechanical press, the current mix was found to be too fine to allow the air to escape in a fast mechanical press. This will be overcome by either designing a die that allows air to easily escape or using a coarser mix.

Figure 3 – Modified Die Pressing with Top Ram

Figure 4 – Modified Die with Bottom Ram Ejecting Brixx

Figure 5 – Brixx in Autoclave after Curing Cycle

Figure 6 – Example Brixx Products



The Brixx produced in this project met the physical property standards in ASTM standard C 902. The Brixx exhibited an average compressive strength of 8480 psi, well above the requirement of 4000 psi for molded pavers. When coated with water repellant, their 2.3% absorption in cold water over 24 hours was well below the 16% maximum. Tested for the saturation coefficient, defined as the ratio of cold-water absorption to absorption in boiling water for 5 hours, they measured 0.27, well below the maximum of 0.78. By monitoring the quantity of material placed in the die for each Brixx, size standards were met within the specified $^{1}/_{16}$”. Brixx were inspected after curing and those with chips larger than ¼” from an edge or $^{3}/_{8}$” from a corner were rejected, crushed, and reused in subsequent mixes. Therefore, the product meets severe weather criteria.

By completing this study, the following conclusions could be drawn:

- Production of 3,000+ Brixx on the pilot plant has shown that this process will be feasible on a commercial scale. Optimizing the mix on the laboratory scale translated into reproducibly strong products on the full-size scale. While Brixx were successfully pressed using a hydraulic press, a mechanical press appears more practical on a commercial scale. Aside from pressing at a faster rate, it can be configured to press to a consistent volume, allowing the die to be filled by volume using an automatic shuttle device. With the ability to reuse any scrap material, this process will generate zero waste. The wear rate on plates exposed to shear forces was measured between 32 and 64 µm per 1000 presses. Future die designs can incorporate features such as beveled edges and rough surfaces to make the Brixx more visually appealing.

- The Brixx produced in this program passed mechanical testing according to ASTM standards. The Brixx exhibited average compressive strength of 8,480 psi, well above the ASTM standard of 4,000 psi for molded bricks. With a water repellent applied, the Brixx exhibited a cold water absorption of 2.3%, well under the 16% limit, and a saturation coefficient of 0.27, again well beneath the limit of 0.78. This product meets severe weather criteria.

- Based on the measured energy consumption utilized by this pilot plant, it appears that the estimated lower energy requirements of a full-scale plant are feasible. The measured energy consumption of this pilot plant was 461 kW*hr per ton of Brixx products (one ton being equivalent to 370 Brixx each weighing approximately 5.4 pounds.) This energy requirement is less than other cited full-scale brick production plants utilizing kilns. This supports the belief that a full scale Brixx Plant will require 123 kW*hr/ton and be 3 to 10 times more energy efficient than current kiln technologies. This plant will be more efficient by using a mechanical press, using an oil-fired boiler, and managing steam usage between two autoclaves. A 13.5 million Brixx per year plant producing pavers similar to those described in this program would save between 10.7 and 42 GW*hr per year over cited clay fired brick kilns. This is an energy savings of 70 to 90%.

- This Brixx process is also environmentally friendly as it will reduce emissions over current clay fired brick technologies and utilize waste materials currently landfilled. Requiring less energy per ton of product will reduce CO_2 emissions. Using the PMET process should reduce emissions by 50% over other kiln-based processes. No HF emissions are expected, as opposed to kiln heated clay brick processes that emit an average of 0.38 lbs per ton of bricks produced. The same 13.5 million Brixx per year plant is expected to reduce CO_2 emissions by 4000 tons per year and HF emissions by 7 tons per year, while utilizing 32,000 tons of waste fly and bottom ash.

This project was successful in demonstrating the feasibility of the Brixx process. It has allowed PMET to refine and verify its commercial economic model, showing the Brixx Process to be competitive with current brick making processes. With the results of this study and some future development, construction and operation of a full-scale Brixx plant is likely.

This work has contributed to utilizing waste fly and bottom ash materials by demonstrating that the Brixx Process will be feasible on the commercial scale. The Brixx have been shown to pass ASTM standards for pavers. Further work includes PMET seeking a licensor of the technology and further developing the technology for that licensor. The Brixx can be further ASTM certified for severe weather performance per ASTM C 902 "If information on the performance of the units in a similar application of similar exposure and traffic is furnished by the manufacturer…" Therefore, PMET has placed 10 Brixx where they will be exposed to freeze/thaw conditions over a period of time. The dried weights of these Brixx have been recorded and freeze/thaw weather conditions will be recorded to demonstrate their ability to withstand these conditions. A streetscape architect commented that, cosmetically, the coloring of the PMET Brixx were too uniform. It was also observed that their smooth surface might be slippery. Future dies will be designed to give the exposed surface of the Brixx a rougher surface. This will break up the uniformity of the color, give the Brixx a more natural look, and provide a rougher, anti-skid surface. The architect preferred some of the edges of Brixx that were rejected for edge chips, stating that they were also more cosmetically appealing. Another feature of the new die will give the Brixx beveled edges. The 3,000+ Brixx produced in this study will be used to pave PMET's sidewalk in New Brighton along 8th Street. This will act as a genuine test site, having to withstand weather conditions and traffic.

Figure 7 – Laboratory Scale Brixx Produced with Roughened Surface

Aside from publishing this paper and making it available on the PMET website, PMET will present their Brixx process at the Engineering Sustainability 2005 Conference in Pittsburgh, PA in a poster presentation. Much of the poster will be based on the work in this project. PMET will also seek LEEDS certification on the Brixx product, which should also help to publicize this technology.

To prove the feasibility of this technology, the budgeted funds were adequate. Supplies and administrative budgets were very close to the actual funds spent. When possible, funds were shifted from 'Supplies', 'Equipment', 'Contract', and 'Other' to labor so that more Brixx could be made. Funds in the 'Equipment' were shifted since an alternative die-maker modified the die for much less than originally budgeted. Some of the Brixx ASTM absorption testing was done in-house rather than at an outside contractor, providing more funds to be available for labor. Finally, funds were shifted from the 'Other' category since the current fork truck at PMET could be utilized. The addition to labor allowed more Brixx to be produced, increasing the wealth of knowledge gained regarding the production of Brixx.

Performance Outcome Data

All energy consumed by the Brixx Pilot Plant during this project was electrical. During production, energy requirements of the high intensity mixer, hydraulic press, and autoclave boiler were calculated on a per ton basis. This usage was 461 kW*hr/ton of product. For the 5.4-pound Brixx pavers produced, one ton of product was equivalent to 370 Brixx.

A NICE[3] report entitled "Innovative Brick Kiln Uses Low Thermal Mass and Low NO_x Technologies to Save Energy and Reduce Emissions" cited energy requirements of 1,278 kW*hr/ton of product. Production of the 3,210 Brixx produced in the Brixx Pilot Plant saved 7,090 kW*hr of energy over that process.

At the commercial scale, it is estimated that a 13.5 million Brixx per year plant would require 123 kW*hr/ton of product. The improvement in energy consumption is due to the utilization of an oil-fired boiler to generate steam that heats the autoclave and the utilization of a mechanical press, which does not require a continuously running hydraulic pump. By using two autoclaves in a commercial plant, steam from one autoclave ending a cycle can be used to heat the second autoclave beginning its cycle. This commercial plant would save over 42 GW*hr of energy per year over the previously cited plant, an energy savings of 90%. A European Study entitled "Market Study into the Introduction of Roller Kilns in the Brick and Heavy Clay Industry" cited a more efficient clay brick kiln process requiring 416 kW*hr/ton. The commercialized PMET Brixx process would save 10.7 GW*hr per year over this process, an energy savings of 70%.

The PMET Brixx Process is also beneficial to the environment. The 13.5 million Brixx per year plant would utilize 32,000 tons of waste fly and bottom ash that would normally require landfilling. Due to the lower energy requirements, CO_2 emissions would decrease by 50%. A U.S. Environmental Protection Agency study entitled "Emission Factor Development of the Brick and Related Clay Products Industry" cited CO_2 emissions at 430 lbs per ton of product. A 13.5 million Brixx per year plant is expected to generate only 212 lbs of CO_2 per ton product, decreasing the total amount of CO_2 generated by nearly 4,000 tons per year. The HF compounds currently emitted from kilns, estimated to be 0.38 lbs/ton of product by the same report would essentially be eliminated since their source in clay bricks will be eliminated in the Brixx process. A 13.5 million clay fired brick per year plant with a Brixx plant would reduce these emissions by 7 tons per year.