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DEVELOPMENT OF ECONOMICALLY STABILIZED PHOSPHOGYPSUM COMPOSITES FOR SALTWATER APPLICATION

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DEVELOPMENT OF ECONOMICALLY STABILIZED PHOSPHOGYPSUM COMPOSITES FOR SALTWATER APPLICATION

FINAL REPORT

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DISCLAIMER

PERSPECTIVE

Every year sees an increase in the on-ground inventory of phosphogypsum both in Florida and other states where phosphoric acid is produced for fertilizer manufacture. Under the present EPA NESHAP rules, phosphogypsum use is prohibited due to the possible adverse health effects related to the radium content of the phosphogypsum. The rule provides for exemptions to allow use for a specific purpose where it can be demonstrated that the risk of using the phosphogypsum is no more than the risk associated with leaving it in the stack.

From the preliminary results it would appear that using phosphogypsum in a marine environment is an ideal means of utilizing this readily available under utilized raw material. While additional longer-term testing will need to be carried out, there does not appear to be any cause for concern about phosphogypsum mixtures contributing to problems in the marine food chain or contaminating the ocean or Gulf waters.

The problem of the stability of the phosphogypsum mixtures in sea water has been solved and the aggregate type particles made from the phosphogypsum mixtures have been shown to be satisfactory for oyster culch and recommended for riprap applications.

This report addresses the most critical question relative to the use of phosphogypsum mixtures, economics. As always, economics of manufacture are tied directly to the quantity of material that will be produced and this report assumes a production rate of 4.5 million tons per year. At this level of production the phosphogypsum mixtures have a cost advantage over the alternate materials that are now used. The question that remains unanswered is how fast the market for these mixtures can be developed and the extent of the market.

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ABSTRACT

An economic analysis of the production cost of PG:Class C fly ash:Portland Type II cement briquettes indicates that the most probable cost of 62%:35%:3% phosphogypsum: Class C fly ash: Portland Type II cement briquettes, based on a 4,500,000 ton per year production facility located near Tampa, Florida, would be $13.62. This estimated production cost does not give credit for the offset disposal cost, a cost that may range from a low of $1.50 per wet ton of PG to as much as $4 per wet ton. The former figure is judged to be a fairly reliable lower bound cost. However, the stated upper limit value is speculative. This cost would be highly dependent on the specific details of the disposal facility and the age of the facility. New disposal facilities will have to be constructed to meet liner and leachate and runoff collection facilities. Thus, the cost of PG disposal is expected to increase in the future. If a $4/ton offset disposal cost is accounted for in the production cost, the most probable cost of PG briquette production would decrease to $10.86/ton.

The range of stated PG briquette production costs can be compared to a cost of $27-28/ton of granite riprap in Tampa, Florida. Considering the comparative cost of PG briquettes and granite, the cost of a granite armored geogrid-reinforced PG briquette composite protective structure will likely be competitive with a protective structure constructed solely of granite riprap. It is possible that the cost of producing the phosphogypsum briquettes may be reduced further by optimizing the type and quantity of admixtures used for production.

ACKNOWLEDGMENT

Foremost, our sincere appreciation goes to the Florida Institute of Phosphate Research for its financial support and assistance in this phosphogypsum project.

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EXECUTIVE SUMMARY

Phosphogypsum (PG, $CaSO_4 \cdot 2H_2O$) is a waste by-product of phosphoric acid production and is classified as a Technologically Enhanced Natural Radioactive (TENR) material by USEPA. PG can release the cancer causing, radioactive gas radon. Approximately 47 million tons of PG are produced annually in the US. Currently, the allowable disposal method for PG is stockpiling. Large PG stackpiles can cover as much as 3 km^2 and up to 60 m high. In US the total surface area covered by stackpiles is more than 34 km^2, with more than half that acreage located in Florida. Researchers at Louisiana State University have been investigating various stabilized PG composite mixtures that have technical and economic potential for commercial fabrication and application. Research has focused on developing a composite that maintains physical integrity and has a long-term survivability under saltwater conditions. Currently, composites using Portland Type II cement and Class C fly ash have shown the most promise. The most recent research demonstrated that a composite composed of 62%:35%:3% PG:Class C fly ash:Portland Type II cement can survive in seawater for more than two years. This research shows the potential for the use of stabilized PG in the coastal application.

The United States has lost a significant amount of wetlands. Louisiana, just one of the coastal states, is losing wetland at the annual rate of 25-35 square miles (Louisiana Coastal Wetlands Conservation and Restoration Task Force 1998). The U.S. Congress enacted the Coastal Wetlands Planning, Protection and Restoration Act (Public Law 101-646, Title III-CWPPRA) in 1990. This act addressed wetlands loss nationally (Louisiana Coastal Wetlands Conservation and Restoration Task Force 1998). The State of Florida has also suffered a serious coastal erosion problem, with 327.9 miles of its coastal line listed as critical beach erosion and 108 miles of its coastal line listed as noncritical beach erosion (Bureau of Beaches and Coastal Systems 2001). The Office of Beaches and Coastal Systems, under the Florida Department of Environmental Protection, is responsible for administering the State's beach management program to protect and restore the state's beaches and coastal systems. The total statewide plan budget is $772 million for the periods of 2002-2008 (Bureau of Beaches and Wetland Resources 2002).

A number of engineering approaches have been used to counteract erosion along populated coastlines. Traditional protective measures have included structures such as seawalls, revetments, groins and detached breakwaters. These structures are made of stone, granite, limestone, concrete (new or recycled) and steel. Regardless of the construction material, such structures are relatively expensive. In Florida, granite riprap used for erosion control and delivered in Tampa by rail costs $27 to $28/ton. Yearly, riprap needs for each coastal erosion control project averages tens of thousands of tons. In Louisiana, the majority of material used as riprap and for dike construction is limestone mined in Arkansas and barged to the state at a cost of $36 to $52/ton, with needed quantities in the tens of thousands of tons per project. There is a significant need for coastal erosion control rip- rap materials in Louisiana and Florida. While there is no data for other Gulf States, similar demands for coastal erosion control riprap materials are likely to exist.

This research project investigated the economic feasibility of using stabilized PG briquettes as an alternative to the riprap currently used in coastal protective structures. This involved the development of an EXCEL spreadsheet that allows the user to estimate the production cost per ton of PG briquettes for variable material quantities costs and offset disposal costs. The capital cost of the plant, amortized over a 10-year period, is based on the original Crescent Technology, Inc., economic analysis for a 4.5 million ton/year PG briquette production facility. However, before this analysis was incorporated into the spreadsheet it was thoroughly reviewed and revised. The Crescent Technology analysis was based on four assumptions: (1) the production facility was scaled to 4.5 million tons of output per year; (2) the cement used in the production of briquettes equaled three percent of the total product weight (dry weight basis); (3) raw phosphogypsum was air dried (original water content of 20% off the stack); and (4) the analysis was performed for a facility located in Louisiana. The current analysis used similar assumptions, with modifications to the site location and ingredient selection. The facility location was changed from Louisiana to a hypothetical location near the Cargill Fertilizer, Inc., facility located in Riverview, Florida. This facility has a barge terminal already in place. Thus, transportation costs to barge the briquette product from the facility to Louisiana are based on this barge terminal as the point of departure. All costs used in this analysis are current, local costs in Tampa, Florida. Parameters inserted as variables included cement content and cost, fly ash content and cost, transportation costs and PG offset disposal costs (including capital, operation and closure cost), providing a generic analysis format that can be easily customized to any given set of conditions. The offset disposal cost is the amount not spent for disposal or saved if the PG is diverted to a briquette production facility rather than a disposal stackpiling facility.

The baseline analysis was performed for the 62%:35%:3% PG:Class C fly ash:Portland Type II cement briquette with no offset disposal cost. Portland Type II cement costs was set at $73.50/ton while Class C fly ash was $25/ton. The $13.62 per ton cost is the most probable cost given the technical research conducted to date. This estimate does not consider the beneficial effect of the disposal cost savings. The cost estimate of a 4,500,000 ton stabilized PG briquette production facility clearly demonstrates that the Class C fly ash cost and Portland Type II cement account for 60% and 15% of the total production cost, respectively. Considering a range of offset costs of PG disposal from $1.50 to $10/ton wet weight, the net cost of PG:Class C fly ash:Portland Type II cement (62%:35%:3%) briquettes would range from a lower bound of $6.73/ton to a high of $12.59/ton. Using the most conservative estimate of disposal/maintenance cost, the baseline production cost can be reduced by 7.6%. With the implementation of the new liner PG disposal system required by Florida Law (Florida Administrative Code 1997, 62-673.650) the disposal offset costs will increase for new disposal facilities and provide a more attractive framework for briquette production in lieu of disposal.

The sensitivity of the PG briquette production cost to the cost of the admixture of fly ash and cement was also investigated. The results clearly indicate that the production cost is sensitive to the cost of fly ash but not to the cost of the Portland Type II cement. When the cost of Class C fly ash increases from $20/ton to $30/ton, the baseline production cost of PG briquettes will increase from $12.00/ton to $15.24/ton.

The break-even production cost in Tampa, Florida for application of PG briquettes in rip-rap material for coastal erosion control is $27.50/ton in Florida and $30.5/ton in Louisiana. The baseline production cost in Tampa, Florida for the 62%:35%:3% PG:Class C fly ash:Portland Type II cement briquette is $13.62/ton. The usage of PG briquettes as a substitute of limestone riprap is competitive to the current commercial available materials in terms of cost of production. In addition, the researchers believe there is room to reduce the cost of the PG: Class C fly ash: Portland Type II cement briquettes by reducing the binding agents. Therefore, using the PG briquettes instead of granite riprap will be more economically feasible.

There is a potential market for PG briquettes as a substitute of limestone riprap in coastal protection. Every coastal protection project needs tens of thousands of tons of riprap materials. The sea level rise that is occurring will increase the needs for coastal protection. PG briquettes are less expensive than limestone riprap and can be used in combination with minimal amounts of high durability riprap to provide the same level of protection. Thus, the use of PG briquettes would reduce the cost of many coastal protection projects by reducing the amount of needed limestone riprap. Also, the PG briquettes will likely reduce the settlement of the protective structure because of the lower unit weight of the PG briquettes. This can be an extremely important consideration in maintaining the level of protection of the facility throughout its service life.

The development of PG briquettes as a substitute of limestone riprap will help the local economy and increase employment. A PG briquette plant with capacity of 4.5 million ton/year will provide 84 employment opportunities. Therefore, the use of PG briquettes as a substitute of limestone riprap would not only provide a use of these byproduct materials, but would also result in the establishment of a marketable industry to benefit the local economy. Historically, fly ash posed a serious disposal problem. Class C fly ash was an environmental disposal problem and had no market value. Today, Class C fly ash is a by-product with a significant market demand and value. Such an opportunity also exists for PG but a long term investment in research and development is needed.

Finally, and more importantly, the usage of PG briquettes as a substitute of granite riprap will directly aid the phosphoric industries by economically reducing the rate of PG accumulation on land and reduce the cost of PG disposal and finally reduce the cost of the phosphate acid production. This technology may help FIPR to achieve his goal of reducing the rate of accumulation of PG per ton of phosphoric acid production by 15% by the year 2002.

INTRODUCTION

BACKGROUND

Phosphogypsum (PG, $CaSO_4{\cdot}2H_2O$) is the by-product of a wet manufacturing process, in which phosphate ore is reacted with sulfuric acid and water to produce phosphoric acid (Thimmegowda 1994):

$$Ca_{10}(PO_4)_6F_2 + 10H_2SO_4 + 20H_2O \rightarrow 10CaSO_4{\cdot}2H_2O + 6H_3PO_4 + 2HF \qquad (1)$$

The wet process requires lower capital investment and production costs and provides greater flexibility of processing different grades of phosphate rock than the dry process (Ferguson 1988). However, this process also results in the production of large volumes of PG containing trace metals and radioactive contaminants that pose potential environmental problems (USEPA 1992). Radium-226 (Ra^{226}) is of particular importance, with approximately 80% of that originally present in the ore being concentrated in the PG by-product (USEPA 1992). Ra^{226} decays to radon gas (Rn^{222}) with a half-life of only 3.8 days. Further decay results in emission of alpha (α) rays, which can do extensive damage to internal organs if digested. Consequently, radon is considered as a cancer causing, radioactive gas (USEPA 2001a). Emission concerns led to the promulgation of disposal/usage guidelines under the National Emission Standards for Hazardous Air Pollutants (NESHAP) and the National Emissions Standards for Radon Emission from PG Stacks (Federal Register, 40 CFR Part 61 Subpart 61, February 3, 1999). The current allowable disposal method for PG is stackpiling (Federal Register, 40 CFR Part 61 Subpart I, December 15, 1989).

Approximately 4.5 metric tons of PG are produced per metric ton of phosphoric acid, resulting in an annual production rate in the range of 40 to 47 million metric tons (USEPA 2001b). After water recovery and evaporation, large PG stackpiles covering as much as 3 km^2 and up to 60 m high are formed (USEPA 2001b). In 1989, a total of 63 PG stackpiles were identified nationwide in 12 different states. Two-third of these stackpiles are located in Florida, Texas, Illinois, and Louisiana (USEPA 2001b). The total surface area covered by stackpiles was about 34 km^2, with more than half that acreage located in Florida (USEPA 2001b).

The accumulation of PG stackpiles causes significant space and environmental problems, placing increasing pressure on the fertilizer industry to find long-term solutions. Various usage alternatives for PG are being sought to decrease risks to humans and the environment, to reduce the cost of storage, and to create an economic market for phosphogypsum products. One such alternative is the use of stabilized PG in the marine environment for aquatic resource enhancement and coastal restoration. This application provides one of the best means to minimize human radon gas exposure because the airborne vector of transmission is essentially eliminated, leaving bioaccumulation as the only potential transfer pathway. Preliminary laboratory data indicated that Portland Type II cement stabilized PG composites support a diverse population of surface-attached, burrowing organisms and oysters (Chen and others 1995), and that bioaccumulation is not a significant pathway of radium transfer (Wilson and others 1998). Most other proposed economic uses aimed at reducing the PG accumulation rate (agriculture, roadbed aggregate, building materials, etc.) have potential problems associated with this fundamental issue of vector transmission.

Researchers at Louisiana State University have been investigating various stabilized PG composite mixtures that have technical and economic potential for commercial fabrication and application. Research has focused on developing a composite that maintains physical integrity and has a long-term survivability under saltwater conditions. Currently, composites using Portland Type II cement and Class C fly ash have shown the most promise (Guo 1998; Guo and others, forthcoming). To produce PG composites that can compete economically with other materials (mostly limestone or granite based), the Portland Type II cement content must be less than 5% on a dry weight basis (Wilson and Keithly 1999). Their analyses were based on admixture costs in Louisiana. The most recent research showed that the 62%:35%:3% PG:Class C fly ash:Portland Type II cement composite can survive in seawater for more than two years. (Guo 1998). While this composition meets the less than 5% cement criterion, the admixture composition has not been optimized. Further optimization will likely lead to reduced production costs.

POTENTIAL FOR USING STABILIZED PG BRIQUETTES AS COASTAL PROTECTION MATERIALS: FLORIDA AND LOUISIANA

The United States has lost a significant amount of wetlands. Louisiana, just one of the coastal states, is losing wetland at the annual rate of 25-35 square miles (Louisiana Coastal Wetlands Conservation and Restoration Task Force 1998). The U.S. Congress enacted the Coastal Wetlands Planning, Protection and Restoration Act (Public Law 101-646, Title III-CWPPRA) in 1990. This act addressed wetlands loss nationally (Louisiana Coastal Wetlands Conservation and Restoration Task Force 1998). The State of Florida has also suffered a serious coastal erosion problem, with 327.9 miles of its coastal line listed as critical beach erosion and 108 miles of its coastal line listed as noncritical beach erosion (Bureau of Beaches and Coastal Systems 2001). The Office of Beaches and Coastal Systems, under the Florida Department of Environmental Protection, is responsible for administering the State's beach management program to protect and restore the state's beaches and coastal systems. The total statewide plan budget is $772 million for the periods of 2002-2008 (Bureau of Beaches and Wetland Resources 2002).

A number of engineering approaches have been used to counteract erosion along populated coastlines. Traditional protective measures have included structures such as seawalls, revetments, groins and detached breakwaters. These structures are made of stone, limestone, concrete and steel (Whiteneck and Lester 1989), all of which are relatively expensive. In Florida, granite riprap used for erosion control is brought in by rail at a cost of $27 to $28/ton (transported to Tampa). Yearly granite needs for each coastal erosion control project average tens of thousands of tons (Lowish 2001). In Louisiana, the majority of material used as riprap and for dike construction is limestone mined in Arkansas and barged in at a cost of \$36 to \$52/ton of material, with needed quantities in the tens of thousands of tons per project (LADNR 2000). Currently, there are over 30 wetland restoration and coastal erosion projects in the Louisiana coastal zone. The Louisiana Department of Natural Resources is actively searching for less expensive materials to compliment or replace the limestone (Knotts 2001). There is a significant need for coastal erosion control riprap materials in Louisiana and Florida. While there is no data for other Gulf states, similar demands for coastal erosion control riprap materials are likely to exist.

The cross-section of shoreline erosion dikes generally consists of a four-foot wide crown with a 2 or 3 to 1 ratio backslope and a 3 or 4 to 1 ratio front slope (water side) and 4-6 feet NGD. Normally, the dike is 2-3 feet are above the water line. The end result is the need for tremendous amounts of material, generally riprap with high durability. Besides cost, one of the problems with the use of riprap is the excessive settlement of the dike due to the consolidation of the underlying soils created by the stress induced in the underlying soils by the dike. Thus, the use of lightweight materials can potentially minimize this problem. Stabilized PG briquette fill material could be used in conjunction with geogrid as the core material, with riprap used as a surface armoring. This configuration would dramatically decrease costs by reducing the amount of needed riprap and would reduce the resulting stress and corresponding settlement.

This report summarizes the results of an economic analysis performed to determine the feasibility of locating and operating a stabilized PG briquetting plant in Florida, with product distribution within Florida and to Louisiana.

METHODOLOGY

SUMMARY OF ECONOMIC ANALYSIS FORMAT FOR THE CONSTRUCTION AND OPERATION OF A STABILIZED PG BRIQUETTING PLANT IN FLORIDA

Previous work conducted by the LSU research team showed that a composite briquette containing PG, Portland Type II cement and Class C fly ash exhibited the greatest potential for long-term aquatic applications (Guo 1998; Guo and others, forthcoming). The field results indicated that a mixture consisting of 62%:35%:3% PG:Class C fly ash:Portland Type II cement can survive under saltwater conditions for more than two years. While the research team believes the cement and/or fly ash content(s) can be reduced, the 62%:35%:3% mixture was used as the starting point for the economic analysis (referred to as the baseline analysis from this point forward). Additional analyses were performed to investigate the effects of varying the amount and costs of Portland Type II cement and Class C fly ash as well as disposal offset costs on the briquette unit production cost.

The original Crescent Technology, Inc., economic analysis (Appendix A) was reviewed, revised and used as the foundation for this analysis. All capital and operating cost were revised to the Year 2001. The Crescent Technology analysis was based on four assumptions: (1) the production facility was scaled to 4.5 million tons of output per year; (2) the cement used in the production of briquettes equaled three percent of the total product weight (dry weight basis); (3) raw phosphogypsum was air dried (original water content of 20% off the stack); and (4) the analysis was performed for a facility located in Louisiana. The current analysis used similar assumptions, with modifications to the site location and ingredient selection. The facility location was changed from Louisiana to a hypothetical location near the Cargill Fertilizer, Inc. facility located in Riverview, Florida. This facility has a barge terminal already in place. Thus, transportation costs to barge the briquette product from the facility to Louisiana are based on this barge terminal as a point of reference. Transportation costs within Florida will vary depending on the locale. Therefore, transportation was included as a variable in the spreadsheet. Other variables included inflation and finance charge rates.

The ingredient component was expanded to incorporate Class C fly ash as an admixture. All costs used in this analysis are current, local costs in Tampa, Florida. Parameters inserted as variables included cement content and cost, fly ash content and cost, transportation costs and disposal offset costs. Thus, the economic analysis spreadsheet provides a versatile analysis format that can be easily customized to any given set of conditions.

This report provides production cost tables for various combinations of the above parameters at levels considered to be technically feasible. All ingredient percentages are based on dry weight. Given the number of possible combinations, the report provides representative examples of various cost analysis scenarios. A copy of the economic analysis (Excel spreadsheet) is provided with this report to facilitate investigations of analysis scenarios not presented in the report.

RESULTS

BASELINE ANALYSIS

The baseline analysis, including capital, operation and closure costs, was performed for the 62%:35%:3% PG:Class C fly ash:Portland Type II cement briquette with no offset disposal cost. Raw material costs were included for Class C fly ash and Portland Type II cement. The Class C fly ash is available locally through the Tampa Electric Company at a cost of $25/ton (transportation included). The Portland Type II cement is available through the Cenex Cement Plant in Brooksville, FL, at an average cost of $73.50/ton, including transportation (Davis 2001).

Manufacturing costs consist of capital and operating costs. The capital cost for 4.5 million tons of annual production, exclusive of finance charges, was estimated to be $27.4 million in 2001 dollars. Financing capital costs at 8% per annum over a ten-year period yields a total annual capital outlay equal to $3.78 million. The spreadsheet allows alternative interest rates to be considered. Expressed on a per ton basis over the 10-year finance period, capital costs would equal $0.84 per ton.

The total annual operating cost at 4.5 million tons of output was estimated to be $57.5 million or $12.8 per ton of briquettes produced. Cement and fly ash costs represent approximately 16% and 63.4%, respectively, of the total production cost. The total capital plus operating cost for a 4.5 million ton production facility was estimated to be $61.3 million, or $13.62 per ton of briquettes produced (Table 1).

Table 1. Summarized Cost (in 2001 Dollars) Estimate of a 4,500,000 Ton Stabilized PG Briquette Production Facility. (This Estimate is Based on a 62%:35%:3% PG:Class C Fly Ash:Portland Type II Cement Composition.)

Capital cost	$27,390,393
Annual interest and principal payment (10 years payout)	$3,779,746
Annual cement cost (Portland Type II)	$9,187,500
Annual fly ash cost (Class C)	$36,458,333
Other annual operating costs (employees, maintenance, energy)	$11,857,158
Total annual operating cost	$57,502,991
Total annual cost	$61,282,737
Cost of production per ton	$13.62

As can be seen, the annual operating costs comprise over 94% of the total annual production cost. Thus, research focused on reducing the operating cost as a function of composition could have a significant impact on the economic feasibility of producing briquettes.

The LSU researchers believe the cement and fly ash contents can be further reduced while still maintaining the physical integrity of the briquettes. The impact of cement (2-5%) and fly ash (15-35%) content on the per ton production costs was evaluated and is presented in Table 2. Portland Type II cement and Class C fly ash have remained at $73.5/ton and $25/ton, respectively.

Table 2. Production Cost Estimate (per Ton) for Varying Class C Fly Ash and Portland Type II Cement Content, with 20% Original Water Content Off the Stack and No Offset Disposal Cost.

Portland Type II Cement Content (%)	Class C Fly Ash Content (%)				
	35	30	25	20	15
2	$12.94	$11.78	$10.62	$9.47	$8.31
3	$13.62	$12.46	$11.30	$10.15	$8.99
4	-------	$13.14	$11.98	$10.83	$9.67
5	-------	-------	$12.66	$11.51	$10.35

It is quite evident that the per ton production costs are highly sensitive to ingredient composition. The $13.62 per ton cost (unshaded) is the most probable cost given the technical research conducted to date. This cost is considered the worst-case scenario. The researchers are highly confident that the admixture composition (cement and fly ash) can be reduced while still maintaining the physical integrity of the briquette. The light gray shading areas in Table 2 represent those compositions the research team believes are technically achievable. The dark shaded areas represent mixtures the research team believes may be achievable. A $2.5/ton reduction in the most probable baseline cost is certainly within the range of possibility. The areas with no costs represent compositions resulting in a per ton cost higher than the $13.62 baseline. The shading characteristics shown in this table are followed throughout the remainder of the report.

COST ESTIMATE OF STABILIZED PG BRIQUETTES AS A FUNCTION OF OFFSET DISPOSAL COSTS

For this analysis, the Portland Type II cement and Class C fly ash costs were fixed at the current levels of $73.50/ton and $25/ton, respectively. When factoring in the offset cost of PG disposal ranging from $1.50 to $10/ton wet weight, the most probable net cost of PG:Class C fly ash:Portland Type II cement (62%:35%:3%) would range from a lower bound of $6.73/ton to a high of $12.59/ton (Table 3). These values were calculated using the following algorithms to convert PG stack wet weight to PG dry weight contained in the briquettes:

Adjusted production cost of stabilized PG briquette
= Baseline cost–PG disposal cost (2)

PG disposal cost = Wet PG amount * Disposal cost (3)

Wet PG amount = Dry PG amount*(1+water content in PG stack) (4)

Dry PG amount = PG content in PG briquette/(1+water content in PG briquette) (5)

The selection of the actual range of offset disposal costs was based on several conversations with various fertilizer companies. This range also reflects potential future disposal costs due to new regulations. Using the most conservative estimate of disposal/maintenance cost (i.e., $1.50/ton), the baseline production cost can be reduced by 7.6%. More importantly, Table 3 illustrates the potential for adjusted production costs to be reduced as much as 50% as disposal costs increase due to the implementation of new regulations.

Table 3. Production Costs (per Ton) of 62%:35%:3% Phosphogypsum:Class C Fly Ash:Portland Type II Cement Briquettes with Offsetting Disposal Costs Ranging from $1.50-10/Ton (Wet Weight).

PG Disposal Cost /Ton, Wet Weight ($)	0	1.5	3	4	7	10
PG Briquette Cost/Ton ($)	13.62	12.59	11.55	10.86	8.80	6.73

According to Florida Law (Florida Administrative Code, 62-673.650), after March 25, 2001, lined disposal systems are required for new PG stacks. This will increase the PG disposal offset cost. The PG briquette option will become more attractive because of higher offsetting costs of PG disposal. There are many benefits in moving away from the current stockpiling disposal method including: the reduction in human contact with radon gas, minimized leaching of metals into groundwater supplies, reduction in land space required for PG storage, and a reduction in legal liability from environmental regulations.

The analysis was further broken down to look at the actual production cost of varying composition PG briquettes with varying offset disposal costs (Tables 4-7).

Table 4. Production Cost of Stabilized PG Briquettes as a Function of Admixture Content and an Offset Disposal Cost of $1.50/Ton (Wet Weight).

Portland Type II Cement Content (%)	Class C Fly Ash Content (%)				
	35	30	25	20	15
2	$11.89	$10.65	$9.41	$8.17	$6.92
3	$12.59	$11.34	$10.10	$8.86	$7.62
4	------	$12.04	$10.80	$9.56	$8.32
5	------	------	$11.50	$10.26	$9.02

Table 5. Production Cost of Stabilized PG Briquettes as a Function of Admixture Content and an Offset Disposal Cost of $4/Ton (Wet Weight).

Portland Type II Cement Content (%)	Class C Fly Ash Content (%)				
	35	3	25	20	15
2	$10.14	$8.76	$7.38	$6.00	$4.62
3	$10.86	$9.48	$8.10	$6.72	$5.34
4	------	$10.21	$8.83	$7.45	$6.07
5	------	------	$9.55	$8.17	$6.79

Table 6. Production Cost of Stabilized PG Briquettes as a Function of Admixture Content and an Offset Disposal Cost of $7/Ton (Wet Weight).

Portland Type II Cement Content (%)	Class C Fly Ash Content (%)				
	35	30	25	20	15
2	$8.04	$6.49	$4.95	$3.40	$1.85
3	$8.80	$7.25	$5.70	$4.16	$2.61
4	------	$8.01	$6.46	$4.92	$3.37
5	------	------	$7.22	$5.67	$4.13

Table 7. Production Cost of Stabilized PG Briquettes as a Function of Admixture Content and an Offset Disposal Cost of $10/Ton (Wet Weight).

Portland Type II Cement Content (%)	Class C Fly Ash Content (%)				
	35	30	25	20	15
2	$5.94	$4.22	$2.51	$0.80	-$0.91
3	$6.73	$5.02	$3.30	$1.59	-$0.12
4	------	$5.81	$4.10	$2.38	$0.67
5	------	$6.60	$4.89	$3.17	$1.46

The analysis of offset disposal cost brings to light some extremely important points. First, without any further research focused on reducing the admixture content, the adjusted production cost of the 62%:35%:3% PG:Class C fly ash:Portland Type II cement briquettes can be reduced by 7.6% - 50.6% just by considering offset disposal costs. Second, further research focused on reducing admixture content can have a significant impact on the economic feasibility of using PG briquettes. With the requirement of liners for new stacks, it is conceivable that the production of stabilized PG briquettes could almost become a no-cost option for the fertilizer plants (Tables 6 and 7). Further, while transportation costs have not yet been factored into the cost of the material at a construction site, it can be seen that the production costs of stabilized PG briquettes is significantly less than the cost of granite and limestone rip-rap material currently used for coastal erosion control.

COST ESTIMATE OF STABILIZED PG BRIQUETTES AS A FUNCTION OF CLASS C FLY ASH COST

For a fly ash cost of $25/ton, the cost estimate of a 4,500,000 ton stabilized PG briquettes production facility (Table 1) shows that the annual Class C fly ash cost is $36,458,333 while the total annual production cost is $61,282,737. Thus, the cost of fly ash accounts for 60% of the total annual production cost. A decade ago, Class C fly ash was an environmental disposal problem and had no market value. Today, Class C fly ash is a by-product with significant but regionally variable market demand. While the unit cost of fly ash is still only 33% of the unit cost of cement, reduction of this admixture component would have a significant impact on the briquette production cost because the fly ash content of the briquette is significantly greater than that of cement.

The cost of Class C fly ash from the Tampa Electric Company is $25/ton. This is relatively expensive compared to the cost of $18/ton in Louisiana. The influence of fly ash cost on the baseline production cost of 62%:35%:3% phosphogypsum:Class C fly Ash:Portland Type II cement briquettes is presented in Table 8. The impact of a Class C fly ash cost of $20 or $30 per ton in combination with offset disposal costs $1.5/ton and $7/ton on the production cost of PG briquette is presented in Tables 9-12.

Table 8. Baseline Production Cost (per Ton) of Stabilized 62%:35%:3% Phosphogypsum: Class C Fly Ash: Portland Type II Cement Briquettes as a Function of Class C Fly Ash Cost.

Class C Fly Ash Cost/Ton ($)	20	22	24	25	26	28	30
PG Briquette Cost/Ton ($)	12.00	12.65	13.29	13.62	13.94	14.59	15.24

Table 9. Production Costs (per Ton) of Stabilized PG Briquettes as a Function of Admixture Content, a Class C Fly Ash Cost $20/Ton and an Offset Disposal Cost of $1.50/Ton (Wet Weight).

Cement Content (%)	Fly Ash Content (%)				
	35	30	25	20	15
2	$10.27	$9.26	$8.25	$7.24	$6.23
3	$10.96	$9.96	$8.95	$7.94	$6.93
4	-------	$10.65	$9.64	$8.63	$7.62
5	-------	-------	$10.34	$9.33	$8.32

Table 10. Production Costs (per Ton) of Stabilized PG Briquettes as a Function of Admixture Content, a Class C Fly Ash Cost of $20/Ton and an Offset Disposal Cost of $7/Ton (Wet Weight).

Cement	Fly Ash Content (%)				
Content (%)	35	30	25	20	15
2	$6.42	$5.10	$3.79	$2.47	$1.16
3	$7.18	$5.86	$4.55	$3.23	$1.92
4	-------	$6.62	$5.30	$3.99	$2.67
5	-------	-------	$6.06	$4.75	$3.43

Table 11. Production Costs (per Ton) of Stabilized PG Briquettes as a Function of Admixture Content, a Class C Fly Ash Cost of $30/Ton and an Offset Disposal Cost of $1.5/Ton (Wet Weight).

Cement	Fly Ash Content (%)				
Content (%)	35	30	25	20	15
2	$13.51	$12.04	$10.56	$9.09	$7.62
3	$14.21	$12.73	$11.26	$9.79	$8.32
4	-------	$13.43	$11.96	$10.49	$9.01
5	-------	-------	$12.66	$11.18	$9.71

Table 12. Production Costs (per Ton) of Stabilized PG Briquettes as a Function of Admixture Content, a Class C Fly Ash Cost of $30/Ton and an Offset Disposal Cost of $7/Ton (Wet Weight).

Cement	Fly Ash Content (%)				
Content (%)	35	30	25	20	15
2	$9.66	$7.88	$6.10	$4.32	$2.55
3	$10.42	$8.64	$6.86	$5.08	$3.31
4	-------	$9.40	$7.62	$5.84	$4.06
5	-------	$10.16	$8.38	$6.60	$4.82

Considering these results, it is evident that the production cost of 62%:35%:3% phosphogypsum: Class C fly ash: Portland Type II cement briquettes is sensitive to the cost of fly ash. When the cost of fly ash increases from $20/ton to $30/ton, the cost of PG briquettes will increase from $10.96/ton to $14.21/ton (or approximately 30%) with an offset PG disposal cost of $1.50/ton. It is recommended that the usage of Class F fly ash as a substitute of Class C fly ash be investigated, as it is much cheaper than Class C fly ash. Class F fly ash contains more Si and less Ca compared to Class C fly ash. It is expected that Class F fly ash can replace some of the Class C fly ash and therefore reduce the production cost of the PG briquette.

COST ESTIMATE OF STABILIZED PG BRIQUETTES AS A FUNCTION OF PORTLAND TYPE II CEMENT COST

For this analysis, Class C fly ash cost was fixed at the current level of $25/ton. The baseline cost estimate of a 4,500,000 ton stabilized PG briquette production facility (Table 1) shows that the annual Portland Type II cement cost is $9,187,500, while the total annual cost is $61,282,737. The annual cost of the Portland Type II cement accounts for 15% of the total annual production cost. The market for, and therefore the cost of, Portland Type II cement is dynamic. Thus, the influence of the cost of Portland Type II cement to the baseline production cost of 62%:35%:3% Phosphogypsum:Fly Ash: Cement briquettes was investigated and is listed in Table 13. The influence of Portland Type II cement on the production cost of different admixtures of Phosphogypsum:Fly Ash: Cement briquettes is listed in Tables 14-17, when an offset disposal cost is considered.

Table 13. Baseline Production Costs (per Ton) of 62%:35%:3% Phosphogypsum: Class C Fly Ash: Portland Type II Cement Briquettes as a Function of Admixture Content, Portland Type II Cement Cost.

Portland Type II cement cost/ton ($)	63	68	73.50	78	83
PG briquette cost/ton ($)	13.33	13.47	13.62	13.74	13.88

Table 14. Production Costs (per Ton) of Stabilized PG Briquettes as a Function of Admixture Content, a Portland Type II Cement Cost of $63/ton and an Offset Disposal Cost of $1.50/Ton (Wet Weight).

Cement	Fly Ash Content (%)				
Content (%)	35	30	25	20	15
2	$11.69	$10.45	$9.21	$7.97	$6.73
3	$12.29	$11.05	$9.81	$8.57	$7.33
4	-------	$11.65	$10.41	$9.17	$7.93
5	-------	$12.25	$11.01	$9.77	$8.53

Table 15. Production Costs (per Ton) of Stabilized PG Briquettes as a Function of Admixture Content, a Portland Type II Cement Cost of $63/Ton and an Offset Disposal Cost of $7.00/Ton (Wet Weight).

Cement	Fly Ash Content (%)				
Content (%)	35	30	25	20	15
2	$7.84	$6.30	$4.75	$3.20	$1.66
3	$8.50	$6.96	$5.41	$3.87	$2.32
4	-------	$7.62	$6.07	$4.53	$2.98
5	-------	$8.28	$6.73	$5.19	$3.64

Table 16. Production Costs (Per Ton) of Stabilized PG Briquettes as a Function of Admixture Content, a Portland Type II Cement Cost of $83/Ton and an Offset Disposal Cost of $1.50/Ton (Wet Weight).

Cement Content (%)	Fly Ash Content (%)				
	35	30	25	20	15
2	$12.06	$10.82	$9.58	$8.34	$7.10
3	$12.85	$11.61	$10.37	$9.13	$7.89
4	-------	$12.39	$11.15	$9.91	$8.67
5	-------	-------	$11.94	$10.70	$9.46

Table 17. Production Costs (Per Ton) of Stabilized PG Briquettes as a Function of Admixture Content, a Portland Type II Cement Cost of $83/Ton and an Offset Disposal Cost of $7.00/Ton (Wet Weight).

Cement Content (%)	Fly Ash Content (%)				
	35	30	25	20	15
2	$8.21	$6.67	$5.12	$3.57	$2.03
3	$9.06	$7.51	$5.97	$4.42	$2.87
4	-------	$8.36	$6.81	$5.27	$3.72
5	-------	-------	$7.66	$6.11	$4.57

The above tabulations demonstrate that the production cost of 62%:35%:3% phosphogypsum: Class C fly ash: Portland Type II cement is relatively un-sensitive to the cost of the Portland Type II cement.

ECONOMIC FEASIBILITY OF USING PG BRIQUETTES IN FLORIDA AND LOUISIANA

In Florida, granite riprap used for erosion control is brought in by rail at a cost of $27 to $28/ton (transported to Tampa). Therefore the break-even production cost in Tampa, Florida for application of PG briquettes in riprap material for Florida coastal erosion control is $27.50/ton. In Louisiana, the majority of material used as riprap and for dike construction is limestone mined in Arkansas and barged in at a total cost of $36 to $52/ton. The shipping cost from Florida to Louisiana is $12-15/ton. Therefore the break-even production cost in Tampa, Florida for application of PG briquettes in Louisiana coastal erosion control is approximately equal to the median value of $36/ton and $52/ton minus the median value of $12/ton and $15/ton. That is $30.5/ton. This is compared to a baseline production cost of $13.62/ton in Tampa Florida for the 62%:35%:3% PG:Class C fly ash:Portland Type II cement briquette. There is a cost saving of $13.88/ton - $16.88/ton, and this provides a significant monetary buffer to compensate for the bad public perception of phosphogypsum.

Table 18 lists PG briquette costs under different typical conditions. Portland Type II cement cost is fixed at the current value of $73.50/ton because the PG briquette cost is not sensitive to the cost of Portland Type II cement. Table 18 indicates that the baseline cost in Tampa, Florida for the 62%:35%:3% PG:Class C fly ash:Portland Type II cement briquette is $13.62/ton, which is significantly lower than the lowest break even production cost of $27.50/ton. Considering the dynamic market of Class C fly ash, the highest baseline PG briquette cost is $15.92/ton with the highest Class C fly ash cost. This number is still significantly lower than the break-even production cost of $27.50/ton. If PG disposal offset cost is included the production cost of PG briquette will decrease. The replacement of PG briquettes with granite riprap will become more attractive. Economically there is a possibility for this application in the states of Florida and Louisiana.

Table 18. Production Costs (Per Ton) of 62%:35%:3% Phosphogypsum: Class C Fly Ash: Portland Type II Cement Briquettes at Different Cost of Fly Ash When Factoring in the Offsetting Different PG Disposal Costs (Wet Weight).

PG Offset	Class C Fly Ash Cost ($) / Ton						
Disposal Cost ($/Ton)	20	22	24	25	26	28	30
0	12	12.56	13.29	13.62	13.94	14.59	15.92
1.5	10.96	11.61	12.26	12.59	12.91	13.56	14.21
3	9.93	10.58	11.23	11.55	11.88	12.52	13.17
4	9.24	9.89	10.54	10.86	11.19	11.84	12.48
7	7.18	7.82	8.47	8.80	9.12	9.77	10.42
10	5.11	5.76	6.41	6.73	7.05	7.70	8.35

SUMMARY

Phosphogypsum is one of the major solid wastes in the US, with a total surface area coverage 34 km^2. More than half of this coverage is located in Florida. The accumulation of PG stackpiles causes significant space and environmental problems, placing increasing pressure on the fertilizer industry to find long-term solutions. The application of stabilized PG briquettes as coastal protection materials may be one of the alternatives to relieve the PG stacking problems. The usage of PG briquettes as a substitute of granite riprap will directly aid the phosphoric industries by reducing the rate of PG accumulation on land and cut the cost of PG disposal. This may help FIPR to achieve to the goal of reducing the rate of accumulation of PG per ton of phosphoric acid production by 15% by the year 2002 (FIPR 1998).

The economic analysis performed for a briquette plant located in Florida indicates that the break even production cost in Tampa, Florida is \$27.5/ton and \$30.5/ton for coastal erosion control in Florida and Louisiana respectively. This is compared to a baseline production cost of \$13.62/ton in Tampa Florida for the 62%:35%:3% PG:Class C fly ash:Portland Type II cement briquette. There is a cost saving of \$13.88/ton - \$16.88/ton, and this provides a significant monetary buffer to compensate for the bad public perception of phosphogypsum. The usage of PG briquettes as a substitute of limestone riprap is competitive to the current commercially available materials.

When factoring in the offset cost of PG disposal ranging from \$1.50 to \$10/ton wet weight, the most probable net cost of PG:Class C fly ash:Portland Type II cement (62%:35%:3%) would range from a lower bound of \$6.73/ton to a high of \$12.59/ton. According to Florida Law the PG disposal offset cost will increases because lined disposal systems are required for new PG stacks. The PG briquette option will become more attractive because of higher offsetting costs of PG disposal. There are many benefits in moving away from the current stockpiling disposal method including: the reduction in human contact with radon gas, minimized leaching of metals into groundwater supplies, reduction in land space required for PG storage, and a reduction in legal liability from environmental regulations.

The development of PG briquettes as a substitute of granite riprap will help local economy and increase employment. A PG briquette plant with capacity of 4.5 million ton/year will provide employment opportunities. Therefore, the use of PG briquettes as a substitute of granite riprap would not only provide a use of these byproduct materials, but would also result in the establishment of a marketable industry to benefit the local economy. Looking back to see the fly ash disposal problem, Class C fly ash was an environmental disposal problem, and had no market value. Today, Class C fly ash is a by-product with a significant market demand. Such an opportunity also exists for PG but a long-term investment in research and development is needed.

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Appendix A

CRESCENT TECHNOLOGY, INC. REPORT

APPENDIX A

CRESCENT TECHNOLOGY, INC. REPORT

The condition of the original Crescent Technology report was such that further reproduction resulted in hard-to-read copies. Therefore, the report has been retyped and carefully checked to match with the original version.

April 15, 1996

Mr. Russ Olivier
IMC Agrico Company
Exit 7250, Hwy. 44
Uncle Sam, LA 70792

Re: Phosphogypsum Studies- Estimates for a 4,500,000 tpy Gypsum Briquette Production Facility

Dear Russ:

Attached are order of magnitude capital and operating estimates for a 4,500,000 ton per year phosphogypsum briquette production facility at the Uncle Sam Plant. The estimated capital cost is $21,870,000 and the estimated annual operating cost is $22,860,000. These estimates are based on the March 1986 estimates by Messrs. M. A. Steele and M. S. Salvatore. The costs have been modified to reflect deletion of facilities to handle red mud (alumina tails), the escalation to 1996 dollars and the increase of the production capacity from 3,942,000 tons per year to 4,500,000 tons per year. I have also included the "Operating Manpower Estimate" and the "Criteria and description" for the facilities.

The estimates are based on reclaiming gypsum from the existing stack. No comparison has been made to the cost of transporting the gypsum directly from the filters in the phos-acid plant. As per our discussion, this will be investigated in the course of other estimates. You may also note that the annual operating cost increase was only 15% over that of the 1986 estimate. This is due to the following:

- The percentage of cement used in the briquettes was 3% in the 1996 estimate and 5% in the 1986 estimate, so despite an increase in capacity and a significant (+ 65%) increase in cement cost, the annual cost of cement actually dropped slightly

- The unit cost of power did not increase over the past 10 years.

At this time I will focus on the costs to estimate the remaining six of the phosphogypsum facilities that we have discussed. I will split these out into two groups. The first will consist of those that are associated with the Louisiana coastline restoration. The second will consist of those dealing with other products from phosphogypsum (revetment, levee armoring poured in place, and plastic lumber).

Please contact me if you have any questions or would like to discuss the estimates submitted, I can be reached at (504) 582-4464.

Sincerely,

Hugh Manson
Sr. Project Engineer

CRITERIA AND DESCRIPTION
FOR A 4,500,000 TONS PER YEAR
GYPSUM PELLET PRODUCTION FACILITY
AT THE IMC/AGRICO UNCLE SAM PLANT

1) Criteria

- Pellet Capacity- 4,500,000 tpy nominal (4,536,000 tpy actual)
- Feed Stocks

  Phosphogypsum (20% water) – 4,400,000 tpy dry

  Cement Type II (dry)- 136,000 tpy (3% of the mix)
- Bulk Densities

  Phosphogypsum- 75 pcf

  Cement Type II- 85-94 pcf
- Storage Capacities

  Phosphogypsum feed bin- 250 ton

  Cement silos (2)- 300 tons total, 150 tons each (19 hours)

  Pelletizer feed bin- 1040 tons (2 hours)

  Pellet Stackpile- 62,000 tons (5 days)

2) Gypsum reclaim facilities- The estimate is based on four large wheel loaders (Cat 988's, 10 ton capacity) feeding 7-25 ton haul trucks. The trucks dump into a hopper feeding the gypsum reclaim conveyor. Operation is 24 hours per day, 365 days per year. The equipment included has the capacity to move the quantities necessary, however, another arrangement may prove more practical. Optimization would be required for an AFE grade estimate.

3) Gypsum reclaim conveyor- The reclaim conveyor runs from the hopper discussed in 2 above to the phosphogypsum feed bin in the blending plant.

4) Blending Plant- The blending plant contains two 400 tph pug mills that are fed by separate feed belts. These belts are fed from the phosphogypsum feed bid via two vibrating weigh feeders and from the cement silos via rotary valves. Cement will be furnished, shipped and unloaded by the cement supplier. Cement supply trucks will be unloaded pneumatically and the dust will be captured in baghouses and transferred to the pug mills. Both pug mills discharge onto a single belt conveyor to the pellet plant.

5) Pelletizing Plant- A single belt conveyor from the blending plant feeds a long pelletizer feed hopper via a belt tripper. The 15 pelletizers (42tph capacity each) are then fed via 15 separate screw feeders. The pelletizers include product air coolers, and they discharge on a single belt conveyor to outside storage.

6) Pellet Storage- Pellet storage is fed via a conveyor from the palletizing plant. This conveyor discharges on a stacker conveyor that can either discharge the pellets on the 120ft x 1000ft x 30ft ht. outside storage pile, or transfer the material to a conveyor feeding the barge loading facility at the dock. The storage pile can hold approximately 62,000 tons of pellets, 5 days production. Truck loading from the pile is handled by 2-10 ton wheel loaders (Cat 988's).

7) Dock Loading Facilities- The present barge mooring system would be relocated and expanded to handle the pellet system. With the proposed arrangement, four dolphins would serve for moving barges under a single stationary ship loader. One dolphin supports the loader. A 36" conveyor transports the pellets from the pellet storage area to the loader. The conveying and loading systems are sized for full production capacity.

8) General- All facilities are based on continuous operation. All facilities are outdoors except for a partially open building over the pelletizer plant, a small office and a switchgear building.

ORDER OF MAGNITUDE COST ESTIMATE FOR A 4,500,000 TONS PER YEAR GYPSUM PELLET PRODUCTION FACILITY AT THE IMC/AGRICO UNCLE SAM PLANT

I. GYPSUM RECLAIMING FACILITIES	1,940,000
a. Site preparation	20,000
b. Approach ramp from stack	15,000
c. Hopper and grizzly feed to gypsum conveyor.	30,000
d. Control feeder belt	15,000
e. Four front end loaders, 10 tons each (Cat 988's)	1,280,000
f. Seven haul trucks, 25 tons each	430,000
g. E & I	140,000
h. Painting	10,000
II. PHOSPHOGYPSUM RECLAIM CONVEYOR	850,000
a. Site Preparation	15,000
b. Foundations	65,000
c. Conveyor and structural support with walkway 36" x 780 LF	640,000
d. E & I	80,000
e. Painting	50,000
III. MATERIAL BLENDING PLANT	1,170,000
a. Site preparation/piling	75,000
b. Concrete foundations	30,000
c. Phosphogypsum feed bin (250 T)	95,000
d. Phosphogypsum bin discharge feeders (2)	55,000
e. Two conveyors to pug mills 175' x24"	95,000
f. Two pug mills- 400 tph capacity each	340,000
g. Two cement storage silos- 150 ton capacity each	135,000
h. Four baghouses	80,000
i. Four screw conveyors	45,000
j. Four rotary valves	20,000
k. E & I	125,000
l. Road construction	50,000
m. Drainage	25,000

IV. PELLETIZING PLANT	7,280,000
a. Site preparation/piling	90,000
b. Concrete	120,000
c. Structural steel, walkways, etc.	300,000
d. Building 50’x150’x45’ eave openside	600,000
e. 250 Foot supply conveyor 36”	185,000
f. Traveling tripper	30,000
g. 15 Pelletizers (42 tph each), with screw feeders and product coolers	4,920,000
h. Pelletizer feed bin 25’w x 125’l x 12’d	275,000
i. E & I control center	650,000
j. Painting	60,000
k. Office	20,000
l. Drainage	30,000

ORDER OF MAGNITUDE COST ESTIMATE
FOR A 4,500,000 TONS PER YEAR
GYPSUM PELLET PRODUCTION FACILITY
AT THE IMC/AGRICO UNCLE SAM PLANT

V. PRODUCT STORAGE CONVEYOR AND FACILITIES	2,210,000
a. Piling	110,000
b. Concrete	30,000
c. Structural steel/conveyor 1,350 LF	890,000
d. Traveling tripper double boom	110,000
e. Two front end loaders, 10 ton each (Cat 988's)	640,000
f. Scale	80,000
g. Levee around storage pile 2,300 LF	30,000
h. Painting	80,000
i. E & I	140,000
j. Road Construction	70,000
k. Drainage	30,000
VI. RIVER DOCK LOADING FACILITIES	3,870,000
a. Dock (5 dolphins, walkway)	1,020,000
b. 3,200 LF Conveyor 36"	2,180,000
c. Loading tipple tower	140,000
d. E & I	140,000
e. Painting	220,000
f. Weightometer	30,000
g. Environmental	140,000
VII. CONSTRUCTION EXPENSE	4,550,000
a. Salaries (US personnel)	70,000
b. Other	140,000
c. Engineering design	2,000,000
d. Engineering field	1,470,000
e. Auto Mileage	30,000
f. Service engr.	40,000
g. R&D testing and permits	200,000
h. Spare parts	600,000
VIII. TOTAL CAPITAL COST	**$21,870,000**

NOTES:

1. Costs are in 1996 dollars
2. No allowance for contingency is included
3. All operations and storage are outdoors except for an open, or partially open-sided building over the palletizing machine and a small office and switchgear building

ORDER OF MAGNITUDE COST ESTIMATE
FOR A 4,500,000 TONS PER YEAR
GYPSUM PELLET PRODUCTION FACILITY
AT THE IMC/AGRICO UNCLE SAM PLANT

I. MATERIAL COSTS	12,380,000
a. Portland cement purchase and delivery 136,000tpy @ $91.00/ton	12,380,000
II. MANUFACTURING COSTS	9,860,000
a. Labor, incl. OH, 85 persons @ (53,000×1.35)	6,080,000
b. Utilities, electric power	1,830,000
c. Utilities, other	150,000
d. Maintenance	1,800,000
III. ADMINISTRATION & FINANCIAL COSTS	620,000
a. salaries, 6 persons (405,000×1.35)	548,000
b. Insurance, fire and liability (0.3% cap)	64,000
c. Tax on Inventory	8,000
IV. Annual Operating Cost	**$22,860,000**

NOTES:

1. Costs are quoted in 1996 dollars.
2. Not included are charges for depreciation and interest.
3. Patent royalties and payments to third parties are not included.
4. Plant capacity is based on the production rate of 15 pellet machines at an operating factor of 0.822.
   15×42×24×365×0.822=4,536,000 tpy
5. Cost for Type II cement is from Blue Circle Cement in New Orleans and is negotiable
6. The operating manpower estimated is attached.
7. Electric power consumption is based on 80% of the projected installed capacity of 8200kw. The other utilities costs are for nominal amounts of natural gas and water.
8. The six administration personnel consist of: 1 manager, 1 general superintendent, 2 foremen, 1 clerk, and 1 secretary.

OPERATING MANPOWER ESTIMATE
FOR A 4,500,000 TON PER YEAR
GYPSUM PELLET PRODUCTION FACILITY
AT THE IMC/AGRICO UNCLE SAM PLANT

Item	Description (and Personnel Required per Shift)	Total Personnel
I	Gypsum reclaim facility Loading- 4 men Hauling- 7 men	51.7
II	Blending plant Operator- 1 man	4.7
III	Pelletizing plant Supervisor/operator- 1 man Operator- 1 man	9.4
IV	Storage facility and truck loading Operators- 2 men	9.4
V	River dock barge loading facility Supervisor/operator- 1 man Operator- 1 man	9.4
VI	Total men required – 18 men per shift	84.6

NOTES:

1. Operating cost is based on 24 hours per day, 365 days per year operation. For each man required per shift, 4.7 men will be required on the payroll to maintain 3 shifts per day, seven days a week, 365 days per year. This includes 4.2 men to fill the position and .5 men to fill in for vacations, illness and holiday relief.
2. The maintenance facilities will require 12 men. Use of the Uncle Sam shop is assumed for required shop work.

APPENDIX B

DEVELOPMENT OF ECONOMICAL STABILIZED PHOSPHOGYPSUM
COMPOSITES FOR SALTWATER APPLICATION

COST CALCULATION SPREADSHEET

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Cost Estimate Application For Stabilized Phosphogypsum (PG) Briquette

This economic analysis allows users to calculate the cost of stabilized PG briquettes. This analysis is based on a 4.5M ton/year production plant located in Riverview, FL. The user can change the following parameters (marked as blue):

(1) Cost of Cement
(2) Cost of fly ash
(3) Water content of raw PG
(4) Disposal cost of PG
(5) Pay out period of capital cost
(6) Interest for the loan of capital cost
(7) Annual inflation rate
(8) Ingredient composition

The calculation results (marked as violet) are shown in Tables 1 - 3 on the Results sheet.
The user can change the ingredient combinations (marked as blue) in the Tables 1 - 3.

Update of Crescent Technology Economic Analysis for Fabrication of PG Composites

Payout period (years)		10
Interest rate/year		0.08
annual inflation rate		1.025
Inflation from 1996 to	2001	1.131408213

ANNUAL CAPITAL COST			
Capital costs from Crescent Technology report			$ 21,870,000.00
Modified materials blending facility to include Fly Ash			$ 2,340,000.00
Total Capital Costs			$ 24,210,000.00
Inflation to	2001 dollars		$ 27,391,392.83
Annual Payment			-$3,779,745.62
INGREDIENT COST			
Cement cost/ton ($) in Tampa, Florida at 2		73.5	$ 9,187,500.00
Flyash cost/ton($) in Tampa, Florida at 20		25	$ 36,458,333.33
Additional Operating costs for Fly Ash (price*amount)			
OPERATING COST			
Original Operating Costs from Crescent Technology report (CTR)			$ 22,860,000.00
Adjusted Operating Costs from CTR after removing cement cost			$ 10,480,000.00
Adjust for inflation			$ 11,857,158.07
Total Costs			$ 57,502,991.40
Annual Capital Costs			$ 3,779,745.62
Total Annualized Costs			$ 61,282,737.02
PG briquette cost/ton (US$)			$ 13.62

Water content	0.2
Disposal cost($/ton)	1.5

Transportation cost ($/ton)	12

Table 1. Cost of production of Phosphogypsum/Fly Ash/Cement briquettes using different percentages of Fly Ash and Cement (2001 cost figures) *without factoring* in the offsetting cost of PG disposal, PG water content or transportation costs.

Cement content	Fly ash Content				
	0.35	0.3	0.25	0.20	0.15
0.02	$12.94	$11.78	$10.62	$9.47	$8.31
0.03	$13.62	$12.46	$11.30	$10.15	$8.99
0.04	$14.30	$13.14	$11.98	$10.83	$9.67
0.05	$14.98	$13.82	$12.66	$11.51	$10.35

Table 2. Cost of production of Phosphogypsum/Fly Ash/Cement briquettes using different percentages of Fly Ash and Cement (2001 cost figures) *when factoring* in the offsetting cost of PG disposal by wet weight and PG water content.

Cement content	Fly ash Content				
	0.35	0.3	0.25	0.20	0.15
0.02	$11.89	$10.65	$9.41	$8.17	$6.92
0.03	$12.59	$11.34	$10.10	$8.86	$7.62
0.04	$13.28	$12.04	$10.80	$9.56	$8.32
0.05	$13.98	$12.74	$11.50	$10.26	$9.02

Table 3. Cost of Production of Phosphogypsum/Fly Ash/Cement briquettes using different percentages of Fly Ash and Cement (2001 cost figures) *when factoring* in the offsetting cost of PG disposal by wet weight, PG water content and and the cost of transportation.

Cement content	Fly ash Content				
	0.35	0.3	0.25	0.20	0.15
0.02	$23.89	$22.65	$21.41	$20.17	$18.92
0.03	$24.59	$23.34	$22.10	$20.86	$19.62
0.04	$25.28	$24.04	$22.80	$21.56	$20.32
0.05	$25.98	$24.74	$23.50	$22.26	$21.02