ECONOMIC ANALYSIS OF PHOSPHOGYPSUM REUSE

The Fertilizer Institute

Submitted by:

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EXECUTIVE SUMMARY

Policy Navigation Group (PNG) conducted this analysis on behalf of The Fertilizer Institute (TFI) to estimate the potential regulatory cost savings of changes that would expand the use of phosphogypsum (PG) to include road construction. This application is in use in Europe and elsewhere, but currently is precluded in the U.S. due to U.S. Environmental Protection Agency (EPA) regulatory restrictions. This section outlines the main steps we undertook to perform the analysis and summarizes the economic benefits of using PG for road construction.

Outline of Steps in Analysis

In the analysis that follows, we take these steps to estimate the potential cost savings of using PG for road construction:

> **Identify the costs to manage PG currently in stacks located at numerous sites.** These include the costs of land for the stacks, the costs to transport PG to the stacks, the costs of managing water at and preserving the physical stability of the stacks, and the costs to close the stacks.
>
> **Assess scenarios for PG reuse in road construction in the near future.** We assume that PG reuse will start modestly and grow over time. Given market uncertainty over the potential demand for PG, we estimate the savings for a lower-bound and an upper-bound scenario; any savings are expected to be within this range. Due to transportation costs and the availability of substitutes, we assume that the PG reuse market faces natural limits and largely is confined to locations relatively close to current plants and stacks.
>
> **Estimate the cost savings from PG reuse.** Companies can incur savings in PG management costs if they send PG to be reused (stack management savings from the regulatory reform). Since the stack management savings from the regulatory reform frees up the labor, capital, and physical land needed for PG stack management, in competitive markets some of these savings are passed through to the companies' customers and purchasers of PG for reuse. Ultimately the savings pass through to the state and local highway departments, companies' shareholders, companies' workers, farmers and other purchasers of fertilizer, and other households and firms.[1] For this reason, these cost savings are also the social benefits of the reform. They are also the deregulatory savings from an EPA action to allow reuse for road construction.

Figure ES-1 summarizes the key inputs used in the analysis and shows the data transformation and resulting outputs.

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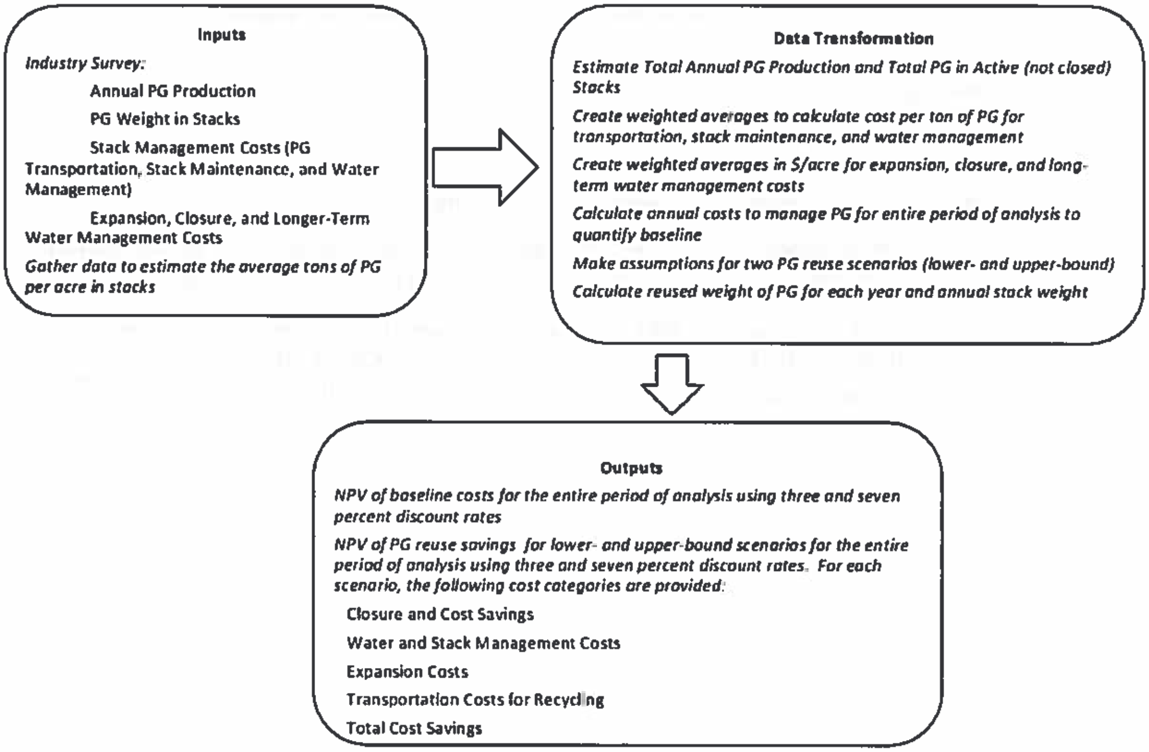
[1] In this analysis, we only consider the direct economic impact of the reform. There will be indirect and induced economic impact of the reform as fertilizer customers have lower input costs and can gain market share from imports and as workers spend their greater compensation on consumer goods and services. These gains then induce additional economic impact such as higher spending by vendors to the fertilizer purchaser and the workers.

Figure ES-1: Diagram Summarizing Analytical Approach for Project[2]



Summary of the Regulatory Savings

The analysis produced by taking the steps above provides a clear picture of the cost savings of using PG for road construction. Table ES-1 presents the baseline costs to manage PG from 2020-2042, which range from $1.3 billion to $0.88 billion using three and seven percent annual discount rates. Table ES-2 summarizes the cost savings from PG reuse for the two reuse scenarios; it shows that the total net present value (NPV) savings range from $37 million to $52 million for the lower-bound scenario and from $110 million to $160 million for the upper-bound scenario, using discount rates of seven and three percent, respectively.[3] We use three and seven percent discount rates to calculate the results from this analysis, as directed by U.S. Office of Management and Budget Circular A-4.

[2] We use three and seven percent discount rates to calculate the results from this analysis, as directed by the U.S. Office of Management and Budget's Circular A-4.

[3] The results presented in this analysis are rounded to two significant figures. Due to rounding, total values in the tables may not sum.

Table ES-1: Net Present Value (NPV) of Baseline Costs to Manage PG

CATEGORY	NPV USING A 3% DISCOUNT RATE (IN $ MILLIONS)	NPV USING A 7% DISCOUNT RATE (IN $ MILLIONS)
Baseline Costs	1,300	880

Table ES-2: Net Present Value (NPV) of Cost Savings from PG Reuse

COST CATEGORY[4]	LOWER-BOUND SCENARIO NPV USING A 3% DISCOUNT RATE (IN $ MILLIONS)	LOWER-BOUND SCENARIO NPV USING A 7% DISCOUNT RATE (IN $ MILLIONS)	UPPER-BOUND SCENARIO NPV USING A 3% DISCOUNT RATE (IN $ MILLIONS)	UPPER-BOUND SCENARIO NPV USING A 7% DISCOUNT RATE (IN $ MILLIONS)
Closure Cost Savings	11	11	33	32
Water and Stack Management Costs	22	13	65	37
Expansion Costs	19	13	57	38
Total Cost Savings	52	37	160	110

In summary, expanding the use of PG in road construction is expected to result in savings not only to PG producers, but also to numerous users of PG and workers, shareholders, and customers of fertilizer firms.[5]

[4] Transportation savings are omitted from the results shown in this table as they amount to zero dollars. Transportation cost from the stack to the construction site is not included because it is assumed that the customer would pay for this transportation as part of the road construction cost.

[5] Savings to users of PG, workers, shareholders, and customers of fertilizer firms are not evaluated in this economic analysis.

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INTRODUCTION

Policy Navigation Group (PNG) conducted this analysis on behalf of The Fertilizer Institute (TFI) to estimate the potential regulatory cost savings of using phosphogypsum (PG) for road construction, an application currently in use in Europe and elsewhere. This section provides a summary of the industry, followed by a description of PG, its production in the U.S., and U.S. Environmental Protection Agency (EPA) PG requirements. It then touches upon PG reuse options and scenarios before concluding with a description of how the remainder of the report is organized.

Summary of Industry

Phosphate rock is predominantly used to produce phosphoric acid, which is primarily used to manufacture fertilizer. The U.S. was previously the largest producer of phosphate rock and leading exporter of phosphate fertilizer, until China increased its production in 2011 and surpassed the U.S. as lead world exporter in 2014.[6] Currently, the U.S. is the second-largest consumer of phosphate rock (consuming 29 million metric tons (MT)) and the second-largest producer of phosphoric acid (producing 14 million MT).[7] Domestically, phosphate rock ore is mined primarily by five firms in four states – with 80 percent of the mining occurring in Florida and North Carolina – to produce approximately 27.1 million tons of marketable product.[8] After being mined in open-pit mines, phosphate rocks are treated, washed, and dried in rotary kilns.[9] The ore is then finely ground and converted into a soluble form through either a wet or dry process. In the U.S., facilities exclusively use a wet process that digests the phosphate rock in a reaction vessel with sulfuric acid, producing both phosphoric acid and a largely calcium sulfate byproduct known as PG.

Total worldwide production of PG is estimated between 100-280 mega tons per year.[10] About 85 percent of world PG production is discarded or stored. The remaining 15 percent of worldwide production is reused as soil amendment, agricultural fertilizer, and set controller for cement and building materials worldwide.

Around the world, PG is used in a range of applications, including:[11]

- In fertilizer for agricultural soils;
- In backfill and road-base material for roadway and parking lot construction;
- As an additive to concrete and concrete blocks;

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[6] Jasinski, "Phosphate Rock."

[7] European Phosphate Fertilizer Alliance, "Data and Statistics: Phosphoric Acid."

[8] Jasinski, "Phosphate Rock."

[9] U.S. Environmental Protection Agency, "Potential Uses of Phosphogypsum and Associated Risks: Background Information Document for 40 CFR 61, Subpart R, National Emission Standards for Radon Emissions from Phosphogypsum Stacks."

[10] Sahu et al., "Natural Radioactivity Assessment of a Phosphate Fertilizer Plant Area."

[11] U.S. Environmental Protection Agency, "Potential Uses of Phosphogypsum and Associated Risks: Background Information Document for 40 CFR 61, Subpart R, National Emission Standards for Radon Emissions from Phosphogypsum Stacks."

- In wallboards;
- In mine reclamation; and
- In the recovery of sulfur.

Prior to the 1992 EPA restrictions on its widespread reuse, PG was critical to the peanut industry as a soil amendment valued for its fertilizer properties across Georgia, North Carolina, Virginia, and Alabama, and on farms across the southeast that grow tobacco, corn, small grain, and sugar cane.[12] As a large peanut producer, Georgia was the largest PG consumer. States such as California also used PG for soils growing citrus, almonds, vegetables, and tomatoes. In these and other locations, PG was widely used, since it had been shown to be a beneficial source of sulfur in improving crop yields.

Description of Phosphogypsum

PG byproduct is filtered from the phosphoric acid and transferred as a water slurry to be stored in open-air areas called PG stacks. The slurry is pumped atop the stack, where an engineered "gypsum stack and pond" is formed. Water impounded from PG stacks is reused in the overall wetting process. Closing PG stacks involves complex engineering, including placing high-density polyethylene liners as caps to prevent rainwater from infiltrating and reduce stack water from percolating out from the bottom of the stacks.[13]

Reuse Options and Scenarios

Other countries, most notably Japan and some nations in Europe, have and currently reuse some PG for specified uses that have included road base material, cement, wallboard, and other building materials.[14]

Road Base

Prior to EPA restrictions on its use in 1992, PG was mixed with ash, sand, gravel, or cement, and was used as a base for roads, parking lots, and storage areas to help control setting times, counteract shrinkages, strengthen cement products, and create resistance to sulfate etching.[15] Numerous publications are available detailing these uses. The following are some examples of how PG was used in Texas, Florida, and North Carolina:[16]

- In Pasadena, Texas, PG was mixed with fly ash and cement for road base at five sections of city streets in La Porte, Texas.
- In Polk County, Florida, PG was mixed with granular sand to construct 2.4 kilometers of road base, surfaced with asphalt.

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[12] U.S. Environmental Protection Agency.

[13] BCI Engineers & Scientists, Inc., "Phosphogypsum Stack Closure: Evaluation of Phosphogypsum as an Alternate Final Cover."

[14] U.S. Environmental Protection Agency, "Potential Uses of Phosphogypsum and Associated Risks: Background Information Document for 40 CFR 61, Subpart R, National Emission Standards for Radon Emissions from Phosphogypsum Stacks."

[15] U.S. Environmental Protection Agency.

[16] U.S. Environmental Protection Agency.

- In Columbia County, Florida, two miles of road base was constructed with 100 percent dehydrated PG and varying mix ratios of PG and sand. The road base was also surfaced with asphalt.
- In North Carolina, PG was commercially used as a fill and sub-base for roads in swampy areas.
- In Bartow, Florida, the Florida Institute of Phosphate Research used a mixture of PG and concrete to pave two thousand yards of driveway and parking areas.

Cement and Concrete Aggregate

PG also has been used to manufacture building materials, including concrete and cement aggregates, particularly outside the U.S.[17] Additionally, it can be used more extensively in building materials, including cement, wallboard, ferrocement panels, plasterboard panels, partition blocks, plaster, tiles, artificial stone, and glass ceramics.[18]

Several studies have demonstrated that PG can help prolong concrete setting times.[19] The increased setting time supports long-term concrete strength. Incremental initial and final setting times increase with increasing PG content. Using PG as a retarder agent is particularly beneficial in civil engineering work involving casting in hot weather, casting retaining deep walls, and casting mass concrete and repair elements, for example.[20]

Including PG in cement also has the benefit of reducing density, increasing chemical resistance, increasing free resistance, and increasing fire resistance.[21] As such, PG has the potential to be used as a partial substitute for materials aggregate in concrete.

Organization of the Report

The rest of the report discusses current PG management costs and incurred savings from PG reuse, showing how we developed scenarios for PG reuse and estimated the cost savings for these scenarios. Since the regulatory change frees up the labor, capital, and physical land needed for PG stack management, these savings are also the social benefits of the regulatory reform.

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[17] U.S. Environmental Protection Agency.

[18] Rashad, "Phosphogypsum as a Construction Material."

[19] Rashad; Shen et al., "Calcium Sulphoaluminate Cements Made with Phosphogypsum: Production Issues and Material Properties"; Singh, "Treating Waste Phosphogypsum for Cement and Plaster Manufacture"; Altun and Sert, "Utilization of Weathered Phosphogypsum as a Set Retarder in Portland Cement."

[20] Rashad, "Phosphogypsum as a Construction Material."

[21] Rashad.

CURRENT PG MANAGEMENT COSTS AND COST SAVINGS FROM PG REUSE

Introduction and Methodology Overview

This section provides an overview of current PG production and PG stored in stacks; details and quantifies the current costs of PG management; describes and quantifies the potential short- and long-term cost savings if a percentage of currently produced PG is reused for road construction; provides baseline and PG reuse scenarios to illustrate several key points; and presents the variables, assumptions, and methodology used in all the above.

A survey was conducted with members of TFI in July 2019. The survey included questions on current PG production; weight of PG stored in active stacks; and costs to transport, manage, expand, and close stacks. The survey was conducted, compiled and summarized by an independent party who removed identifying information before data was provided to PNG for analysis. The survey questions are provided in Appendix 1.

Using the survey information, we estimate averages for current production, average weight of PG stored in active stacks, and costs. With these estimates, we calculate the current costs of managing PG — the baseline costs. Then, we create two scenarios (lower- and upper-bound) to estimate the cost savings if a percentage of the PG produced is beneficially reused.

The timeline of the analysis is from 2020 to 2042. All future values are discounted using a three and seven percent discount rate and presented in 2019 dollars.[22] The values in the tables are rounded to two significant digits. Therefore, the totals shown in some tables may not sum exactly. We only consider active PG stacks for this analysis, as according to information received from the industry, it is unlikely that PG from closed stacks would enter the reuse market.

PG Production and Annual Growth Rate

Survey participants provided annual PG production data (in tons per year) for 2016, 2017, and 2018 for nine active stacks. Data was provided by the largest PG producers in the U.S., but it does not include all active stacks and PG producers in the country. To account for variability across stack data (both, on annual basis and by stack), we calculate weighted averages. To calculate the weighted annual production rate, we estimate the average growth (in tons) for each stack from 2016 to 2017 and from 2017 to 2018. Then, we estimate the corresponding weighted average growth rate for each period (from 2016 to 2017 and 2017 to 2018). We derive industry representative weighted averages by weighing each stack's size by its proportion of the sum of the size for all the stacks in the survey.

To estimate the annual production of PG available for reuse, we calculate the weighted average across all the active stacks. For this estimate, we quantify the multi-year average per active stack (from 2016 to 2018) and then the weight of the multi-year average per stack in relation to all the active stacks. This gives a weighted average annual production of PG of 5.1

[22] U.S. Department of Labor, Bureau of Labor Statistics, "CPI Inflation Calculator."

million tons. We multiply this value by nine stacks to obtain a weighted annual total U.S. production of 46 million tons of PG.

For this report, we assume that PG production in the U.S. will not experience growth in the timeline of the analysis — that it will remain at the same level as in the baseline. We make this assumption because information received from the industry for this analysis forecasts no growth. Furthermore, the survey data spans only a three-year period and varies by company and year, rendering it difficult to determine any long-term trend in terms of growth. We note that this assumption is in line with market reports from Europe, which show near-zero growth for PG production between 2012 and 2017.[23]

Table 1 summarizes the PG production data used for the analysis.

Table 1: PG Production

ITEM	AMOUNT
Weighted Average of Production, Per Year, Per Stack	5,100,000 tons
Total Annual Production of PG	46,000,000 tons

PG Stored in Stacks

For the nine active stacks discussed in the previous subsection, we received the approximate amount of PG stored in each. For eight of the nine stacks, the weight was provided in tons. For one of the stacks, we were provided the volume in cubic yards, which we converted into tons using a density factor of 1.9 tons per cubic yard.[24]

The surveyed companies also provided information for inactive stacks, as PG from inactive stacks may be used.

Using the survey information, we add the total weight in both active and inactive stacks. Additionally, we calculate the weighted average tons for both types of stacks by creating weights per stack (that is, how much each stack represents of the total in the corresponding category). These weights are further used to estimate the average costs per ton (see subsection below).

[23] Layr and Hartlieb, "Market Analysis for Urban Mining of Phosphogypsum."

[24] City of Moorpark, "Construction Demolition Conversion Table." This value comes from a conversion factor for gypsum used in drywall.

Figure 1: Projected New PG Production and PG in Stacks[25]

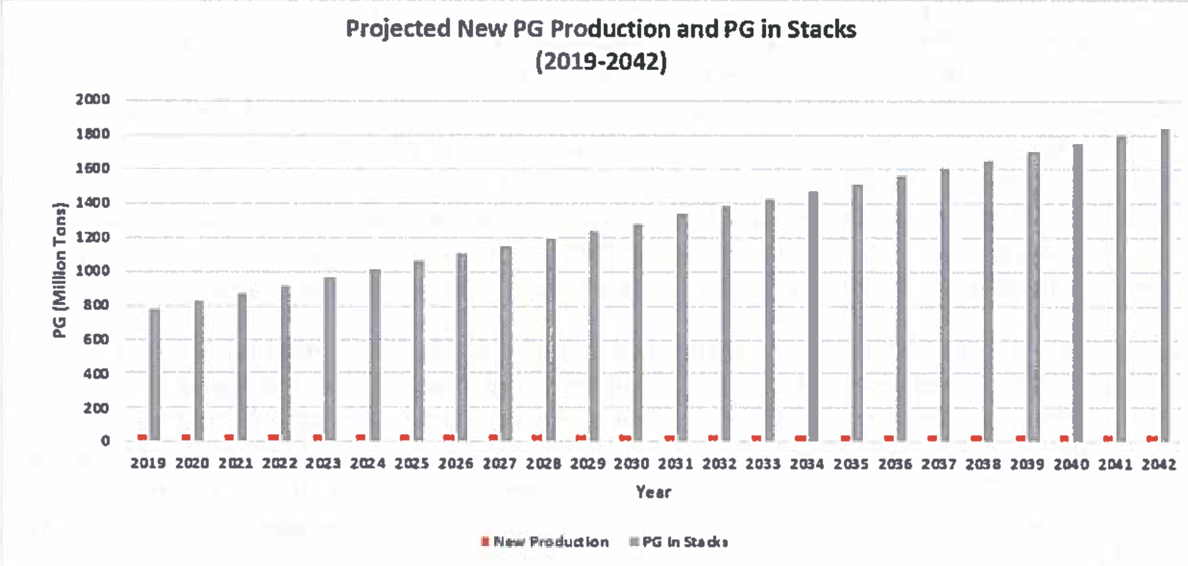

Table 2 summarizes the PG stored in stacks and Figure 1 shows both the PG in stacks and the projected new production of PG. While the period of analysis is 2020-2042, Figure 1 includes data for 2019, as the PG in stack value for 2020 must include the weight for 2019.

Table 2: PG in Stacks

ITEM	ACTIVE STACKS	INACTIVE STACKS	TOTAL
Total PG Stored (million tons)	517	217	734
Weighted Average Per Stack (million tons)	69	65	N/A

Costs to Manage PG

In response to the survey, companies provided annual costs per stack for the following categories[26]:

- Transportation costs – costs to transport PG from the plant to the stacks
- Stack maintenance costs – labor, monitoring, inspection, and reporting costs
- Water management costs – costs for water balancing and water treatment

[25] Figure 1 reflects the current baseline and does not show the PG reuse scenarios discussed later in the analysis.

[26] The cost information was provided by stack and was not tied to PG production levels.

We then use the weights calculated for PG production and PG stored in stacks (see previous subsections) and apply those to the survey data's cost per stack. For the transportation costs, we use the weights for PG production, as transportation costs are incurred in transporting PG from the plant to the stacks; once the PG is in place at the stack, no additional transportation costs are assumed to be incurred. For stack maintenance and water management costs, we use the weights corresponding to PG stored in stacks and apply them to the whole amount of PG stored in a stack. Then, we calculate the weighted average cost per category. To do this, we multiply the corresponding weight by the cost per year per stack, add those products, and divide the resulting sum by the sum of the weights used. Finally, we obtain the average cost per ton by dividing the weighted average by the number of tons per cost category.

The volume of water generated and treated (the water management volume) can be affected by factors such as weather conditions, the manufacturing process, and the age of the PG. The major climate consideration would be variability in precipitation among different geographic regions. While water management volumes would decrease over time due to reduction in size and number of PG stacks, it would not completely disappear. As with all new sustainability strategies, innovation and synergies may lead to additional water management reductions as yet to be determined.

Thus, in practice, the stack water generation and treatment volumes can vary significantly by the location and by the age of the stack. While we asked respondents for typical, current values for water management costs, we are unaware if respondents provided data that represents average climate conditions and PG aging.

Table 3 provides the weight of PG in active stacks, the weighted average costs and the cost per ton for the three cost categories.

Table 3: Weight of PG in Active Stacks and Costs

ITEM	TRANSPORTATION COSTS	STACK MAINTENANCE COSTS	WATER MANAGEMENT COSTS
Weighted Average ($ millions)	7.2	6.8	7.4
Total Tons of PG in Category (million tons)	8.3	570	380
Average Cost Per Ton ($)[27]	0.87	0.012	0.02

[27] Average cost per ton is obtained by dividing the weighted average by total tons of PG. For example, for transportation costs 7.2/8.3=$0.87. Note that values in the table are rounded to two significant figures as noted earlier in the analysis. As a result, total values in table may not sum exactly.

Other Stack-Related Costs

Survey participants indicated that, in addition to transportation, water management, and stack maintenance costs, there are other long-term costs associated with PG stacks — stack closure costs, water inventory costs, and stack expansion costs. These costs are expected to be incurred in the next five years (between 2020 and 2024).

To avoid providing identifiable information, the surveyed companies provided costs for those long-term categories in dollars per acre of PG stack. In some instances, they provided a lower- and upper-bound estimate for the category. Also, some companies reported zero costs for the category or reported them as part of another category. For this analysis, we create upper- and lower-bound estimates per category, then calculate the middle-point value. Table 4 outlines these costs.

Table 4: Long-Term Costs of PG Management

<table>
<tr><th>ITEM</th><th>STACK CLOSURE COSTS</th><th>WATER INVENTORY COSTS</th><th>STACK EXPANSION COSTS</th><th>TOTAL</th><th>UNIT</th></tr>
<tr><td>Average — Lower Bound</td><td>91,000</td><td rowspan="2">23,000</td><td>220,000</td><td>330,000</td><td>$/acre</td></tr>
<tr><td>Average — Upper Bound</td><td>100,000</td><td>240,000</td><td>360,000</td><td>$/acre</td></tr>
<tr><td>Total Average</td><td>96,000</td><td>23,000</td><td>230,000</td><td>350,000</td><td>$/acre</td></tr>
</table>

Cost Summary

Table 5 summarizes the cost savings due to PG reuse. The most significant savings occur from deferring stack closure and expansion, which together represent almost $350,000 per acre of PG. Since one stack can contain more than 70 million tons of PG, the cost savings of reusing PG are significant.

Table 5: Short- and Long-Term Costs of PG Management

ITEM	COST	COST TYPE	UNIT
Transportation Costs	0.87	Short-term	$/ton
Stack Maintenance Costs	0.01	Short-term	$/ton
Water Management Costs	0.02	Short-term	$/ton
Stack Closure Costs (includes water inventory costs)	120,000	Long-term	$/acre
Stack Expansion Costs	230,000	Long-term	$/acre

Cost Savings from PG Reuse Scenarios

Baseline Scenario

In this scenario, we quantify the current costs of managing PG at phosphoric acid plants. As outlined in Table 1, the weighted annual PG production is approximately 46 million tons. Figure 1 outlines the total amount of PG expected to be produced per year from 2020 to 2042. It also presents the amount of PG expected to be stored in stacks during that same period. Given the current regulatory restrictions on using PG, this scenario assumes that all new PG produced is put into stacks.

To estimate the costs for the baseline scenario, we first multiply the weighted annual production of PG by the transportation costs per ton ($0.87). We then multiply the weight of PG stacked by the sum of stack maintenance and water management costs per ton of PG ($0.03). Finally, we add the transportation, stack maintenance, and water management costs for the entire period and calculate the net present value (NPV) using discount rates of three and seven percent.

PG Reuse Scenarios

Lower-Bound Scenario

In this scenario, we assume that a percentage of PG produced annually is reused. When PG is reused rather than put into stacks, PG producers incur savings in water management costs, stack maintenance costs, and long-term savings for the amount of PG reused; the only costs they incur are those associated with transport of PG from the facility to the construction site. The NPV of these cost savings minus the transportation costs to the construction site (at discount rates of three and seven percent) are the results for this scenario.

This scenario assumes that five percent of current PG production is reused in each year in 2020 and 2021, 7.5 percent is reused each year in 2022 and 2023, and 10 percent is reused in 2024 (see Table 9). Between 2025-2042, the assumed reuse percentage remains at 10 percent. We arrive at this representative reuse scenario by assuming that the PG reuse market will start slowly due to the availability of competing products that already have market share and may be sold through longer-term contracts. Additionally, since PG has been off the market for almost 20 years, this assumption accounts for the idea that it may take PG sellers some time to convince potential customers of PG's beneficial qualities. With these assumptions in place, we calculate water management, and stack maintenance savings by multiplying the sum of the annual weight of PG reused (in tons) plus the weight of PG reused in previous years by $0.03 (see Table 6).[28]

Upper-Bound Scenario

In this scenario, we assume that PG suppliers will offer favorable pricing relative to competing products, effectively promoting greater PG reuse that grows robustly over time. Specifically, we assume that 10 percent of current PG production is reused in 2020, 15 percent is reused in 2021, 20 percent is reused in 2022, 25 percent is reused in 2023, and 30 percent is reused from 2024 (see Table 6). As in the lower-bound scenario, we arrive at this representative reuse scenario by assuming that the PG reuse market will start slowly due to the availability of competing products that already have market share and may be sold through longer-term contracts, and that it may take PG sellers some time to convince potential customers of PG's beneficial qualities. With these assumptions in place, we calculate water management, and stack maintenance savings by multiplying the sum of the annual weight of PG reused (in tons) plus the weight of PG reused in previous years by $0.03 (see Table 6).

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[28] Water management and stack maintenance savings are recurrent annual costs. Therefore, they are calculated over the sum of PG reused in a given year plus PG reused in the previous years. For example, for the upper-bound scenario in 2022, water management and stack maintenance savings are calculated over 20.7 tons (sum of amount reused from 2020-2022).

Table 6: PG Reused

YEAR	LOWER-BOUND SCENARIO PERCENTAGE REUSED (%)	LOWER-BOUND SCENARIO AMOUNT REUSED (MILLION TONS PER YEAR)	UPPER-BOUND SCENARIO PERCENTAGE REUSED (%)	UPPER-BOUND SCENARIO AMOUNT REUSED (MILLION TONS PER YEAR)
2020	5	2.3	10	4.6
2021	5	2.3	15	6.9
2022	7.5	3.5	20	9.2
2023	7.5	3.5	25	12
2024	10	4.6	30	14
2025	10	4.6	30	14
2026	10	4.6	30	14
2027	10	4.6	30	14
2028	10	4.6	30	14
2029	10	4.6	30	14
2030	10	4.6	30	14
2031	10	4.6	30	14
2032	10	4.6	30	14
2033	10	4.6	30	14
2034	10	4.6	30	14
2035	10	4.6	30	14
2036	10	4.6	30	14
2037	10	4.6	30	14
2038	10	4.6	30	14
2039	10	4.6	30	14
2040	10	4.6	30	14
2041	10	4.6	30	14
2042	10	4.6	30	14

Comparison of Reuse Scenario versus Current Demand for Road Construction

We compare this reuse scenario to the size of local markets as one measure of the reasonableness of the scenario. To validate that our assumptions on PG reuse are feasible given the overall size of the road aggregate market, we contacted the Florida Department of Transportation. We selected Florida as a representative construction market since a majority of the nation's PG is generated in Florida.

Due to the high cost of transporting PG to be used in road construction, we consider that the potential demand for PG is limited to within one day's hauling of the production location, or approximately 200 miles. Both the lower and upper bound scenarios of PG reuse are well within Florida's projected future demand for aggregate for road construction.

Stack Closure Costs

We assume that by reusing a percentage of current production, PG producers will be able to defer stack closure costs. Thus, less PG would need to be stored in stacks, and current stack capacity would last longer. However, it is difficult to predict the number of stacks that may be closed — or expanded — in the period of analysis (and thus estimate the potential cost savings from those deferred stack closures). We believe this to be the case based on insights provided by survey respondents, which suggest that stack closure and stack expansion decisions require long-term strategic planning and are subject to company-specific PG production forecasts and stack capacity.

Recognizing the limitations of generalizing from company-specific conditions to a industry-representative average, in this analysis, we start by assuming that stack closure costs are deferred until 2039 for both the lower- and upper-bound scenarios. The assumption that a stack is closed in 2039 is consistent with historic stack closure reports, as stacks are generally closed after reaching a certain acreage. The purpose of this estimate is to show the potential savings that could arise from deferring stack closure due to PG reuse. For these estimates, the closure cost per acre of PG corresponds to the sum of the water inventory management and stack closure costs ($120,000). Closure occurs in 2039, but the period of analysis covers years until 2042 to allow for the completion of active stack closure activities.

The weight of PG in the survey is provided in tons, while the long-term costs are provided in dollars per acre. Therefore, we next need to estimate how much PG is generally found in one acre. For this estimate, we use a dataset with stack data for Florida.[29] This dataset has information on stack area and length. We assume that all stacks in the Florida dataset are 100 meters in height, have a rectangular base, and have a side slope of 1:3. To estimate the stack width, we divide area by length. Then, we calculate the volume per stack and multiply that volume by an assumed density of PG of 2.3 g/cm^3.[30] (The approach to estimate the stack

[29] State of Florida, "Florida Gypsumstacks."

[30] U.S. EPA, Region 4, Superfund Division, "Engineering Evaluation/Cost Analysis: Closure of the East Gypsum Stack and North Ponds, Mississippi Phosphates Corporation Site, Pascagoula, Jackson County, Mississippi."

volume was derived from EPA and Florida Department of Environmental Protection sources.[31]) Finally, since the Florida dataset uses data in metric units, we convert square meters into acres. Thus, we conclude that one acre contains approximately 850,000 tons of PG. We then divide the total tons of PG reused in 2039 for the lower- and upper-bound estimates by 850,000 to obtain the equivalent number of acres, multiply it by the actual cost per acre ($120,000), and present the NPV using three and seven percent discount rates.

In this report, based on the estimated reused PG from 2020-2039, we assume that a PG stack of 97 acres is closed in 2039 for the lower-bound scenario and a PG stack of 290 acres is closed in 2039 for the upper-bound scenario.

Stack Expansion Costs

To estimate the potential cost savings from stack expansion, we first divide the weight of PG reused per year by 850,000 to convert it into acres. We then multiply the resulting quotient by $230,000, which is the cost to expand one acre. Finally, we discount the costs using three and seven percent rates.

Stack Maintenance and Water Management Costs

To estimate the potential cost savings from stack maintenance and water management, we first multiply the sum of the annual weight of PG reused (in tons) plus the weight of PG reused in previous years by $0.03. We then calculate the NPV for the entire period of analysis using three and seven percent discount rates.

Transportation Costs to Reuse Location

We assume that PG transportation costs are essentially the same as the cost of transporting alternative materials; therefore, from a social cost perspective, there is no marginal savings by transporting PG or another aggregate. This leads to the conclusion that there are no potential benefits related to savings from transportation costs. Thus, transportation costs are not shown in Table 9 considering that they are zero.

Table 7 provides the key assumptions for PG reuse used in the analysis.

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[31] Florida Department of Environmental Protection, "Florida Gypsumstacks, Phosphogypsum Stack System Layer."; U.S. Environmental Protection Agency, "National Emission Standards for Hazardous Air Pollutants; National Emissions Standards for Radon Emissions from Phosphogypsum Stacks; 40 CFR Part 61," 13-19; and Appendix B.

Table 7: Key Assumptions for PG Reuse Scenario

ITEM	LOWER-BOUND SCENARIO	UPPER-BOUND SCENARIO
PG reused in 2020	5% of annual production	10% of annual production
PG reused in 2021	5% of annual production	15% of annual production
PG reused in 2022	7.5% of annual production	20% of annual production
PG reused in 2023	7.5% of annual production	25% of annual production
PG reused in 2024	10% of annual production	30% of annual production
Year in which stack closure occurs	2039	2039
Conversion rate for PG (tons into acres)	850,000	850,000

Results of Cost Savings from PG Reuse

Table 8 shows the total NPV of baseline costs associated with managing PG stacks, which range between $0.88 billion and $1.3 billion at seven and three percent discount rates, respectively.

Table 8: NPV of Baseline Costs to Manage PG

CATEGORY	NPV USING A 3% DISCOUNT RATE (IN $ MILLIONS)	NPV USING A 7% DISCOUNT RATE (IN $ MILLIONS)
Baseline Costs	1,300	880

The total NPV of cost savings between 2020-2042 is presented in Table 9. It shows savings associated with PG reuse ranging between $37 million and $52 million for the lower-bound scenario and $110 million and $160 million for the upper-bound scenario, using seven and three percent discount rates, respectively. It also presents the estimated cost savings for stack closure, water and maintenance management, expansion, and transportation costs. The largest savings result from the deferred stack expansion costs, with the second-largest savings a result of deferred stack closures.

Table 9: NPV of Cost Savings from PG Reuse

COST CATEGORY[32]	LOWER-BOUND SCENARIO NPV USING A 3% DISCOUNT RATE (IN $ MILLIONS)	LOWER-BOUND SCENARIO NPV USING A 7% DISCOUNT RATE (IN $ MILLIONS)	UPPER-BOUND SCENARIO NPV USING A 3% DISCOUNT RATE (IN $ MILLIONS)	UPPER-BOUND SCENARIO NPV USING A 7% DISCOUNT RATE (IN $ MILLIONS)
Closure Cost Savings	11	10	33	32
Water and Stack Management Costs	22	13	65	37
Expansion Costs	19	13	57	38
Total Cost Savings	52	37	160	110

Executive Order 13771 Deregulatory Savings

Under E.O. 13771, EPA's action to allow PG to be reused as a road construction material would constitute a deregulatory action and would generate savings that could help EPA achieve its regulatory allocation.

Assuming that EPA either changes its existing regulation to allow a regulatory exemption for PG reuse in road construction or gives a one-time, broad approval of a petition for road construction reuse, EPA's action would constitute a deregulatory action under E.O. 13771. The Office of Management Budget's implementing memorandum for E.O. 13771 draws the distinction between routine regulatory actions and one-time actions that produce on-going savings. Agency actions that require regular agency approvals - e.g., quotas, permits - are not deregulatory actions under E.O. 13771. However, if EPA's approval of PG petitions does not require further approvals, is not conditioned on satisfying reporting requirements, and is broadly applicable to PG producers, it would likely qualify as a deregulatory action. EPA then could count it as part of meeting E.O. 13771's ratio of one deregulatory action for every two regulatory actions.

The action would also generate deregulatory savings. Under E.O. 13771, agencies are granted a regulatory allocation for each fiscal year.[33] The regulatory costs of significant economic regulatory actions and the deregulatory savings must add up to less than the agency's allocation. Agencies must align the savings and costs in the same fiscal year; in this case, the deregulatory savings from allowing PG reuse occur in future years. Table 10 gives the

[32] Transportation costs are omitted from the table as they are zero. Potential revenue obtained from selling PG is not estimated in this report.
[33] "Executive Order 13771 of January 30, 2017, Reducing Regulation and Controlling Regulatory Costs."

estimated annual savings for the next five years, an illustrative period to demonstrate how savings increase in the near-term before reaching a relatively constant value.

Table 10: Estimated Cost Savings from 2021-2025

TOTAL COST SAVINGS (IN MILLIONS $)	2021	2022	2023	2024	2025
At 3 and 7 Percent Discount Rate	1.1-3.2	1.7-4.5	1.8-5.8	2.4-7.2	2.6-7.7
At 7 Percent Discount Rate	1.1-3.2	1.7-4.5	1.8-5.8	2.4-7.1	2.6-7.6

Summary

In summary, the analysis shows that the potential regulatory cost savings of changes that would allow the reuse of PG ranges between $37 million and $160 million. These results represent the NPV of savings for the period of analysis (2020-2042). These results strongly support the reuse of PG for beneficial applications such as road construction in the U.S. — applications already permitted and used in Europe and elsewhere. Additionally, they support the idea that using PG for road construction offers the possibility of significant savings not only to PG producers, but also to state transportation agencies to the extent they replace a percentage of the aggregates currently used for road construction with PG.

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APPENDIX 1

1. Current producers of phosphoric acid/phosphogypsum (PG) in the U.S., including annual PG production, per stack. If PG production is not available, what is the annual phosphoric acid production (weight)?

Production Company Identifier	2018 Production Amount: PG (T/stack) - Phosphoric Acid (T/year)	2017 Production Amount: PG (T/stack) - Phosphoric Acid (T/year)	2016 Production Amount: PG (T/stack) - Phosphoric Acid (T/year)	Information Provided: PG or Phosphoric Acid?
[Enter response]	[Enter response]	[Enter response]	[Enter response]	[Enter response]

2. Number of PG stacks your company manages and the approximate weight of PG stored in each stack as of 12/31/18. Include those stacks that are inactive, but that have not been closed. Do not include stacks that are permanently closed (not good candidates for PG reuse).

Production Company Identifier	Approximate Weight of PG Stored in Each Stack (T/stack)	Stack Status (Active/ Inactive)
[Enter response]	[Enter response]	[Enter response]

3. With a focus on the process of PG stacking, and an emphasis on active stacking disposal areas, for each active stack, please include the annual costs for: (a)Transporting the gypsum from the phosphoric acid facility to the stack (b)Stack maintenance, including labor costs and monitoring, inspection, reporting requirements (c)Stack process water management, including water balancing and water treatment.

Phosphoric Acid Facility	(a) Annual Gypsum Transportation Cost ($/year)	(b) Stack Maintenance Cost ($/year)	(c) Stack Process Water Management Cost ($/year)	Year in which Costs Are Provided (e.g., $2019 Dollars)
[Enter response]	[Enter response]	[Enter response]	[Enter response]	[Enter response]

4. Please identify longer term (next five years in aggregate) stack closure costs on a per acre basis (include the costs associated with long term water inventory management)

Phosphoric Acid Company	Stack Closure Management Costs [2020-2024] ($/acre)	Water Inventory Management Costs [2020-2024] ($/acre)	Stack Expansion Costs [2020-2024] ($/acre)	Year in which Costs Are Provided (e.g., $2019 Dollars)
[Enter response]	[Enter response]	[Enter response]	[Enter response]	[Enter response]