# Towards a Management and Regulatory Strategy for Phosphoric Acid and Phosphogypsum as Co-Products[1]


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**Abstract.** Since 1946, the United States, to date global leader in diammonium phosphate (DAP) production, has in the same process generated billions of tonnes of phosphogypsum (PG) - some five tonnes of PG for every tonne of phosphoric acid. Most US PG is stored in 20 huge "stacks" in central and north Florida, with significant holdings in other states. Since 1992, USEPA, concerned about potential risks from its radioactivity, has defined PG as a "waste by-product [… of] limited economic or environmental value". In consequence, the mandatory stacking regime imposed has had a strong impact both on the rest of the world's perceptions of PG and its regulatory regimen. PG is classed as a toxic waste, with containment as the only acceptable management and disposal method. In that there are many highly beneficial uses for PG, to predefine it as a waste is incorrect: a product is only a waste when it has no foreseen, or foreseeable, use. Large quantities of PG can be safely used in agriculture, construction, road building and landfill management. PG is a beneficial soil amendment, which has recently been shown by the University of Sevilla's Huelva study to yield agricultural and environmental benefits. Given that at least 50 countries in the world already have PG stacks, and that globally some 150 million tonnes, and rising, are produced each year, increasingly in the emerging economies of Brazil, China and India, it is perhaps time to re-examine PG as a developmental resource not a waste, reclassifying it, as it once was, as a co-product of wet process phosphoric acid production. This will have far-reaching benefits for perception, regulation and exploitation of PG worldwide and may reduce or eliminate the unnecessary and expensive risk of PG ending as a very costly "negative externality" of fertiliser production.


## 1. Introduction: towards a world without stacks of phosphogypsum?

When in the early 1960s President John F Kennedy (JFK) mandated NASA to send a man to the moon and back safely by the end of the decade [1], the management technique he invoked was to make the outcome of his instruction non-negotiable, but the means of delivery wholly open to discussion. After initially responding that it could not be done, to which JFK simply said: "But if I were to say, my fellow citizens, that we shall send to the moon, […] a giant rocket more than 300 feet tall […] then return it safely to earth, […] and do it first before this decade is out--then we must be bold" [2]. NASA changed tack and successfully set about executing the mission. The structured negotiation technique is one that John Nash describes in his Nobel-prize winning work as "The Bargaining Problem", [3] where the overall objective is changing the point of equilibrium [4] in an apparently intractable situation [5].

The project **Stack Free by 53? Beneficial Uses of Phosphogypsum** (Stack Free?) (see www.stackfree.com) has followed this Kennedy/Nash method: as a "thought experiment" it posits a non-negotiable outcome – a world by 2053 in which stacks, or piles, of phosphogypsum (PG) no longer exist, other than as holding piles for future use – whether in road building, construction, agriculture or the potentially hundreds of other applications that continue to be proposed for PG use. It then "reverse engineers" a pathway to achieve that goal, taking into account, in sequence, the four main critical success factors for arriving at the end point. These are:


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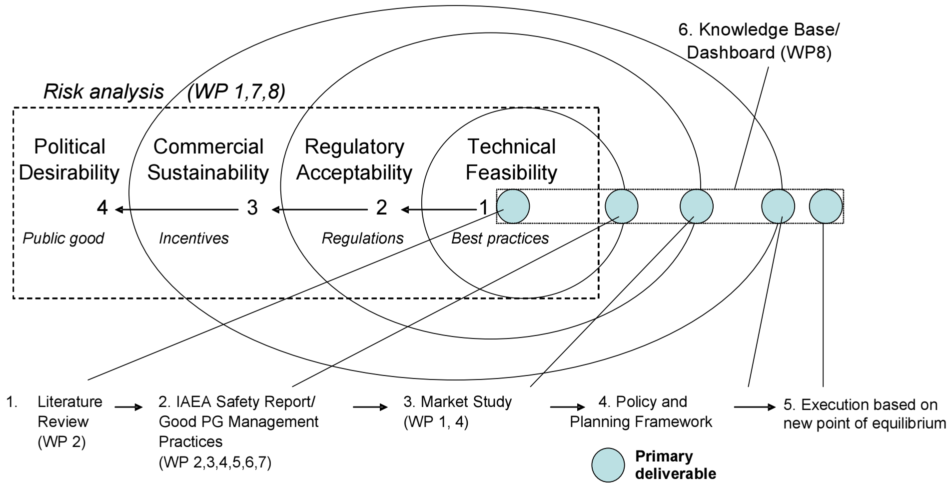
1. technical feasibility
2. regulatory acceptability
3. commercial sustainability
4. political will.

Only if all four conditions can be met simultaneously will the "Stack Free?" proposition stand and a new "point of equilibrium" be established. The methodology is schematised as follows in Fig 1:

*FIG.1, Stack Free by 53? The Onion Ring Methodology*




The whole Stack Free? project derives much of its initial momentum from the seminal paper (1998) by Armand Davister, Phosphogypsum: a waste (more or less harmful) or a resource? [6]

### *1.1 What is phosphogypsum and how is it made?*

Phosphoric acid ($P_2O_5$) and phosphogypsum (PG) are the twin products of the "wet process" method for making phosphoric acid, in which phosphate rock is digested with acid, most commonly sulphuric. For every tonne processed of $P_2O_5$ there are five of PG. This simple 1:5 ratio is at the heart of the PG problem – the sheer quantity produced in order to meet demand for $P_2O_5$. The basic chemistry of the wet process "is exceedingly simple": [7]

> The tricalcium phosphate in the phosphate rock is converted by reaction with concentrated sulphuric acid into phosphoric acid and the insoluble salt calcium sulphate.
>
> $$Ca_3(PO_4)_2 + 3\ H_2SO_4 \longrightarrow 2H_3PO_4 + 3CaSO_4$$
>
> The insoluble calcium sulphate is then separated from the phosphoric acid, most usually by filtration. The reaction between phosphate rock and sulphuric acid is self-limiting because an insoluble layer of calcium sulphate forms on the surface of the particles of the rock. This problem is kept to a minimum by initially keeping the rock in contact with recirculated phosphoric acid to convert it as far as possible to the soluble monocalcium phosphate and then precipitating calcium sulphate with sulphuric acid.
>
> $$Ca_3(PO_4)2 + 4H_3PO_4 \longrightarrow 3Ca(H_2PO_4)_2$$
> $$Ca(H_2PO_4)_2 + 3\ H_2SO_4 \longrightarrow 3CaSO_4 + 6H_3PO_4$$

Calcium sulphate exists in a number of different crystal forms depending particularly on the prevailing conditions of temperature, $P_2O_5$ concentration and free sulphate content. [8]

As shown in Fig 2. (Central Florida) stacks may be of several km sq in size, and up to 100m high.

*FIG.2. Central Florida PG Stack*

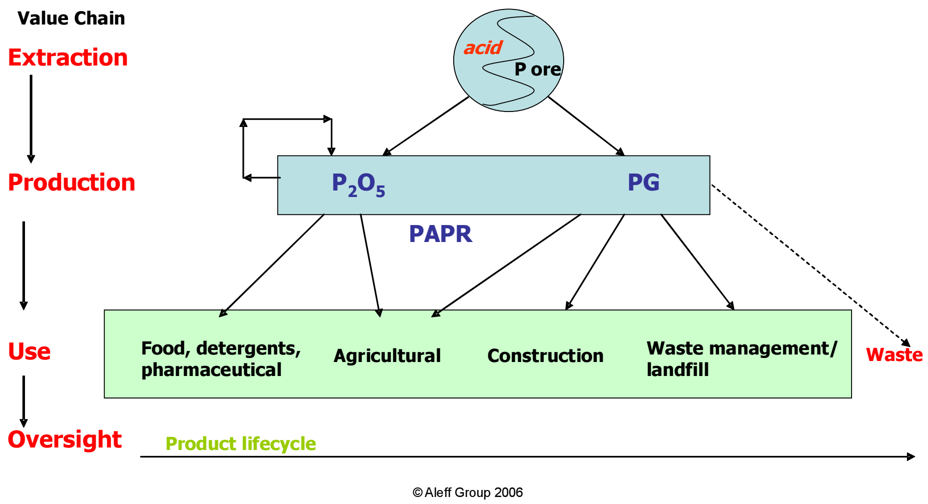
Current PG capacity is approximately 150 million tonnes per year [9], scheduled to increase by one-third in the coming ten years as new capacity, for example in Saudi Arabia, comes on stream. The consequence [10] is that, in the absence of a solution being found to using PG as a resources, PG tonnages stored worldwide will double some time between 2025 and 2040, the earlier date being increasingly more likely, especially if Morocco stops its current practice of ocean disposal.

### *1.2 Looking backwards and forwards*

The issue is driven by a combination of retrospection and forward planning. On the retrospective side, there are the twin challenges, first, in the United States of closing old style stacks at very high cost (up to $ US 500 million per stack) and secondly, of making good use of current global holdings in 50 or more countries. On the planning side, there is the challenge of preventing a possible doubling of current tonnages in stacks as a) global production increases overall and b) the practice of ocean disposal still practised in some producing environments winds down or is banned. Such a planned approach opens the prospect of an integrated management system for both phosphoric acid and PG, as co-products of the same process of reaction phosphate rock with sulphuric acid, in which the full life cycle of production and consumption is planned from the outset with a "minimum legacy" objective in mind, including mining, use and eventual management disposal of necessary waste.

The timing of such a change is perhaps as good as it is likely to be for decades to come in that at this time the industry is currently showing a significant trend relocating production based in developed countries (notably US and Europe) East and "South" in or closer to the emerging economies, notably Brazil, China, India and the Middle East. Whatever solution is found to the PG challenge is likely to be in place for a long time hence.

*FIG.3. Phosphate rock, phosphoric acid and PG: co-product model*




**2. “Negative externality”**

The theory of externality examines the impact of activities when these "spill over" onto third parties. [11] When the result is a cost that is imposed on third parties, it is called a negative externality. When third parties benefit from an activity in which they are not directly involved, the benefit is deemed positive. Economists frequently cite pollution as an example of negative externality; a necessary process, industrial manufacture, has pollution as a side-effect. As is now vigorously under debate regarding $CO_2$ emissions, this externality may reach such a level that it defeats the benefits of the causative process. This tipping point has seemingly been reached in the US for older design PG stacks, notably in central Florida. [12] In 2001, a medium-sized production company in Florida, Mulberry Phosphates Inc. went bankrupt, leading to the abandonment of its two stack and pond water systems, one of which, Piney Point is in a highly sensitive area right next to Tampa Bay. This site also contained some 1.0 - 1.5 billion gallons of acidic water requiring treatment. For two years immediately following the bankruptcy, there was little intervention to maintain the integrity of the stack and Florida at that point had enjoyed a number of years of moderate to low hurricane activity. In 2003, the situation changed, and by mid year was at emergency point. Both state and federal authorities were forced to intervene, at very high cost. By late 2006, the site, now largely remediated, was sold out of receivership into private hands, but at a very high cost.

The evidence from the Piney Point stack closure process has led to provisional figures of up to $500US million per stack being identified as the likely level of liability that will be required in financial reports to shareholders and stakeholders under Sarbanes-Oxley reporting rules. [13] If such liabilities are unresolved there is a significant possibility that the losses of the phosphate industry will exceed total profits to date, effectively putting the industry at risk worldwide. Leaving aside the aspect of financial liability, there is also growing concern that even in terms of safety and environmental legacy, stacks may not be the best long-term solution [14].

***2.1 Current state***

According to the onion ring model Fig. 1, Stack Free? methodologically had satisfied the conditions for progressing from activity 1, technical feasibility, to activity 2 regulatory acceptability by mid 2006.

*2.1.1 Critical success factor 1 — technical feasibility*

Technical feasibility has been established in two primary ways: 1) the assembly of a “blue ribbon” team of production experts from both industry and academia to conduct an ongoing peer review and 2) a literature review.

*Blue ribbon team*

The blue ribbon team meets regularly and is progressively extending its membership as more and more examples of good practice become known to it. It now includes members from around the world, and is in the process of building a information exchange network, based on the project website.

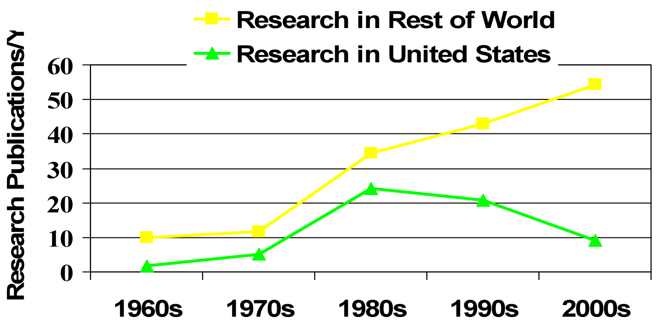
*Literature review*

A literature review, focused to date on English language publications but now extending to other key sources in Spanish, Portuguese, Russian and other languages, has reviewed some 1900 publications from more than 50 countries which are now assembled into a database. The database currently:

- contains peer-reviewed literature from 58 countries
  - US, India and Poland are top 3 sources, accounting for 53% of titles
- identifies and classifies more than 50 beneficial uses of PG, which have been researched, of which the top 4 in respect of potential volume of use are
  - agriculture
  - construction materials
  - landfill/waste
  - roads.

While PG research in the US has slowed since the 1989 promulgation of the Phosphogypsum “Rule”, it is still increasing in the world at large, as seen in Fig 4 [15]:

*FIG. 4. PG Research Publications per Year vs Time*




Based on the literature review to date, we have broadly concluded that beneficial use is technically feasible, even desirable, in domains such as agriculture and construction. The scale of potential use could result in a significant reduction of new phosphogypsum tonnage and even, in suitable settings, to the removal of stacks altogether.

*2.1.2. Critical success factor 2 — regulatory acceptability*

By 2007, the premise of acceptability, while still not fully resolved, is sufficiently robust that the boundary condition between regulatory acceptability and commercial sustainability is now being explored, for example through an analysis of global PG market potential. There are perhaps two touchstone aspects to the current regulatory debate surrounding PG; the first is definitional, the other numerical.

*Definitional*

In definitional terms, the creative tension that characterises the most recent EU legislation [16] is indicative of global debate as to how to define waste. For, while from a strict definitional point of view: "'waste' shall mean any substance or object in the categories set out in Annex I which the holder discards or intends or is required to discard" [17], the framing condition within which this definition is set is: "The recovery of waste and the use of recovered materials as raw materials should be encouraged in order to conserve natural resources. It may be necessary to adopt specific rules for reusable waste." [18] PG sits nicely caught between these two statements, in that in some jurisdictions it is required to be "discarded" (stacked in the US) but at the same time other authorities are trying to promote reuse, both in general but also specifically for PG.

*Numerical*

From a numerical point of view the debate is in some respects more precise [19]. On the one hand USEPA (and Canada) define the activity concentration threshold above which PG is sufficiently radioactive to be a potential danger as 0.37 [20], while the IAEA regards activity concentration levels below 1.0 as "not requiring regulatory attention", [21] and between 1 and 2 as permissible subject to the appropriate permit or exemption. The great bulk of PG "reserves" world wide sit between these two values, so the consequence of USEPA agreeing to abide by, or at least accept under strict conditions, the IAEA limit would be to release a very large quantity of PG into potential use.

*2.1.3. A Publication Pathway*

Stack Free? proposes as a practical way of resolving this debate a sequence of tiered publications as follows, designed to negotiate the basis for a transparent, safe practice of PG use.

*A Culture of Safety: IAEA*

Independently of Stack Free?, in 2005 IAEA had embarked on a review of NORM and safety issues in the phosphate industry. A fruit of the European ALARA Network Workshop in Augsburg, October 2005, and subsequent consultative meetings with IAEA in February and October 2006 was the decision to collaborate on the background research and drafting that would be necessary to compile such a report. The drafting process at the time of preparation of this paper is well advanced and, when published, the IAEA Safety Report on *Radiation Protection and NORM Residue Management in the Phosphate Industry* may give encouragement to the "public good" perspective on PG regulation, while at the same time emphasising the need to see it as a recoverable resource (co-product) not a waste.

*Good PG Management Practice*

While the emphasis of the IAEA publication will be worker, public and environmental safety, a closely allied publication, currently in development by the Stack Free? expert team consists of a White Paper Good Phosphogypsum Management Practices (GPGMP). The alignment to Good Practice standards, such as Good Clinical Practice (GCP), Good Laboratory Practice (GLP) and Good Manufacturing Practice (GMP) by design sets the prospective regulatory environment for PG in the context of well-established "Good Practice" methods of addressing risk management and best practices within a single, globally accepted standard. The "GXP" process has also, by tradition and practice brought together major stakeholders, such as government, industry, academia (centres of excellence) and international organisations in a consensus-building approach to the management of processes that, while inherently risky, are of existential significance to the world as a whole – whether for the production of safe wholesome food, or safe, efficacious drugs. In particular, the International Conference on Harmonisation [22] managed to develop and have implemented worldwide a global GCP standard [23] that both significantly reduced the negative externality of drug development (focusing on patient benefit and risk avoidance, allowing mutual acceptance of data across major markets, eliminating duplicate and repeat trials) but also demonstrated that a global standard (or protocol) could be achieved. The implementation process itself is arranged in five steps, and contuse to respect local and regional differences within the global standard. This is significant in view of the need in PG regulation to preserve the concept and practice of regionality, as detailed below..

*Manuals*

One of the lessons learned, rather ruefully, from the literature review is the extent to which known solutions to problems has been ignored, overlooked or simply not been available. Stack Free? proposes to develop Manuals, with associated management aids and decision-support tools – probably on line – to enable a better informed approach to PG management. Manuals will address to a level of operational detail topics such as PG in road beds, and, where possible be coupled with training and support systems that effect and support knowledge transfer.

**3. The case for change**

At its simplest, PG is a direct consequence of the global production of food, and the case for a change of approach to PG, towards a proactive culture of safe use, is nowhere more evident than in agriculture and food production. The University of Sevilla, supported by Government of Andalucia, Spain has recently completed a case study of the progressive removal of a major stack in the estuary mouth town of Huelva [24] for use by local farmers. As is evident from Fig 5., the town of Huelva, once remote from its PG stack, is now within 200m of it, a process mirrored in central Florida, where once isolated stacks are now encroached by residential and commercial development. As a result of an injunction on PG use sought by local Andalusian environmental groups, a case based partly on their invocation of USEPA standards, the traditional practice of spreading PG on local soils, dating back to the 1950s was suspended.

The Huelva farmers challenged the injunction and were granted relief, enabling the practice to resume. As a condition of the resumption however, the Government of Andalucia required under court supervision, the close monitoring of phosphogypsum use in local agriculture, both for reclamation and as fertilizer including potential environmental impact and residue take-up into crops and on into the food chain. The methodology used by Professors Abril and Tenorio and their team, whose results have demonstrated that phosphogypsum is safe and beneficial, has led to its registration under Spanish law as a fertilizer, subject of course to authorized, "on label" application. [25] In addition to the benefits restored to the farmers and the local economy, Huelva also demonstrates a significant reversal of the externality effect, from negative, to positive; for in this case a former stack site has also been reclaimed for a public park, which in a densely populated area such as Huelva is of very considerable interest to the local community. While this paper is too brief to detail the principle fully, it is clear that the Huelva example shows how a regional approach to problem solving, within a framework on international standards and best practices, can achieve Nash's goal of a redefined point of equilibrium.

The regional solution [26] has the following outline characteristics, which may form the basis for a revised regulatory approach, based on a "regionality" principle:

- Transparency
- Consistent global regulatory and safety standards for evidence-based decision-making processes, leading to local, and locally accountable, solutions
- Cooperation between
  - Local/ regional government
  - Centres of excellence, local and international
  - Industry – producers and customers
  - Community
- Common policy objectives
- Complementary, mutually reinforcing, stakeholder reasons for change
- Inclusivity in decision-making, but not rights of veto
- Clear communications with all stakeholders
- On going monitoring and surveillance.

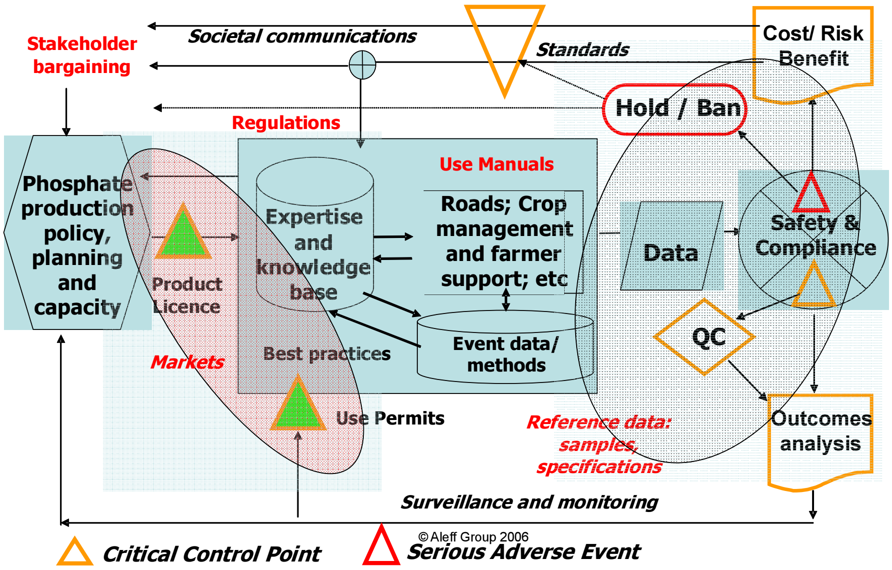
*FIG. 5. Huelva PG Stack and Reclaimed Park.*


**4. An integrated, safe, transparently regulated system, based on "regionality"**

Huelva demonstrates a way in which the risk of what Nash calls the "non-cooperative game" model which has blighted US approaches to PG since 1992, can be managed into a cooperative process. This cooperative process begins with the recognition of PG as a co-product of phosphoric acid, in and of itself a "cooperative game" tactic. [27] Inherently, the radiation safety case made against PG is inconsistent and seemingly arbitrary, since, typically, there is as much radioactivity in phosphoric acid as there is in PG. [28] And at the point where the assessment of the relative risks and benefits of PG use as opposed to storage a) affects livelihoods and b) impacts public amenities such as parks, decision-makers have a wider frame of reference to work within than the relative abstractions of numerical thresholds of activity concentration or legal definitions of waste.

In that there is a risk of regulatory "spillover" from the US to other countries, it is crucial that the cooperative approach prevail over the non-cooperative one. In such a cooperative mode, as ICH GCP has shown, it is possible to promulgate and support global standards and procedures without violating local accountability and adaptability to local requirements and perceptions. This is in no way to argue for a deregulation of PG, or a "blank cheque" for use. In fact, the appropriate type of regulatory regime for PG, as has been achieved in Spain, can be the basis for sustainable success.

*FIG. 5. Safety and Public Good:*
*A cooperative bargaining solution for co-product P/ PG in use.*




As a contribution to the transition to a cooperative mode, the schematisation above is offered as an attempt to embed Nash's methods into the regulatory process, very much in the spirit of GCP. There are risks in any process, but well-managed, and independently monitored, these risks are outbalanced by benefit to a sufficient extent that even in a risk vs risk model, the risk of use is substantially lower than the risk of containment.

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