Phosphogypsum in the Circular Economy

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“Wet Process” Phosphoric Acid Production and Phosphogypsum (PG)

(fluorapatite) $\text{Ca}_{10}\text{F}_2\text{(PO}_4\text{)}_6 + 10\text{H}_2\text{SO}_4 + 10n\text{H}_2\text{O} \rightarrow 10\text{CaSO}_4\cdot n\text{H}_2\text{O (PG)} + 6\text{H}_3\text{PO}_4 + 2\text{HF}$

- Di-hydrate process, $n=2$
- Hemi-hydrate process, $n=1/2$

• Dihydrate process producing 4.9 tons of PG per ton of $\text{P}_2\text{O}_5$, versus 4.3 tons from Hemihydrate

• Generating approximately 185 – 215 million tons of PG per year

• Some 3-4 billion tons of PG stacked globally
  - Over 1.2 billion tons stacked in Florida
So Why Do We Stack PG? According to the USEPA...

- “Phosphogypsum is a radioactive waste product”
- “EPA requires that phosphogypsum be managed in above-ground stacks, which are designed to keep emissions of radon and other radionuclides in line with acceptable risk practices.”
- The current EPA PG rule allows very little use only in agriculture, and restricted by radium-226 concentration
The Risk Model That Allows the PG Rule to Exist

Models for the Health Risks from Exposure to Low Levels of Ionizing Radiation

- Hypersensitivity
- LNT
- Threshold
- Hormesis
- Epidemiological data

Approximate lowest dose where excess cancer has been observed


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Is There a Reasonable Alternative to Stacking?

- There are many safe and beneficial uses for phosphogypsum
- In fact, post WWII it was used for road building, parking lots and sold for agriculture
- A stack in California was completely used to ground level
- A lot of research was taking place prior to the EPA’s rulemaking on PG in the 80s and 90s
Research continued after the Rule but declined in the US and increased elsewhere.
Beneficial Uses Found via R&D

• Agriculture: Fertilizer/Soil Conditioner
• Road building
• Construction Materials
• Landfill cover
• Glass/ceramic
• Marine projects
• Raw material
  – Sulfur & Cement
  – Rare Earth Elements
Case Study: Huelva, Spain – Result

- Numerous studies were conducted by universities in Spain
- Cadmium uptake in crops was measured and many decades of PG applications to soils were simulated
- After judicial review, it was ruled that not only was use of PG in agriculture safe, but PG was specified in law as a fertilizer
Effects on Water Resources

• Phosphogypsum can be used as a soil amendment to repair sodic/saline or magnesium-affected soils, and those in low exchangeable calcium

• It also tends to reduce crusting and enhance water retention properties of soil
  – Decreases water consumption
  – Reduces runoff and pollution of surface waters
PG Use on Salt-affected Irrigated Lands in Kazakhstan

- Cotton production area with yields around 1.0-1.5 t/ha due to high levels of magnesium in soils and waters
- Poor farming communities
- PG interventions
  - Control (No PG)
  - Soil application of PG at 4.5 t/ha
  - Soil application of PG at 8.0 t/ha

Source: Dr. Manzoor Qadir
Soil Repaired for Agriculture Using Phosphogypsum

Source: Dr. Manzoor Qadir

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Willows and Poplars in Canada, 2017

Afforestation for green energy and carbon sequestration

Source: Dr. Connie Nichol
Can grow many things in PG...

Source: Connie Nichol
Demand in Brazil for PG – A “Waste”?

Farmers in Brazil are paying up to $25/ton for PG and hauling it as far as 200 km.
Paradeep Phosphates Ltd. PG Fertilizer

- Granulated, bagged PG fortified with micronutrients (magnesium, zinc, boron)

- “Zypmite fortified helps improve soil fertility, increases the intake of NPK fertilizers and improves quality of yield.”
The Case for “Constructive Regulation”


- Using Constructive Regulation Techniques to Align Risk Management and Sustainability Goals for Essential NORM Industries: Case Study – Phosphates (Buenos Aires, May 15, 2008)

Foreword, INTRODUCTION, BACKGROUND, OBJECTIVE, SCOPE
1. OVERVIEW OF THE PHOSPHATE INDUSTRY
2. GENERAL RADIATION PROTECTION CONSIDERATIONS
3. MINING AND BENEFICIATION OF PHOSPHATE ORE
4. PRODUCTION OF PHOSPHORIC ACID BY THE WET PROCESS
5. MANUFACTURE AND USE OF AMMONIUM PHOSPHATE FERTILIZERS
6. SUPERPHOSPHATE FERTILIZERS
7. NITROGEN PHOSPHATE FERTILIZERS
8. ANIMAL FEED PHOSPHATES
9. PHOSPHOGYPSUM
10. DECOMMISSIONING OF WET-PROCESS PLANTS
11. EXTRACTION OF URANIUM FROM PHOSPHORIC ACID
12. PRODUCTION OF PHOSPHORUS BY THE THERMAL PROCESS

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Glossary: Phosphate Industry Terms
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Phosphoric acid (PA) and phosphogypsum (PG) are co-products of wet process phosphoric acid (PA) production.

- There is no radiological objection to use of PG; some uses may merit some restrictions depending on the precise characterization of the PG under consideration.
  - Natural radioactivity and metals content depend on the source of rock used and the processing conditions.
  - Consequently, care must be taken to match a given source of phosphogypsum to the appropriate end use.

- Use is environmentally preferable to stacking or disposal to open waters.

- Regulators should be encouraged to promote beneficial uses as alternatives to disposal, in line with the waste hierarchy.
If Not a “Radioactive Waste”, Then...

- Disposal as last resort
  - Indefinite disposal imposes on the coming generations a legacy that we should not force on them
  - Breaches the principle of intergenerational trust which is at the heart of sustainability

PG Reuse and Recycling Feeds the Circular Economy

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China has a *Forced* Circular Economy

- Zero Waste Policy
- Government has put in place rules for phosphate fertilizer companies mandating graduating percentages of PG use
- Non-compliance will result in steep fines
- This is not a desirable regulatory approach, but it has resulted in R&D and successful use of PG in a variety of applications
Shift from R&D to Commercialization

- Belgium (Prayon) - stucco
- Brazil – uses most of its PG for agriculture (5 mil. t/yr) following re-classification by the regulator
- Canada (Agrium) – agriculture; afforestation, developing “anthrosols” primarily PG with some soil added (9:1) - working with forestry service
- China (Wengfu Group) – over half of PG for agriculture & construction, recycling as ammonium sulfate/ calcium carbonate, iodine recovery; (Industry Association) – sulfuric acid – towards “zero waste”
- Kazakhstan (UN) - large-scale remediation of saline/sodic soils
- India (FAI, Paradeep, + 2) – classed PG as a co-product, not hazardous waste (2008)
  - PG is sold for construction, agriculture, affordable soil amendment, cement
  - Afforestation: tree plantation established for green energy - similar to Agrium efforts
    - Joint study by Coromandel and The Energy and Resources Institute (TERI), New Delhi
    - Paradeep constructed a new pilot PG road; marketing bagged fertilizer
- Russia (PhosAgro) – using PG in agriculture and construction, roads
- Tunisia (GCT) Sfax remediation / return of land to productive use; Bricks, Road Construction; Housing (CNSTN)
- United States (?)

- **50-60 million tons/yr PG now being utilized worldwide**
Value Swing from Costly Waste to Valuable Resource

- IAEA: No radiologic reasons to not use PG (2013)
  - Member States also relaxing corresponding NORM regulations
- UNECE: PG is a secondary resource
  - Aligned to UN Sustainable Development Goals (SDGs)
- MENA Region: Arab Authority for Agricultural Investment and Development
  - Interest in PG to repair degraded soils and combat desertification (aligns to SDGs) (could use substantial amounts of the current PG inventory)
United Nations 2030 Sustainable Development Agenda

Ambitious agenda with 17 goals; 169 targets

Many of the goals and targets can be addressed by using phosphogypsum, which is recognized as an important resource by UNECE

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Cost of Stacking

- Permitting, Initial Construction Cost
- Requires Lining of Stack Area at a Cost of About $1/ton of Stacked Phosphogypsum
- Requires Strict Operating Procedures
- Requires Draining and Lining of Stack When Stack is Full
- Full closure costs approaching $5/ton of PG
- All told: about $25-30/ton of PG
- Perhaps the Cost of a Sinkhole or Accidental Spill ($80 M for the last one)
The Economics of PG Brought Back into the Circle

• We know customers will pay $15-25/ton for phosphogypsum
• Since it costs about $25/ton to stack and maintain, that would be a $40-50/ton value swing
• If it sold for only $5/ton, it would be a $6 billion asset in Florida instead of at least $2 billion liability!
Benefits of Removing PG Stacks and Applying PG to Degraded Lands

Source: Dr. Manzoor Qadir
Conclusions

• Phosphogypsum (PG) can be used safely and it is not a waste.
• PG is an affordable resource that has a value and a range of well-tested beneficial uses.
• PG has been widely used directly “as is” in both agriculture and construction and is also recycled and/or reprocessed in significant quantities as an industrial resource for other applications.
Conclusions (Cont.)

• Stacking is not a sustainable option, failing on social, environmental and economic requirements.

• Unreasonable application of the Precautionary Principle burdens the fertilizer industry, which is vital to national and global food security.

• Constructive Regulation develops win-win outcomes, converts liabilities to profits, and supports United Nations Sustainable Development Goals.
These rail cars in Florida don’t move PG to customers, but maybe they should

Thank You!

http://www.fipr.state.fl.us