Global Phosphate Rock Reserves and Resources, the Future of Phosphate Fertilizer

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Two major types

- Sedimentary – carbonate apatite, 80%-90% world production
- Igneous – fire-formed (fluor-chlor-hydroxyl-apatite), 10%-20% world production

Apatite – “Apane,” Greek Goddess of deceit, guile, fraud and deception released from Pandora’s Box
World Mine Production of Phosphate Concentrate, 1945-1981

Global Phosphate Rock Production

- **Others**
- **Russia\(^a\)**
- **China\(^b\)**
- **Morocco**
- **United States**

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a. 1992-1997 Former Soviet Union data includes Kazakhstan, Uzbekistan, and Russia data; 1988-2008 FSU data includes Russia only.
b. Official China data.

World Phosphate Rock Production, 1998-2012

Source: U.S. Geological Survey (USGS)
Developed Countries: Nitrogen, Phosphate, Potash and Total NPK Consumption, 1961-2011

- Nitrogen
- Phosphate
- Potash
- Total NPK

million nutrient tons

Global Phosphate Rock Production

- >160 mmt – 1988, 1989
- >160 mmt – 2004-2008
- 210 mmt – 2012 (estimated)
Will Phosphate Rock and Phosphate Fertilizer Be Important in the Future?
## Main Drivers of Agricultural Intensification
### #1 World Population

<p>| | | | |</p>
<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>2010</td>
<td>~7 billion</td>
<td></td>
<td></td>
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<tr>
<td>UN low</td>
<td>~2040</td>
<td>Peak – 8 billion</td>
<td></td>
</tr>
<tr>
<td>UN medium</td>
<td>~2080</td>
<td>Flatten – 10 billion</td>
<td></td>
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<tr>
<td>UN high</td>
<td>~2100</td>
<td>15-16 billion</td>
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Main Drivers of Agricultural Intensification

- Demand for Food, Fiber and Crop Output-Based Bioenergy
  - Changing Lifestyles
  - Changing Diets
- Land and Water Scarcity
- Environmental Issues
- Advances in Technology

High Yield Crops = High Nutrient Requirements
Resource Depletion

Numerous articles have suggested phosphorus (phosphate rock) reserves and resources will be depleted in the 21st century.

- Rosemarin 2004
- Rosemarin et al. 2009
- Cordell, Dragert and White 2009
- de Haes et al. 2009
- Vaccari 2009
- Numerous others – to present

Institute of Ecology, 1971
Phosphate rock reserves exhausted in 90-130 years.
Demand for food/fiber increasing.
Depletion of cheap phosphate rock reserves is occurring.
Global price hikes – fertilizer, grains.
Morocco leads new OPEC for phosphate.

*Global economy flips from oil to phosphorus based.
Indicative peak phosphorus curve, illustrating that, in a similar way to oil, global phosphorus reserves are also likely to peak after which production will be significantly reduced (Jasinski, 2006; European Fertilizer Manufacturers Association, 2000).

Source: Cordell, Dragert and White, 2009

Assumes Reserves Are Static!!
Many articles on phosphorus depletion rely on USGS data for phosphate rock reserve and resource estimates.

16 billion tons reserves (USGS, 2010)
# World Phosphate Rock Reserves and Resources

<table>
<thead>
<tr>
<th>Country</th>
<th>IFDC Reserves&lt;sup&gt;a&lt;/sup&gt; (Product)</th>
<th>IFDC Resources&lt;sup&gt;b&lt;/sup&gt; (mmt)</th>
</tr>
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<tbody>
<tr>
<td>United States</td>
<td>1,800</td>
<td>49,000</td>
</tr>
<tr>
<td>Australia</td>
<td>82</td>
<td>3,500</td>
</tr>
<tr>
<td>Brazil</td>
<td>400</td>
<td>2,800</td>
</tr>
<tr>
<td>Canada</td>
<td>5</td>
<td>130</td>
</tr>
<tr>
<td>China</td>
<td>3,700</td>
<td>16,800</td>
</tr>
<tr>
<td>Egypt</td>
<td>51</td>
<td>3,400</td>
</tr>
<tr>
<td>Israel</td>
<td>220</td>
<td>1,600</td>
</tr>
<tr>
<td>Jordan</td>
<td>900</td>
<td>1,800</td>
</tr>
<tr>
<td>Morocco</td>
<td>51,000</td>
<td>170,000&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Russia</td>
<td>500</td>
<td>4,300</td>
</tr>
<tr>
<td>Senegal</td>
<td>50</td>
<td>250</td>
</tr>
<tr>
<td>South Africa</td>
<td>230</td>
<td>7,700</td>
</tr>
<tr>
<td>Syria</td>
<td>250</td>
<td>2,000</td>
</tr>
<tr>
<td>Togo</td>
<td>34</td>
<td>1,000</td>
</tr>
<tr>
<td>Tunisia</td>
<td>85</td>
<td>1,200</td>
</tr>
<tr>
<td>Other countries</td>
<td>600&lt;sup&gt;d&lt;/sup&gt;</td>
<td>22,000&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>World total (rounded)</td>
<td>60,000</td>
<td>290,000</td>
</tr>
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<sup>a</sup> Reserves as usable or marketable product.

<sup>b</sup> Resources as unprocessed phosphate rock of varying grades or concentrate.

<sup>c</sup> Including hypothetical resources based on the area limits of the deposits, Morocco resources may be about 340,000 mmt.

<sup>d</sup> Includes data from Algeria, Finland, Peru and Saudi Arabia (Al-Jalamid).

<sup>e</sup> Includes data from Algeria, Angola, Finland, Kazakhstan, Peru and Saudi Arabia.
Morocco
 Identified minable reserves placed by OCP in 1984 at 56.25 billion tons (Savage, 1987)
 Verified conclusions and methodology with OCP

World Totals
 IFA – Informal survey with members verified totals
Morocco

USGS – Verified ore volumes with Moroccan government

World Total

IFDC and USGS Reserves

- USGS (2011) Reserves: 65
- USGS (2012) Reserves: 71
- USGS (2013) Reserves: 67
Reserves

- Established on technology, potential market, prices and costs of production.
- Established with study and considerable manpower.
- Established on a planning horizon (15-20 years, longer for some producers).

Reserves Are Dynamic
Mining, Beneficiation, P$_2$O$_5$ Recovery

Mining – Economic = Large-Scale

Beneficiation – Generally as simple and least costly as possible
  – Froth flotation employed in U.S. in 1920s-1930s, employed in North Africa and Middle East in last 15 years

P$_2$O$_5$ – Grade inversely proportional to recovery

*Carbonate flotation breakthrough – IFDC, 1990s

Today, phosphate rock production is geared to phosphoric acid production based on acceptable impurities and losses.
## PR Supply

### Capacity Increases

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<th>2016</th>
<th>2017</th>
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<tbody>
<tr>
<td><strong>All Projects</strong></td>
<td></td>
<td>290</td>
</tr>
<tr>
<td><strong>IFA Assessed</strong></td>
<td>245</td>
<td>260</td>
</tr>
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From: Prud’homme (2013) 81st IFA Annual Conference, Chicago (USA), 20-22 May 2013
North African Phosphate Rock Prices

2004-2012 – Relative value of $, ÷ by 1.17-1.32
PR Mine Expansions

Europe and Central Asia
  Russia
    Acron – 2 mt eventually
    Kovdor
  North America
    New mines mainly offset old mines

Latin America
  Copebras – 1.4 mt
  Bayovar – 1.9 mt

Africa
  Morocco – 18-20 mt
  Tunisia
  Algeria

West Asia
  Jordan – 2.5 mt

China
  Rationalization - Improvements

Projects – Exchange listed, others ~45
Peak Phosphate?
World Phosphate Deposits
(Based on USGS and IFDC Data)
Phosphate Fertilizer Today

- Summation of Research Efforts – Tennessee Valley National Fertilizer Development Center (1933-1992) – (SJVK)

- Water-soluble high-analysis fertilizers – the most effective (predictable), fastest acting and cost-effective over a wide range of agro-climatic conditions, especially when produced in large-scale plants at the lowest cost possible.
Phosphate Rock
What do we use it for now?

72% – Phosphoric Acid
12% – SSP
  2% – TSP (excludes $\text{P}_2\text{O}_5$ from PA)
14% – Other Uses
(Nyri, 2010)

Total $\text{P}_2\text{O}_5$

82% – Fertilizer
18% – Industrial Uses
(Prud’homme, 2010)
High-Analysis Fertilizers

DAP  (18-46-0)  
MAP  (10-50-0)  
   (11-55-0, others)  
TSP  (0-46-0)  

Globally, half of all fertilizer applications

32 new phosphoric acid units planned for 2012-2017  
(Prud’homme, 2013)  

- High-quality materials required  
- Lower cost per unit of $P_2O_5$ transportation
The Future

- Reserves exist to make high-analysis P fertilizers for hundreds of years – on a worldwide basis.
- PR costs and P fertilizer costs will increase.
- The high cost of high-analysis fertilizers in developing countries will promote the use of indigenous lower grade and lower quality PR resources and production of non-conventional products.
The Future

Non-Conventional Lower Cost Fertilizers

- Lower analysis
- More $P_2O_5$ recovery?
- Less waste?
- Higher cost per unit $P_2O_5$?
- Transportation – a problem
Instead of food, make fertilizer and technology available to people in developing countries so they can feed themselves; maximize return on investment.

Effective Technology $\rightarrow$ Efficient Technology

Efficient: Capable of producing desired results without wasting materials, time or energy.
Efficiency

Efficiency – Can be measured from some standard

Mining and Beneficiation – Highly variable

Phosphate Fertilizer Production – Generally near or over 95% raw material efficient

Fertilizer Use – Highly variable

Are we using our inputs wisely?
Phosphate Rock

Geology
Reserves and resources
PR beneficiation - removing impurities, increasing grade

Potentially Cost-Effective Alternative Phosphate Products

Indigenous phosphate rock (PR) – low-grade or quality
Direct application PR (DAPR)
Products produced using appropriate technology
Heat-treated Fe-Al phosphates
Off-grade SSP, TSP, MAP
Urea-based NPKs
Composted NPKs
Blended NPKs
Composted PR – inoculated
Organic acid induced PR dissolution
Disruptive Innovation

- Most demanding use
- High quality use
- Disruptive Technology
- Medium quality use
- Low quality use

Performance vs. Time
Phosphorus Resource Depletion

Significant Factors

- Population
- Worldwide Inventory
- Recycling
- Political Disruptions
- Rationalization of fertilizer use in China, India and other countries
  - Increased costs, Subsidy factor, Environmental issues
- Increasing pressure from environmental concerns – worldwide

Are we using our inputs wisely?
Phosphate rock is a finite nonrenewable resource.

Reserves and resources.
- Reserves are a dynamic quantity.
- The sky is not falling!

Phosphate rock prices are increasing and new mines are being developed.

World trade will be dominated by established producers of sedimentary rock with vertical integration of fertilizer production.

With cost increases, development of smaller indigenous resources will occur if they are technically and economically favorable!