World Phosphate Rock Reserves and Resources

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Numerous articles have suggested phosphorus (phosphate rock) reserves — 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

**Institute of Ecology 1971**
Phosphate rock reserves exhausted in 90-130 years
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
Many recent articles on phosphorus depletion rely on USGS data for phosphate rock reserve and resource estimates.
Phosphorus From Phosphate Rock

- Two major types
  - Sedimentary – carbonate apatite
  - Igneous – fire-formed (fluor-chlor-hydroxyl-apatite)

Apatite – “Apaté,” Greek Goddess of deceit, guile, fraud and deception released from Pandora’s Box
Economic and Potentially Economic Phosphate Deposits of the World

- Igneous Deposits
- Sedimentary Deposits
- Island Deposits
World Mine Production of Phosphate Concentrate, 1945-1981

Anonymous (1976)  
UNIDO Report  
November 16–18, 1976 meeting in Vienna, Austria  

World phosphate rock production for fertilizer would be on the order of 210 million tons per year by year 2000. Total phosphate rock production therefore might be about 260 million tons per year.
Global Phosphate Rock Production

- > 160 mmt – 1988, 1989
- > 160 mmt – 2008
a. 1992-1997 Former Soviet Union data includes Kazakhstan, Uzbekistan and Russia data; 1998-2008 FSU data includes Russia only.
b. Official Chinese data.
c. Year 2009 estimated.
Phosphate Rock

72% – Phosphoric Acid
12% – SSP
 2% – TSP (excludes P₂O₅ from PA)
14% – Other Uses
(Nyri, 2010)

Total P₂O₅

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

Over next five years, 40 new DAP, MAP and TSP units in 10 countries
(Prud’homme, 2010)

Phosphate Fertilizer Demand

2009–2012 = 3.2% CAGR
(Jung, 2010)
World Phosphate Rock Production
(USBM/USGS Mineral Commodity Summaries, 1982–2010)

\[
y = 0.0677x + 7.2845 \\
R^2 = 0.0025
\]

Production (million tons)

Year

- World Total
- United States
- Morocco
- China
- Russia
- Other
- World Total Trend
Current and Projected U.S. Mine Production Capacity

Source: Jasinski, 2005.
There has been a continuous decrease in world phosphate rock quality as reserves of high-grade and high-quality phosphate rock are being depleted.

— Is this true?
Total World Phosphorus Production

\[ y = 58.346x - 97351 \]

\[ R^2 = 0.0659 \]
World Phosphorus Production by Grade

- 30% P2O5 and under
- 31% P2O5
- 32% P2O5
- 34% P2O5
- 36% P2O5 and over

World P Production (Thousands of Tonnes)

Year

Phosphate Rock Has Been a Relatively Low-Value Bulk Commodity
Fertilizer Prices (FOB, bulk) Monthly Averages January 2001–October 2010

1. Derived from Green Markets. 2. Derived from FMB Weekly.

IFDC Reserve-Resource Study

- Literature review
- Past reserve-resource estimates
- Evaluate current phosphate rock mining, beneficiation methods and $P_2O_5$ recovery
- Make a preliminary estimate of world reserves and resources
Phosphate Rock Literature Review

- Limited traditional sources since early 1990s
- Information from websites, trade magazines, conference papers, papers with limited distribution, company annual reports, stock market reports
- Reserve-resource terminology is not standardized
## Past World Phosphate Rock Reserve and Resource Estimates Based on Author’s Terminology

<table>
<thead>
<tr>
<th></th>
<th>Phosphate Rock Resources</th>
<th>Estimated Recoverable Product</th>
<th>Reserves</th>
<th>Reserve Base</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[metric tons x 10^9 (U.S. Billion)]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emigh (1972)</td>
<td></td>
<td>1,200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wells (1975)</td>
<td></td>
<td>530 (30% P_{2}O_{5})</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DeVoto and Stevens (1979)</td>
<td>1,200</td>
<td>265 (~30% P_{2}O_{5})</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cathcart (1980)</td>
<td>91</td>
<td></td>
<td>20 (≥30% P_{2}O_{5})</td>
<td></td>
</tr>
<tr>
<td>Fantel et al. (1988)</td>
<td></td>
<td></td>
<td>37</td>
<td></td>
</tr>
<tr>
<td>Notholt, Sheldon and Davidson (1989)</td>
<td>163 (~22.5% P_{2}O_{5})</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>USGS (2009)</td>
<td></td>
<td>15^a</td>
<td>47^b</td>
<td></td>
</tr>
</tbody>
</table>

*a. Originally described as phosphate rock that could be produced at less than US $40/ton.
*b. Originally described as phosphate rock that could be produced at less than US $100/ton.

Emigh (1972) – No data for Middle East, North Africa.
DeVoto and Stevens (1979) – Only for free world.
Fantel et al. (1988) – Little or no data for much of Middle East. No data for China.
Mining, Beneficiation, \( \text{P}_2\text{O}_5 \) 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

\( \text{P}_2\text{O}_5 \) recovery – Grade inversely proportional to recovery
  – Geared to phosphoric acid production based on acceptable impurities and losses
# Phosphate Losses

<table>
<thead>
<tr>
<th>Loss of Phosphate Rock</th>
<th>Approximate Loss of P$_2$O$_5$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mining</strong></td>
<td></td>
</tr>
<tr>
<td>Bed too thin, not suitable</td>
<td>100%</td>
</tr>
<tr>
<td>Open pit</td>
<td>5-50%</td>
</tr>
<tr>
<td>Underground</td>
<td>15-35%</td>
</tr>
<tr>
<td><strong>Beneficiation</strong></td>
<td></td>
</tr>
<tr>
<td>Southeast U.S.</td>
<td>40-80</td>
</tr>
<tr>
<td>West U.S.</td>
<td>30</td>
</tr>
<tr>
<td>South America</td>
<td>40</td>
</tr>
<tr>
<td>North Africa</td>
<td>30</td>
</tr>
<tr>
<td>West Africa</td>
<td>Up to 60</td>
</tr>
<tr>
<td>Middle East</td>
<td>30</td>
</tr>
</tbody>
</table>
Reserves and Resources – This Study

- Reserves – Phosphate rock that can be economically produced at the time of the determination to make suitable products, reported as tons of concentrate

- Resources – Phosphate rock of any grade that may be produced at some time in the future, including reserves
Phosphate Rock Reserves as Published in USBM/USGS Mineral Commodity Summaries
Reserves and Resources – This Study

- Original, most current literature or other sources
- Evaluated if reserves were given as ore or concentrate
- Assumed mining recovery – 95% open pit – accepted underground recoverable ore estimates
- Applied appropriate ore-to-concentrate ratios
- Estimated reserves as product
- Resources – mmt of raw materials, range of grades
## IFDC Reserve and Resource Estimate

<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>
</thead>
<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>
</tbody>
</table>

**Notes:**

a. Reserves as usable or marketable product.
b. Resources as unprocessed phosphate rock of varying grades or concentrate.
c. Including hypothetical resources based on the area limits of the deposits, Morocco resources may be about 340,000 mmt.
d. Includes data from Algeria, Finland, Peru and Saudi Arabia (Al-Jalamid).
e. Includes data from Algeria, Angola, Finland, Kazakhstan, Peru and Saudi Arabia.
Identified minable reserves placed by OCP in 1984 at 56.25 billion tons

Speculated – total resources may approach 140 billion tons

World Survey of Phosphate Deposits (Savage, 1987)
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
Phosphate Rock Prices Will Increase

- More overburden, deeper mines
- Challenging environments
  - Underground
  - Offshore
- Lower grade ore
- Increased processing costs
Summary

- Phosphate rock is a finite, non-renewable resource
  - Maximum recovery, utilization and recycling of phosphate rock, fertilizers, byproducts and wastes should be emphasized

- Reserves and resources
  - Reserves are a dynamic quantity
  - Resources can become reserves
  - There is no evidence for a “peak phosphorus” event
Extractable Phosphate Rock
Current Resource Base

Year 2100 Depletion
Best Estimates 20–35%
Worst Case 40–60%

Phosphate Rock Reserves and Resources

- Needs further analysis
- World Phosphate Rock Reserves and Resources Workshop 2011
World Phosphate Rock Reserves and Resources