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

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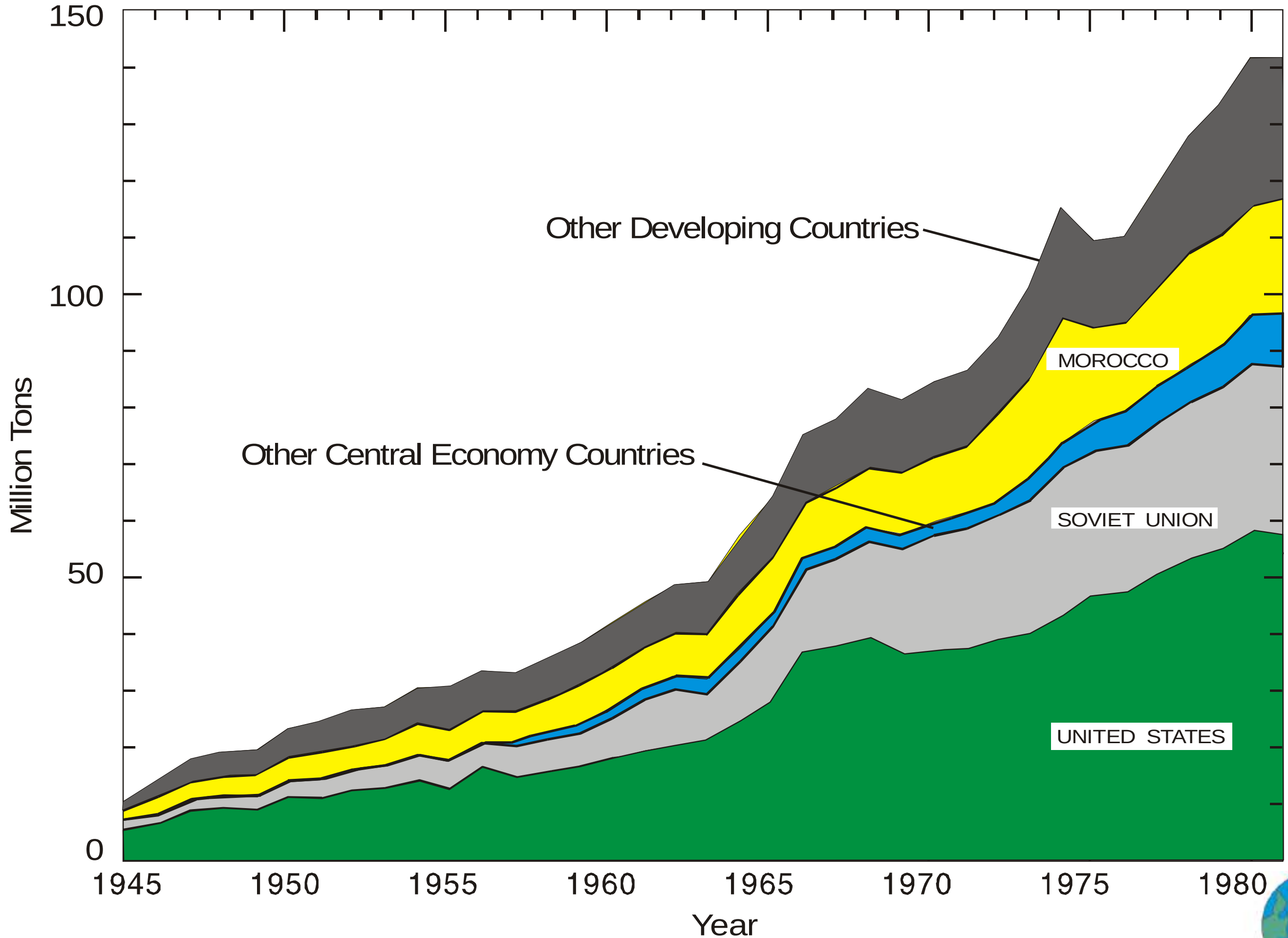
Phosphorus From Phosphate Rock

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

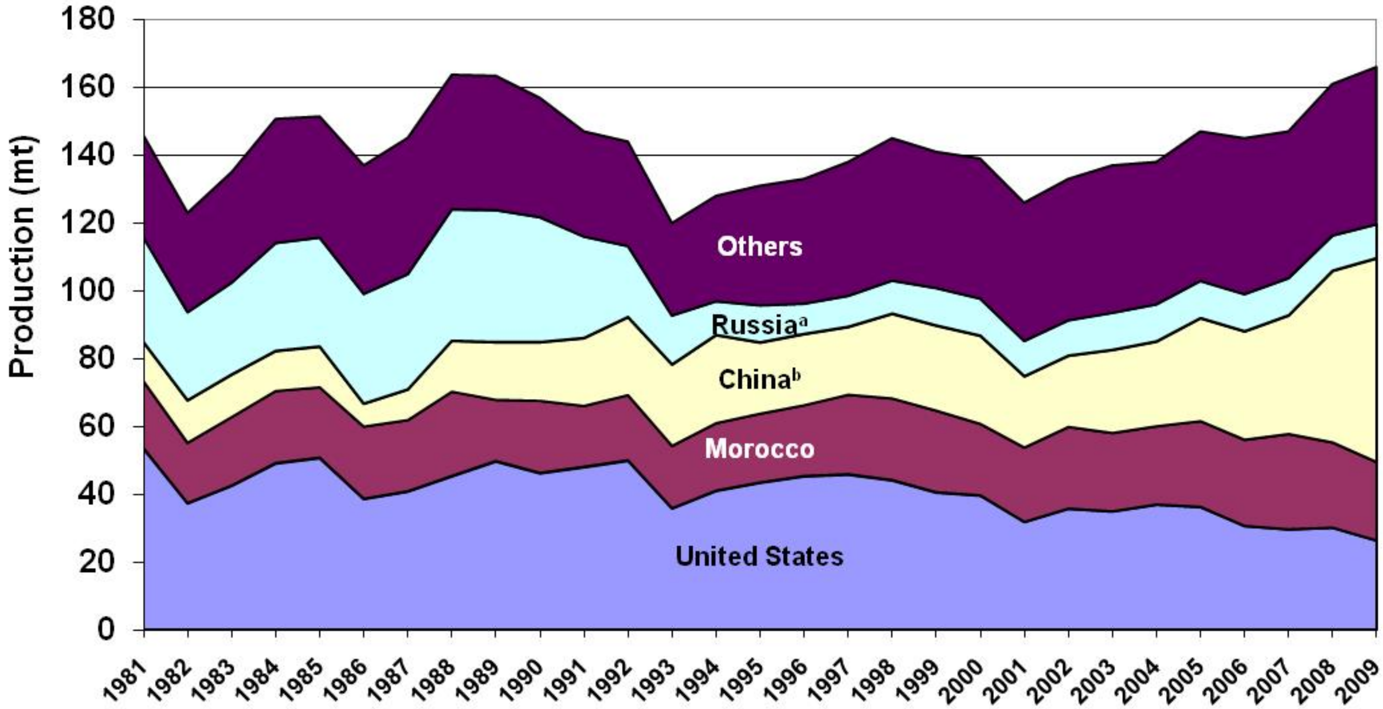
Apatite – "Apate," Greek Goddess of deceit, guile, fraud and deception released from Pandora's Box

World Mine Production of Phosphate Concentrate, 1945-1981



Source: Krauss, Saam, and Schmidt, 1984.

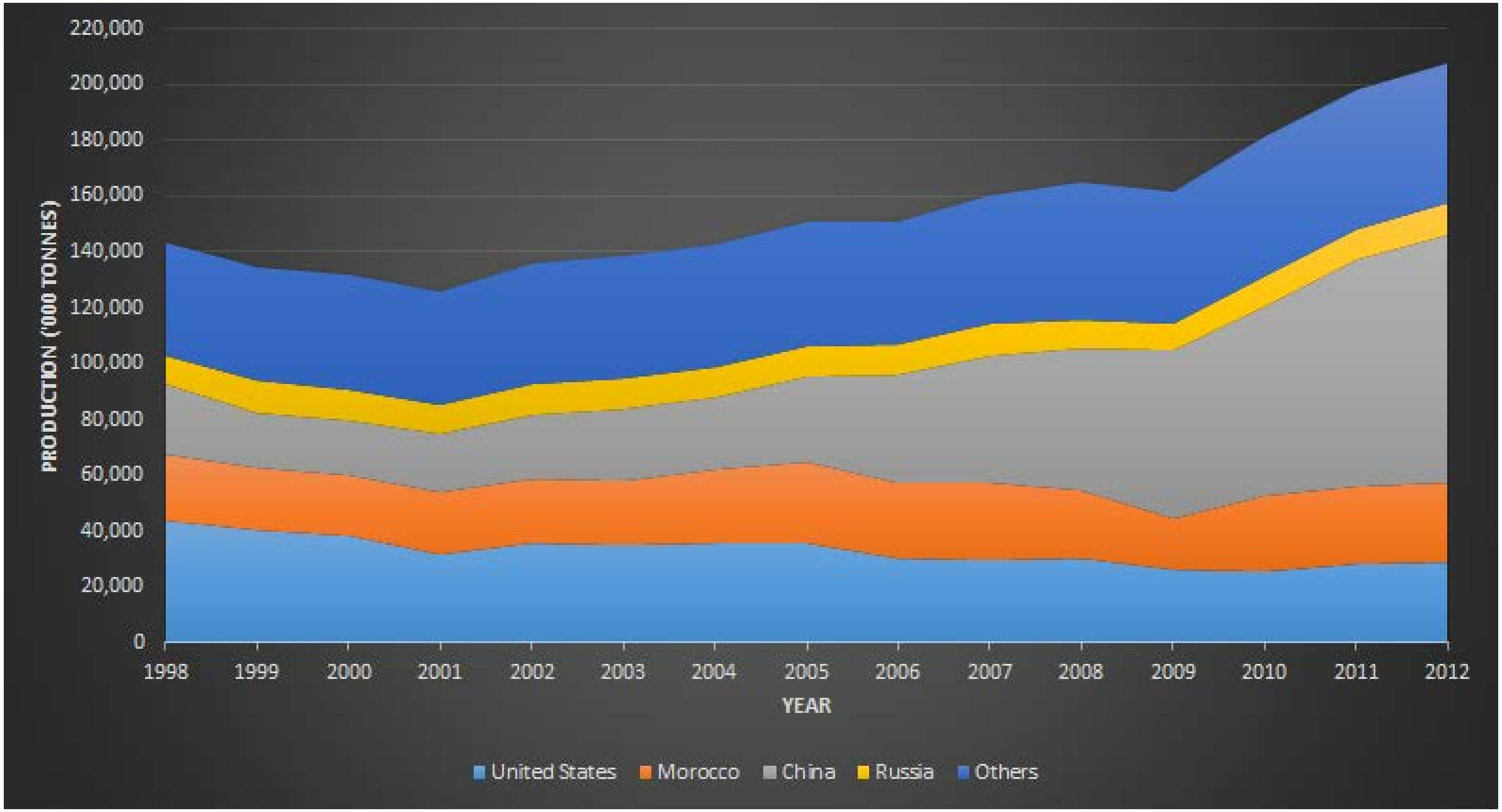
Global Phosphate Rock Production



a. 1992-1997 Former Soviet Union data includes Kazakhstan, Uzbekistan, and Russia data; 1998-2008 FSU data includes Russia only.
b. Official China data.

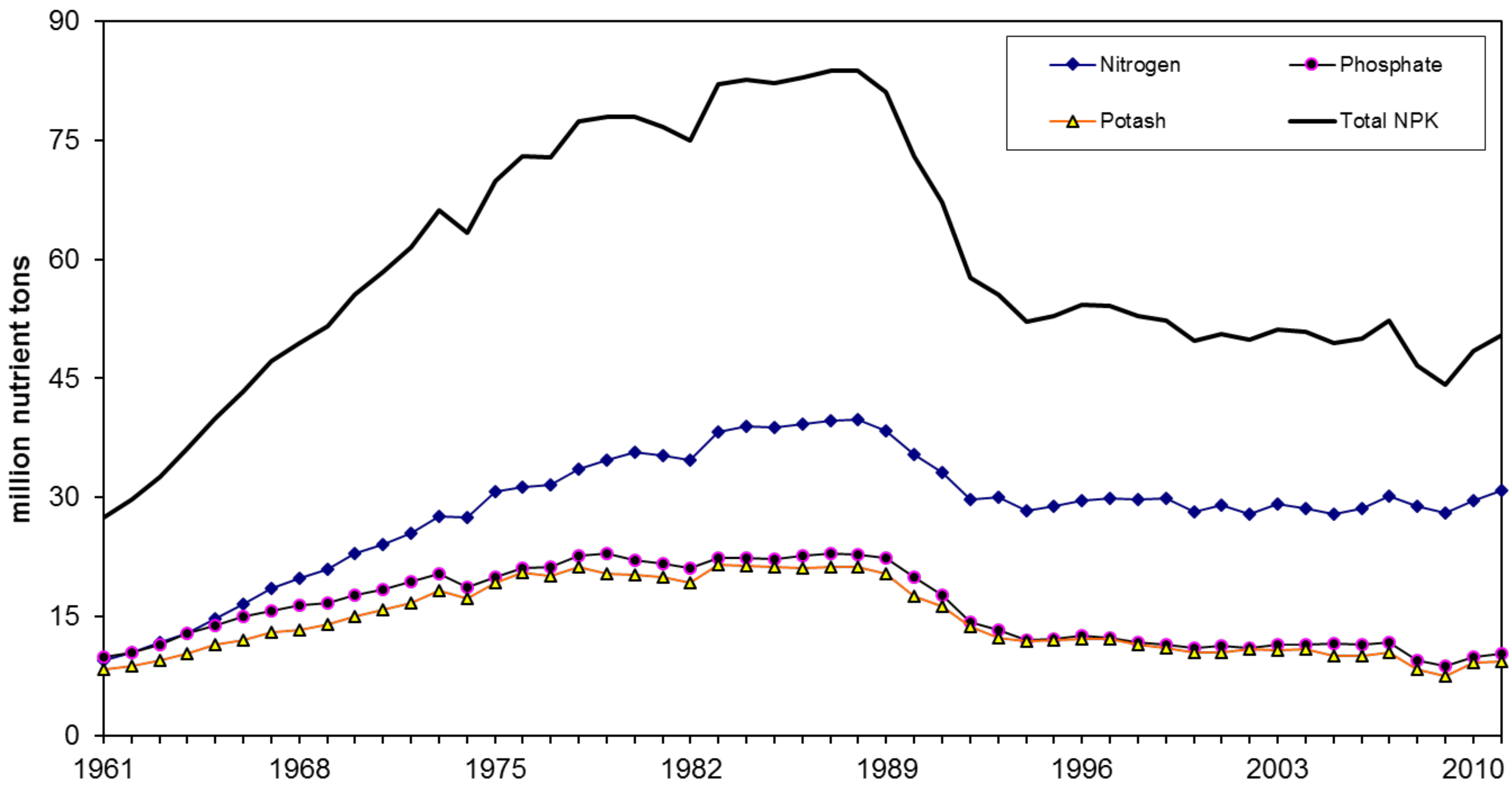
Source: Compiled from U.S. Bureau of Mines (USBM), 1984–1995; U.S. Geological Survey (USGS), 1996-2011.

World Phosphate Rock Production, 1998-2012



Source: U.S. Geological Survey (USGS)

Developed Countries: Nitrogen, Phosphate, Potash and Total NPK Consumption, 1961-2011



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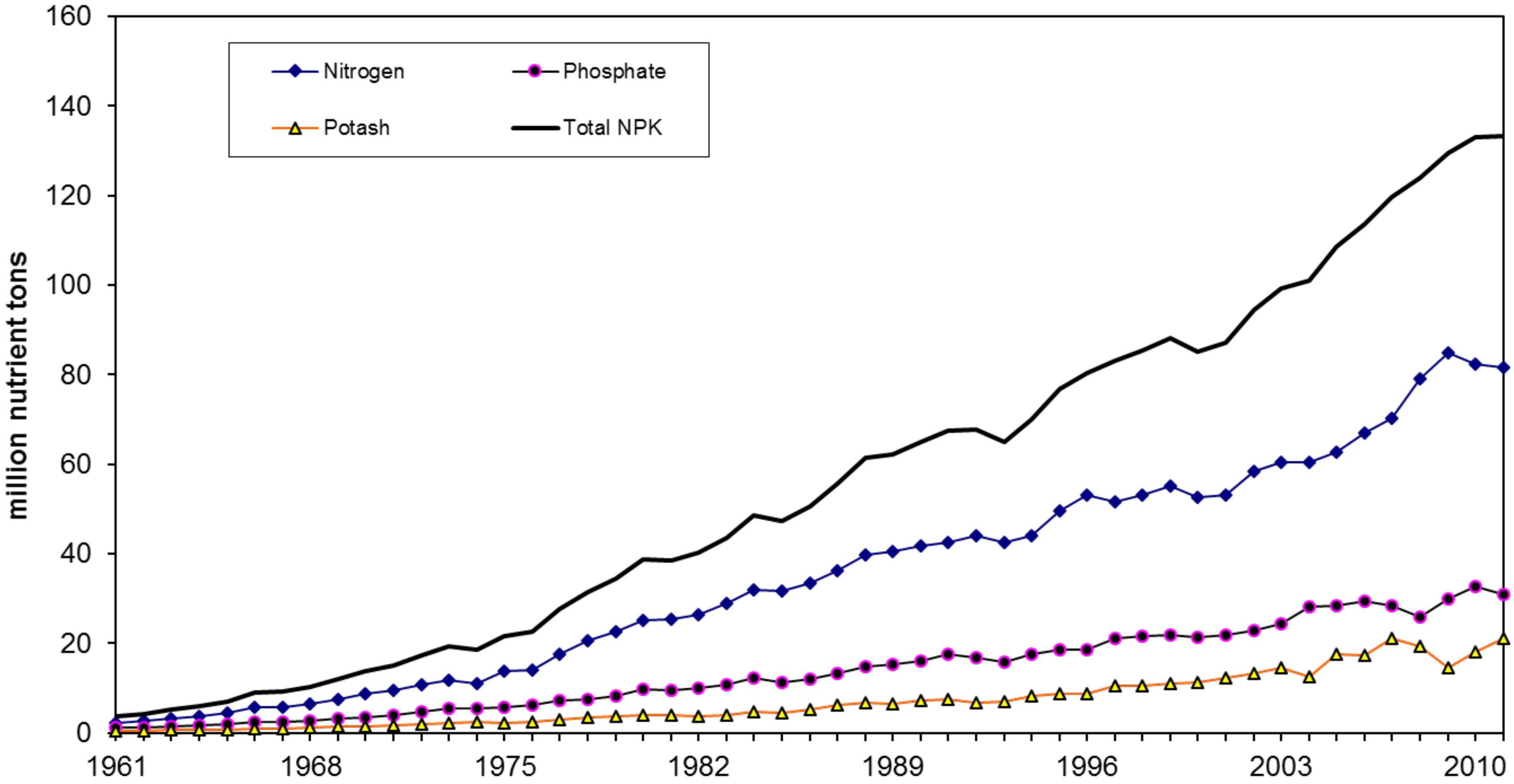


Global Phosphate Rock Production

- >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

2010		~7 billion
UN low	~2040	Peak – 8 billion
UN medium	~2080	Flatten – 10 billion
UN high	~2100	15-16 billion

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

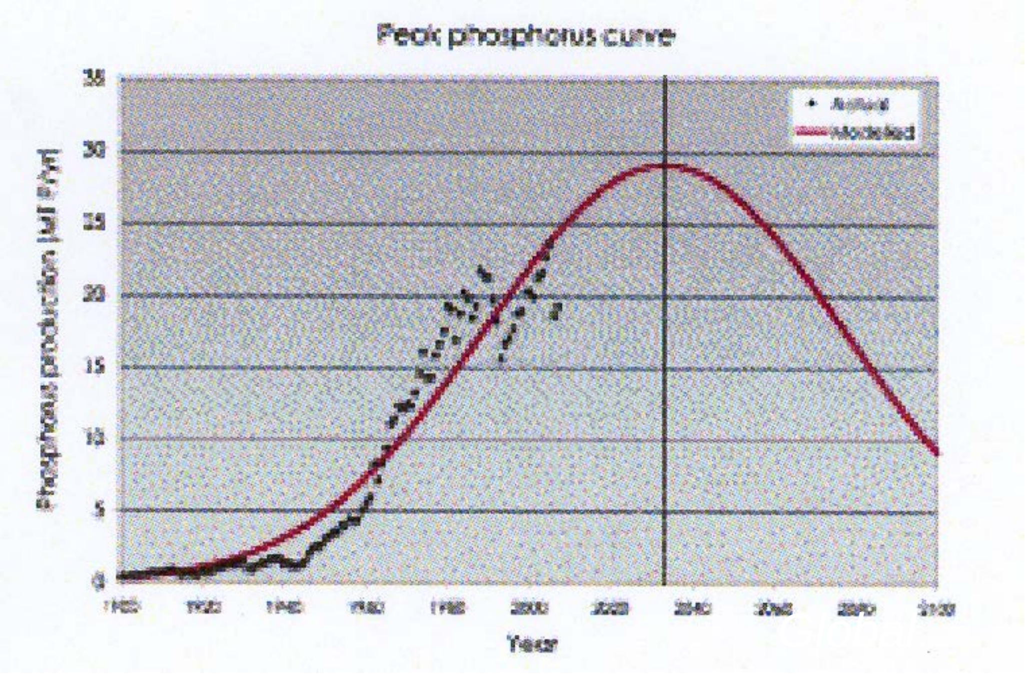
Phosphate rock reserves exhausted in 90-130 years.

Rosemarin and Caldwell, 2007 Probable Scenarios by 2020 (Summarized by SJVK)

- 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.

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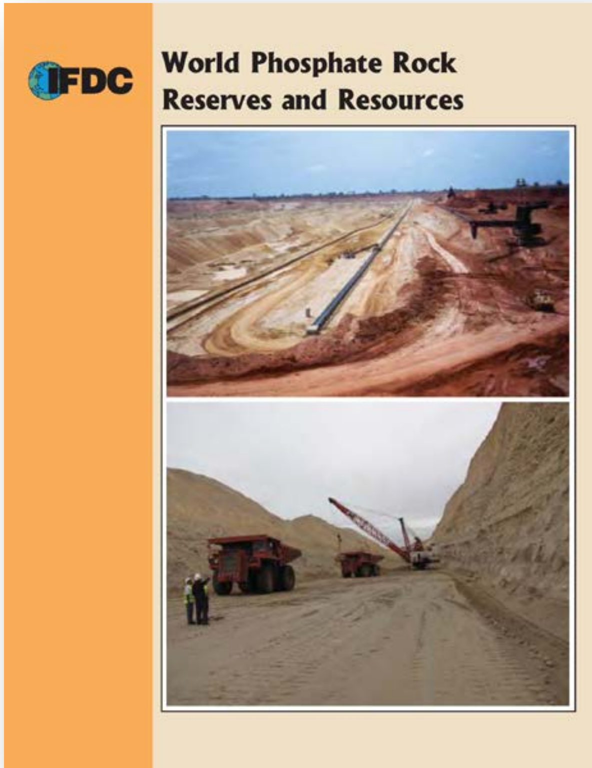
16 billion tons reserves (USGS, 2010)



Country	IFDC Reserves[a] (Product)	IFDC Resources[b]
	(mmt)	
United States	1,800	49,000
Australia	82	3,500
Brazil	400	2,800
Canada	5	130
China	3,700	16,800
Egypt	51	3,400
Israel	220	1,600
Jordan	900	1,800
Morocco	51,000	170,000[c]
Russia	500	4,300
Senegal	50	250
South Africa	230	7,700
Syria	250	2,000
Togo	34	1,000
Tunisia	85	1,200
Other countries	600[d]	22,000[e]
World total (rounded)	60,000	290,000

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.

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

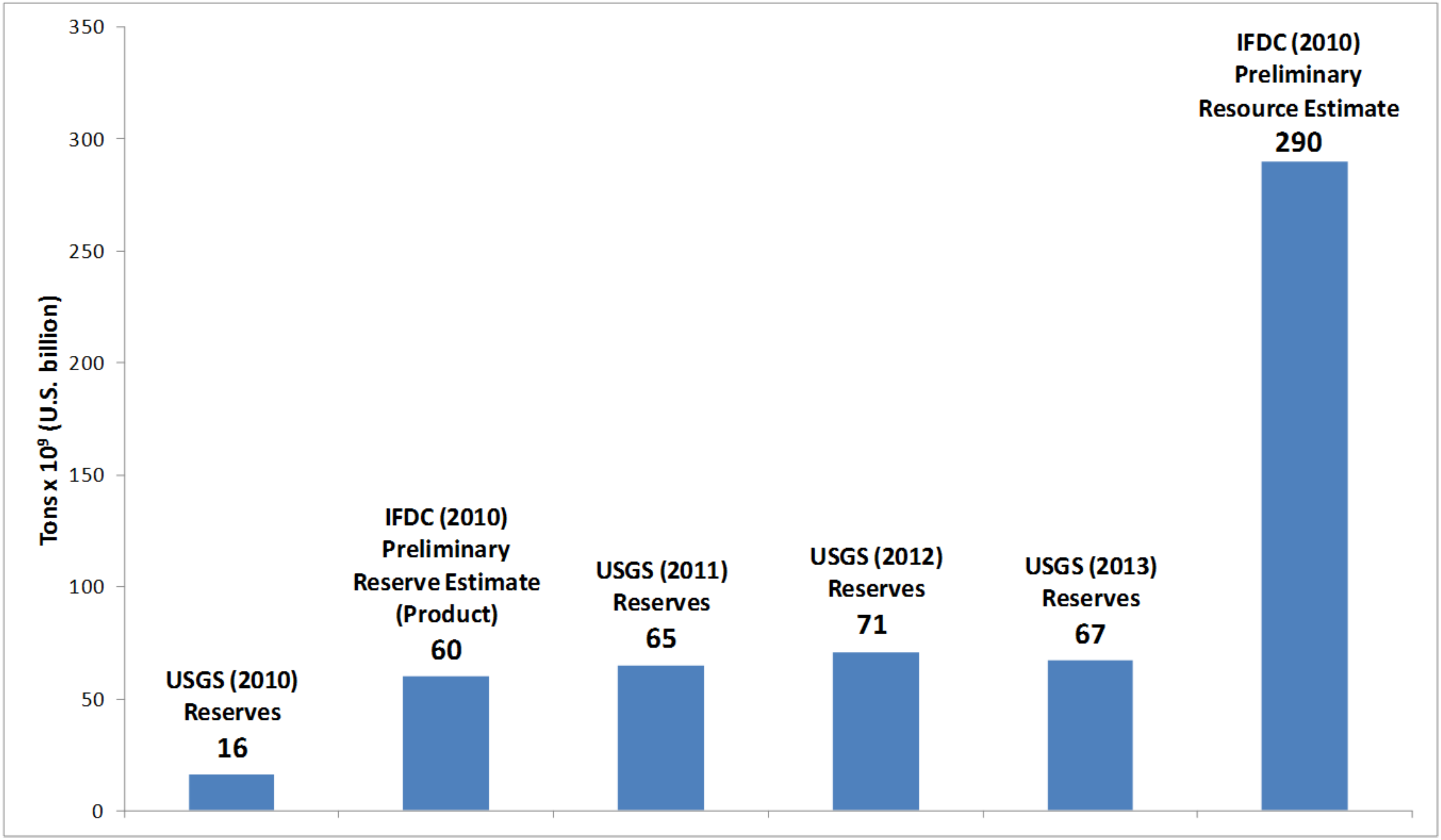
Morocco

USGS – Verified ore volumes with Moroccan government

World Total

World Bank (1984) – Estimated world reserves of product = 67,130 million tons

IFDC and USGS Reserves



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_2O_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_2O_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.

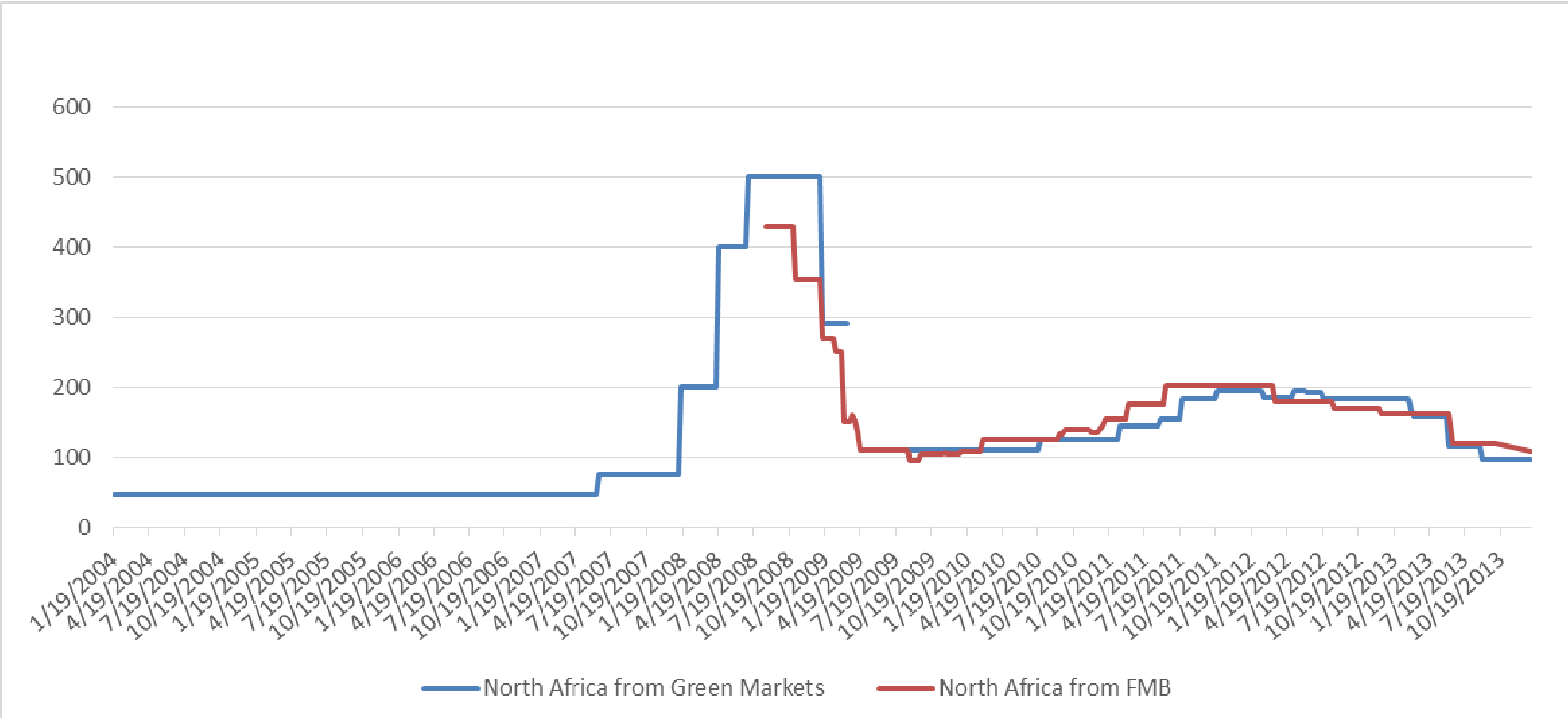
PR Supply

Capacity Increases

	2016	2017
	(mmt)	
All Projects		290
IFA Assessed	245	260

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

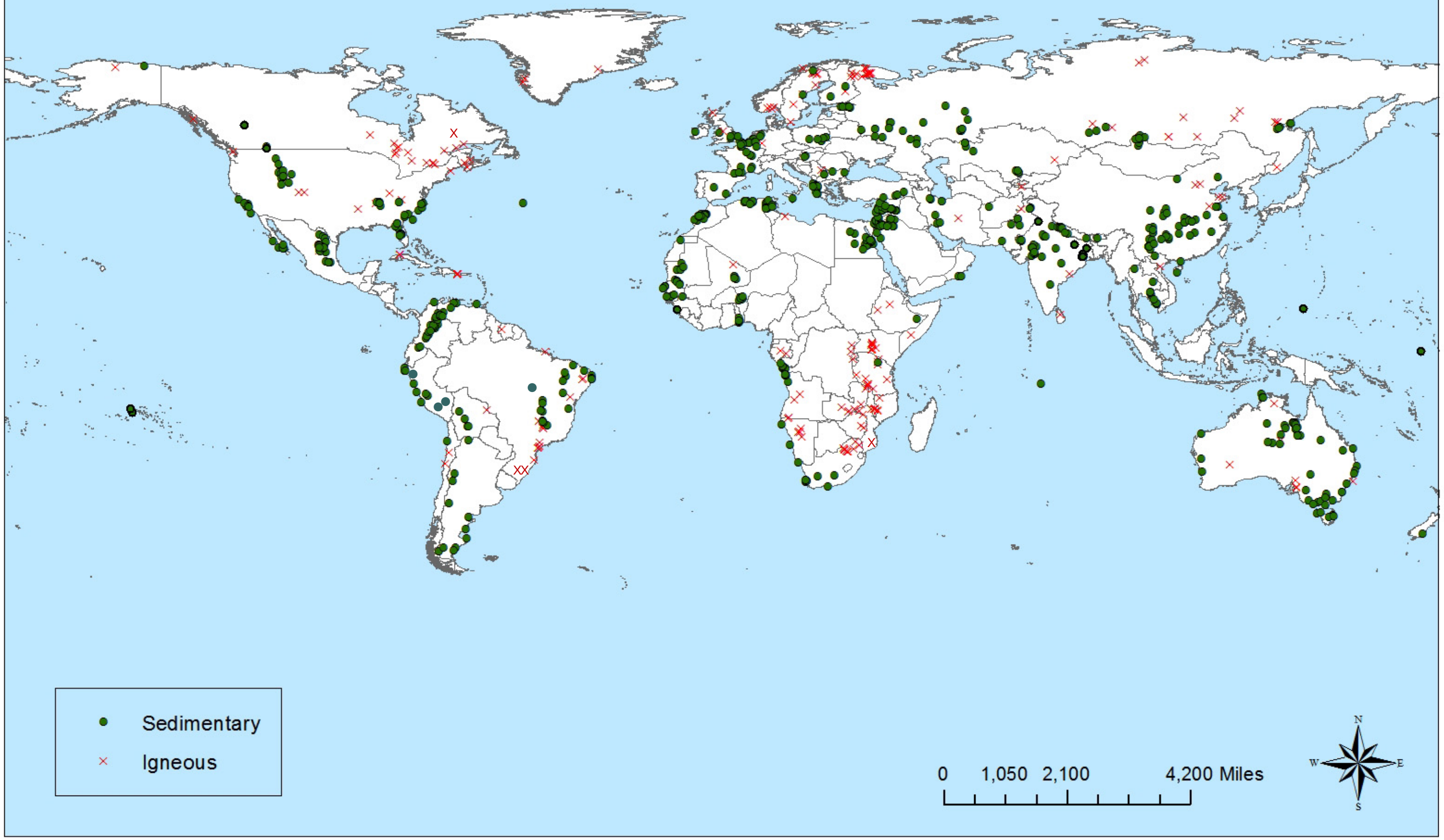
West Asia
- Jordan – 2.5 mt

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 P_2O_5 from PA)
14% – Other Uses
(Nyri, 2010)

Total P_2O_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

IFDC Research

- Instead of food, make fertilizer and technology available to people in developing countries so they can feed themselves; maximize return on investment.
- Effective Technology → 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?

IFDC Phosphate Product Research

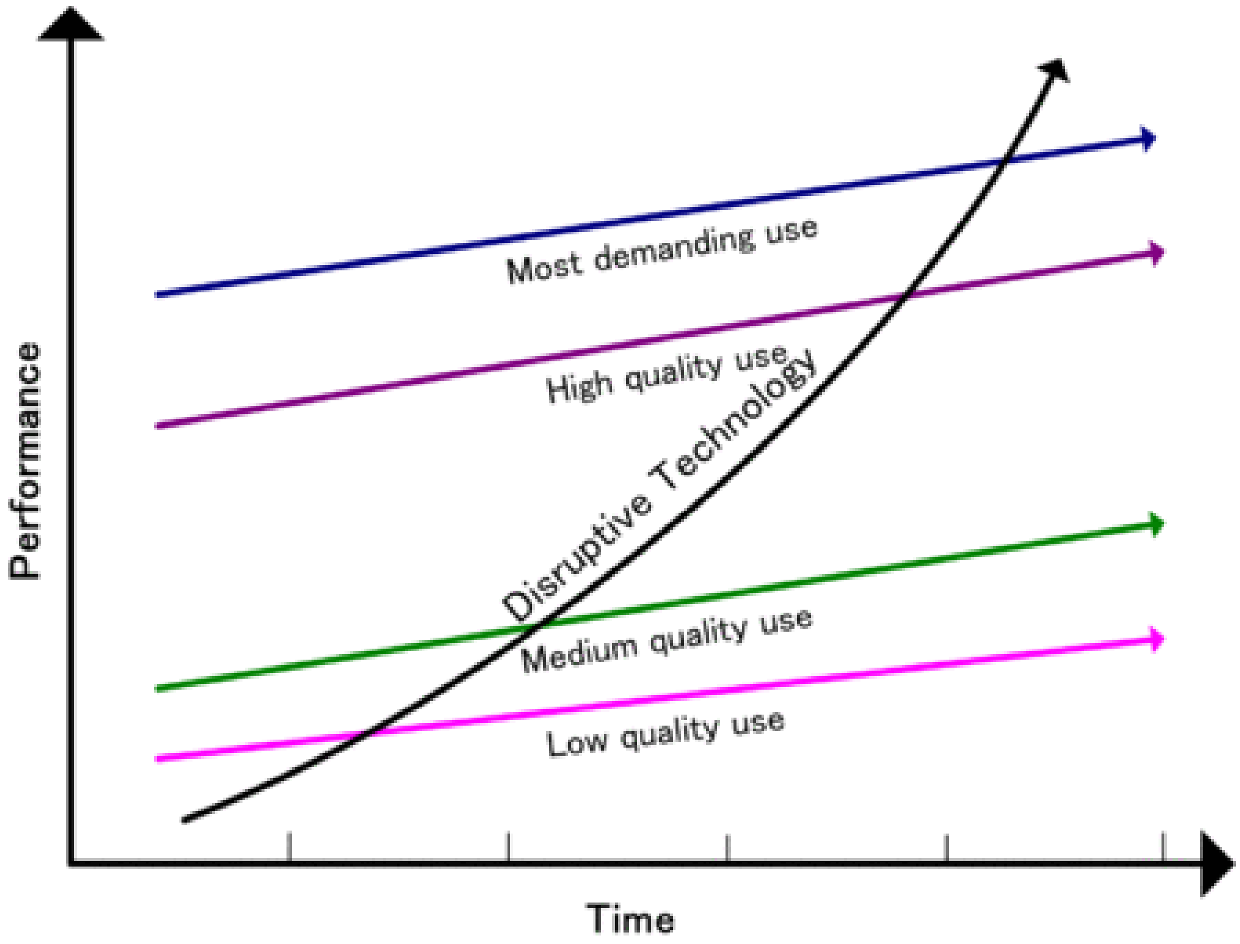
Phosphate Rock

- 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



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?

Summary

- **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!**