World Phosphate Rock Reserves and Resources

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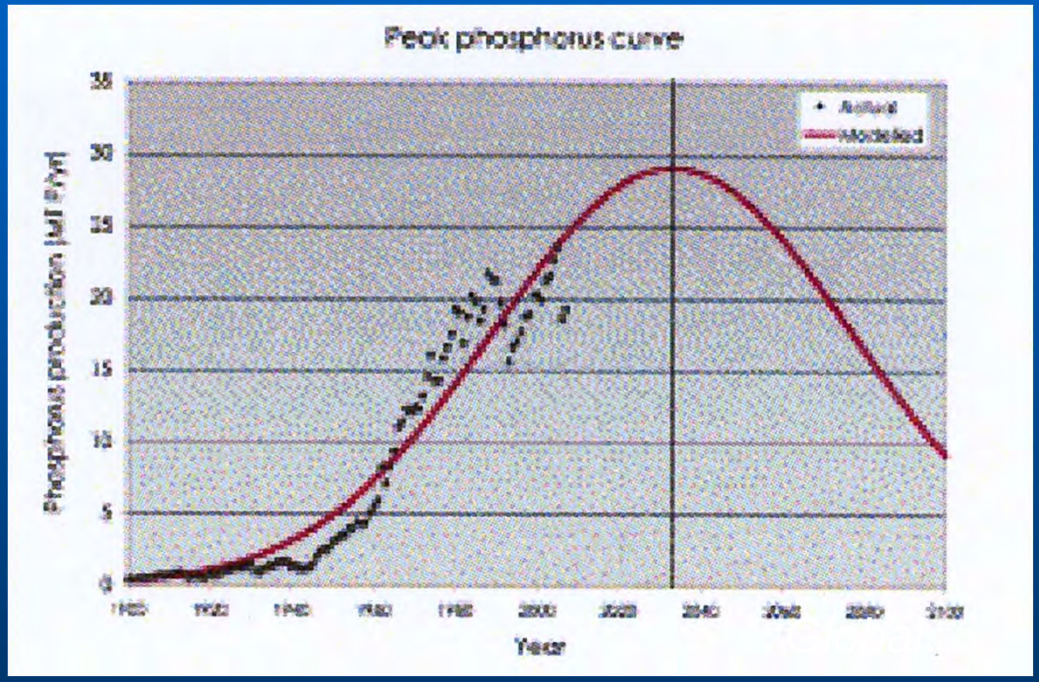
Numerous articles have suggested phosphorus (phosphate rock) reserves — resources will be depleted in the 21st century.

- **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-hydroxl-apatite)**

Apatite – “Apate,” Greek Goddess of deceit, guile, fraud and deception released from Pandora’s Box

Economic and Potentially Economic Phosphate Deposits of the World

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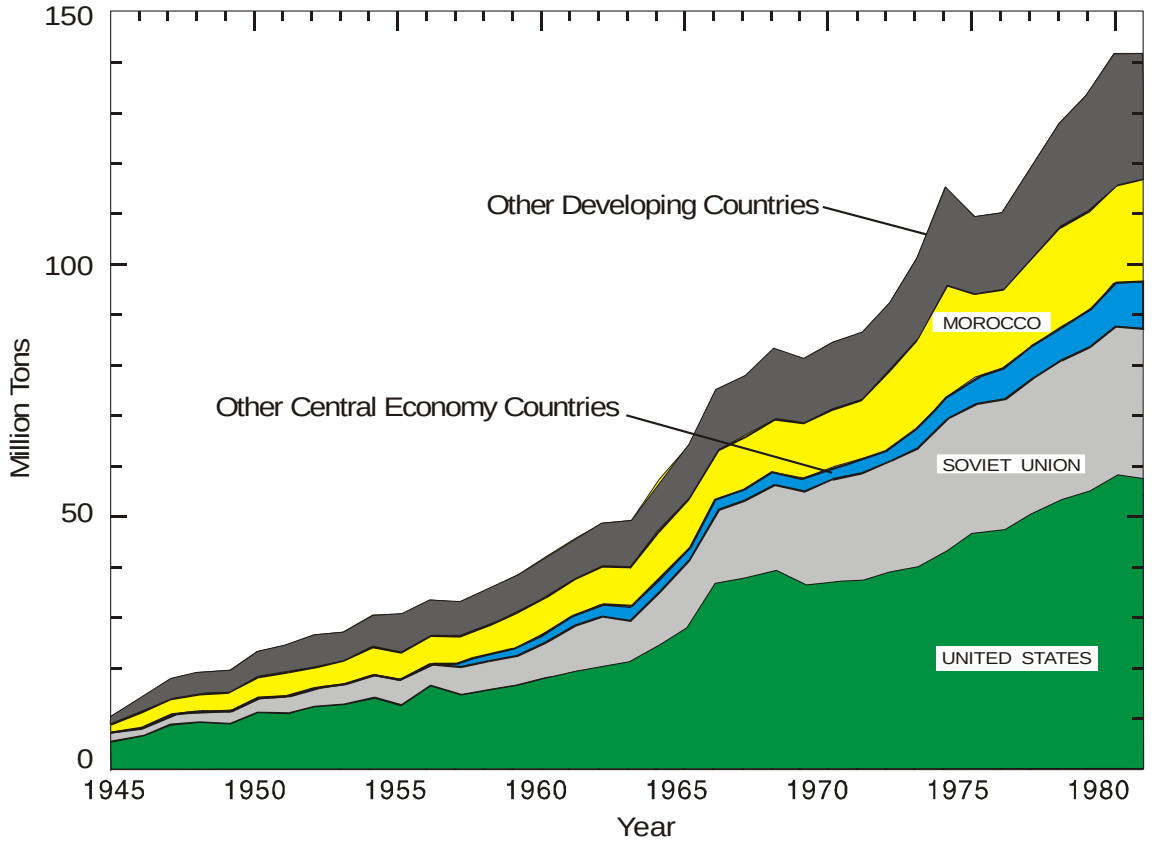
World Mine Production of Phosphate Concentrate, 1945-1981



Source: Krauss, Saam, and Schmidt, 1984.

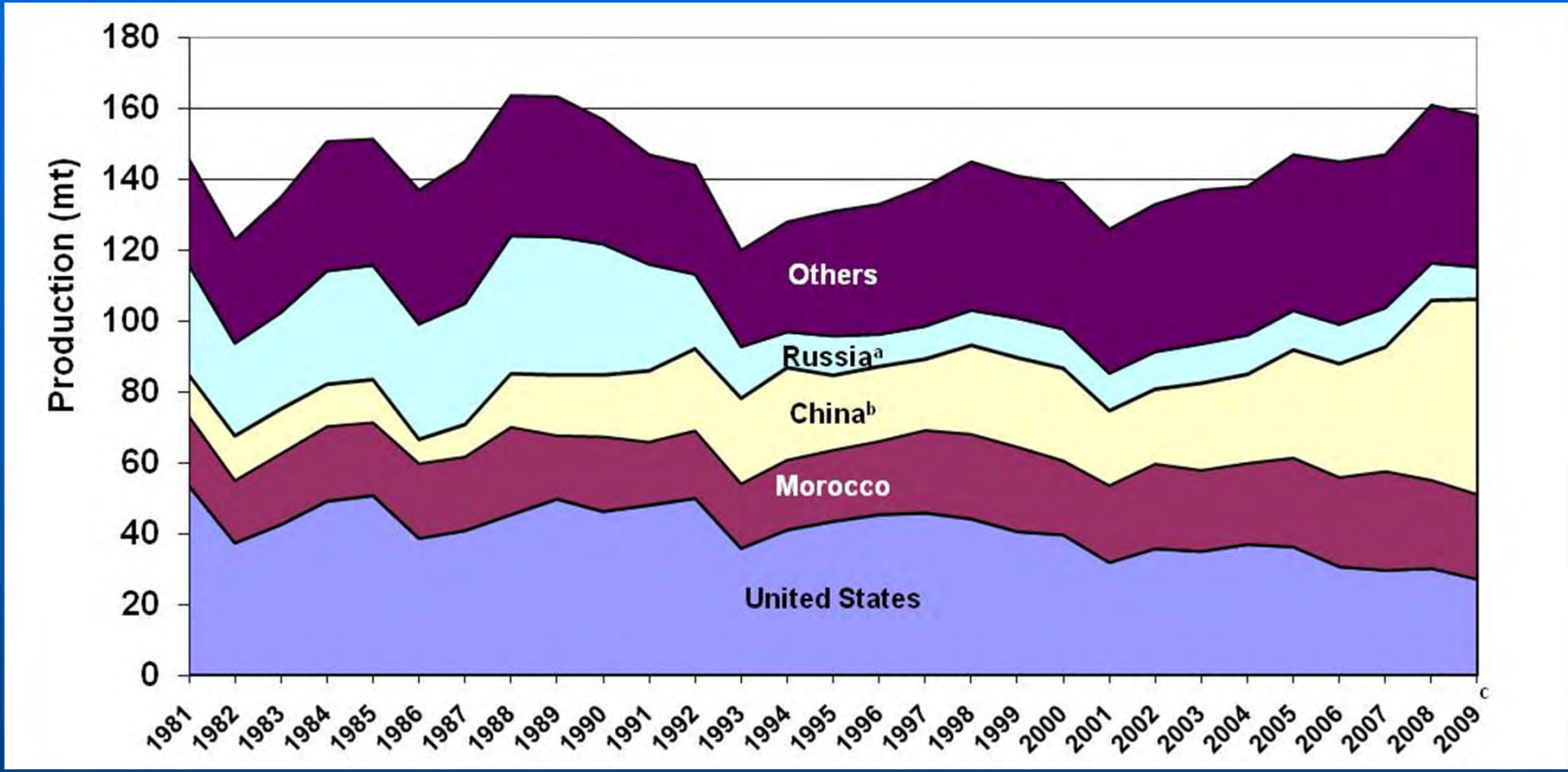
Anonymous (1976) UNIDO Report November 16–18, 1976 meeting in Vienna, Austria

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.

d. Source: Compiled from U.S. Bureau of Mines (USBM), 1984-1995; U.S. Geological Survey (USGS), 1996-2010.

Phosphate Rock

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

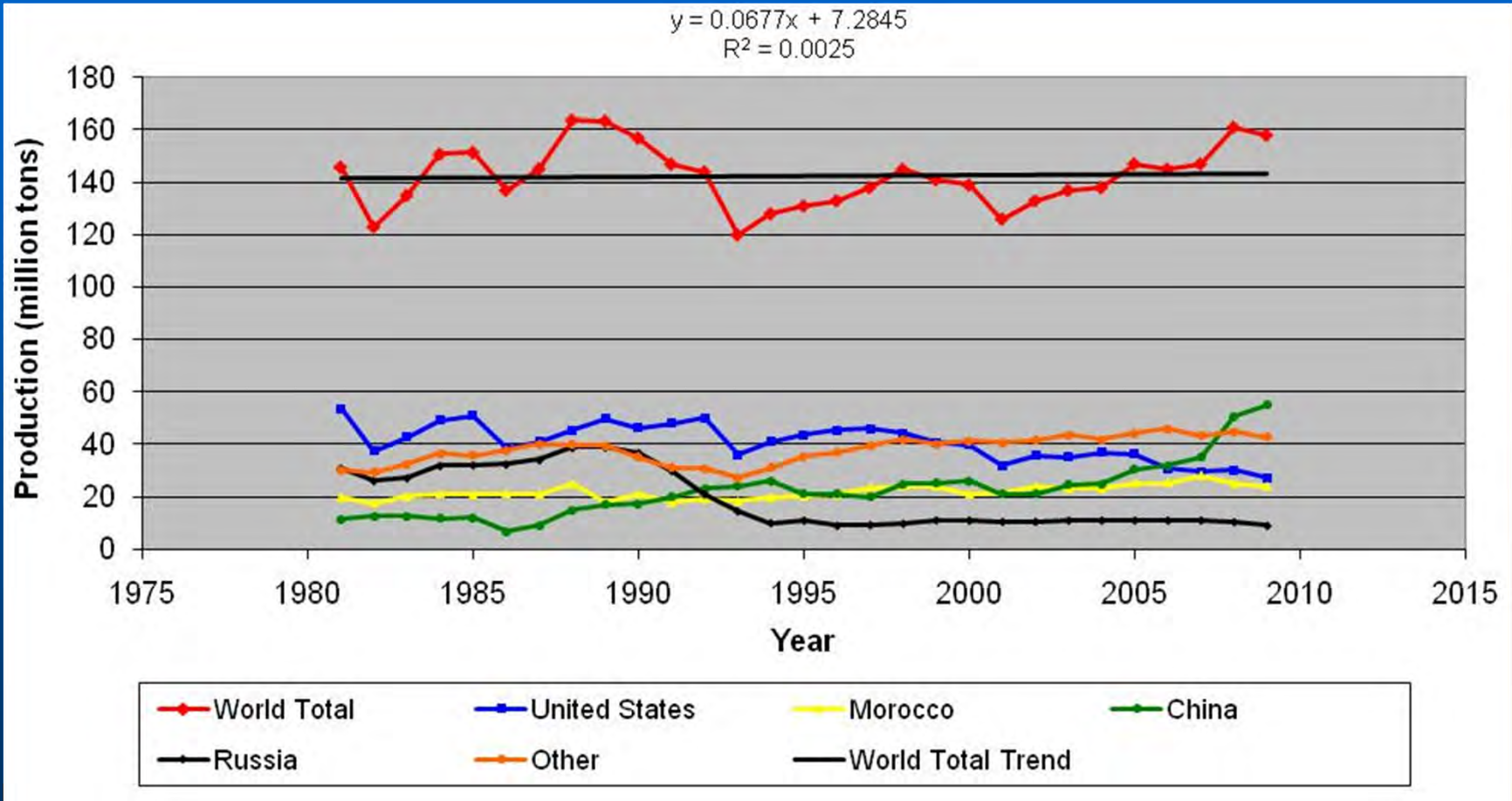
Over next five years, 40 new DAP, MAP and TSP units in 10 countries (Prud'homme, 2010)

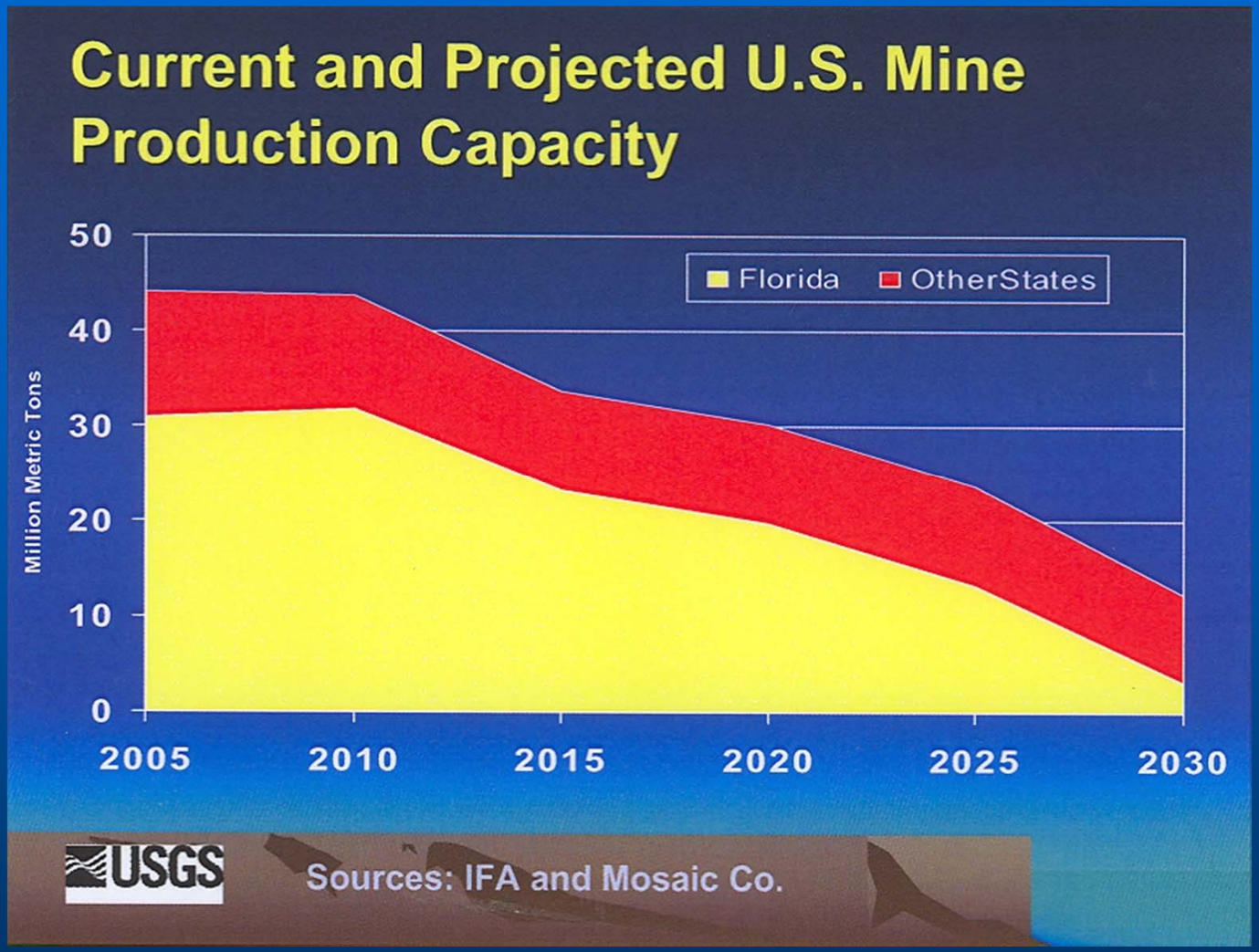
Phosphate Fertilizer Demand

2009–2012 = 3.2% CAGR
(Jung, 2010)

World Phosphate Rock Production

(USBM/USGS Mineral Commodity Summaries, 1982–2010)



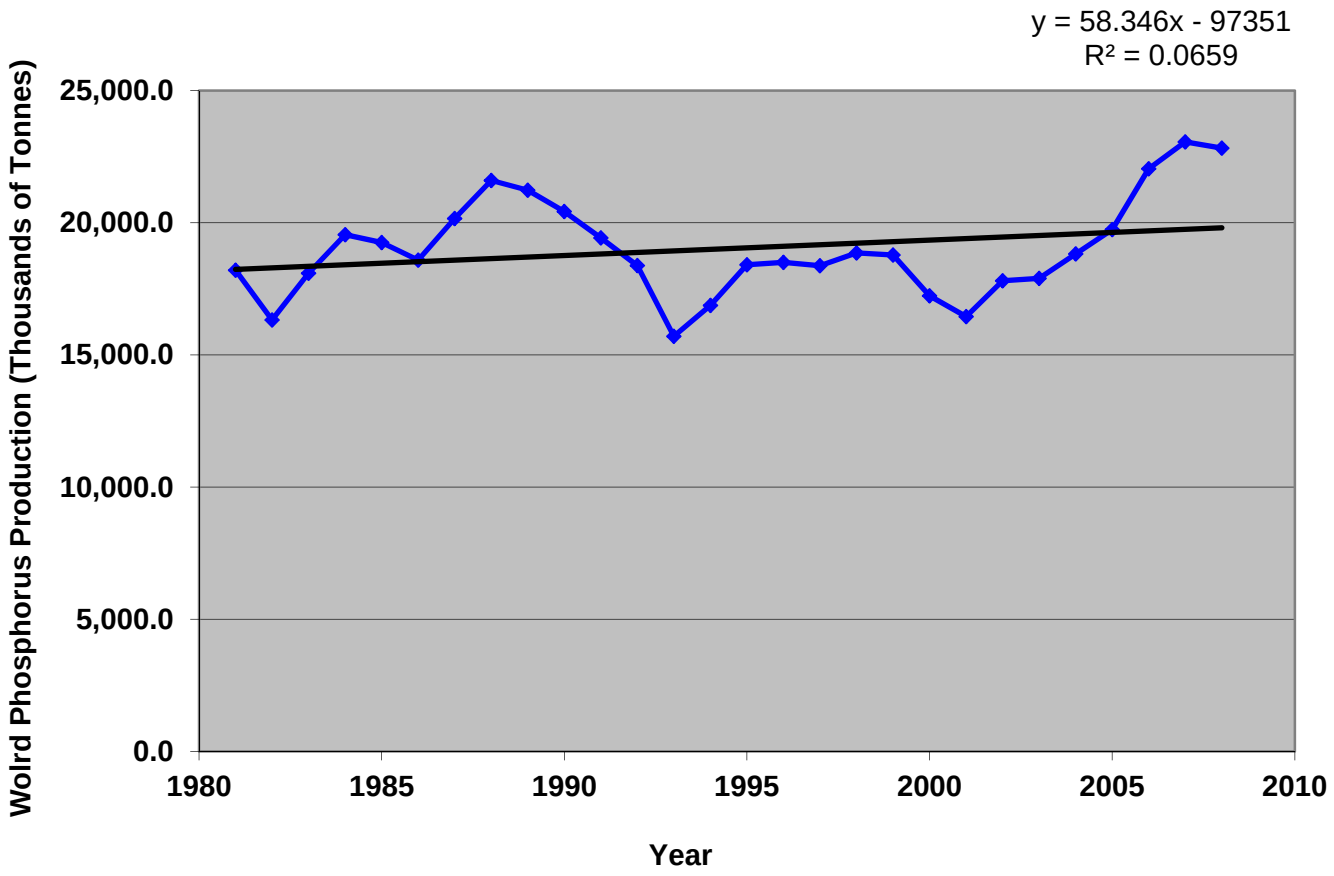


Source: Jasinski, 2005.

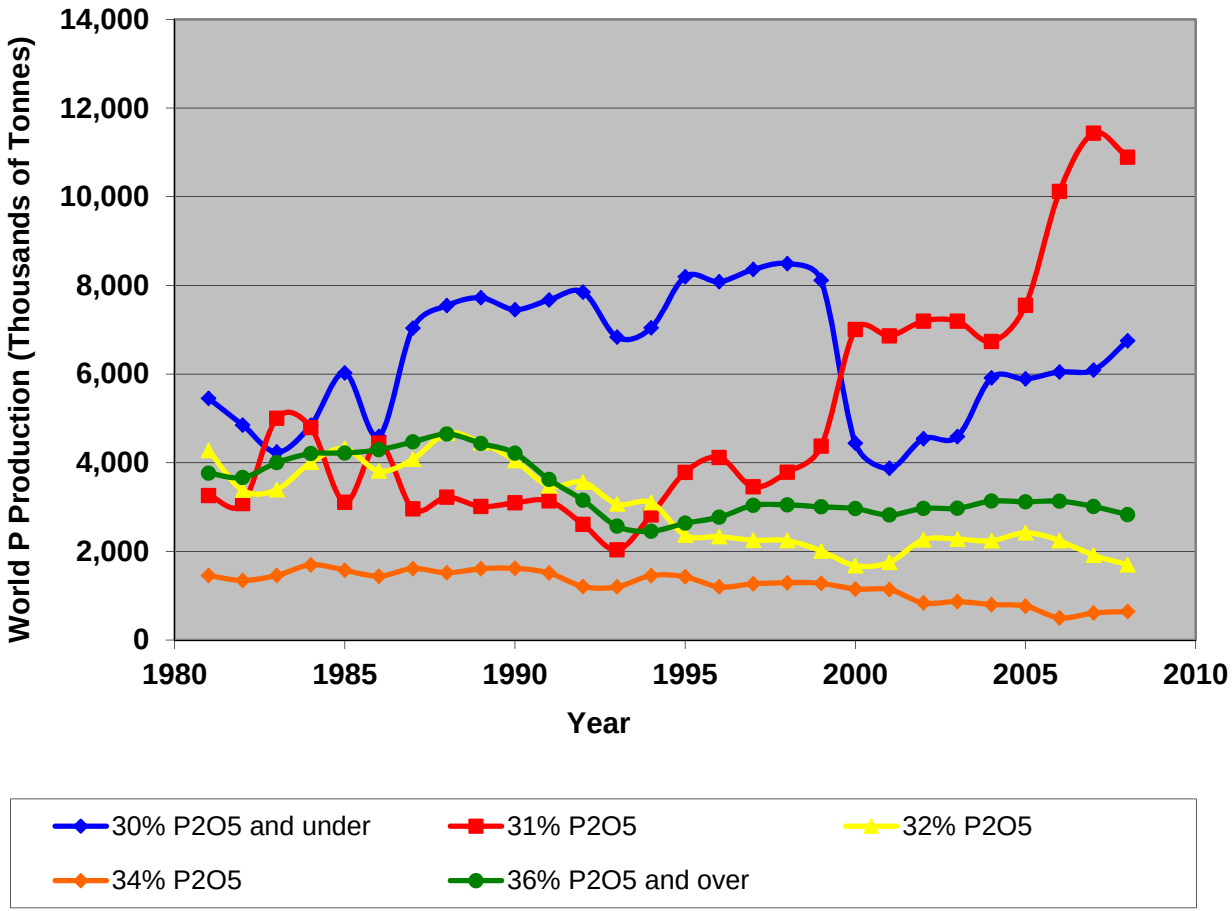
There has been a continuous decrease in world phosphate rock quality as reserves of high-grade and high-quality phosphate rock are being depleted.

— Is this true?

Total World Phosphorus Production

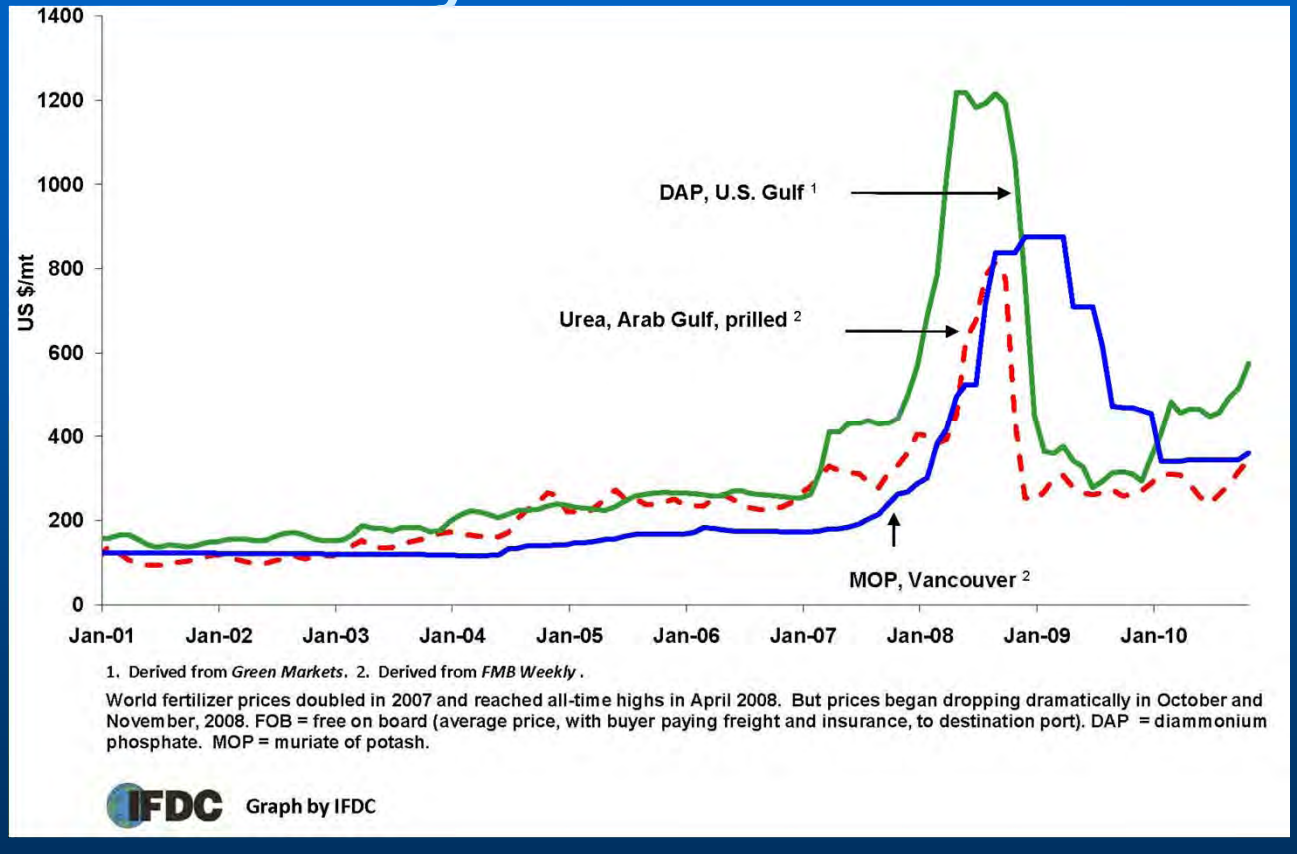


World Phosphorus Production by Grade



Phosphate Rock Has Been a Relatively Low-Value Bulk Commodity

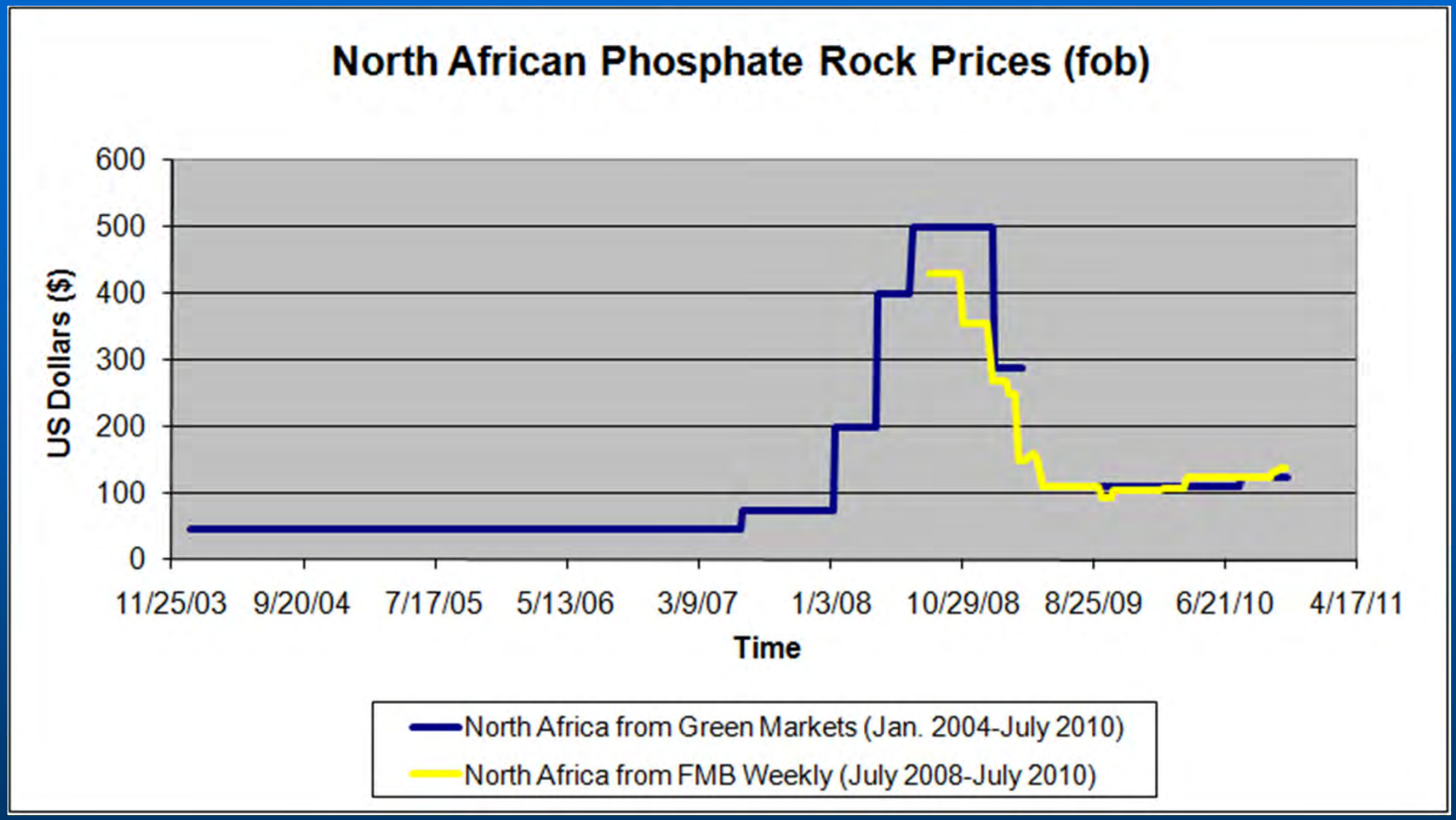
Fertilizer Prices (FOB, bulk) Monthly Averages January 2001–October 2010



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

World fertilizer prices doubled in 2007 and reached all-time highs in April 2008. But prices began dropping dramatically in October and November, 2008. FOB = free on board (average price, with buyer paying freight and insurance, to destination port). DAP = diammonium phosphate. MOP = muriate of potash.

IFDC Graph by IFDC


North African Phosphate Rock Prices (fob)
US Dollars ($)
600
500
400
300
200
100
0
11/25/03
9/20/04
7/17/05
5/13/06
3/9/07
1/3/08
10/29/08
8/25/09
6/21/10
4/17/11
Time
North Africa from Green Markets (Jan. 2004-July 2010)
North Africa from FMB Weekly (July 2008-July 2010)

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

	Phosphate Rock Resources	Estimated Recoverable Product	Reserves	Reserve Base
	[metric tons x 10^9 (U.S. Billion)]			
Emigh (1972)			1,200	
Wells (1975)			530 (30% P_2O_5)	
DeVoto and Stevens (1979)	1,200	265 (~30% P_2O_5)		
Cathcart (1980)	91		20 (≥30% P_2O_5)	
Fantel et al. (1988)		37		
Notholt, Sheldon and Davidson (1989)	163 (~22.5% P_2O_5)			
USGS (2009)			15[a]	47[b]

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, 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 recovery – Grade inversely proportional to recovery
– Geared to phosphoric acid production based on acceptable impurities and losses

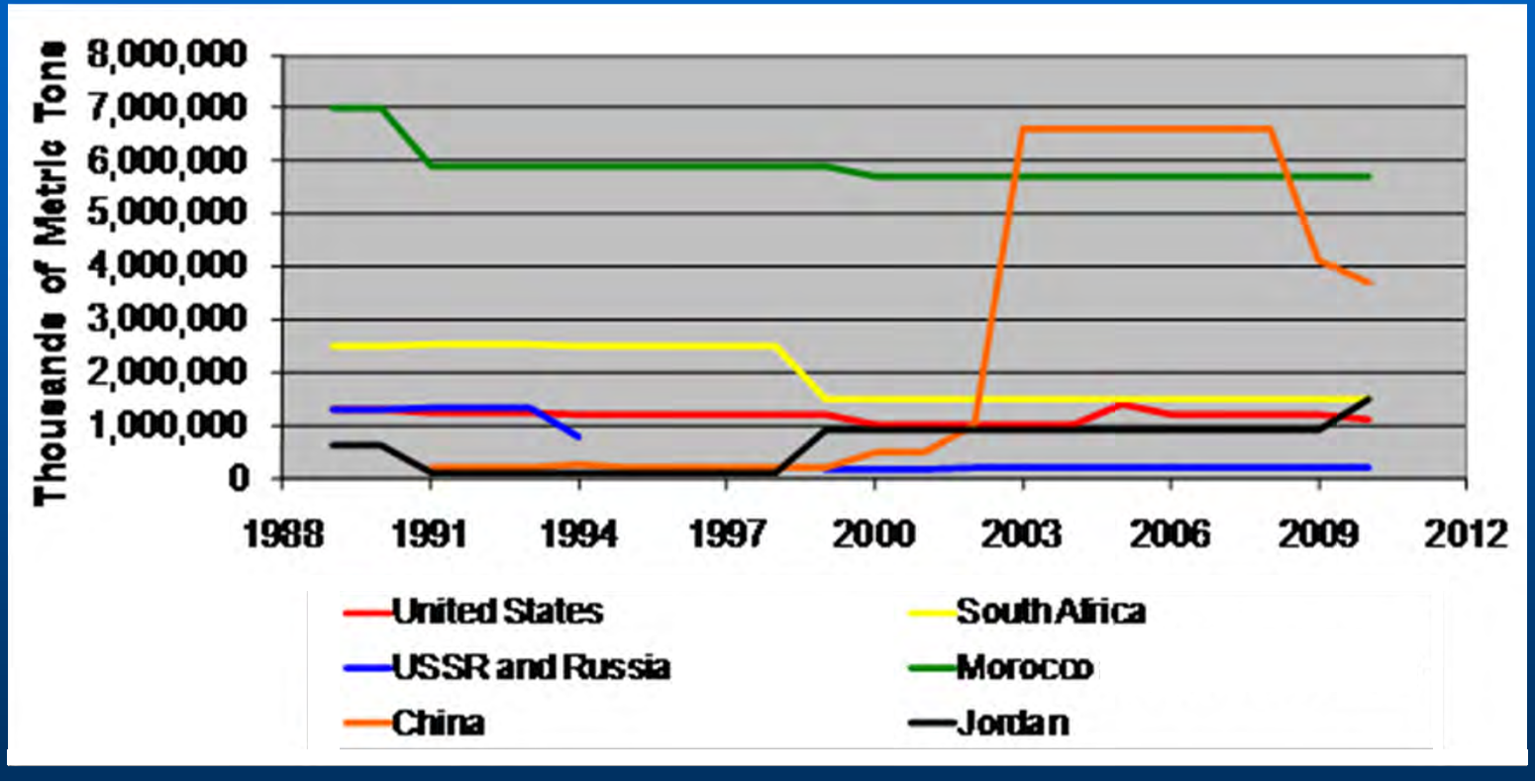
Phosphate Losses

	Loss of Phosphate Rock
Mining	
Bed too thin, not suitable	100%
Open pit	5-50%
Underground	15-35%
	Approximate Loss of P_2O_5 (%)
Beneficiation	
Southeast U.S.	40-80
West U.S.	30
South America	40
North Africa	30
West Africa	Up to 60
Middle East	30

Reserves and Resources – This Study

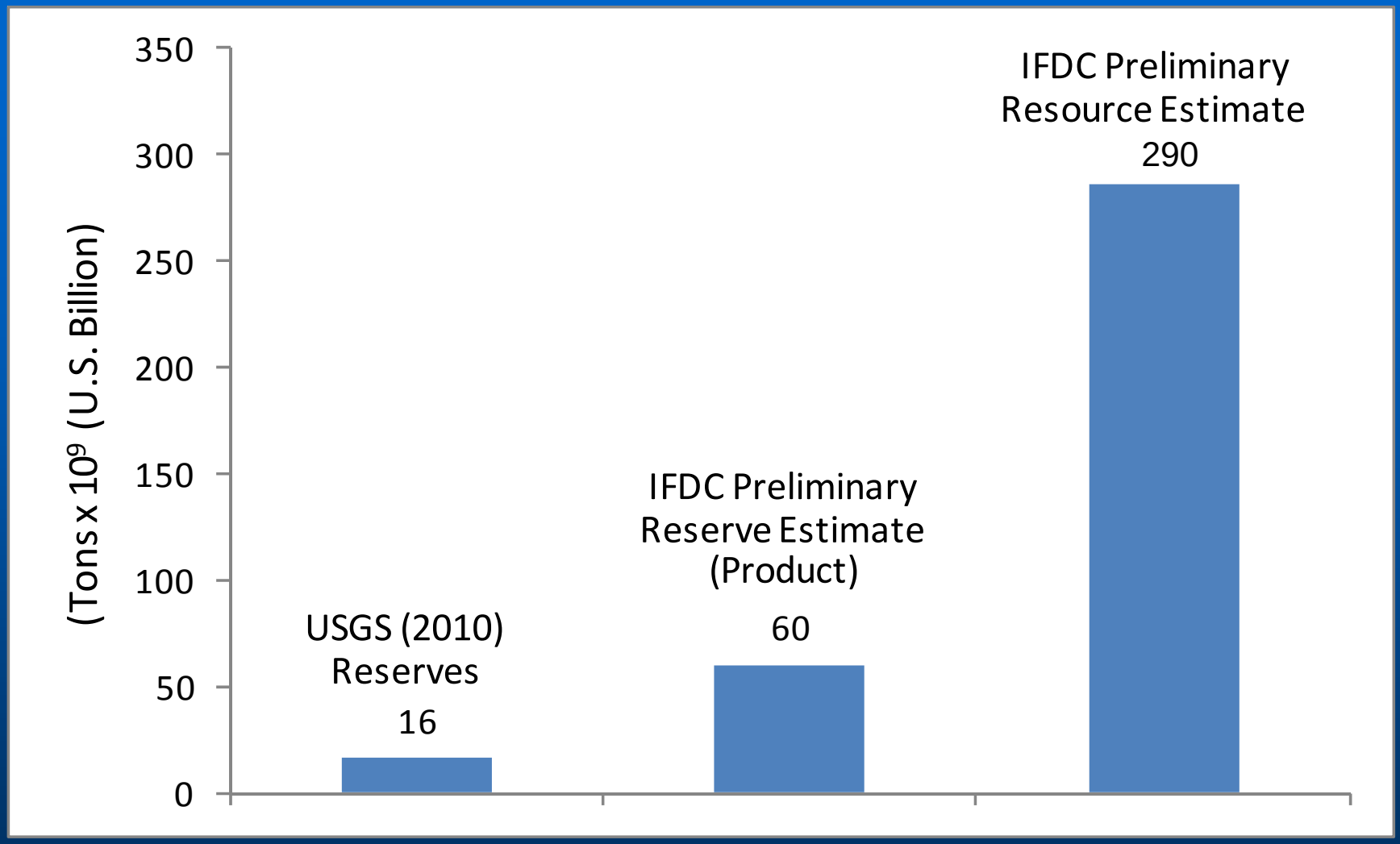
- **Reserves – Phosphate rock that can be economically produced at the time of the determination to make suitable products, reported as tons of concentrate**
- **Resources – Phosphate rock of any grade that may be produced at some time in the future, including reserves**

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


350
300
250
200
150
100
50
0
(Tons x 10^9 (U.S. Billion)
USGS (2010) Reserves
16
IFDC Preliminary Reserve Estimate (Product)
60
IFDC Preliminary Resource Estimate
290

IFDC Reserve and Resource Estimate

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.

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%**

Van Vuuren, D.P., A.F. Bouwman and A.H.W. Beusen. 2010. Phosphorus Demand for 1970–2100 Period: A Scenario Analysis of Resource Depletion, *Global Environmental Change*, 20:428-439.

Phosphate Rock Reserves and Resources

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

World Phosphate Rock Reserves and Resources