Phosphorus as a critical material.

James Elser
School of Life Sciences

ASU SCHOOL OF Life Sciences
ARIZONA STATE UNIVERSITY

The School of Life Sciences is a division of the College of Liberal Arts and Sciences

Phosphorus Inside the Beltway

I cannot over-emphasize the importance of Phosphorus not only to agriculture and soil conservation but also to the physical health and economic security of the people of the nation.

source: wikimedia commons

Phosphorus Inside the Beltway

BY THE COMPTROLLER GENERAL 12180

Report To The Congress

OF THE UNITED STATES

Phosphates: A Case Study Of A Valuable, Depleting Mineral In America

This report discusses the many problems and long leadtimes involved in phosphate development in the United States, world's largest producer of phosphates. Phosphate rock is the only known practical source of phosphorus, crucial to fertilizer used in agriculture.

Over the next two decades the richest U.S. phosphate deposits are likely to be depleted. There is cause for concern as to how new sources may be developed to meet the Nation's growing agricultural needs.

GAO recommends that the highest levels of Government begin promptly an assessment of access impediments to phosphate minerals and review of the Nation's long-range phosphate position regarding future availability, including legislative changes as may be needed to ensure supply.

GAO report 1979

UNITED STATES GENERAL ACCOUNTING OFFICE

EMD-80-21
NOVEMBER 30, 1979

007947

source: wikimedia commons

15

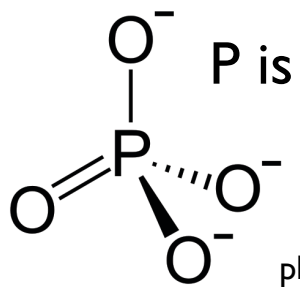
P

Phosphorus

30.973761

P is elemental.

Phosphorus in the 15th element in the Periodic Table.

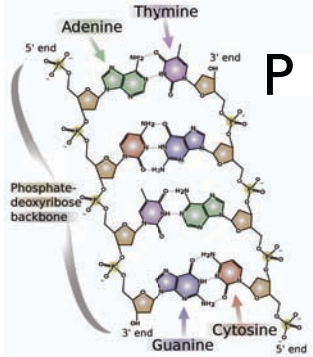


P is elemental.

phosphate

source: Wikimedia

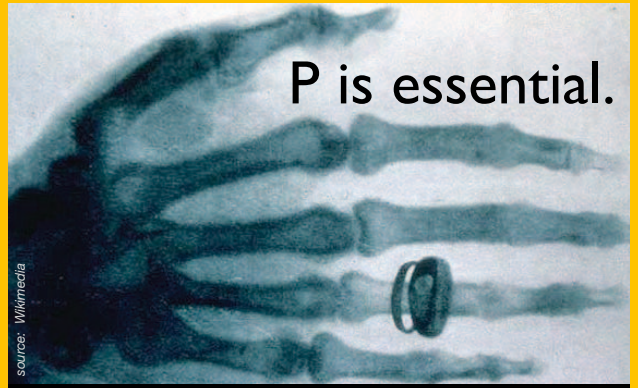
Phosphorus is normally found as phosphate.



P is essential.

source: Wikimedia

Every living thing needs P.



P is essential.

source: Wikimedia

An adult human body contains about 2 pounds of P.

P is limiting.

Source: Wikimedia

In both natural and agricultural ecosystems.

P is a pollutant.

Source: ED DeBruyn, DFO

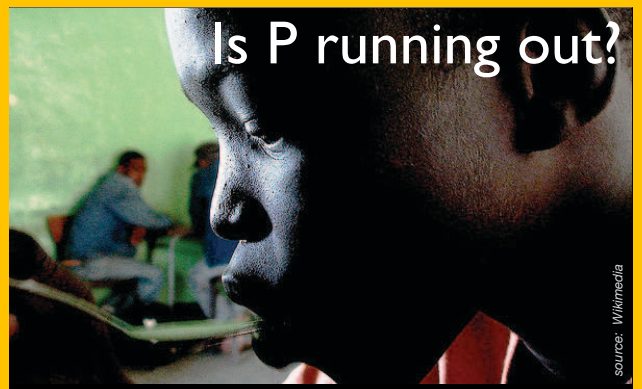
P from cities and from farm runoff leads to "eutrophication".

P is scarce.

Source: Wikimedia

Satellite view of phosphate mining region in Jordan.

Geological sources of P are not widely distributed.



Is P running out?

source: Wikimedia

Will there be enough P in the future?

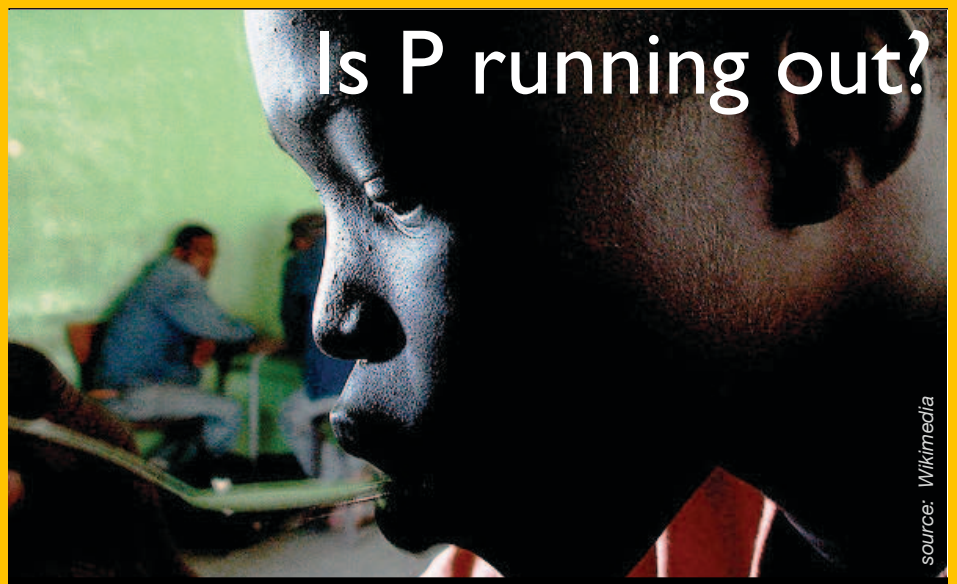
Finding P solutions.

source: Wikimedia

What to do?

Two axes of P sustainability

P from cities and from farm runoff leads to "eutrophication".



Will there be enough P in the future?

UK Foresight Report on Food and Farming

24 Jan 2011

BBC Mobile | News | Sport | Weather | Travel

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24 January 2011 Last updated at 06:32 ET

Report: Urgent action needed to avert global hunger

By Pallab Ghosh
Science correspondent, BBC News

A UK government-commissioned study into food security has called for urgent action to avert global hunger.

The Foresight Report on Food and Farming Futures says the current system is unsustainable and will fail to end hunger unless radically redesigned.

It is the first study across a range of disciplines deemed to have put such fears on a firm analytical footing.

The report is the culmination of a two-year study, involving 400 experts from 35 countries.

According to the government's chief scientific adviser, Professor Sir John Beddington, the study provides compelling evidence for governments to act now.

The report calls for an urgent change to food production in order to feed future generations

The report emphasises changes to farming, to ensure that increasing yields does not come at the expense of sustainability and to provide incentives to the agricultural sector that address malnutrition.

It also recommends that the most resource-intensive types of food are curbed and that waste is minimised in food production.

"We know in the next 20 years the world population will increase to something like 8.3 billion people," he told BBC News.

Related stories

World food prices 'at fresh high'

Green ham with your eggs?

Index shows global

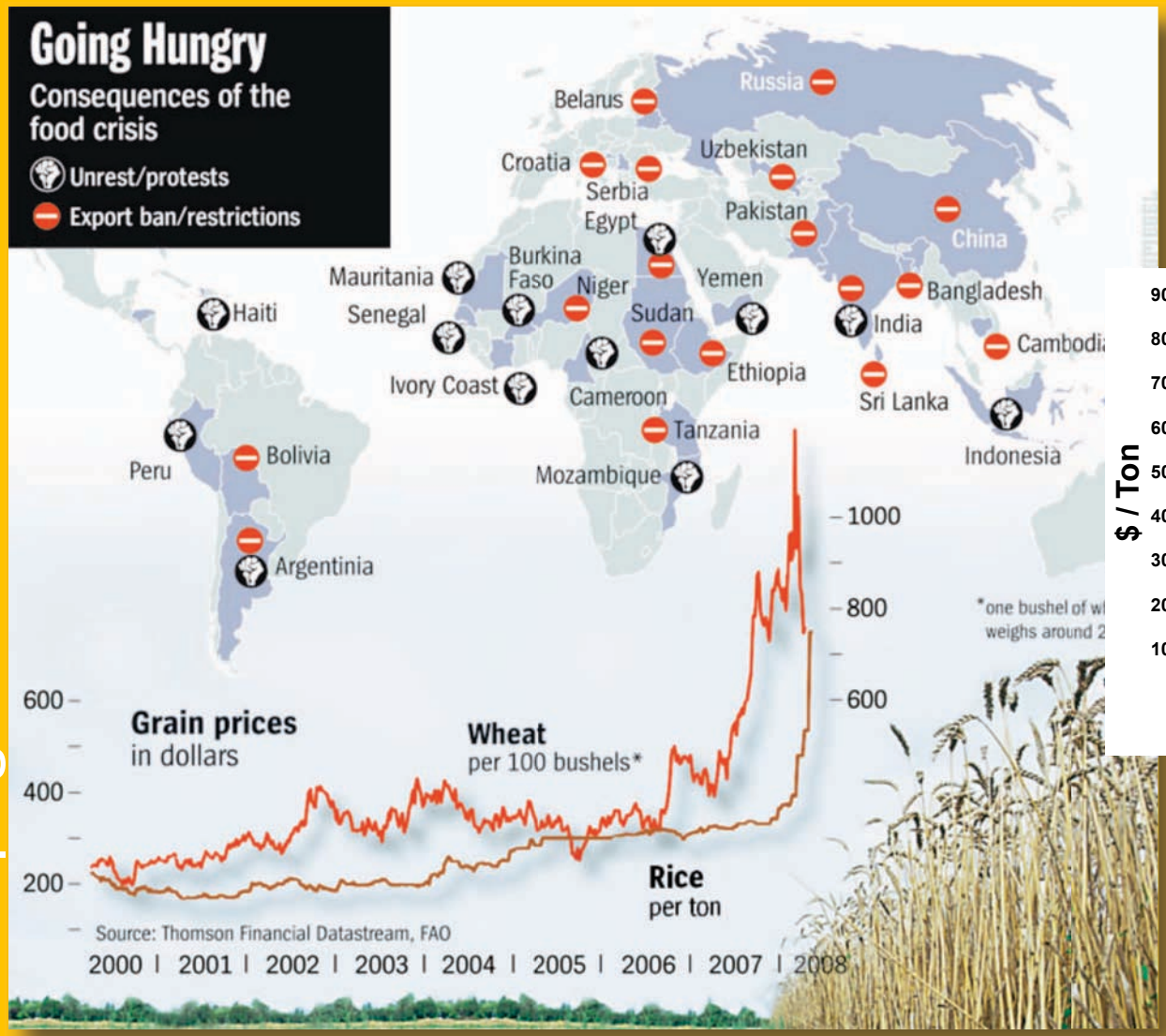
"[the global] agricultural system is unsustainable and will fail to end hunger* unless radically redesigned."

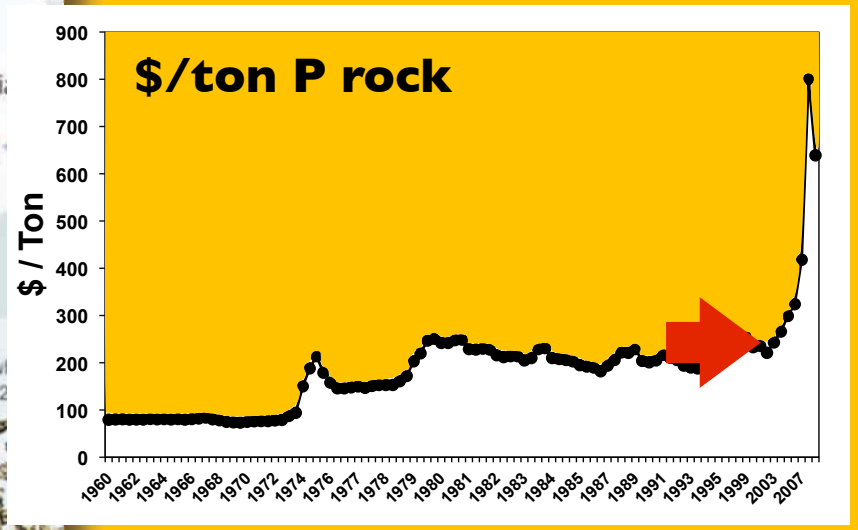
*~1 billion people currently under-nourished.

Global food security = US national security

2008

Der Spiegel

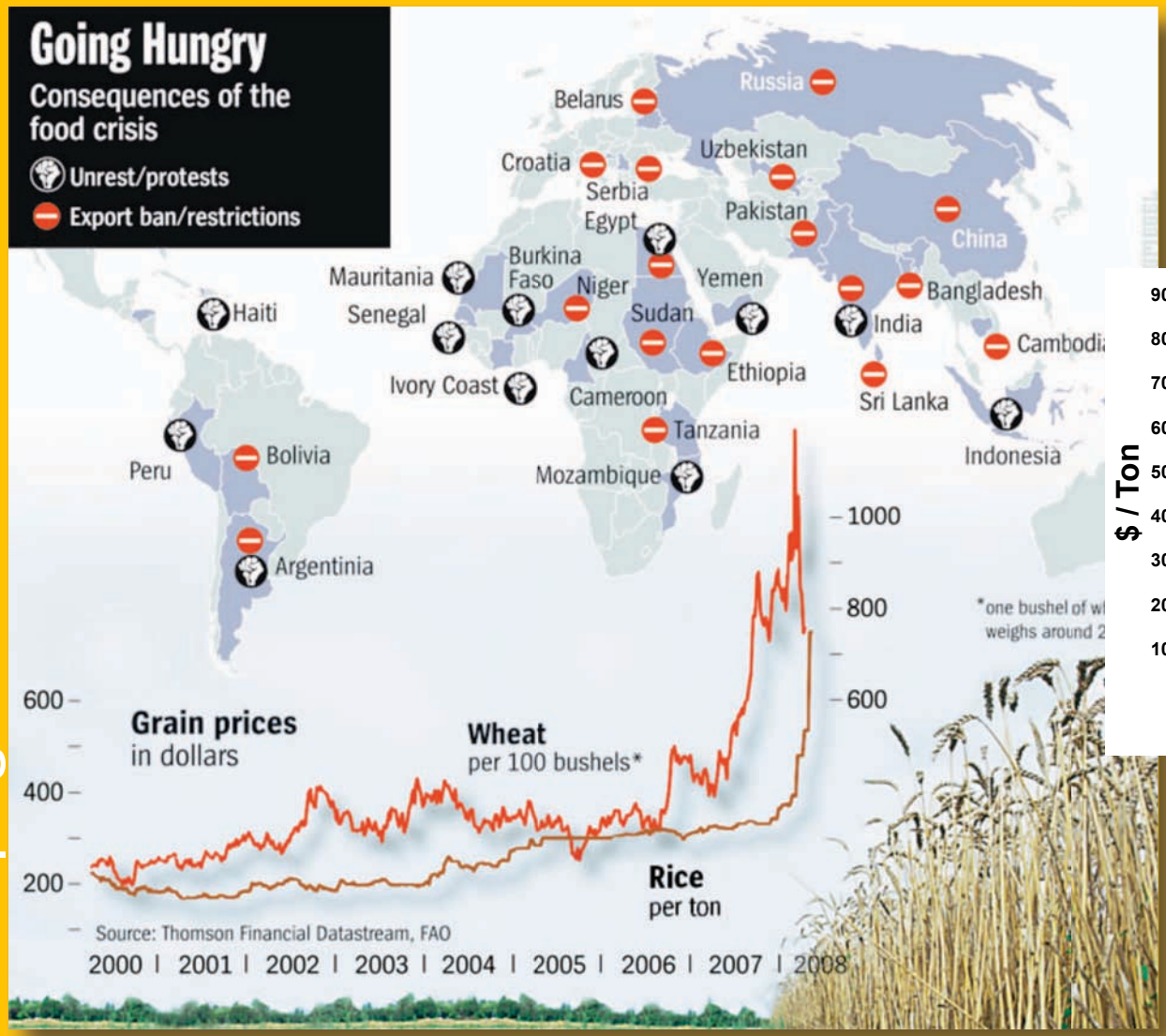


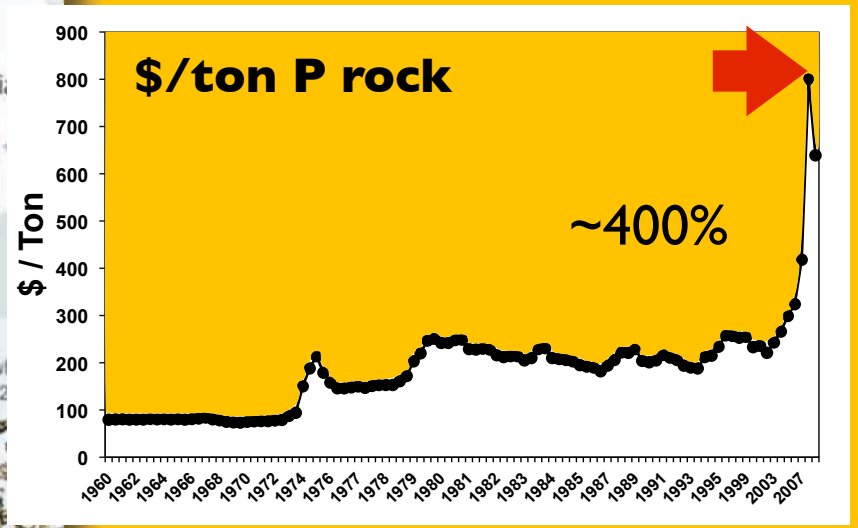


Global food security = US national security

2008

Der Spiegel





Global food security = US national security

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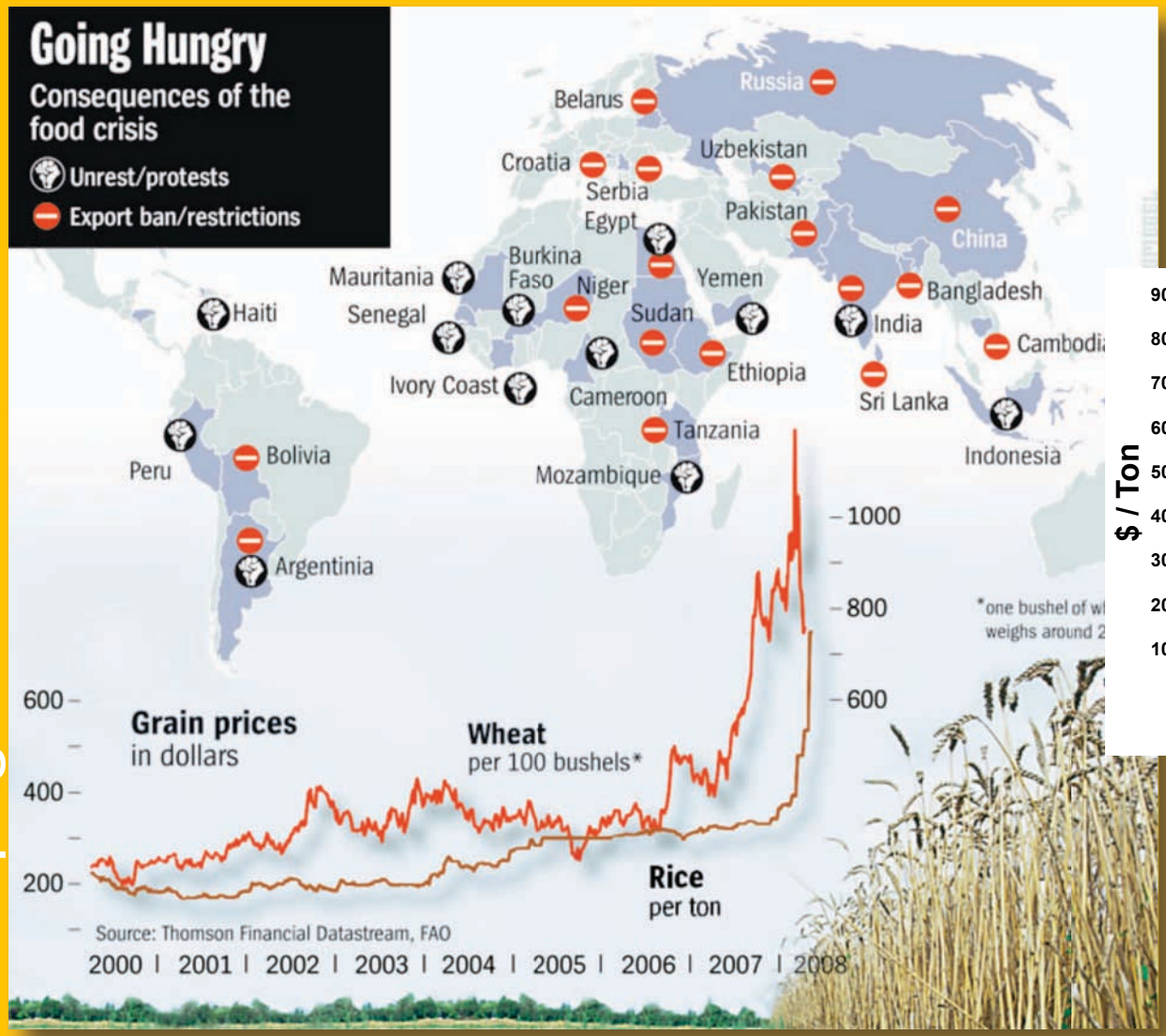
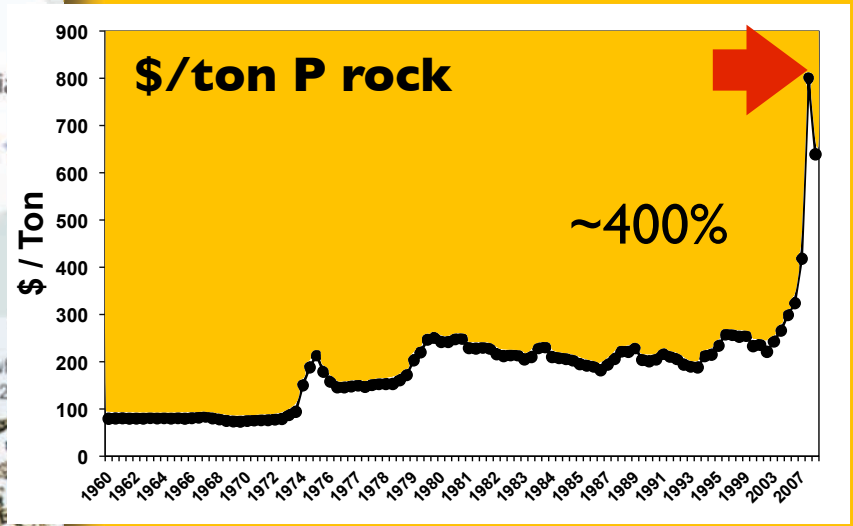
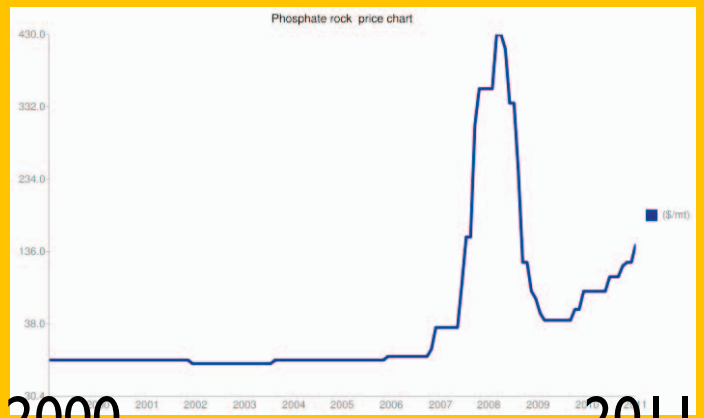
Der Spiegel







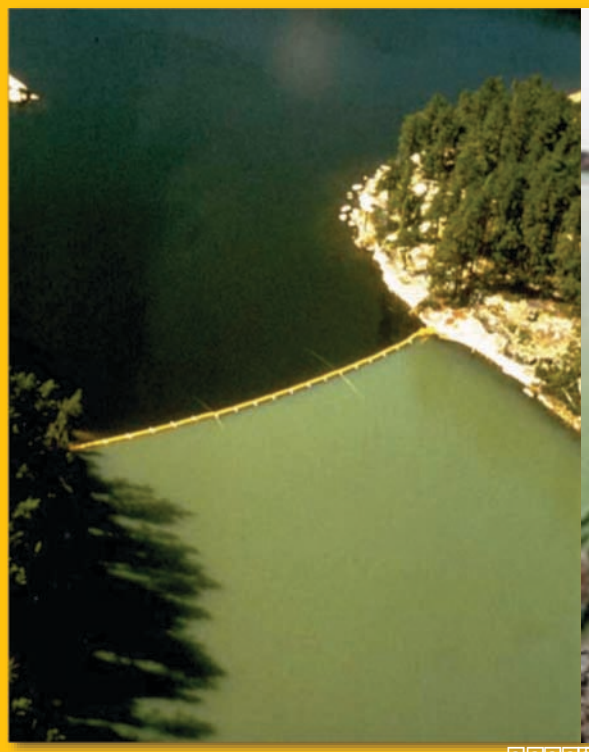
Two axes of P sustainability

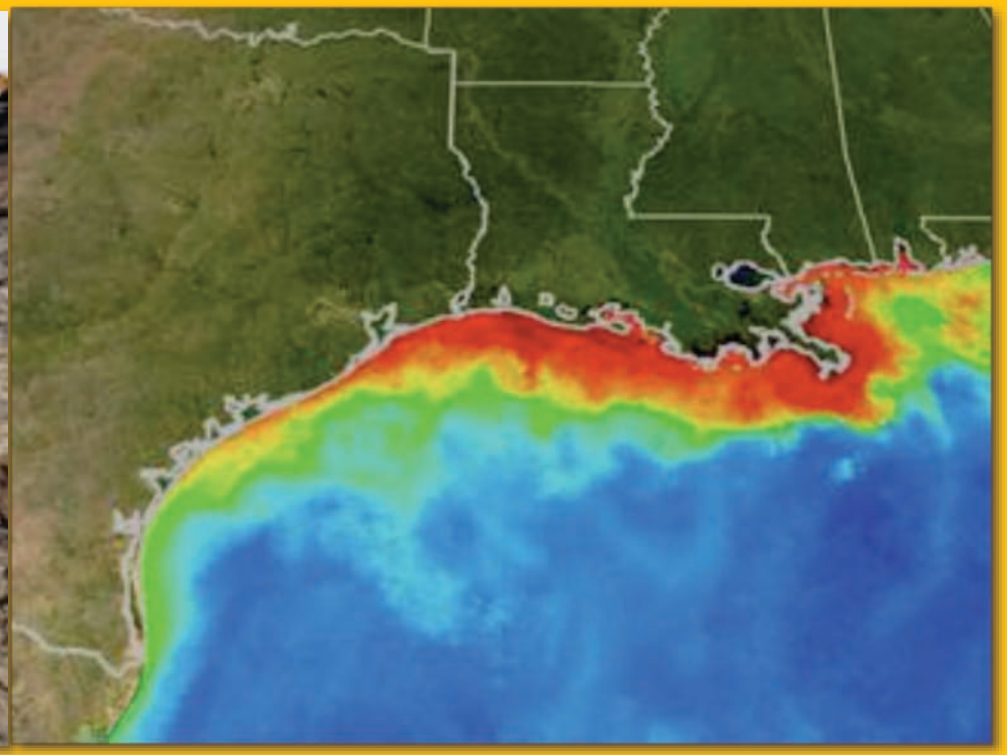
Certainty

&

Uncertainty

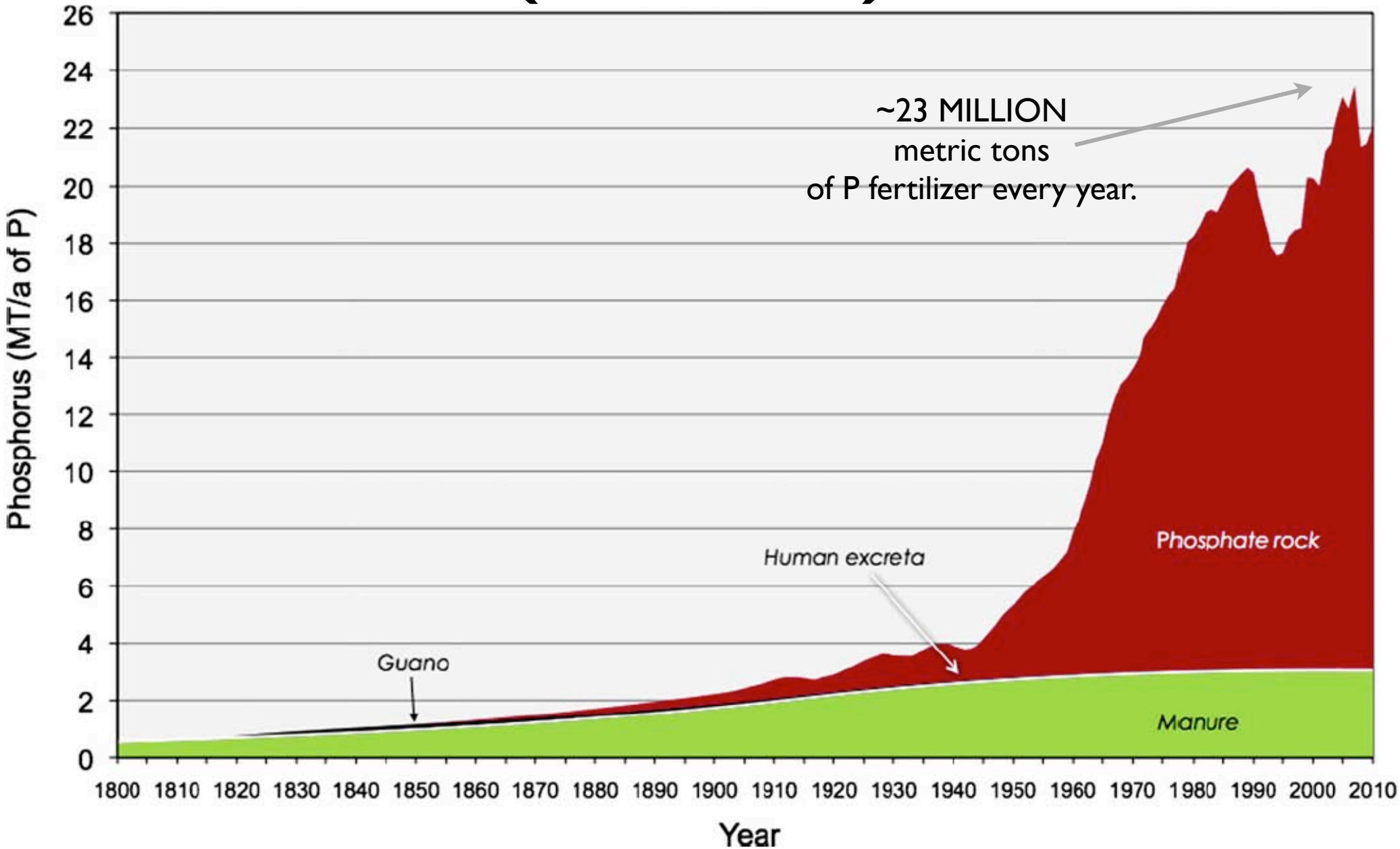
Certainty





Uncertainty.

Historical Sources of P for Agriculture (1800-2010)



Updated from: Cordell D, Drangert J-O, White S. 2009. The story of phosphorus: Global food security and food for thought. *Global Environmental Change* **19**: 292–305.

Phosphorus: A Looming Crisis

This underappreciated resource—a key part of fertilizers—is still decades from running out. But we must act now to conserve it, or future agriculture will collapse • By David A. Vaccari

KEY CONCEPTS

- Mining phosphorus for fertilizer is consuming the mineral faster than geologic cycles can replenish it. The U.S. may run out of its accessible domestic sources in a few decades, and few other countries have substantial reserves, which could also be depleted in about a century.
- Excess phosphorus in waterways helps to feed algal blooms, which starve fish of oxygen, creating "dead zones."
- Reducing soil erosion and recycling phosphorus from farm and human waste could help make food production sustainable and prevent algal blooms.

—*The Editors*

As complex as the chemistry of life may be, the conditions for the vigorous growth of plants often boil down to three numbers, say, 19-12-5. Those are the percentages of nitrogen, phosphorus and potassium, prominently displayed on every package of fertilizer. In the 20th century the three nutrients enabled agriculture to increase its productivity and the world's population to grow more than sixfold. But what is their source? We obtain nitrogen from the air, but we must mine phosphorus and potassium. The world has enough potassium to last several centuries. But phosphorus is a different story. Readily available global supplies may start running out by the end of this century. By then our population may have reached a peak that some say is beyond what the planet can sustainably feed.

Moreover, trouble may surface much sooner. As last year's oil price swings have shown, markets can tighten long before a given resource is anywhere near its end. And reserves of phosphorus are even less evenly distributed than oil's, raising additional supply concerns. The U.S. is the world's second-largest producer of phosphorus (after China), at 19 percent of the total, but 65 percent of that amount comes from a single source: pit mines near Tampa, Fla., which may not last more than a few decades. Meanwhile nearly 40 percent of global reserves are controlled by a single country, Morocco, sometimes referred to as the "Saudi Arabia of phosphorus." Although Morocco is a stable, friendly nation, the imbalance makes phosphorus a geostrategic ticking time bomb.

In addition, fertilizers take an environmental toll. Modern agricultural practices have tripled the natural rate of phosphorus depletion from the land, and excessive runoff into waterways is feeding uncontrolled algal blooms and throwing aquatic ecosystems off-kilter. While little attention has been paid to it as compared with other elements such as carbon or nitrogen, phosphorus has become one of the most significant sustainability issues of our time.

Green Revelation

My interest in phosphorus dates back to the mid-1990s, when I became involved in a NASA program aiming to learn how to grow food in space. The design of such a system requires a careful analysis of the cycles of all elements that go into food and that would need to be recycled within the closed environment of a spaceship. Such know-how may be necessary for a future trip to Mars, which would last almost three years.

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Our planet is also a spaceship: it has an essentially fixed total amount of each element. In the natural cycle, weathering releases phosphorus from rocks into soil. Taken up by plants, it enters the food chain and makes its way through every living being. Phosphorus—usually in the form of the phosphate ion PO_4^{3-}—is an irreplaceable ingredient of life. It forms the backbone of DNA and of cellular membranes, and it is the crucial component in the molecule adenosine triphosphate, or ATP—the cell's main form of energy storage. An average human body contains about 650 grams of phosphorus, most of it in our bones.

Land ecosystems use and reuse phosphorus in local cycles an average of 46 times. The mineral then, through weathering and runoff, makes its way into the ocean, where marine organisms may recycle it some 800 times before it passes into sediments. Over tens of millions of years tectonic uplift may return it to dry land.

Harvesting breaks up the cycle because it removes phosphorus from the land. In prescientific agriculture, when human and animal waste served as fertilizers, nutrients went back into the soil at roughly the rate they had been withdrawn. But our modern society separates food production and consumption, which limits our ability to return nutrients to the land. Instead we use them once and then flush them away.

Agriculture also accelerates land erosion—because plowing and tilling disturb and expose the soil—so more phosphorus drains away with runoff. And flood control contributes to disrupting the natural phosphorus cycle. Typically river floods would redistribute phosphorus-rich sediment to lower lands where it is again available for ecosystems. Instead dams trap sedi-

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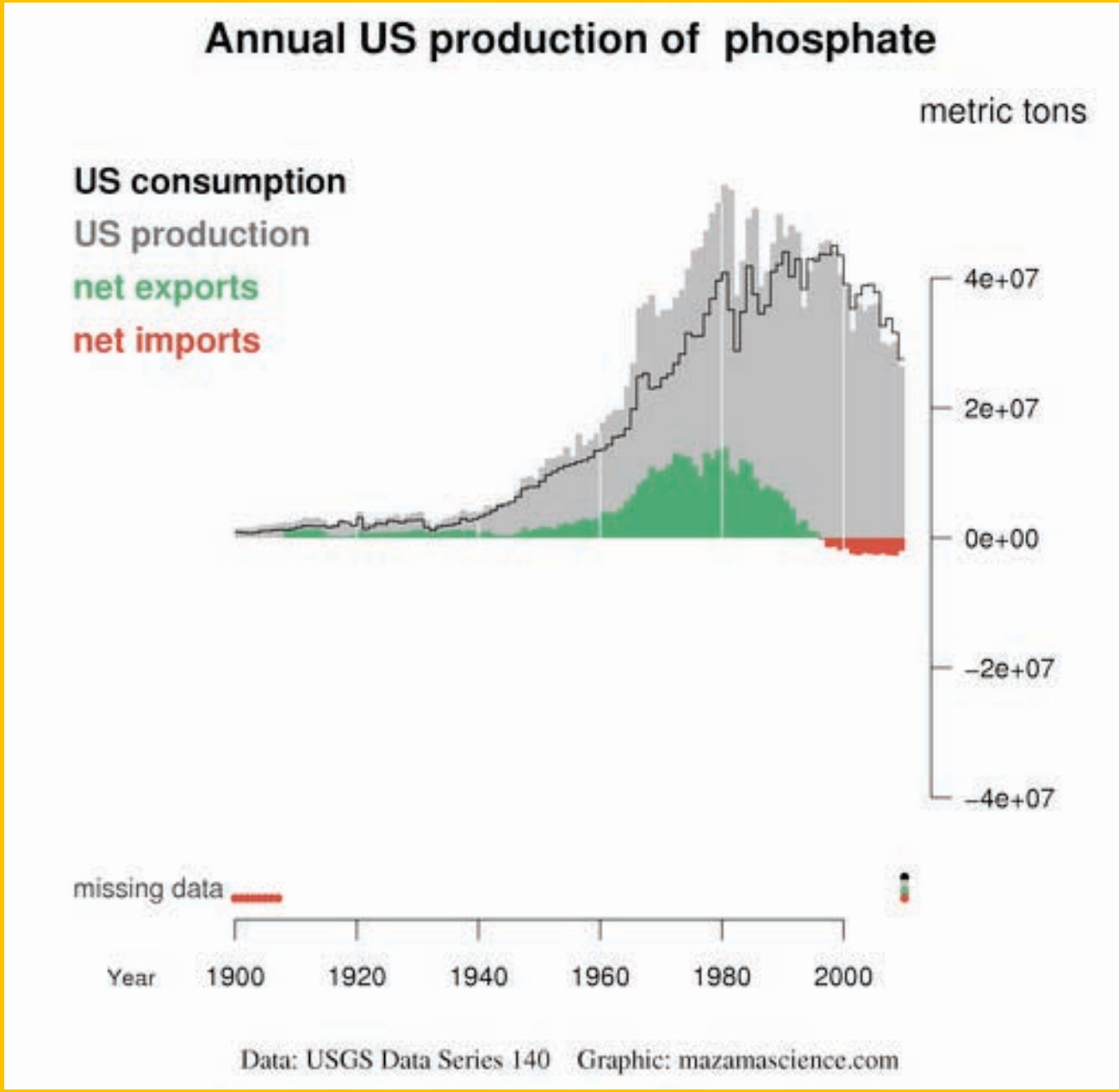
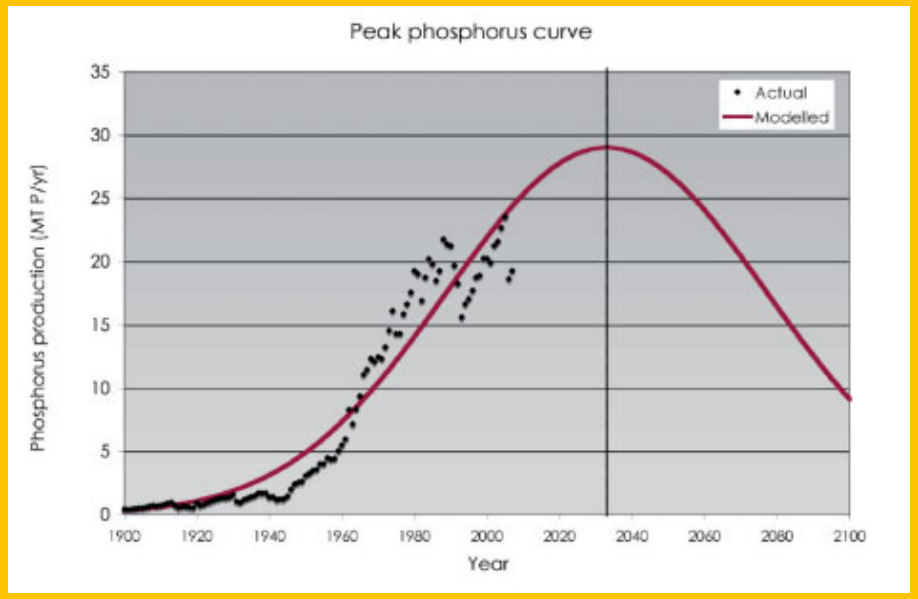
(Rhymes with Squeak) Phosphorus??



http://mazamascience.com/Minerals/USGS/

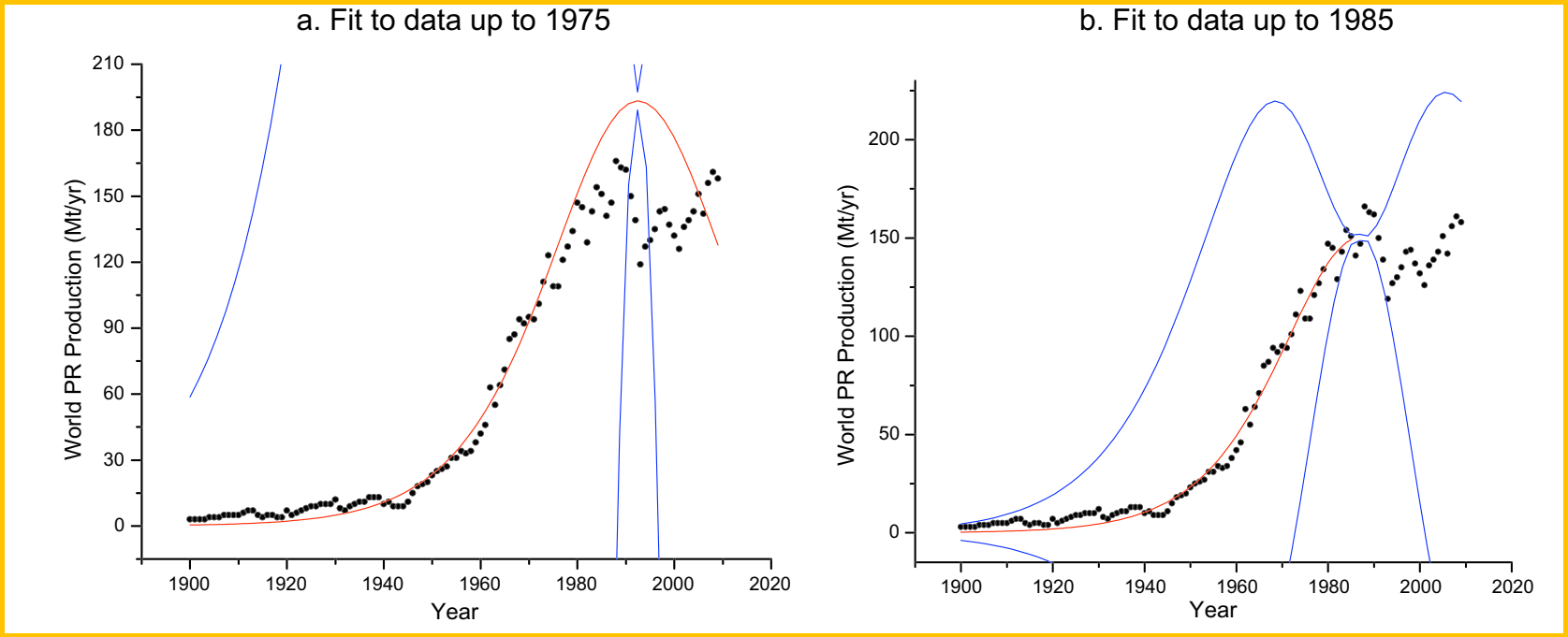
(Rhymes with Squeak) Phosphorus??



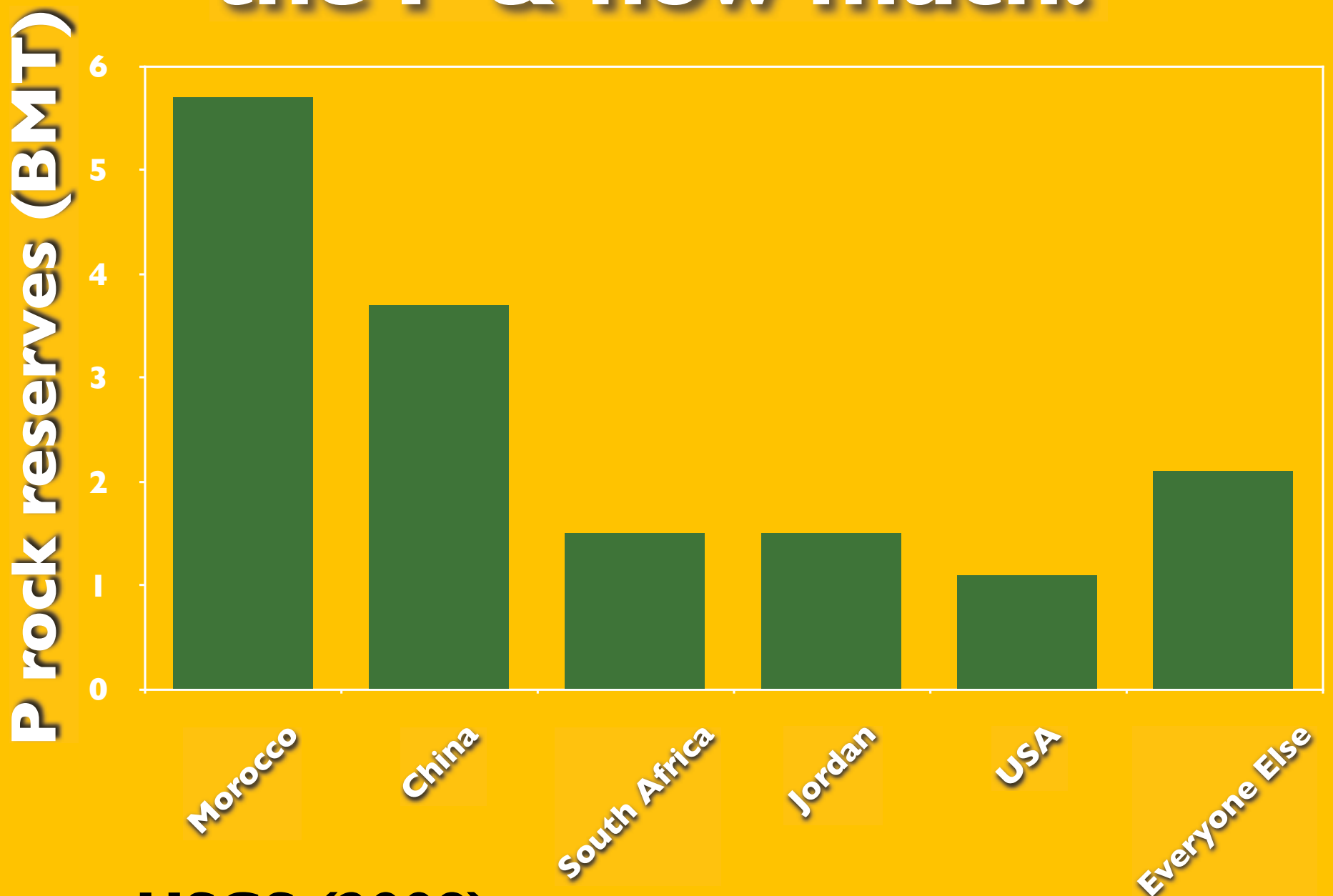
(Cordell 2009)

Some attempts at Hubbert-style analysis of P dynamics.

(Vaccari & Strigul 2011)



Uncertainty: Who has the P & how much?



Source: USGS (2009)

Uncertainty: Who has the P & how much?

new adjustment by IFDC*

* "not known if all of this is truly producible at today's costs and prices."

"run-out time" of ~300-400 years.

(*Note: based on* *<u>current</u>* *P production.*)

Source: IFDC (2010)

Putting the "geo" in geopolitics

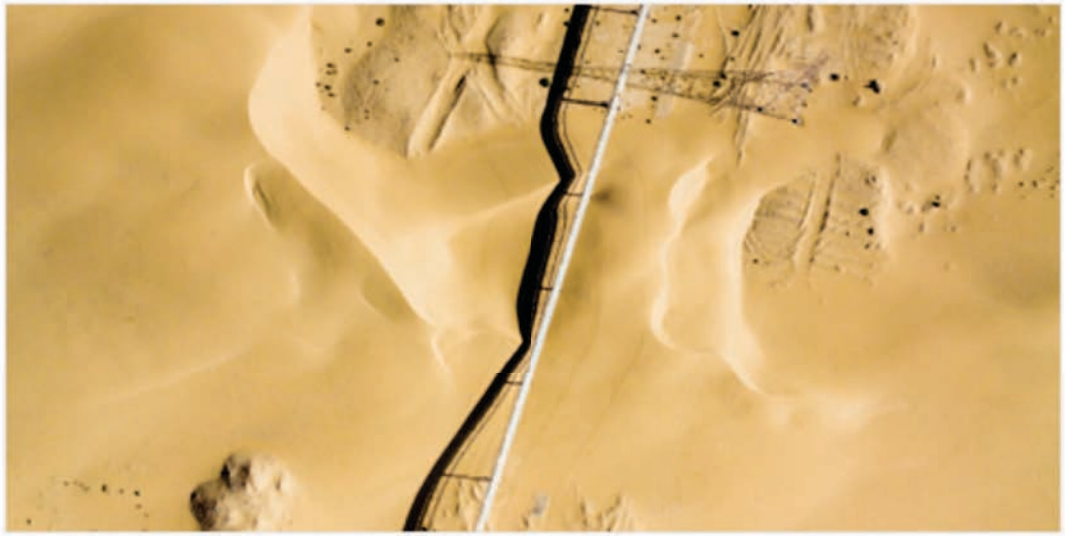
Morocco: The Dubai of P?

Bloomberg.com | Business Exchange

Bloomberg Businessweek

Phosphate: Morocco's White Gold

Phosphate is used in everything from fertilizer to rechargeable batteries. And Morocco's King Mohammed VI has cornered the market



In UN-patrolled Western Sahara, phosphate goes to port via a 62-mile-long conveyor belt Michael Fay/National Geographic/Getty Images

By Brendan Borrell and Daniel Grushkin

"a fantasyland glorifying the country's mineral inheritance"

"Fossils .... displayed in a sparkling museum powered by wind and sun"

"a depleted mine... transformed into gardens, performance spaces, and housing"

"a 'mega-amusement park' including an equestrian center, a cable car, and an indoor ski slope on a pile of mine waste."

Putting the "geo" in geopolitics

What about China?

China uses 36% of global fertilizer.

In December 2010, China applied a 110% peak season export tax on fertilizer.

Future demand for phosphorus:

On the <u>increase</u> side:

- **Population** Estimates indicate that, to achieve global food security in 2050, food production will need to *double*.
- **Growing affluence** Meat consumption is increasing as developing countries become more affluent. Meat is P intensive.
- **Bioenergy** In 2009, ~10% of all USA P fertilizer use was for corn grown for ethanol production.
- **Non-agricultural use** The lithium-iron-phosphate batteries in an electric car contain 60 kg P.

On the <u>decrease</u> side:

- **Soil P saturation** Many developed world soils are now P-saturated and can probably lower P application w/o reduced yield.
- **Overapplication** Rates of P application in some regions, e.g. China, can probably be scaled back w/o reducing yield.

Issue comes down to:

Issue comes down to:

How much P,

Issue comes down to:

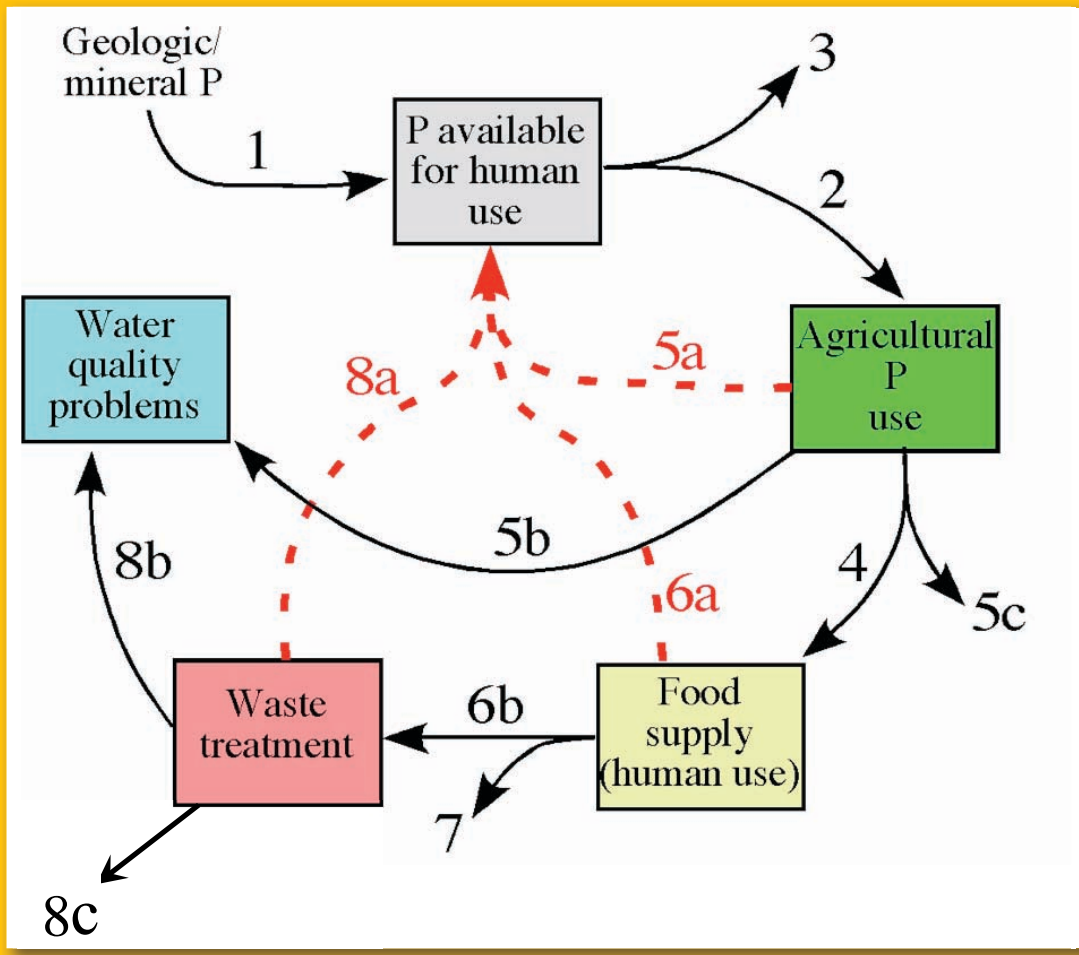
How much P, for whom,

Issue comes down to:

How much P, for whom, & at what price?

More uncertainty.

Where is the P going?



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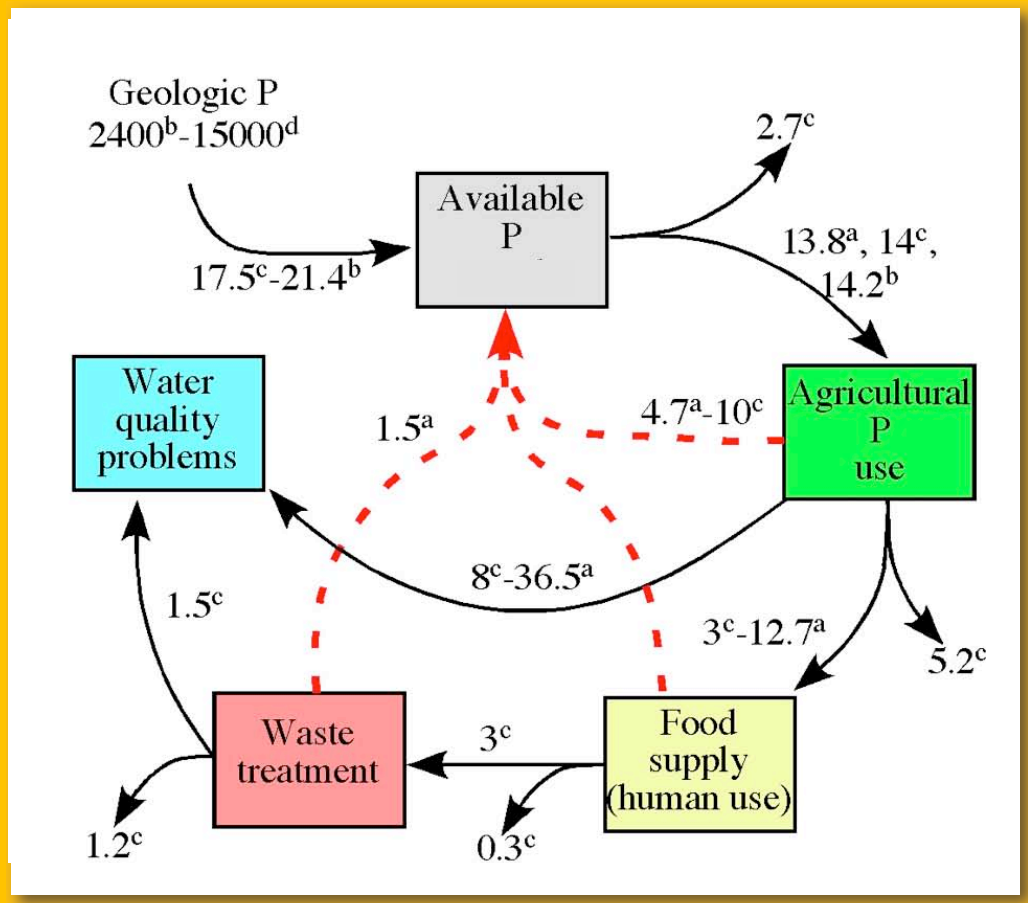
Childers, D.L., J. Corman, M. Edwards, and J.J. Elser. Sustainability challenges of phosphorus and food: Solutions from closing the human phosphorus cycle. Bioscience **61**: 117-124.

Where is the P going?



1. This is NOT a cycle.
2. Great uncertainties (2-5 fold) among studies in magnitude of estimated fluxes.

Childers, D.L., J. Corman, M. Edwards, and J.J. Elser. Sustainability challenges of phosphorus and food: Solutions from closing the human phosphorus cycle. Bioscience **61**: 117-124.

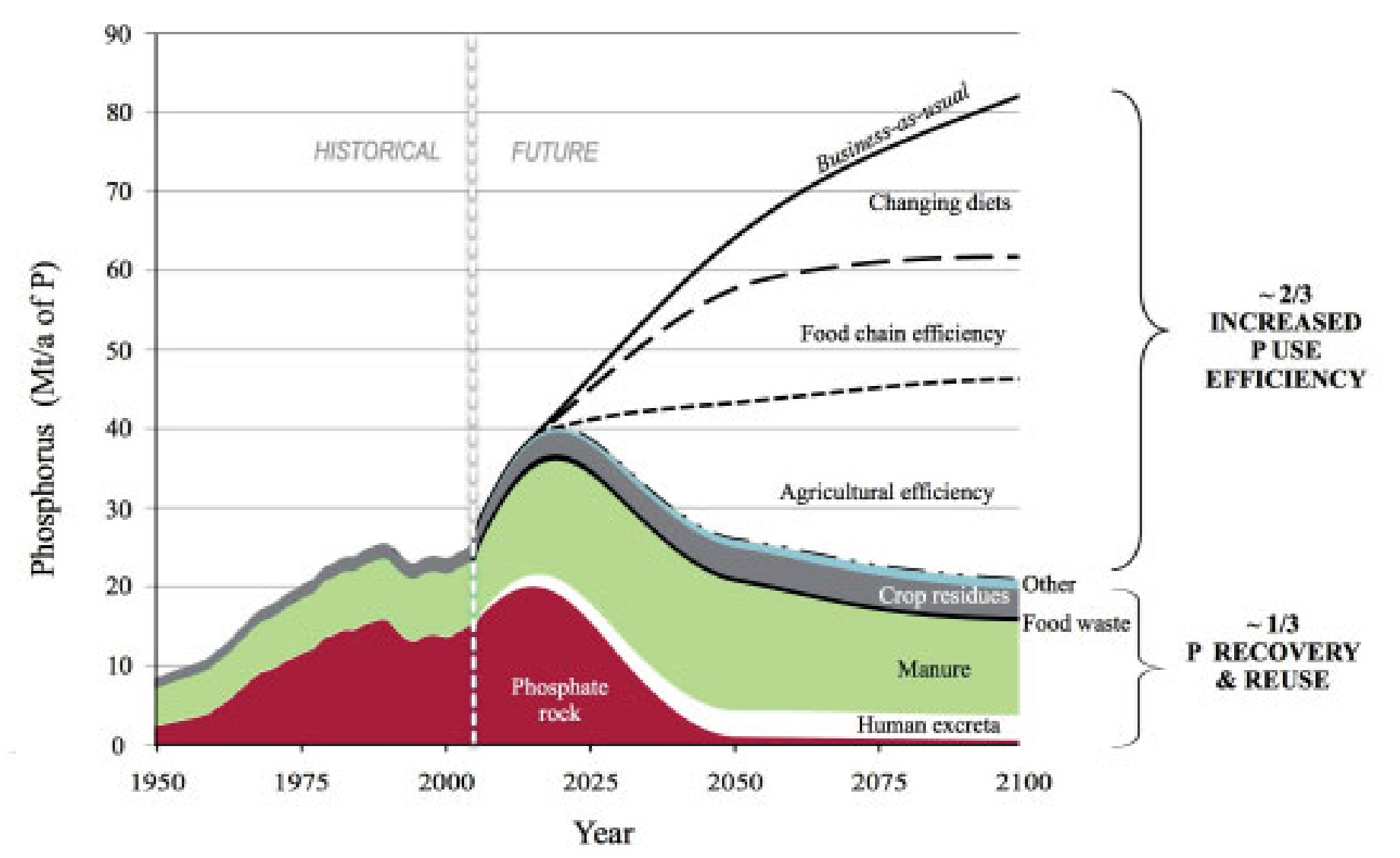
Which leads me to say:

"This is no way to run a biogeochemical cycle."

- J. Elser

in *Environmental Health Perspectives* (May 2011)

A better way to run the P cycle?



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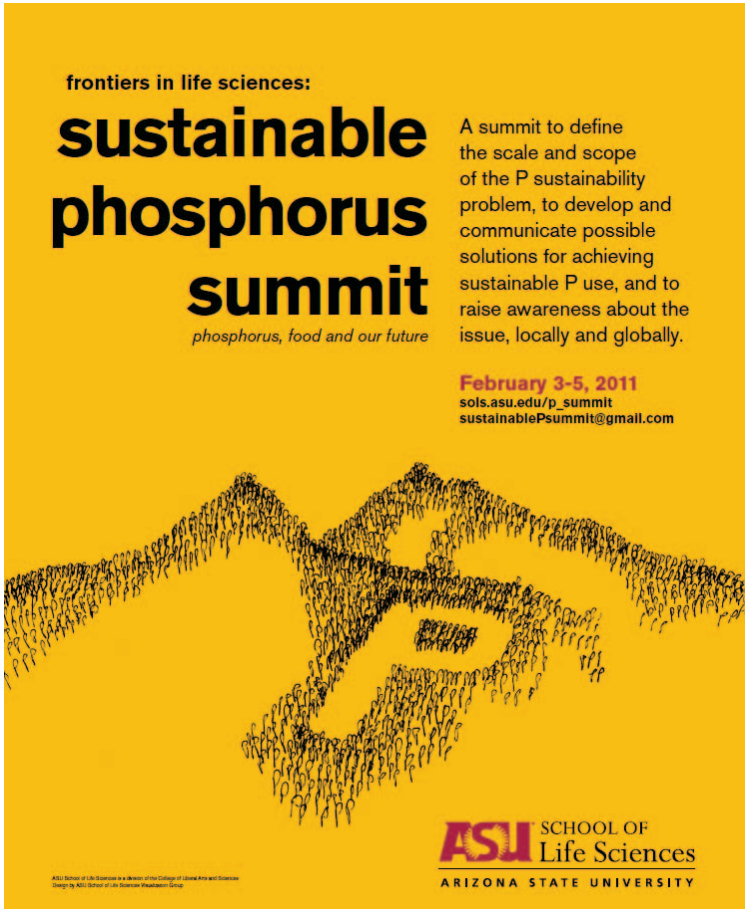
To get there, we might need:

- An **independent means to assess and verify global P** reserves and resources.
- Analysis of **geopolitical scenarios** for key regions, such as north Africa and China.
- Analysis of **institutional gaps** in the phosphate / food system from rock to farm to fork to feces.
- Economic analyses of **phosphate system as a whole** and coupled to other key commodities, especially **energy**.
- Research to **improve P use efficiency** in agriculture.
- Research to **jump-start technologies and strategies** to diversify agricultural P supplies, both nationally and globally.

Consensus Statement: Sustainable Phosphorus Summit



From 3-5 February 2011, more than 100 scientists, engineers, entrepreneurs, farmers, policy-makers, educators, artists, and others took part in The Sustainable Phosphorus Summit on the campus of Arizona State University in Tempe. The event was part of an emerging global dialogue around the diverse dimensions of human phosphorus use.

The Phoenix Phosphorus Declaration

We have achieved broad agreement on important issues surrounding phosphorus sustainability challenges and opportunities and seek to raise global awareness about them among all those with a stake in the future of food, water, and the biosphere. All of humanity, and indeed all living species, has this stake.

- **Essential and limited.** *Phosphorus is essential for all life because it is part of critical molecules like DNA. It is a limited natural resource needed to sustain the vitality and productivity of all ecosystems,* including farms.
- **Imbalanced cycle.** *Mining of phosphorus for fertilizer production has massively altered the cycling of phosphorus on Earth.* This increased phosphorus use has greatly expanded global capacity for food production but also has led to amplified phosphorus losses from cities, towns, and farms that can lead to degraded water quality, impair freshwater and marine fisheries, and alter natural biodiversity.
- **Food security.** *Phosphorus has a key role in global food security,*
to affordable fertilizer can allow farmers to improve yields and increase quality of life, especially in the developing world.
- **Recycle and reuse.** Currently, much phosphorus is lost in crop waste, food spoilage, and animal & human waste. *Recycling this phosphorus can reduce geopolitical and other uncertainties surrounding phosphorus fertilizer markets* enhance farmer prosperity.
- **Reduce demand.** *Phosphorus natural resources can be extended* by improving efficiency of use in agriculture, reducing erosion, limiting losses in mining & industry, and eating lower in the food chain.
- **Interconnected.** *Phosphorus stewardship is coupled to other major global sustainability challenges,* including those involving energy, water, and other chemical elements.
- **Entrepreneurship.** There are great *economic opportunities to innovate and create new industries* for phosphorus supply diversification and for improved agricultural phosphorus efficiency. However, the suitability of such measures will differ for different environments, cultures, and contexts.

By closing the human phosphorus cycle and transforming wastes into resources and uncertainty into security, humanity can implement a “new alchemy” in which people become more secure and enjoy greater well-being in a healthy environment.

Participants in the 2011 Sustainable Phosphorus Summit Tempe, Arizona, USA

~ End of Declaration ~

“By closing the human phosphorus cycle and transforming wastes into resources and uncertainty into security, humanity can implement a ‘new alchemy’ in which people become more secure and enjoy greater well-being in a healthy environment.”

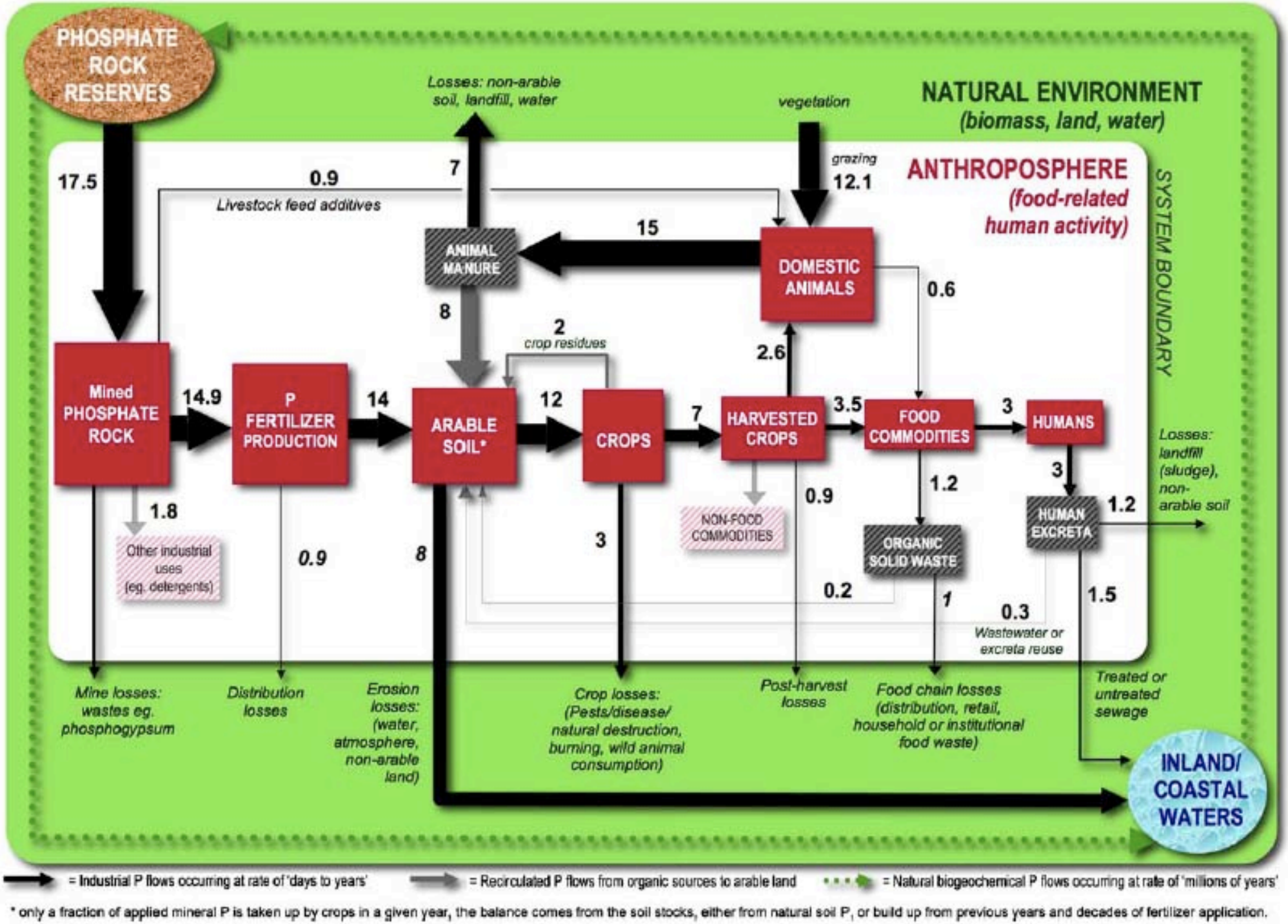
-Consensus Statement, Sustainable P Summit (Feb 2011)

What to do?

Phosphorus as a critical material.

Discussion panel

Stephen Jasinski, U.S. Geological Survey
Donna Perla, U.S. Department of Agriculture
David Vaccari, Stevens Institute of Technology



Cordell D, Drangert J-O, White S. 2009. The story of phosphorus: Global food security and food for thought. *Global Environmental Change* **19**: 292–305.