15
P
30.973761

hosphorus , Food, & Our Future

Jim Elser @DrLimnology

Director & Bierman Professor of Ecology

FLATHEAD LAKE BIO STATION
UNIVERSITY OF MONTANA

Research Professor

ASU Julie Ann Wrigley Global Futures Laboratory
Arizona State University

PHOSPHORUS

Past and Future

JIM ELSER AND PHIL HAYGARTH

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How much P do you have in your body?

A. 0.01 lb (4.5 g)

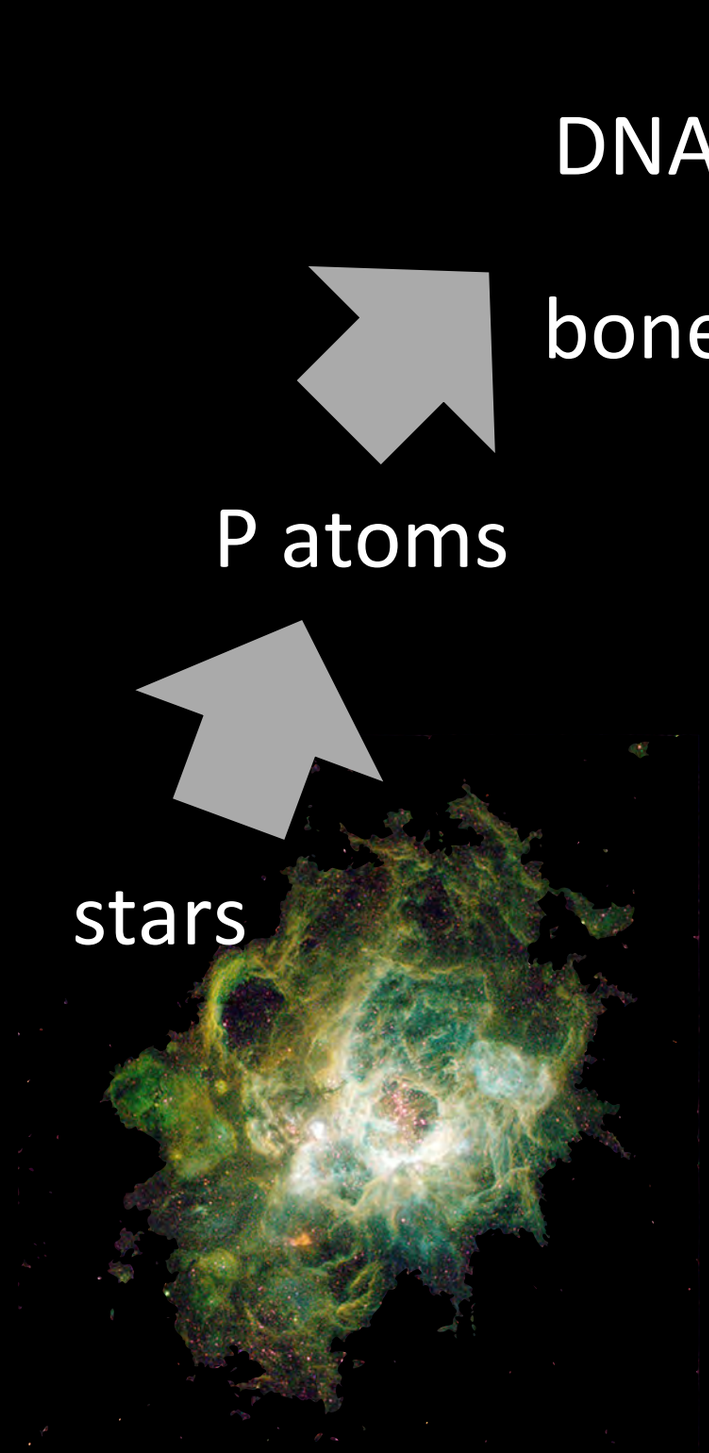
B. 0.1 lb (45 g)

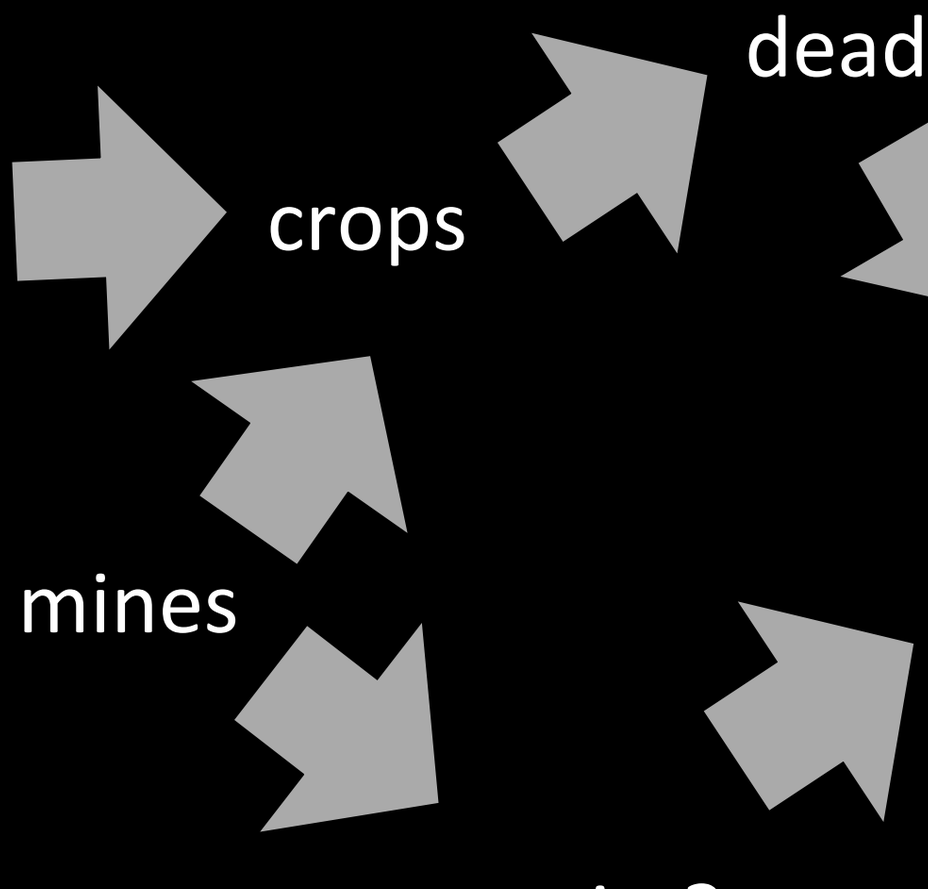
C. 1 lb (450 g) ← ~1.4 lbs actually

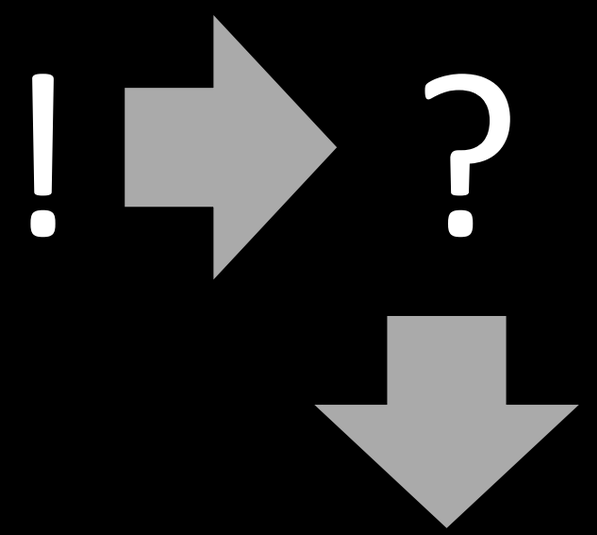
D. 10 lbs (4.5 kg)

E. 100 lbs (45 kg)

The storyline:







solutions!

source: Wikimedia

15

P

Phosphorus

30.973761

P is elemental.

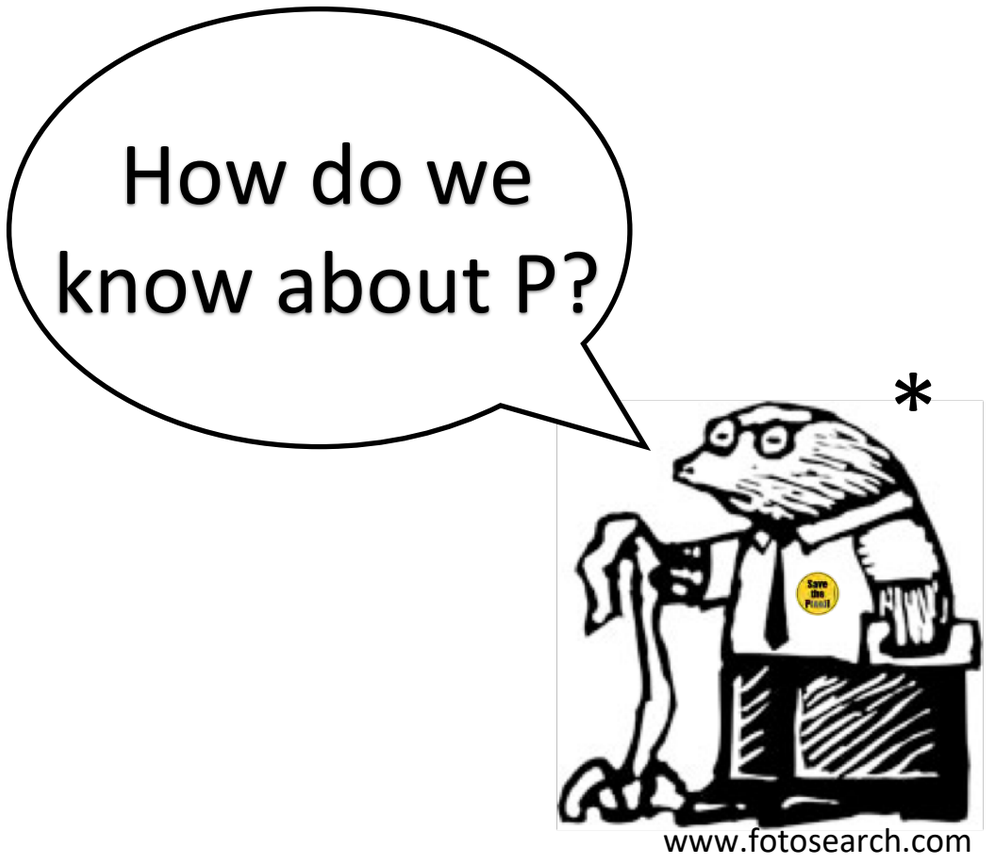
Phosphorus in the 15th element in the Periodic Table.

Periodic Table of the Elements

Most of these were made billions of years ago in stars and in supernova explosions!

1 **H** Hydrogen 1.00794																	2 **He** Helium 4.003
3 **Li** Lithium 6.941	4 **Be** Beryllium 9.012182											5 **B** Boron 10.811	6 **C** Carbon 12.0107	7 **N** Nitrogen 14.00674	8 **O** Oxygen 15.9994	9 **F** Fluorine 18.9984032	10 **Ne** Neon 20.1797
11 **Na** Sodium 22.989770	12 **Mg** Magnesium 24.3050											13 **Al** Aluminum 26.981538	14 **Si** Silicon 28.0855	15 **P** Phosphorus 30.973761	16 **S** Sulfur 32.066	17 **Cl** Chlorine 35.4527	18 **Ar** Argon 39.948
19 **K** Potassium 39.0983	20 **Ca** Calcium 40.078	21 **Sc** Scandium 44.955910	22 **Ti** Titanium 47.867	23 **V** Vanadium 50.9415	24 **Cr** Chromium 51.9961	25 **Mn** Manganese 54.938049	26 **Fe** Iron 55.845	27 **Co** Cobalt 58.933200	28 **Ni** Nickel 58.6934	29 **Cu** Copper 63.546	30 **Zn** Zinc 65.39	31 **Ga** Gallium 69.723	32 **Ge** Germanium 72.61	33 **As** Arsenic 74.92160	34 **Se** Selenium 78.96	35 **Br** Bromine 79.904	36 **Kr** Krypton 83.80
37 **Rb** Rubidium 85.4678	38 **Sr** Strontium 87.62	39 **Y** Yttrium 88.90585	40 **Zr** Zirconium 91.224	41 **Nb** Niobium 92.90638	42 **Mo** Molybdenum 95.94	43 **Tc** Technetium (98)	44 **Ru** Ruthenium 101.07	45 **Rh** Rhodium 102.90550	46 **Pd** Palladium 106.42	47 **Ag** Silver 107.8682	48 **Cd** Cadmium 112.411	49 **In** Indium 114.818	50 **Sn** Tin 118.710	51 **Sb** Antimony 121.760	52 **Te** Tellurium 127.60	53 **I** Iodine 126.90447	54 **Xe** Xenon 131.29
55 **Cs** Cesium 132.90545	56 **Ba** Barium 137.327	57 **La** Lanthanum 138.9055	72 **Hf** Hafnium 178.49	73 **Ta** Tantalum 180.9479	74 **W** Tungsten 183.84	75 **Re** Rhenium 186.207	76 **Os** Osmium 190.23	77 **Ir** Iridium 192.217	78 **Pt** Platinum 195.078	79 **Au** Gold 196.96655	80 **Hg** Mercury 200.59	81 **Tl** Thallium 204.3833	82 **Pb** Lead 207.2	83 **Bi** Bismuth 208.98038	84 **Po** Polonium (209)	85 **At** Astatine (210)	86 **Rn** Radon (222)
87 **Fr** Francium (223)	88 **Ra** Radium (226)	89 **Ac** Actinium (227)	104 **Rf** Rutherfordium (261)	105 **Db** Dubnium (262)	106 **Sg** Seaborgium (263)	107 **Bh** Bohrium (262)	108 **Hs** Hassium (265)	109 **Mt** Meitnerium (266)	110 (269)	111 (272)	112 (277)	113	114				

58 **Ce** Cerium 140.116	59 **Pr** Praseodymium 140.90765	60 **Nd** Neodymium 144.24	61 **Pm** Promethium (145)	62 **Sm** Samarium 150.36	63 **Eu** Europium 151.964	64 **Gd** Gadolinium 157.25	65 **Tb** Terbium 158.92534	66 **Dy** Dysprosium 162.50	67 **Ho** Holmium 164.93032	68 **Er** Erbium 167.26	69 **Tm** Thulium 168.93421	70 **Yb** Ytterbium 173.04	71 **Lu** Lutetium 174.967
90 **Th** Thorium 232.0381	91 **Pa** Protactinium 231.03588	92 **U** Uranium 238.0289	93 **Np** Neptunium (237)	94 **Pu** Plutonium (244)	95 **Am** Americium (243)	96 **Cm** Curium (247)	97 **Bk** Berkelium (247)	98 **Cf** Californium (251)	99 **Es** Einsteinium (252)	100 **Fm** Fermium (257)	101 **Md** Mendelevium (258)	102 **No** Nobelium (259)	103 **Lr** Lawrencium (262)



* in chemistry,

a “mole” = 6.023×10^{23} atoms of an element

Henning Brand (1630 -1710)

German alchemist & the discoverer of phosphorus while searching for the “philosopher’s stone”.

But from where did he get this P?

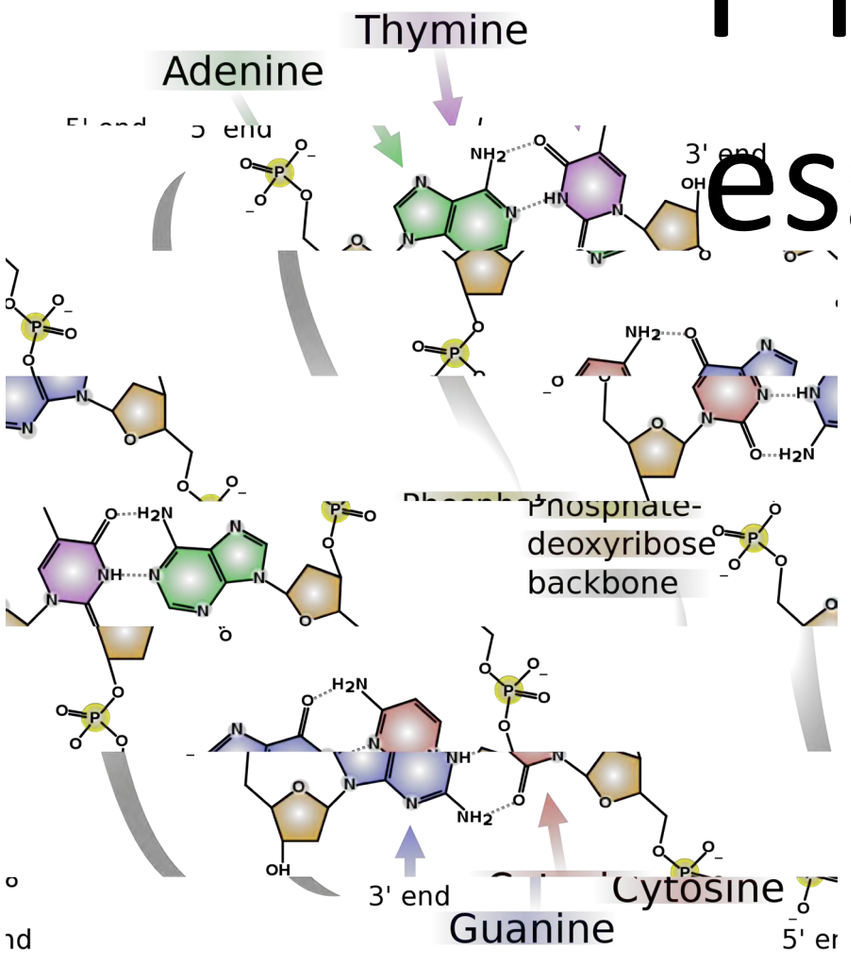
Ripley's Believe It or Not!®

HENNING BRAND,
A GERMAN DOCTOR AND ALCHEMIST,
DISCOVERED THE ELEMENT
PHOSPHORUS
IN 1669
WHILE ATTEMPTING TO DISTILL
URINE INTO GOLD!

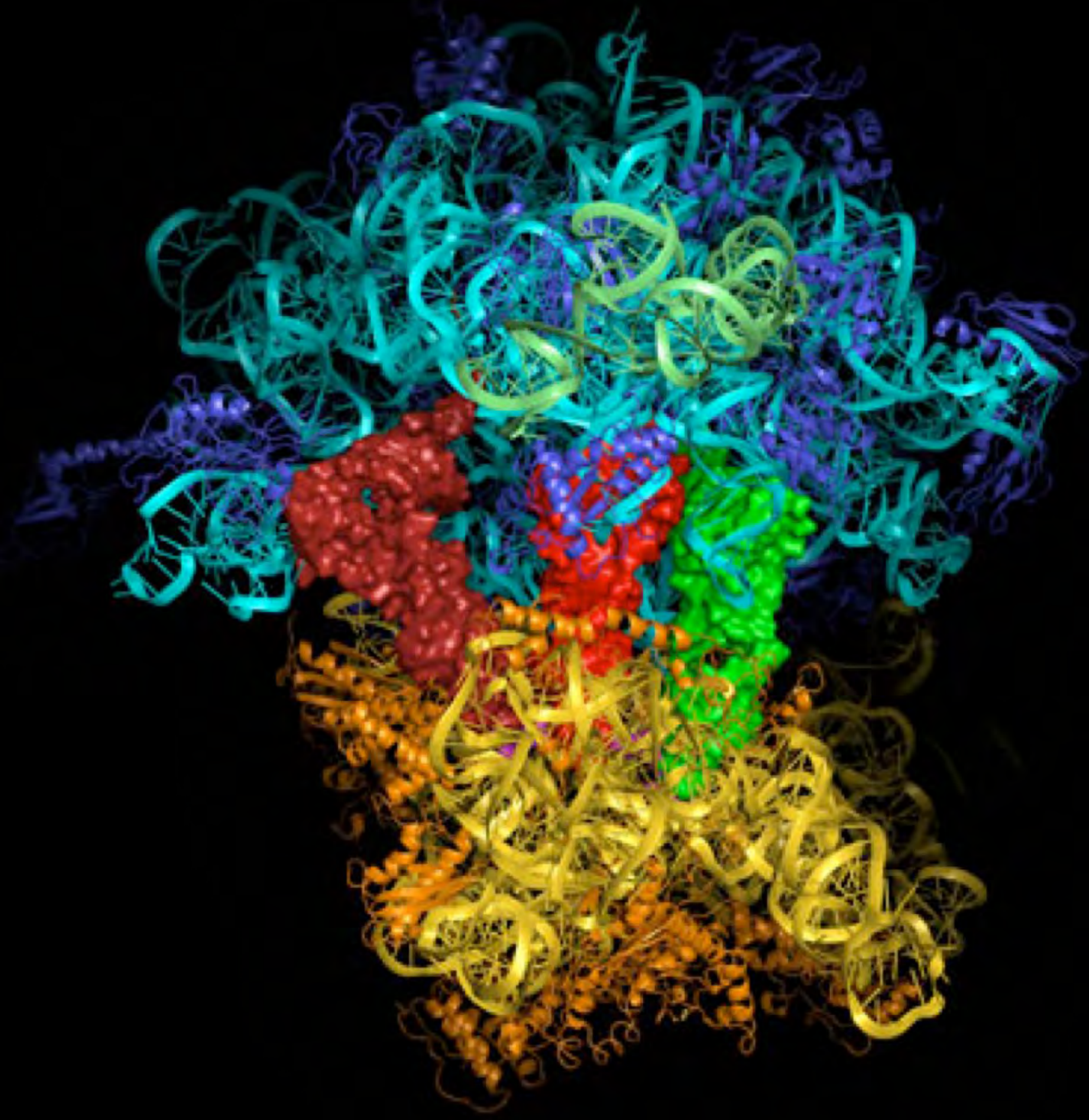
www.comics.com

Is P important?

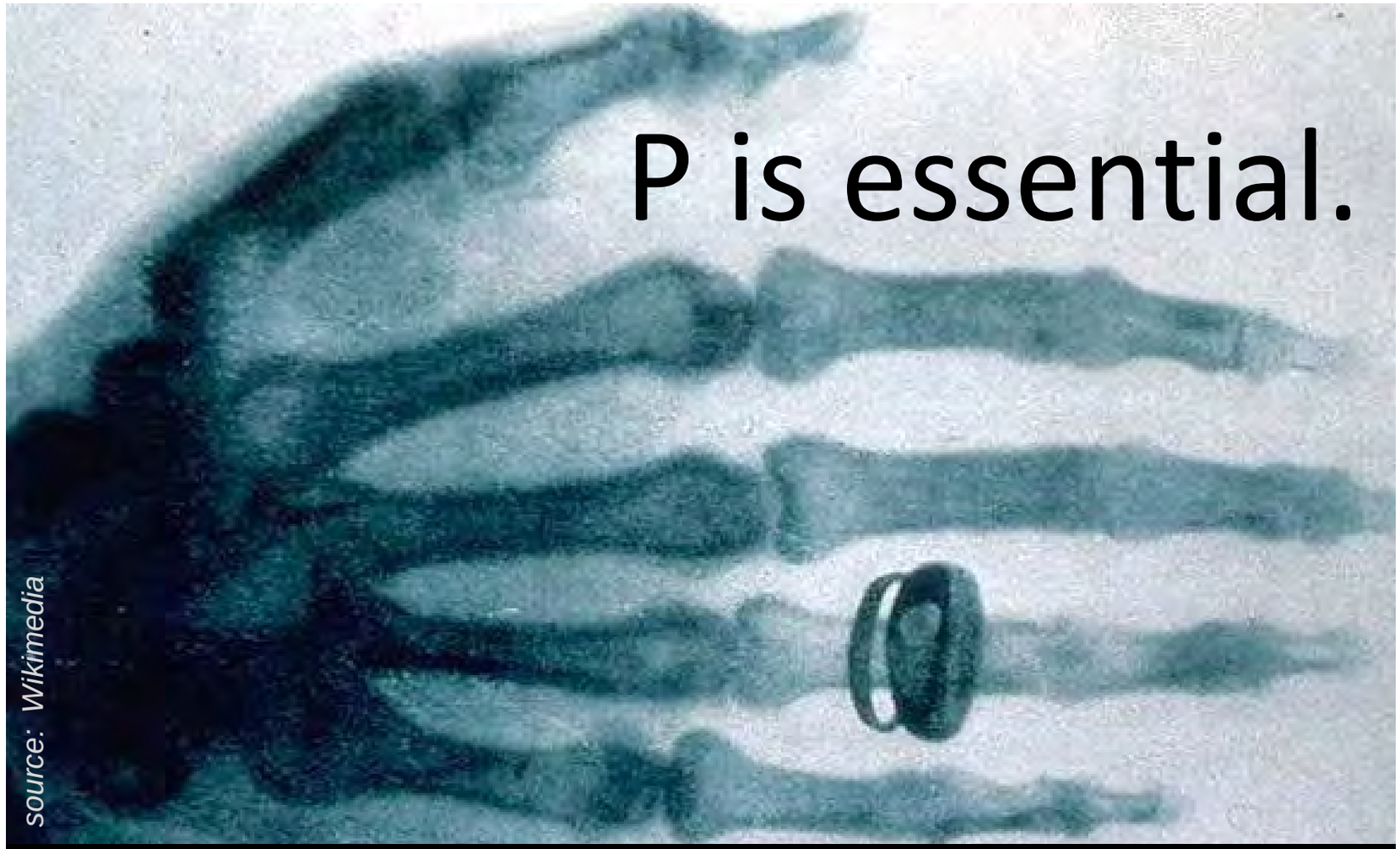
P is essential.



Every living thing needs P.



ribosomes (RNA + protein):
P-rich growth machines!



An adult human body contains about 1.4 pounds of P.

In both natural and agricultural ecosystems.

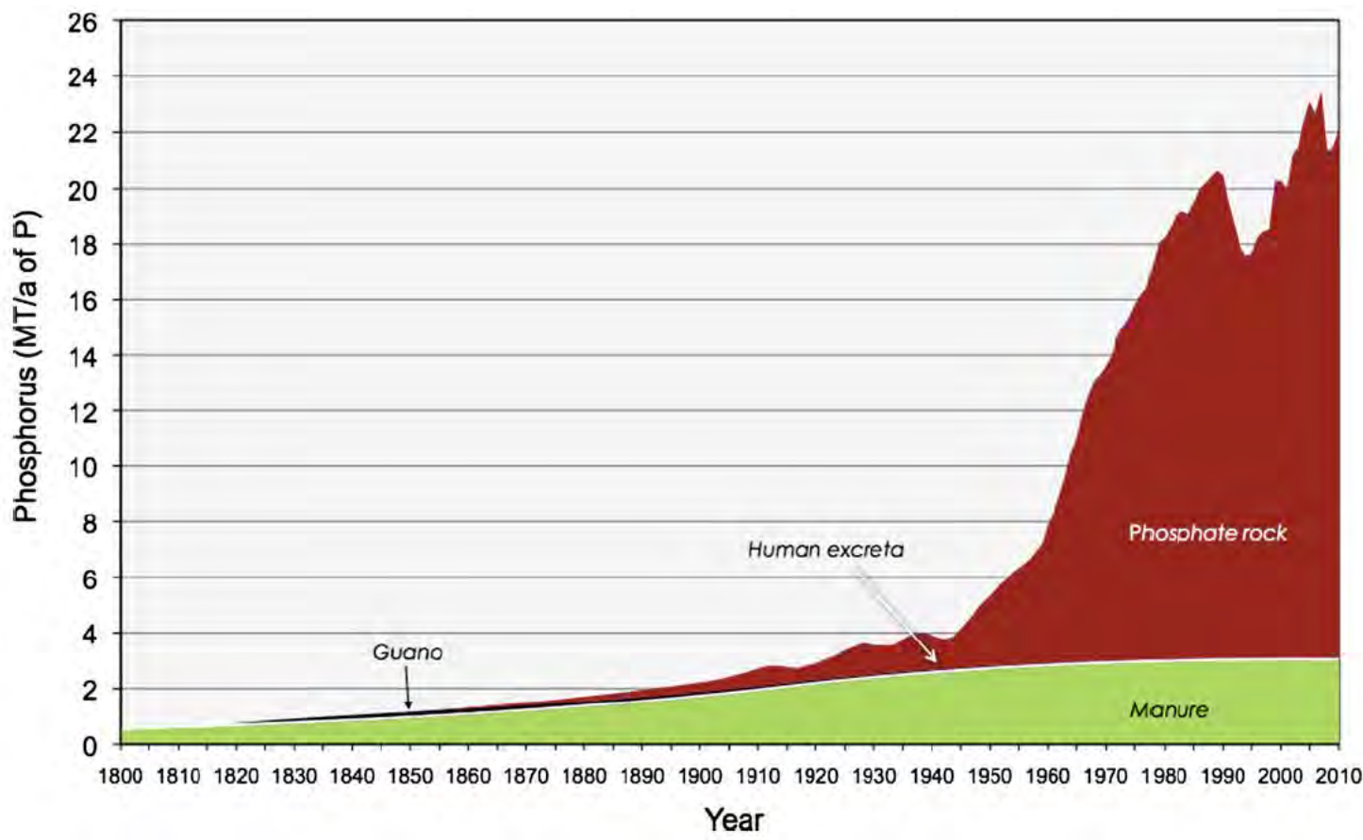
source: wikimedia commons

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.

Sources: 1 - The World at Six Billion; Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, World Population Prospects: The 2004 Revision and World Urbanization Prospects: The 2003 Revision, <http://esa.un.org/unpp> 2 - United Nations, 197[illegible] Consequences of Population Trends, Vol.1" (United Nations, New York). United Nations, (forthcoming). "World Population Prospects: The 1998 Revision" (United Nations, New York). <[illegible]/www.geohive.com/global/>

"Green Revolution" =

high yield crops + water + fertilizer



P is a pollutant.

This side of the lake received carbon and nitrogen only.

This side of the lake received carbon, nitrogen AND phosphorus.

Source: ED DeBruyn DFO

Inputs of P from cities and from farm runoff lead to "eutrophication".

Dave Schindler

Excess P is a pollutant.

China Daily .com.cn 中国日报网

Algae bloom causes water crisis in E. China city

(Xinhua)
Updated: 2007-05-31 08:57

WUXI, Jiangsu -- A fast-spreading blue-green algae has polluted a lake that provides drinking water for millions of people in the eastern Chinese city of Wuxi, Jiangsu Province.

Customers queue to buy bottled water at a supermarket in Wuxi, East China's Jiangsu Province, May 30, 2007. Local residents in Wuxi rushed to buy bottled water when the tap water developed a strange smell. The blue-green algae outbreak in Taihu Lake affected the underground water in Wuxi and caused the water crisis, Xinhua said. [newsphoto]

Click for more news photos...

Wuxi, an economically dynamic city 128 km from Shanghai with a population of more than 5 million, saw panic buying of bottled water and bread on Wednesday, a day after Taihu Lake started to stink with a blue-green algae bloom.

2007 Lake Taihu
City of Wuxi (5 million)
No drinking water for one week.

Excess P is a pollutant.

SCIENCE | MATTER

Cyanobacteria Are Far From Just Toledo's Problem

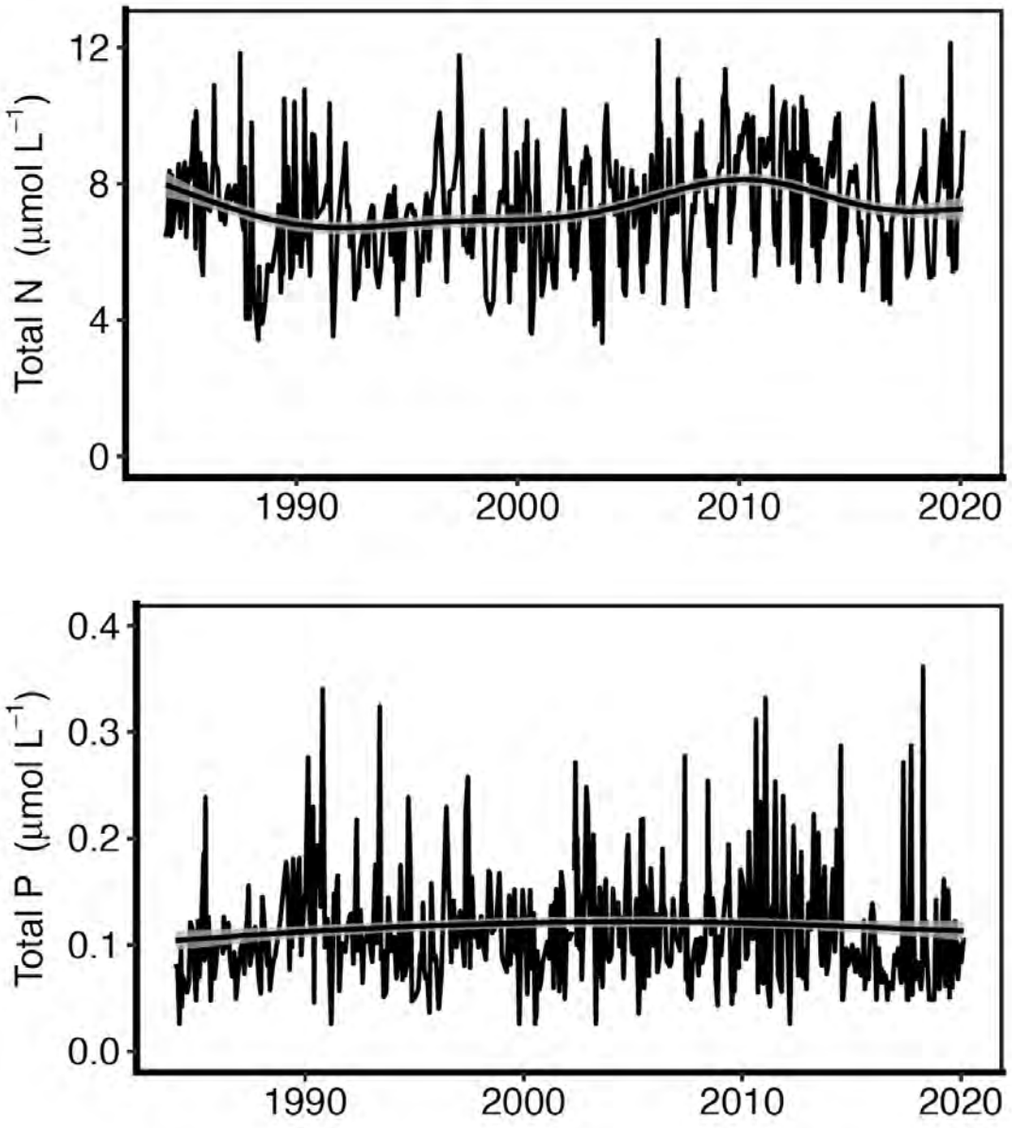
By CARL ZIMMER AUG. 7, 2014

The algae-clogged waters of Lake Erie as seen from Maumee Bay State Park near Toledo, Ohio. Joshua Lott for The New York Times

2014
City of Toledo
No drinking water for three days.

What about Flathead Lake?

In-lake concentrations of nitrogen and phosphorus



N

P

- Flathead Lake nitrogen (N), phosphorus (P) concentrations are variable but showing little systematic change. Good news!

- Why are N and P in Flathead Lake constant?

PNAS INAUGURAL ARTICLE | ECOLOGY OPEN ACCESS

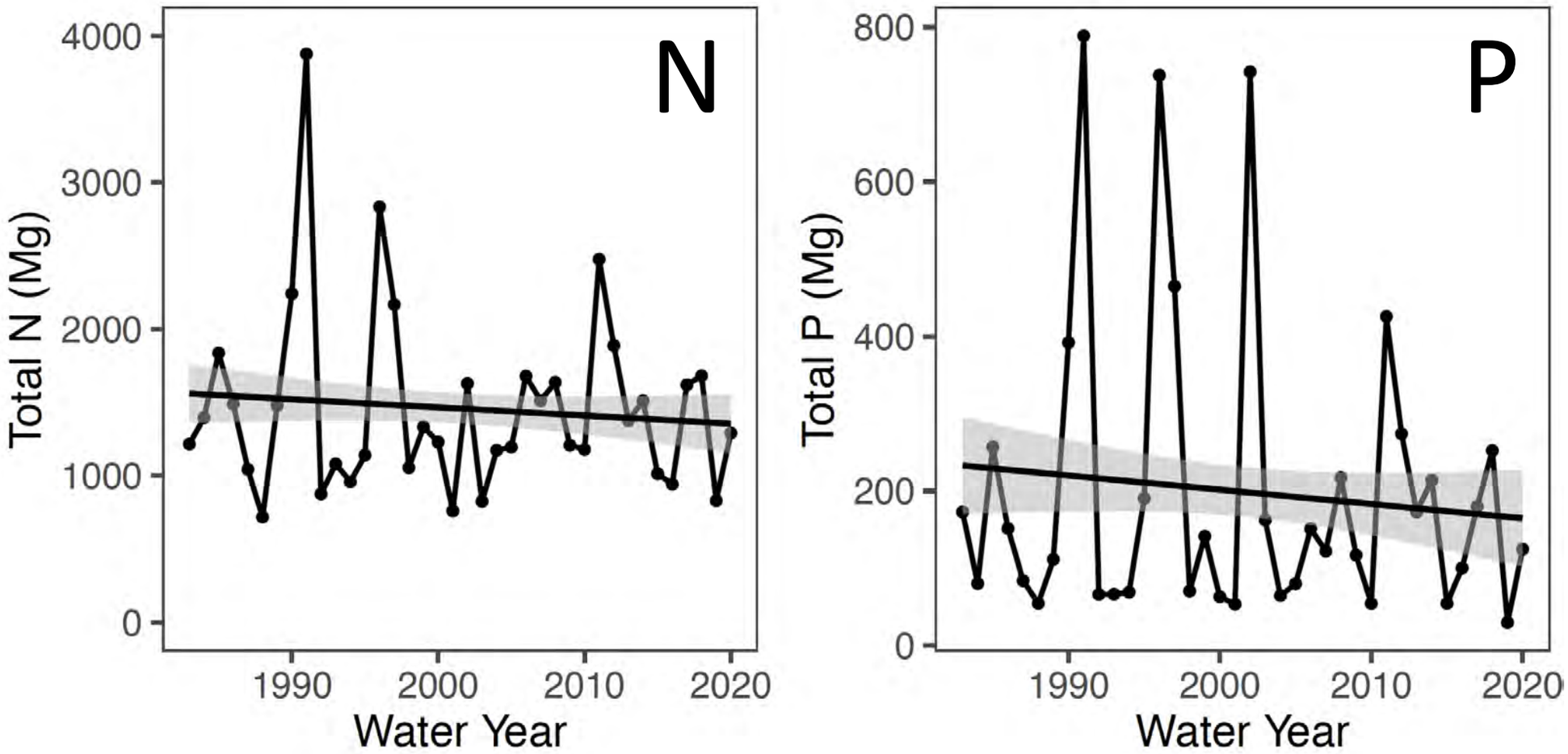
Sustained stoichiometric imbalance and its ecological consequences in a large oligotrophic lake

James J. Elser[a,1], Shawn P. Devlin[a], Jinlei Yu[b], Adam Baumann[a], Matthew J. Church[a], John E. Dore[c], Robert O. Hall Jr.[a], Melody Hollar[d], Tyler Johnson[e], Trista Vick-Majors[a,f], and Cassidy White[g]

This contribution is part of the special series of Inaugural Articles by members of the National Academy of Sciences elected in 2019.
Contributed by James J. Elser; received February 13, 2022; accepted June 2, 2022; reviewed by Roxane Maranger and Jacques Finlay

What about Flathead Lake?

River inputs of nitrogen and phosphorus



- River inputs of N & P are variable (due to discharge) but showing little systematic change. Declining? Good news!

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Implications and Actions

- These data are exciting and encouraging.
- We did the right things for Flathead Lake!
  - Watershed protection (Glacier NP, wilderness areas)
  - Phosphate detergent ban
  - Investment in advanced wastewater treatment

- What do we still need to do?
  - Remain diligent and alert
  - Continue to invest in advanced wastewater treatment
  - Maintain and modernize septic systems
  - Consider modular wastewater treatment
  - Protect wetlands & other critical habitat
  - Get a handle on agricultural N, P use
  - Tackle air pollution (N deposition, P in dust)
  - Tackle climate change (forest fires)

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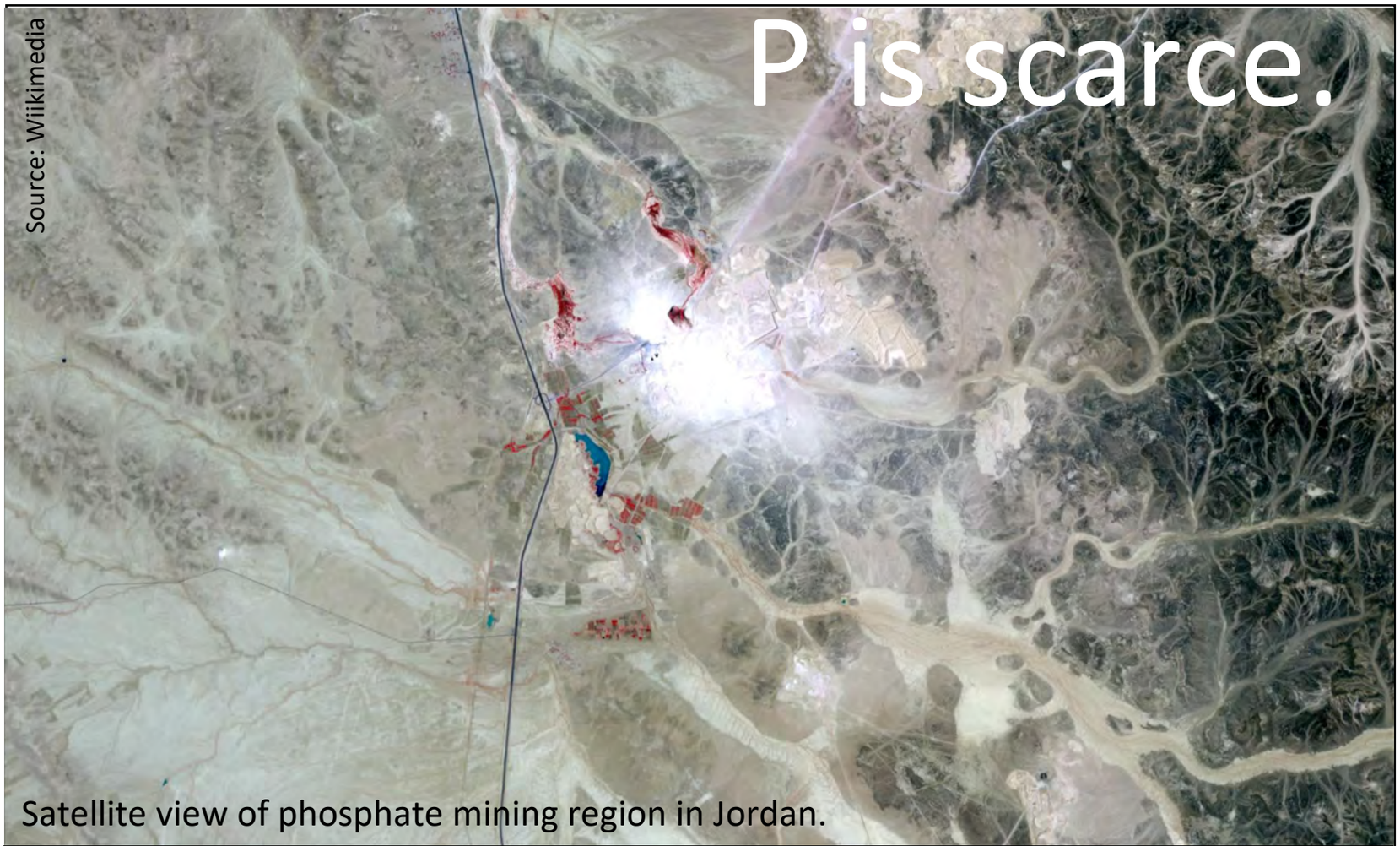
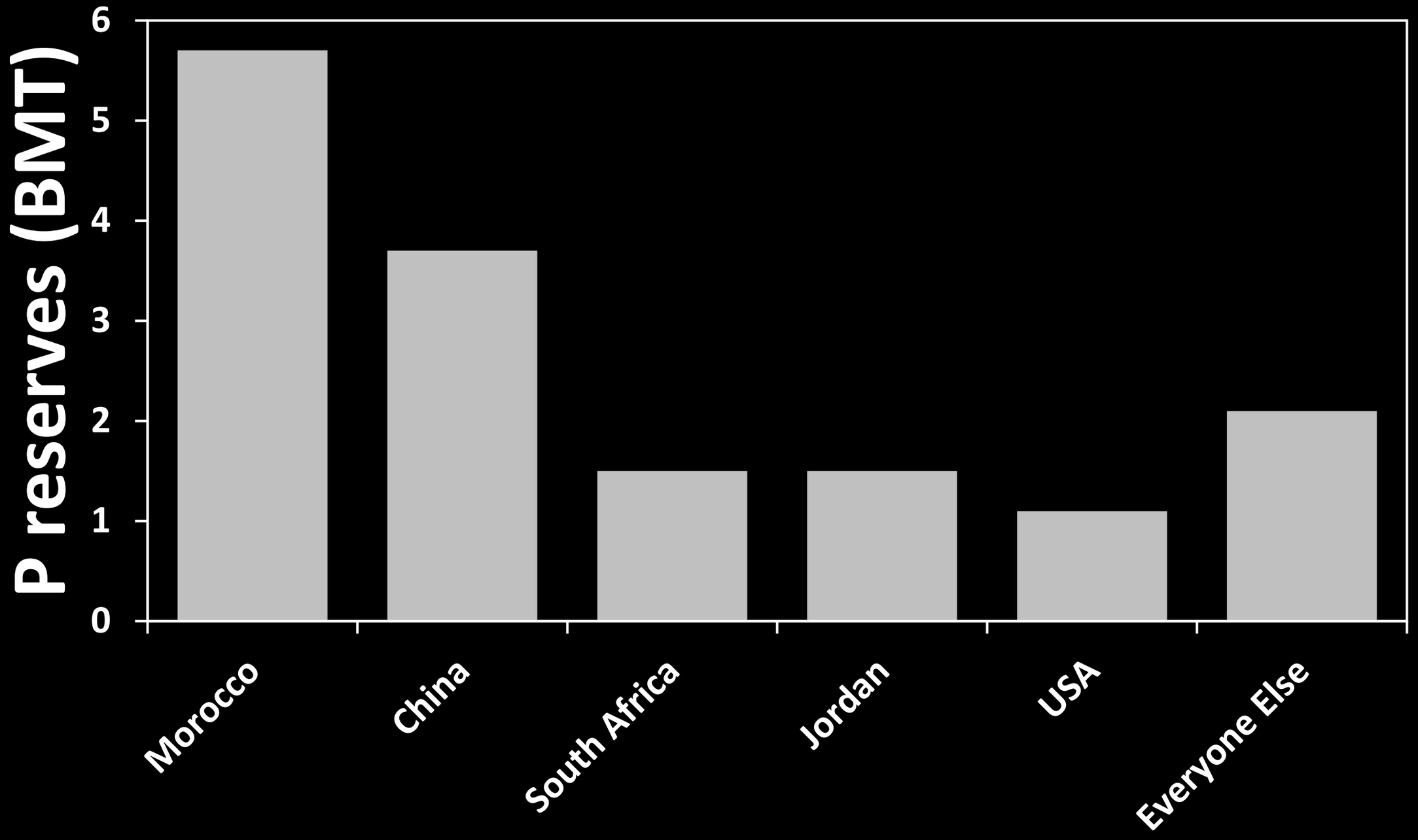
OK, but where does all this P come from?



Satellite view of phosphate mining region in Jordan.

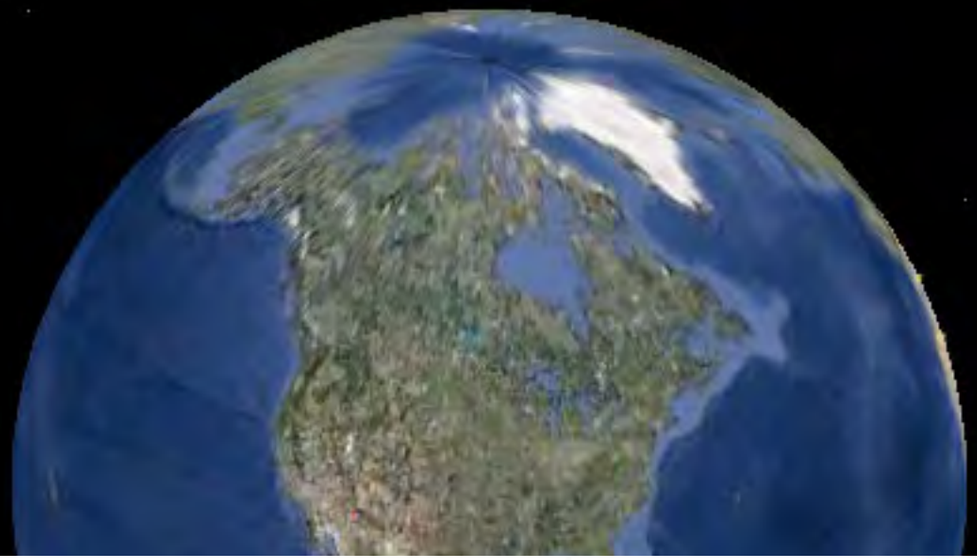
Geological sources of P are not widely distributed.

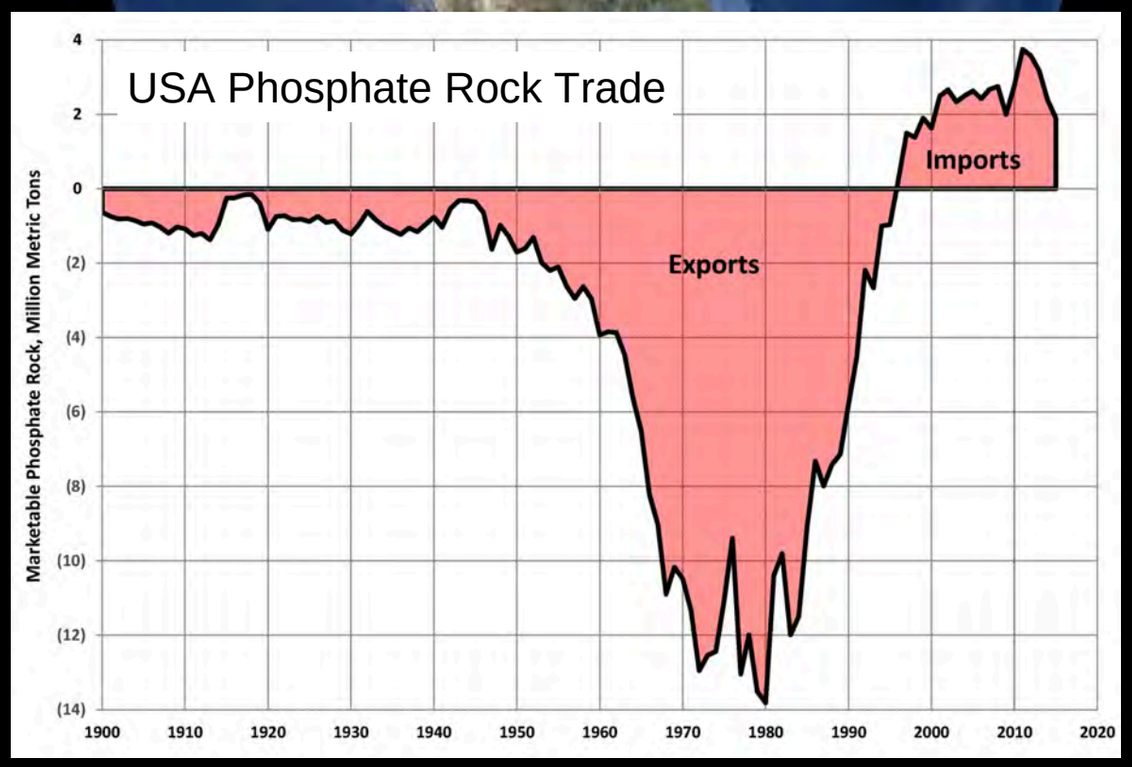
How much P do we have?



Source: USGS (2009)

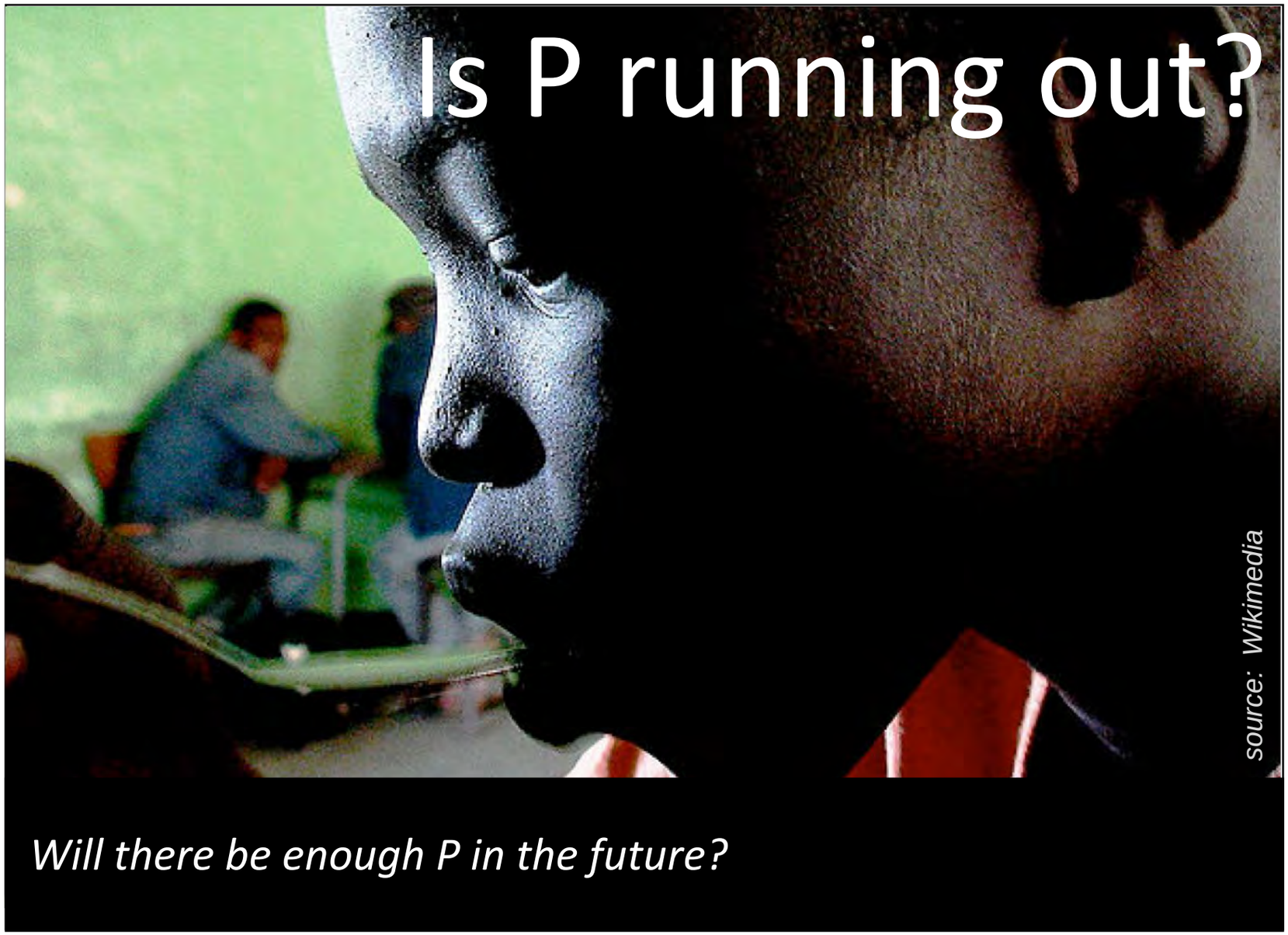
Meet N. America's Phosphorus...





Meet your future Phosphorus...

Yeah but there's more P where that came from, right?



Will there be enough P in the future?

Spiralling demands for P

growing population
(11 billion by 2050?)

growing global affluence
(meat consumption)

growing biofuel economy

2008

TIMESONLINE

From The Times
June 23, 2008

Scientists warn of lack of vital phosphorus as biofuels raise demand

Leo Lewis, Asia Business Correspondent

Battered by soaring fertiliser prices and rioting rice farmers, the global food industry may also have to deal with a potentially catastrophic future shortage of phosphorus, scientists say.

Researchers in Australia, Europe and the United States have given warning that the element, which is essential to all living things, is at the heart of modern farming and has no synthetic alternative, is being mined, used and wasted as never before.

Massive inefficiencies in the "farm-to-fork" processing of food and the soaring appetite for meat and dairy produce across Asia is stoking demand for phosphorus faster and further than anyone had predicted. "Peak phosphorus", say scientists, could hit the world in just 30 years. Crop-based biofuels, whose production methods and usage suck phosphorus out of the agricultural system in unprecedented volumes, have, researchers in Brazil say, made the problem many times worse. Already, India is running low on matches as factories run short of phosphorus; the Brazilian Government has spoken of a need to nationalise privately held mines that supply the fertiliser industry and Swedish scientists are busily redesigning toilets to separate and collect urine in an attempt to conserve the precious element.

TIMES RECOMMENDS
› Household spend falls at fastest rate since 1980
› BA - record loss of £401m in 'toughest year'
› Moody's stops Wall Street plunge

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Summary GO
› Company Lookup
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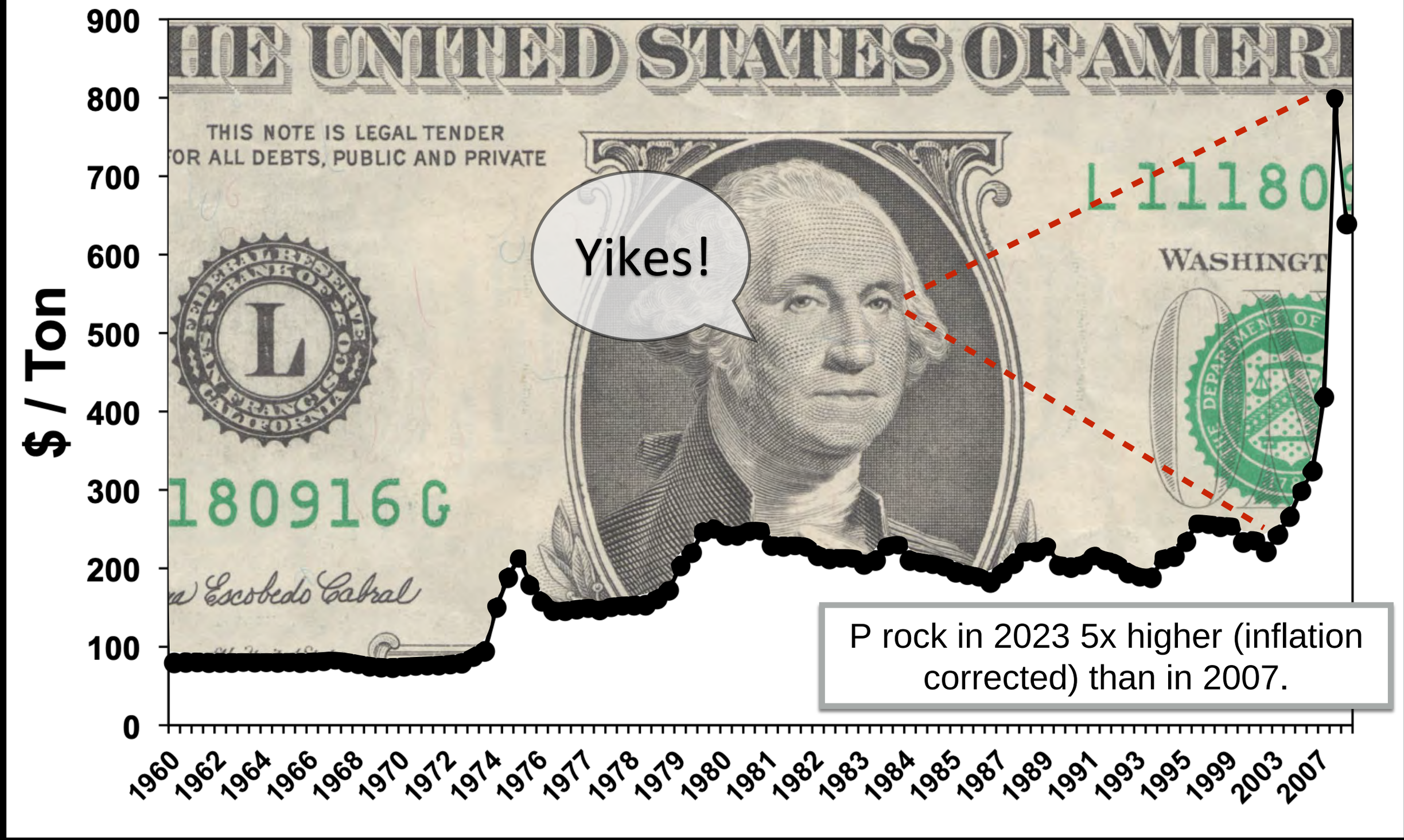
WORLD MARKETS
Market Data - 21:31 UK › Markets
FTSE 100 4,365.29

The Price of P

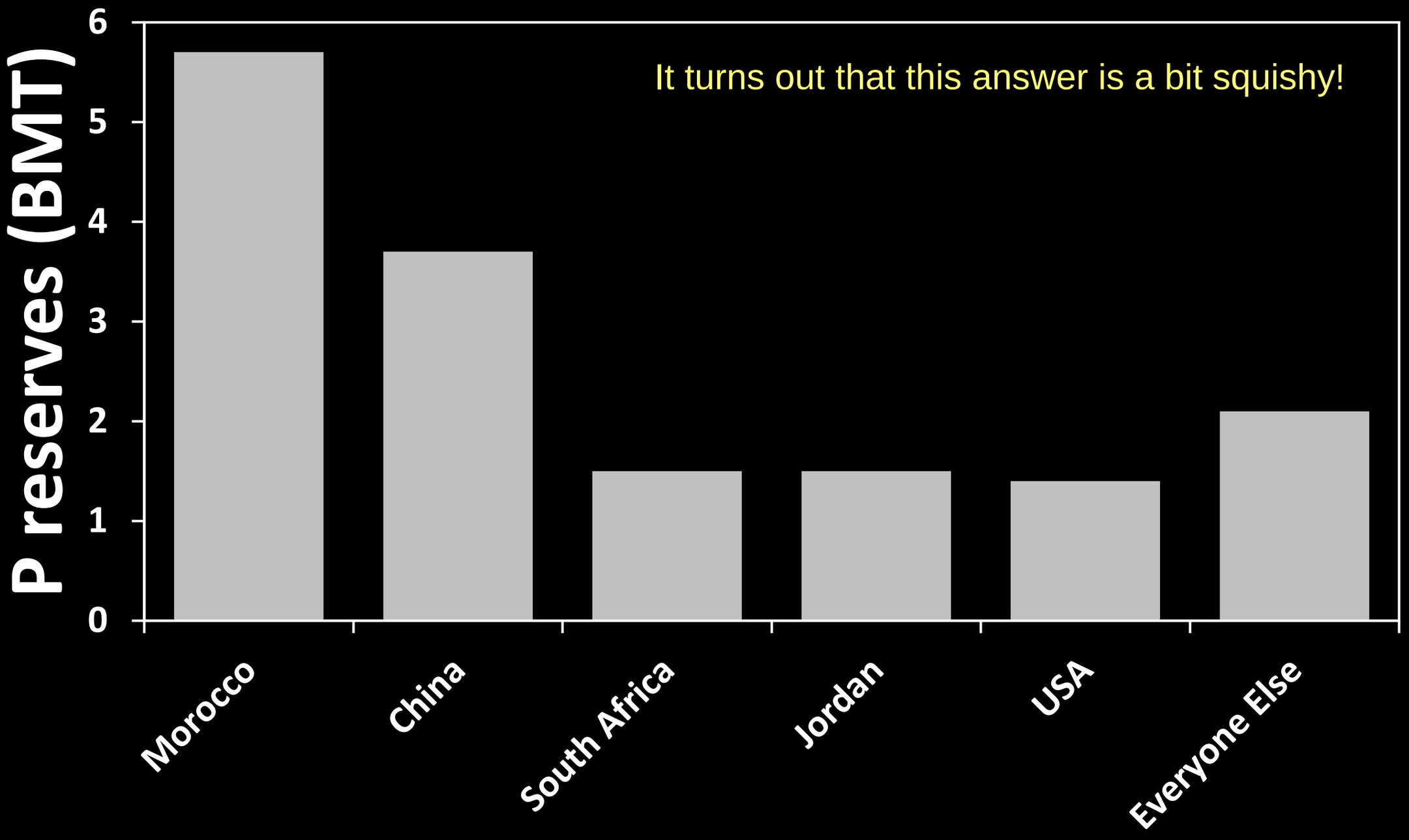


From: Elser and White. Foreign Policy magazine (online, 4/22/10)

“Quite simply, without phosphorus we cannot produce food.
At current rates, reserves will be depleted in the next 50 to 100 years.”

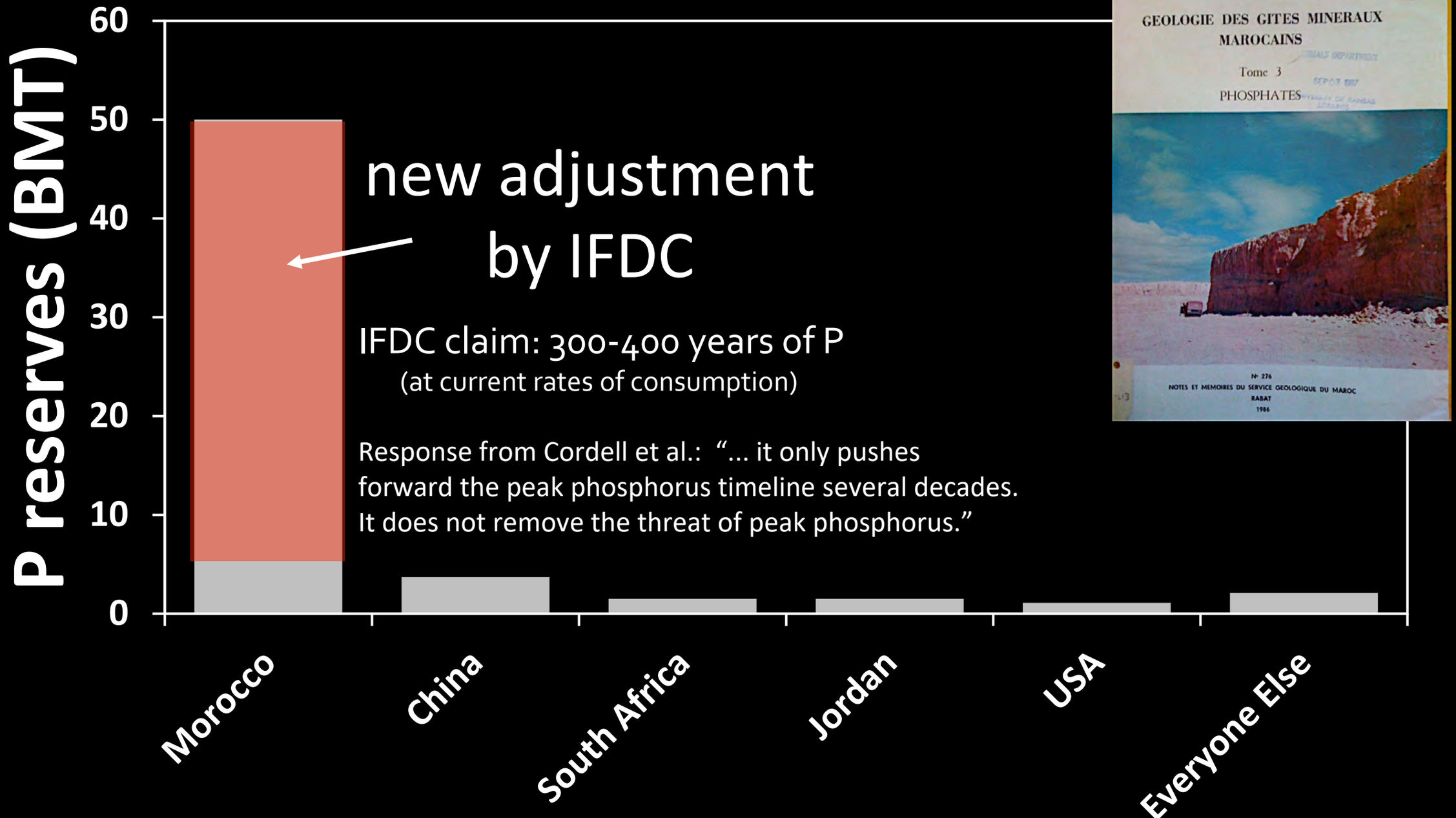
Dr. Dana Cordell (in 2008)
senior researcher
Institute for Sustainable Futures
University of Technology, Sydney

How much P do we have?



Source: USGS (2009)

How much P do we have?



Source: USGS (2012)

Morocco: The Dubai of Phosphorus

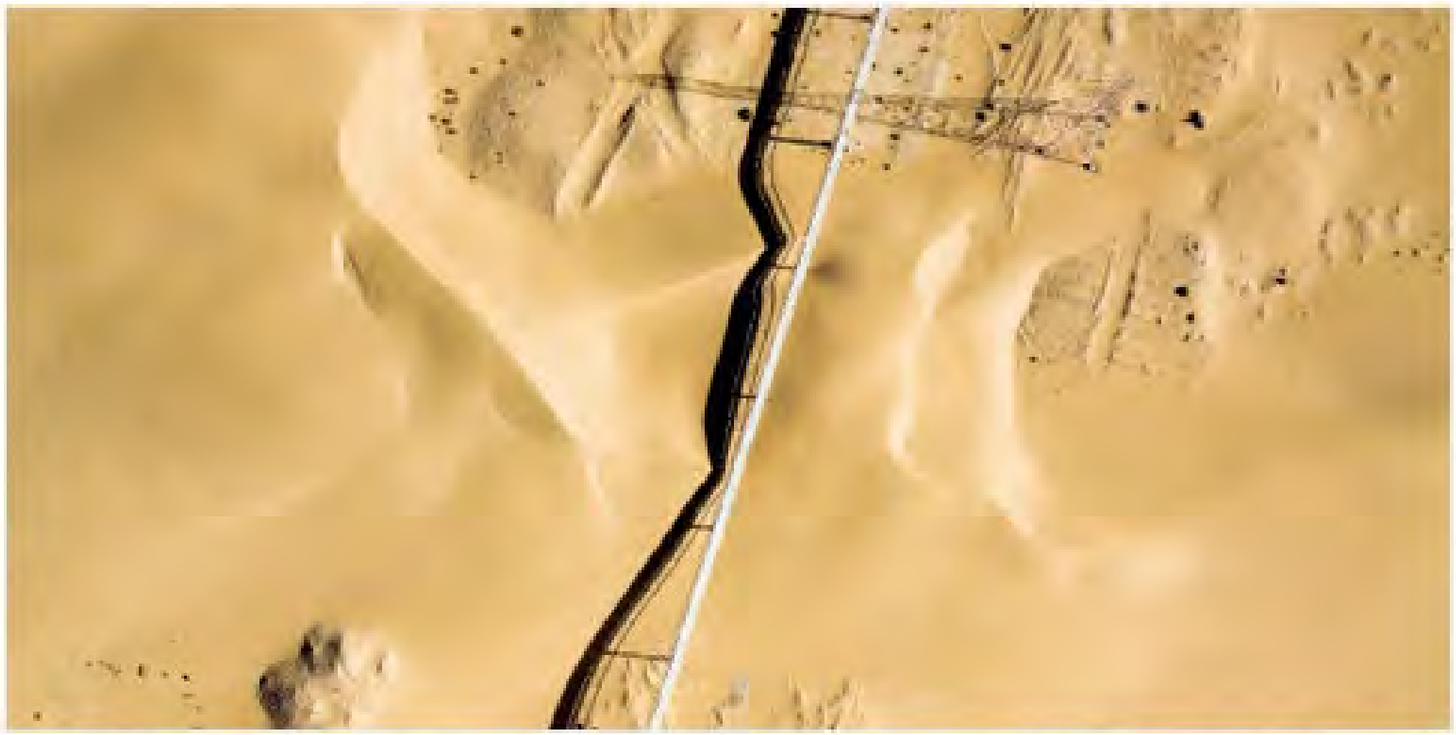
Nov 4 2010

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."

What about China?

China uses 36% of global fertilizer.

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

The main issues now?

Geological availability? (How much extractable P IS there, really? Costs? Quality?)

Geopolitical volatility? (Will China continue to close its P market? How will Morocco handle its new position in global P economy?)

Key question is three-fold:

How much P, for whom, & at WHAT PRICE?

A new alchemy.

Resistance

Productivity

Absurdity

Hunger

Finding P solutions.

What to do?

Five R’s

geology
agronomy
genetics
agroecology
biogeochemistry
civil engineering
economics
political science

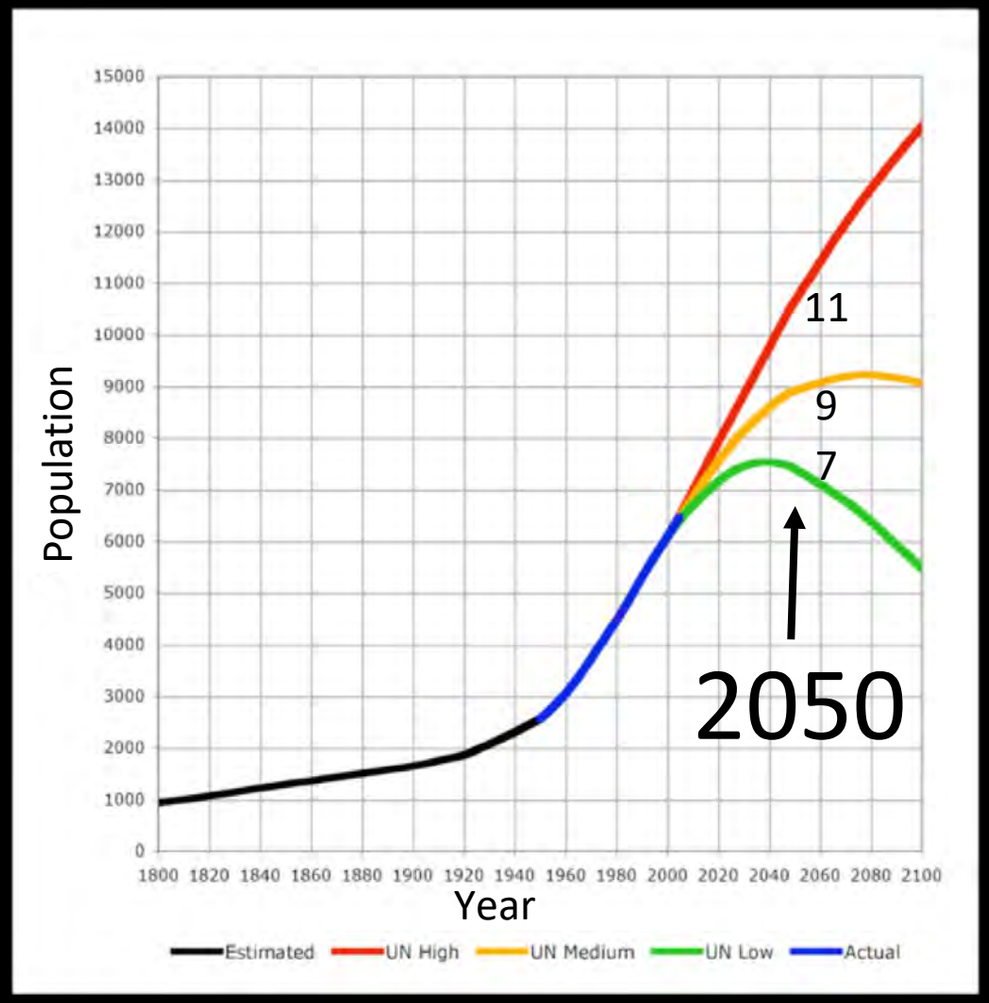
Five R’s

Reduce.

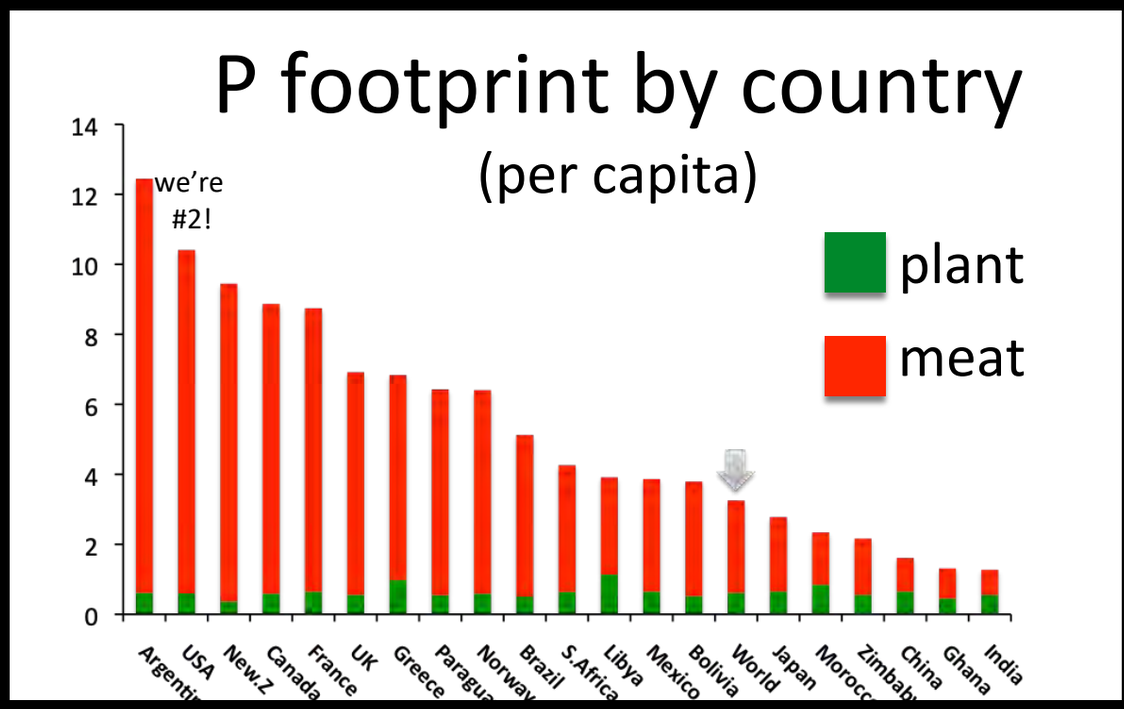
erosion

Five R’s

UN population forecast



Five R's



We estimate that 1/3 of increased human P demand during last 50 years is due to changing diet (more meat).

Metson, G, E. Bennett, and J.J. Elser. 2012. The role of diet in phosphorus demand. Environmental Research Letters **7**: 044043

Phosphorus Footprint

>

>

>

source: *Wikimedia*

Five R’s

Cellular agriculture.

MEMPHIS MEATS

FORK&GOODE

BlueNalu

Finless Foods

mosameat
THE MEAT REVOLUTION

Five R’s

Reduce food waste.

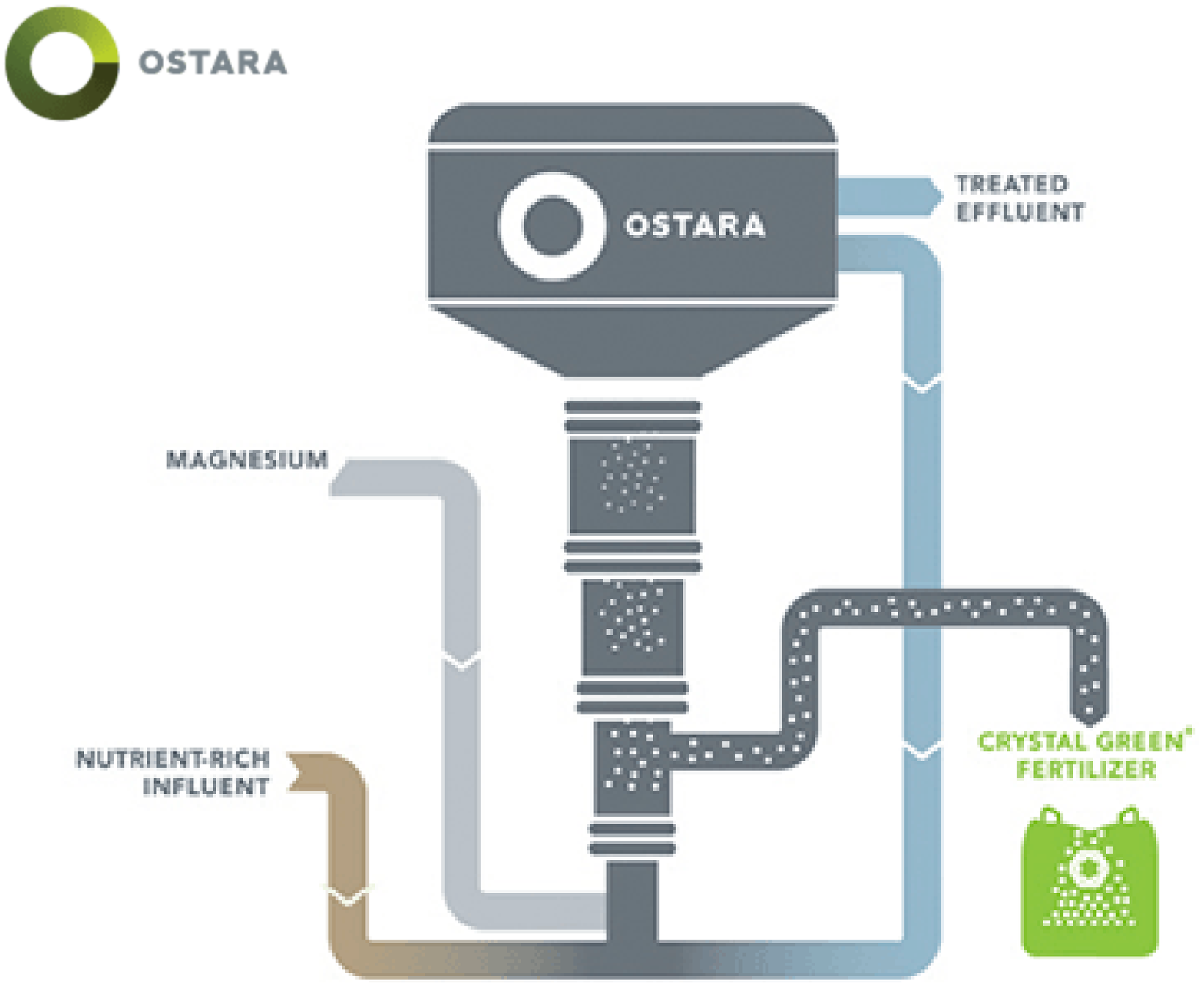
~30-40% of food is wasted globally (for lots of reasons).

Five R’s

source: Wikimedia

“No-mix” Toilet

For human waste in cities (centralized, developed).

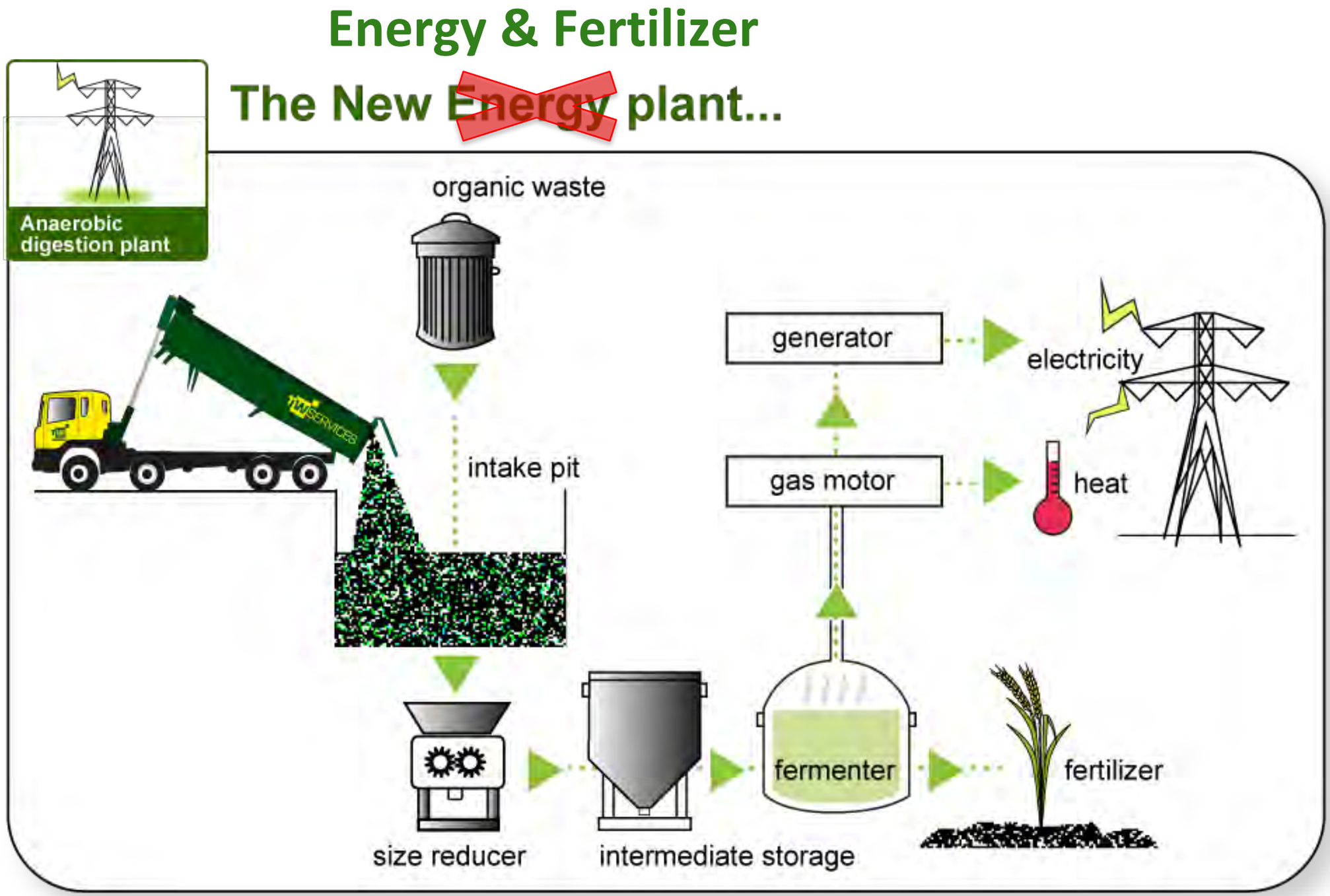


Struvite clogging pipes.

Struvite
$NH_4MgPO_4 \cdot 6H_2O$

http://www.ostara.com/nutrient-management-solutions

For food waste in cities.
For manure from feedlots.



http://www.richboroughenergyplant.co.uk/

Five R's

Re-imagine
& Re-engineer.

agriculture
cities
"waste"
bioenergy

In 2010, 10% of total fertilizer P use in USA was used for corn ethanol.

Nice R’s, but what are people actually doing about it?

The Sustainable P Initiative at ASU

solutions.

A consortium of natural and social scientists, engineers, educators, and communicators focused on P sustainability.

ASU GLOBAL INSTITUTE of SUSTAINABILITY

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Research

Browse Current Research

Sustainability Scientists & Scholars

RCN-SEES: Coordinating Phosphorus Research to Create a Sustainable Food System

2011 Phosphorus Summit

Challenge 1
(phosphorus efficiency)
Challenge 2
(phosphorus recycling)
Challenge 3
(integrating phosphorus efficiency and recycling)

Key

- Working Group meetings at ASU
- Workshops in Washington D.C. with core members and stakeholders
- digital communcation

Kick-off Workshop

At-Large members

Working Groups

Synthesis Workshop

Outputs

At-Large members

Working Groups

Wrap-up Workshop

Outputs

YEAR ONE | YEAR TWO | YEAR THREE | YEAR FOUR | YEAR FIVE

PHASE I | PHASE II

Academics mostly just move air molecules & electrons around.
Maybe time for ***action***, no?

Modelled on;
European Sustainable
Phosphorus Platform
(ESPP)

Participate
Collaborate
Innovate

Leadership

Jim Elser
Director, Sustainable Phosphorus Alliance
Jim Elser is a limnologist and National Academy of Sciences member with research focused on the effect of key limiting nutrients such as nitrogen and phosphorus in lake ecosystems. He is a Research Professor and Distinguished Sustainability Scientist in ASU's School of Life Sciences and School of Sustainability and serves as the Director for the Sustainable Phosphorus Alliance. He is also director of the Flathead Lake Biological Station of the University of Montana.

Matt Scholz
Senior Project Manager, Sustainable Phosphorus Alliance
Matt Scholz is the Senior Project Manager for the Sustainable Phosphorus Alliance. He worked for 3 years as a Senior Research Scientist for The Sustainability Consortium after completing a postdoc in the Department of Chemistry at Colorado School of Mines and a PhD at the University of Arizona, where his research focused on algal biofuels. He has worked in maize molecular genetics and holds an MS in environmental engineering from the University of Arizona.

Rebecca Muenich
Research Scientist, Sustainable Phosphorus Alliance
Rebecca Muenich is an environmental engineer with expertise in environmental modeling, especially in evaluating the impact of land management decisions on nutrient inputs into the environment. She recently completed a postdoctoral position at the University of Michigan where she focused on finding win-win solutions to address excess phosphorus inputs into Lake Erie. She is currently an Assistant Professor in ASU's School of Sustainable Engineering and the Built Environment and serves as a Research Scientist with the Sustainable Phosphorus Alliance. She holds a BS in biological engineering from the University of Arkansas, and MS and PhD degrees in agricultural and biological engineering from Purdue University.

Olga Borquez
Program Manager, Sustainable Phosphorus Alliance
Olga Borquez is the Program Manager for the Sustainable Phosphorus Alliance. She worked for 4 years as a Sustainability Manager in the organic agriculture industry at Wholesum Family Farms in the US and in Mexico, focusing on data analysis for efficient use of resources, CSR reporting, grant development, environmental planning and community impact work.

Sustainable Phosphorus Alliance

PhosphorusAlliance.org

@sustainP

Sustainable Phosphorus Alliance

Our Vision

We envision a food system that manages phosphorus more sustainably to provide abundant, nutritious food while protecting the health of rivers, lakes, and oceans.

Allies Addressing a Complex Problem

We recycle only a small fraction of the phosphorus we use, nearly all as unprocessed manures whose over-application pollutes our wa
organization driven to innovate and implement solutions the phosphorus challenge.

Our mission is to be North America's central forum and advocate for the sustainable use, recovery, and recycling of phosphorus in the food system.

Webinars
Annual Phosphorus Forum
Focused Research Projects
Phosphorus Science Now! series

Founding/Current Members and Strategic Partners

OCP
NACWA
THE Water Research FOUNDATION
OSTARA
AQUASMART INC
RENEWABLE NUTRIENTS
GreenEdge® GreenTechnologies, LLC
THE SUSTAINABILITY CONSORTIUM™
Mosaic®
Biochar Now
ARVA INTELLIGENCE
PHOSPHOLUTIONS

Strategic Partners

AgSTAR
Water Environment Federation the water quality people
nebra North East Biosolids & Residuals Association
Global Water Works

The global phosphorus sustainability movement 2003 - now…

DEUTSCHE PHOSPHOR PLATTFORM
2013

STEPS 2021

VLAAMS NUTRIËNTENPLATFORM
2012

European Sustainable Phosphorus Platform
2013

SPA 2016

NUTRIENT PLATFORM NL
2010

NSF
P-RCN 2013

THE GRAND CHALLENGE
A $10 MILLION SCIENCE PRIZE
2014

Ontario

SPS
2011

CCME
Canadian Council of Ministers of the Environment / Le Conseil canadien des ministres de l'environnement
2013

United Nations Environment Programme
UNEP Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA)
GPNM 2009

Welcome to the GLOBAL PHOSPHORUS NETWORK
2010

INEMAD
2012

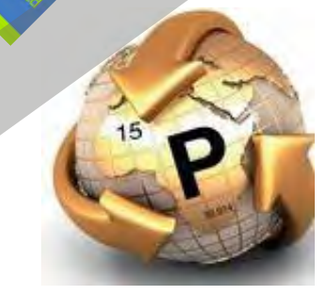
GLOBAL PHOSPHORUS RESEARCH INITIATIVE
2008

Phosph'OR
2011

P-REX
2012

Global Phosphate Forum
2007

リン資源リサイクル推進協議会
Phosphorus Recycling Promotion Council
2008



2010

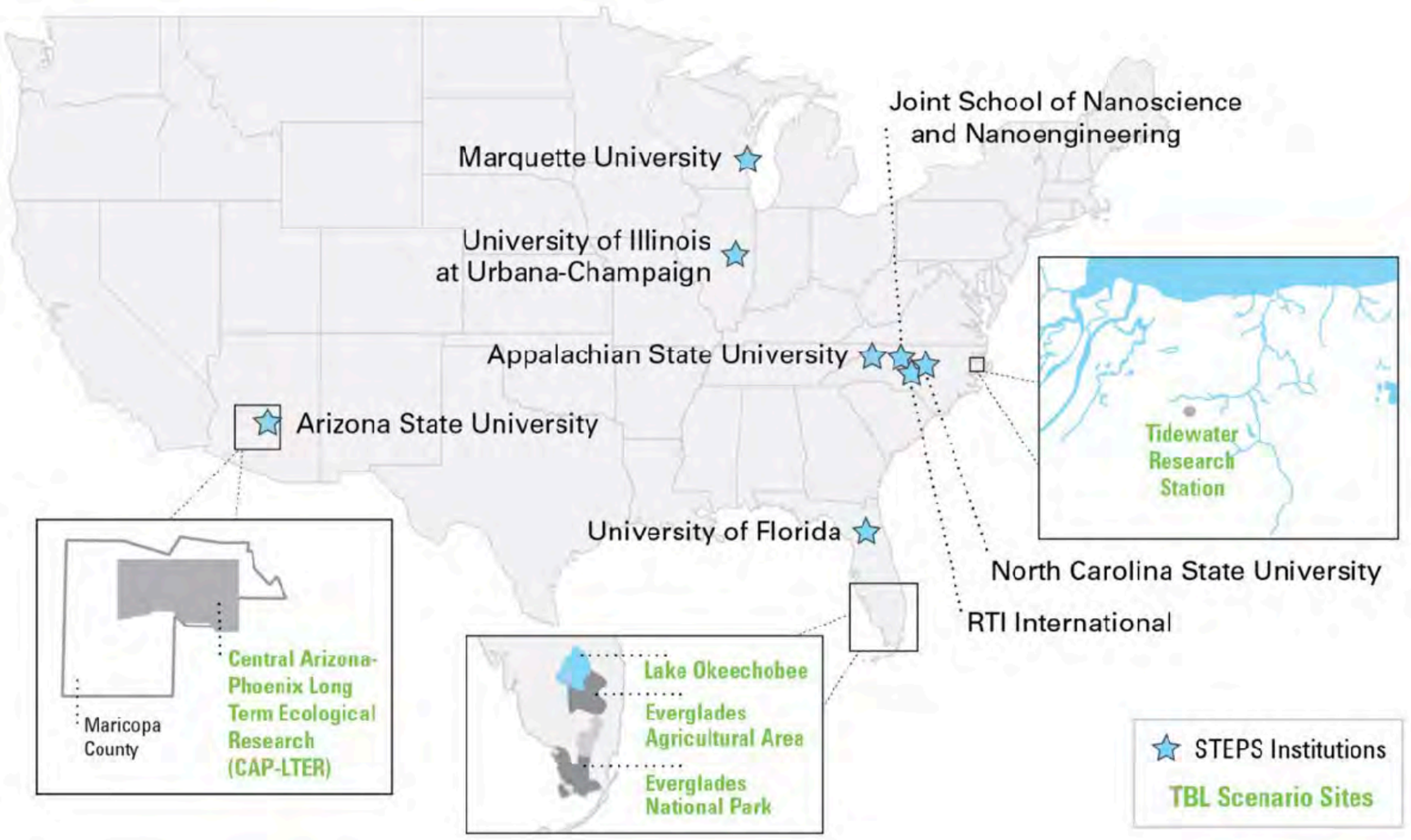
2003

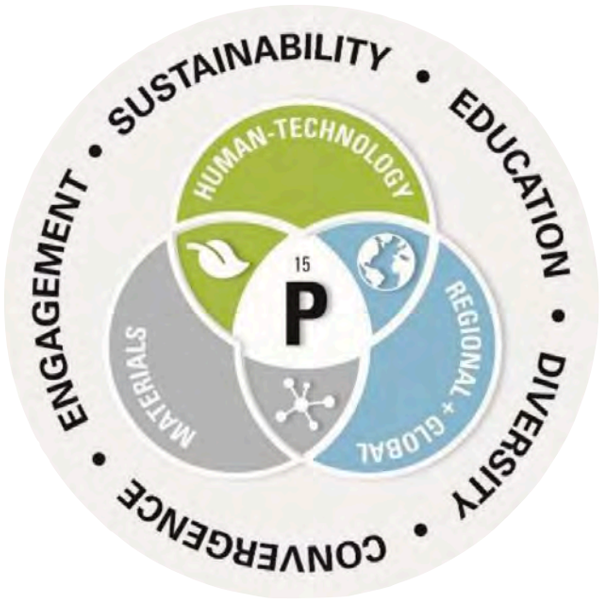
STEPS

Science and Technologies for Phosphorus Sustainability

$25M over 5 years

Our Partners





- Consider your diet. Less meat. Less P-intensive meat.
- What about that lawn?
- Reduce your food waste.
- Maintain your septic system.
- Support nutrient recovery infrastructure in your town / city.
- Support nutrient management as a political priority for clean water sustainable food security, and climate change mitigation.

source: Wikimedia

In discussions leading up to Pope Francis' encyclical on climate change:

"This requires a miracle of love and unselfishness."

Walter Munk
Scripps Institution of Oceanography
UC San Diego
(1917-2019)

phosphorusalliance.org

Thanks.

Thanks to our supporters:

National Science Foundation
ASU Office of Knowledge Enterprise Development
ASU School of Life Sciences
ASU Global Institute of Sustainability & School of Sustainability
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