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INSTITUTE of TECHNOLOGY
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Global Cycles of Phosphorus and Nitrogen – Resources and Leaks

AAEES Nutrient Recovery Workshop

NJWEA Annual Conference

Atlantic City, NJ

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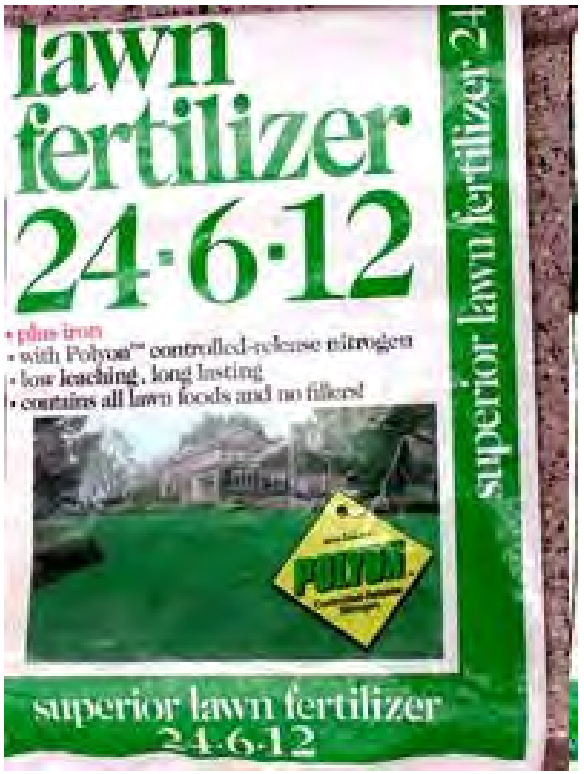
David A. Vaccari
dvaccari@stevens.edu

Outline

- Nutrients and life
- Environmental impacts of P and N
- Phosphorus resources
- The Phosphorus Cycle
- The Nitrogen Cycle
- Forecasting Phosphorus Demand
- A Vision of Sustainability

What do plants need to grow?

- Sunlight
- Soil/substrate
- CO_2 and H_2O
- Macronutrients: N, P, K
  S, Ca, Mg
- Micronutrients: Fe, Cl, Mg



Nitrogen and Phosphorus in Life

- Redfield (Molar) Ratio: C:N:P = 106:16:1
  - Due to homeostatic ratio of proteins to rRNA
- Nitrogen:
  - Proteins
  - DNA, etc.
- Phosphorus:
  - ~0.65 kg P per person, 85% in bones
  - Bones are 60% Calcium hydroxyapatite [$Ca_{10}(PO_4)_6(OH)_2$]
  - DNA, RNA, ATP, Phospholipid membranes
  - 700 mg/d P reference dose; 1500 mg/d typical
  - Drinking water corrosion control – lead and copper

Nitrogen and Phosphorus Pollution

- Nitrogen:
  - Eutrophication (marine environments)
  - Greenhouse gases – NO_2
  - Acid rain (NO_X)
  - Smog (NO_X)
  - Nitrogenous oxygen demand (organic-N, ammonia)
  - Nitrates in drinking water (methemoglobinemia in infants)
- Phosphorus:
  - Eutrophication (aquatic and marine environments)
  - "Gypstacks" blight the landscape near mines

Freshwater Eutrophication

P > 50 ppb

http://phys.org/news/2015-12-severe-algal-blooms-lake-erie.html

“Dead Zones” – Hypoxic Zones
– not just nitrogen any more

Where do we get our phosphorus from?

How long will it last?

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US Phosphorus Sources

A phosphate mine in Hardee County in central Florida.
Seventy-five percent of the phosphate used in the United States comes from the region.
By Adrianne Appel, New York Times, August 4, 2007

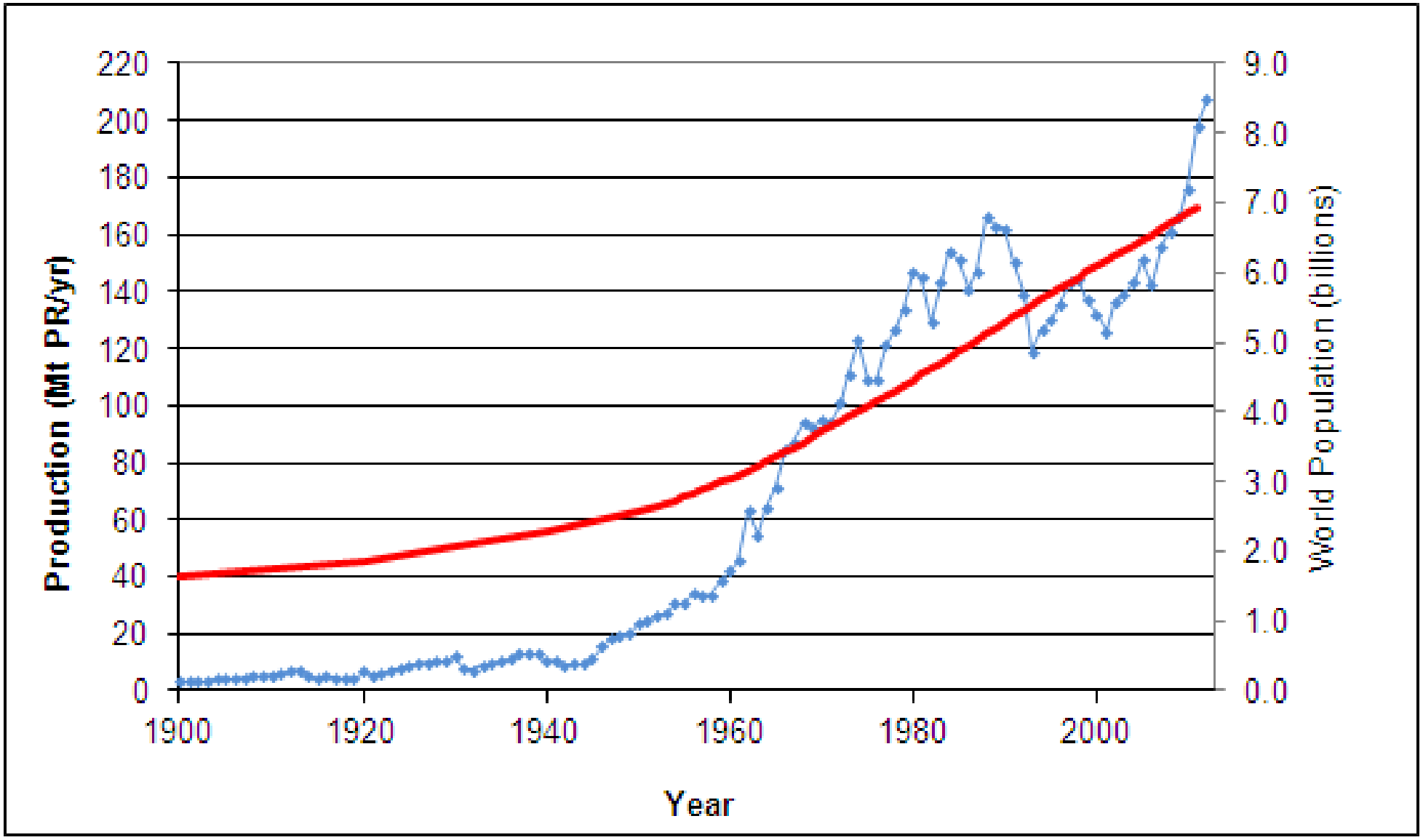
12,000 hp = 9 MW

2012 estimation of global reserves - USGS

Mt or Mt/yr	Production	Reserves	Life	Production % of global	Reserves % of global
Morocco_and_Western_Sahara	28.00	50,000	1786	13.3%	74.4%
China	89.00	3,700	42	42.4%	5.5%
Algeria	1.50	2,200	1467	0.7%	3.3%
Syria	2.50	1,800	720	1.2%	2.7%
Jordan	6.50	1,500	231	3.1%	2.2%
South_Africa	2.50	1,500	600	1.2%	2.2%
United_States	29.20	1,400	48	13.9%	2.1%
Russia	11.30	1,300	115	5.4%	1.9%
Peru	2.56	820	320	1.2%	1.2%
Saudi_Arabia	1.70	750	441	0.8%	1.1%
Australia	2.60	490	188	1.2%	0.7%
Iraq	0.15	460	3067	0.1%	0.7%
Other_countries	30.01	1,318	496	14.3%	2.0%
World_total (rounded)	**210**	**67,000**	**319**		

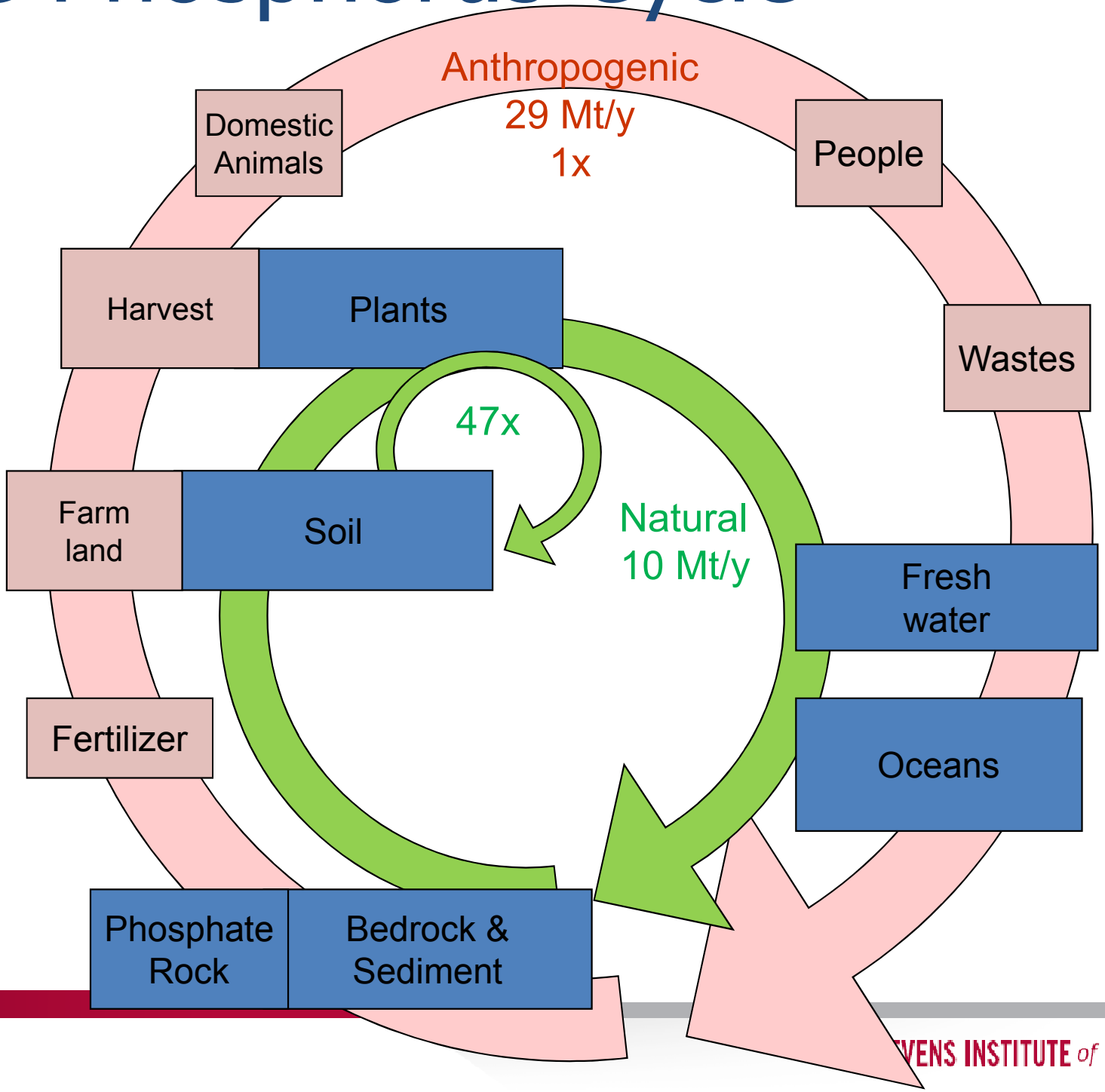
Morocco and Western Sahara – The Saudi Arabia of Phosphorus

Global Trend in Production and Population



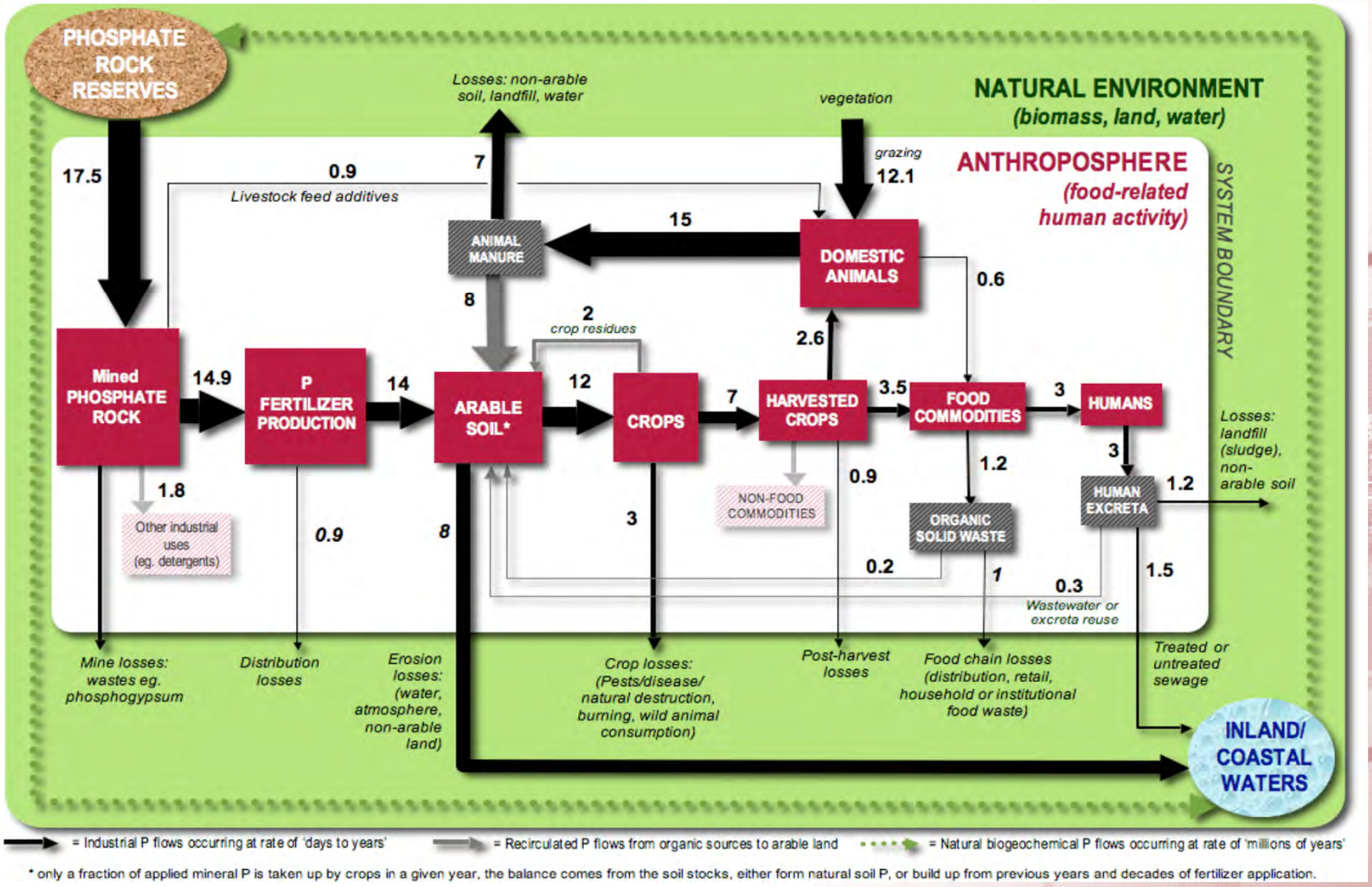
Natural Sources: Erosion, Sedimentation, Flooding

The Phosphorus Cycle

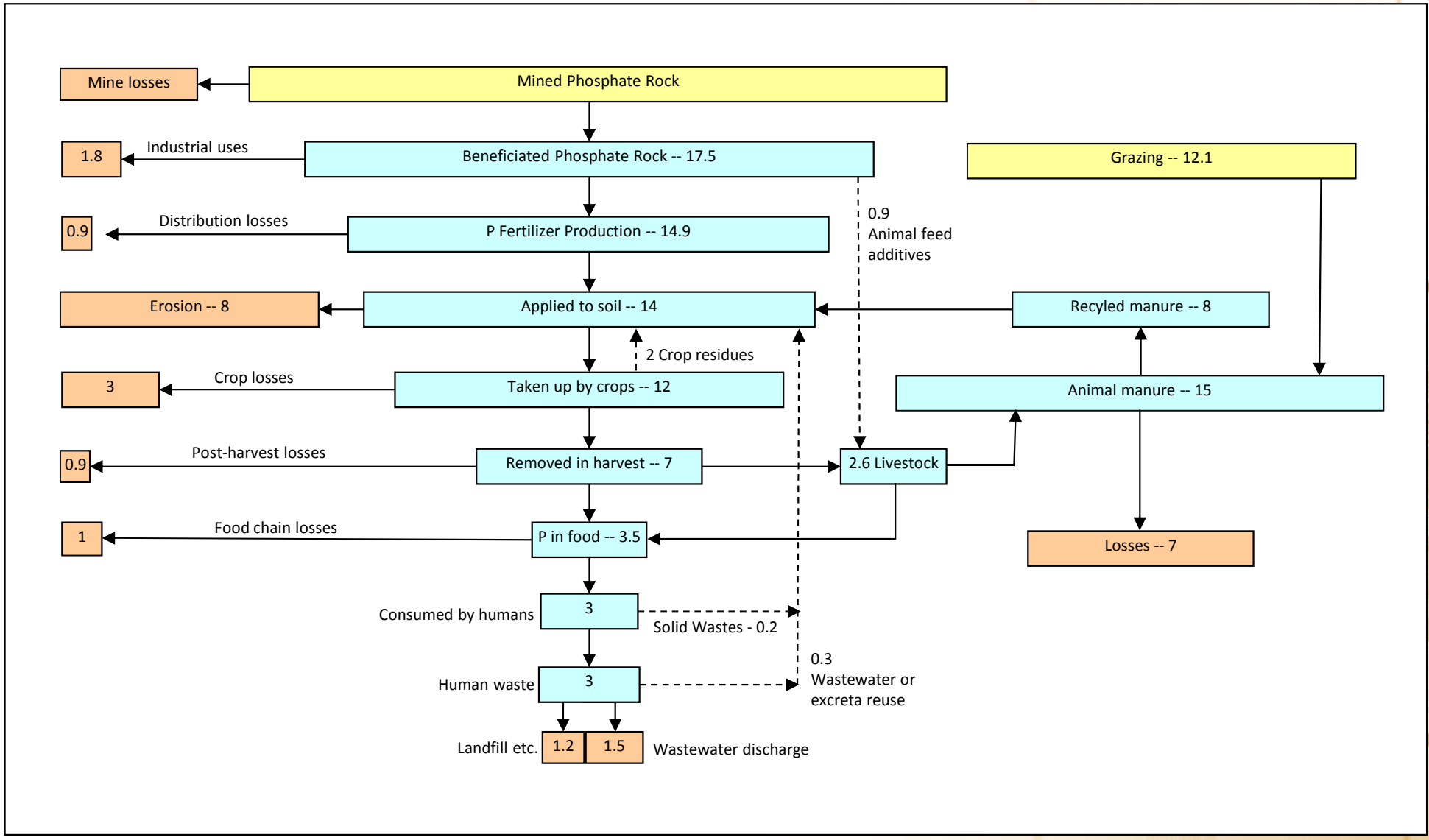


Global Substance Flow Analysis for P

Cordell, Drangert and White, 2009



Flow of P in our Food System

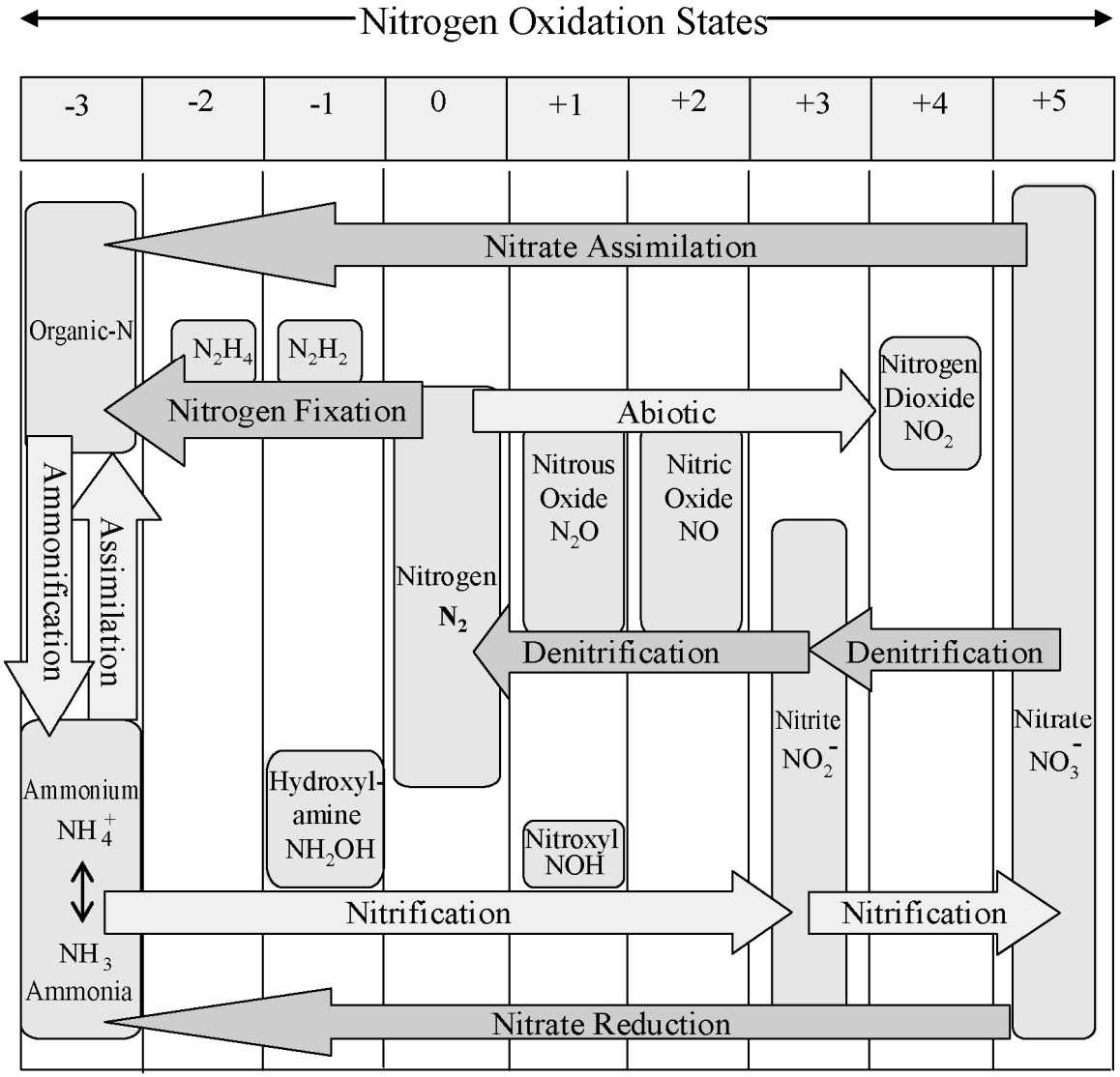


Where Does Bioavailable Nitrogen Come From?

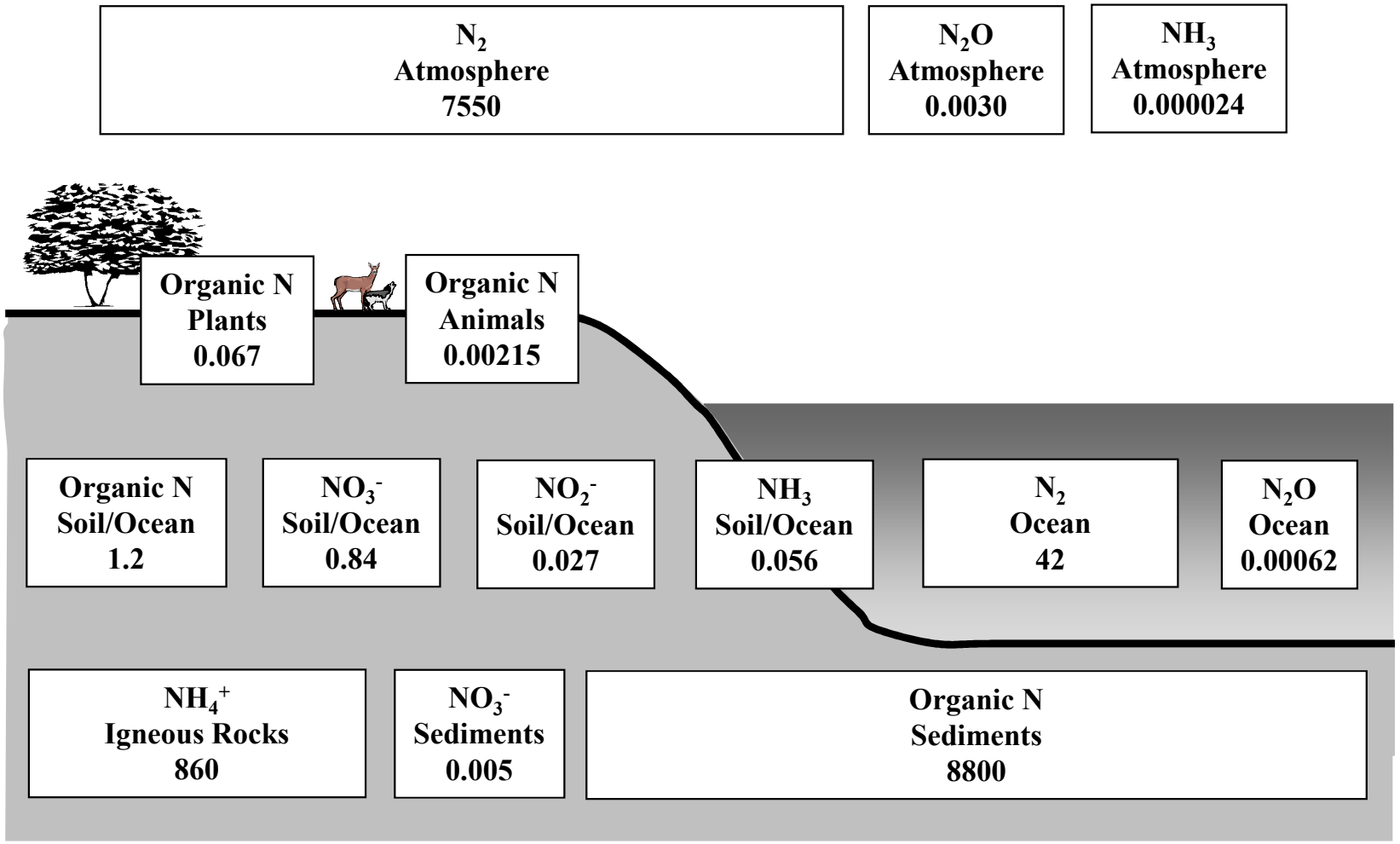
- **Natural sources – nitrogen fixers**
  - Rhizobium (in legumes)
  - Azotobacter (free-living in soil)
  - Some Cyanobacter (Blue-Green Bacteria)

- **Agro-industrial sources:**
  - Guano (depleted)
  - Haber-Bosch Process

Biochemical transformations of N

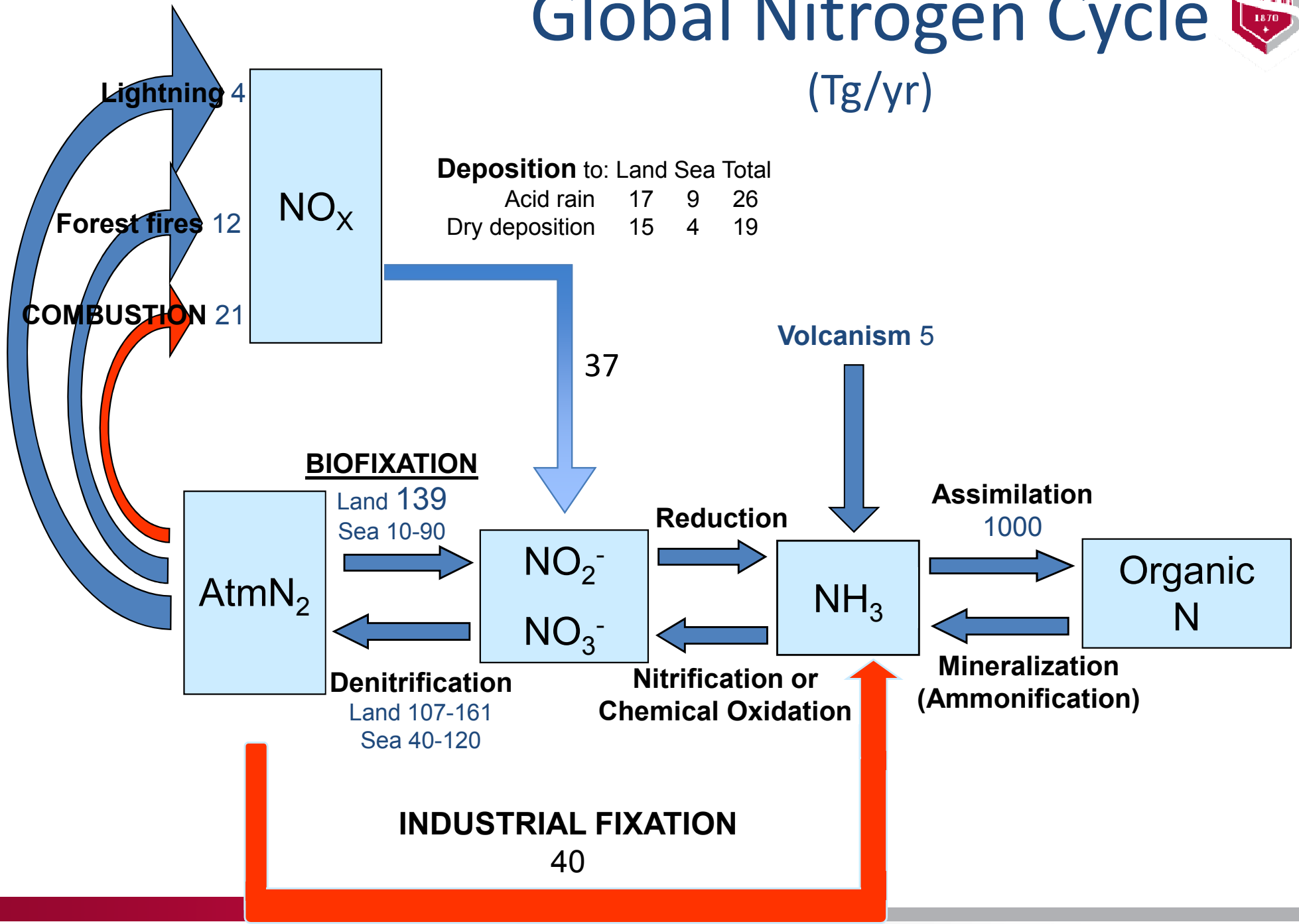


Storage reservoirs of nitrogen. Values are kg/m^2.
(Based on Whittaker, 1975.)

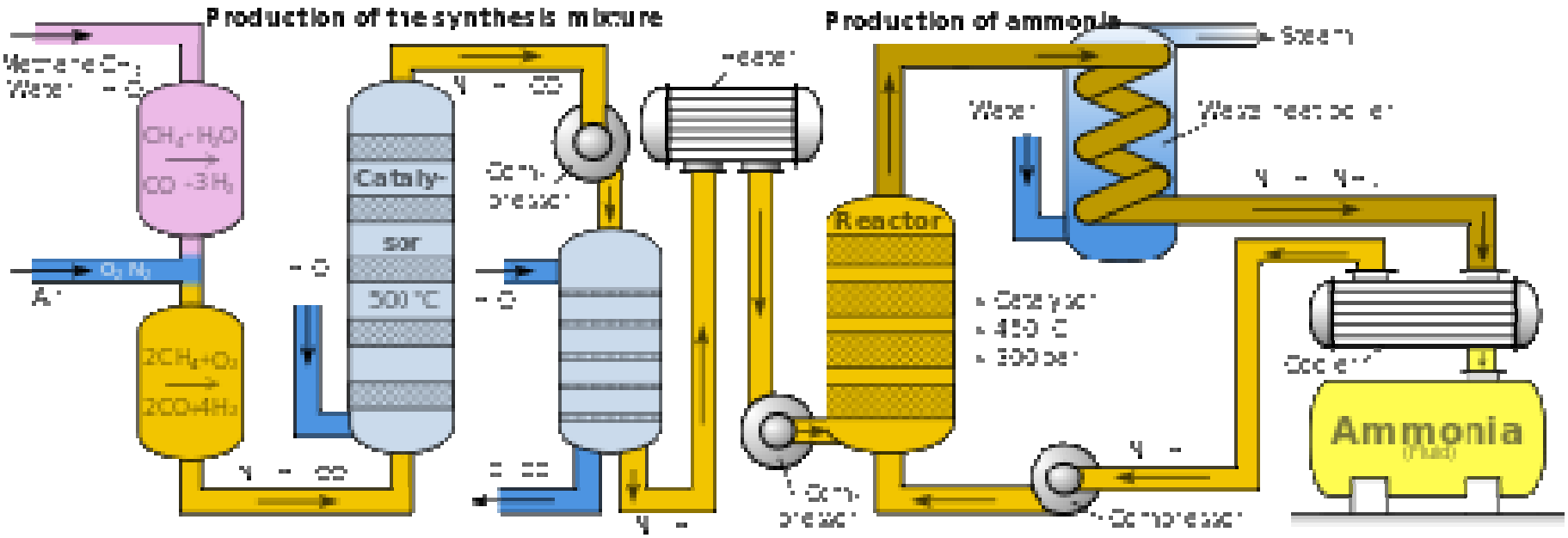


Global Nitrogen Cycle

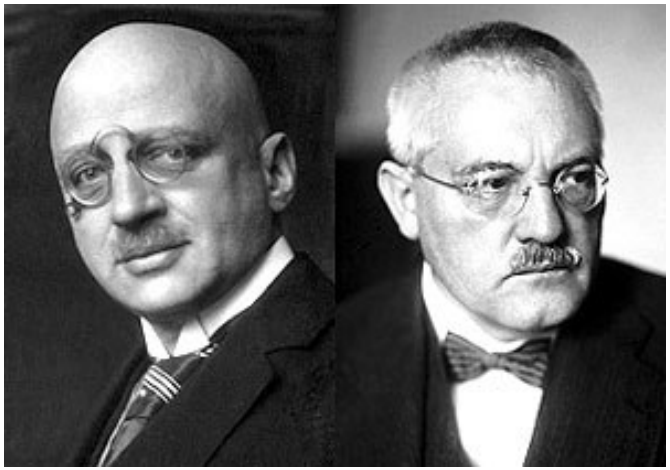
(Tg/yr)



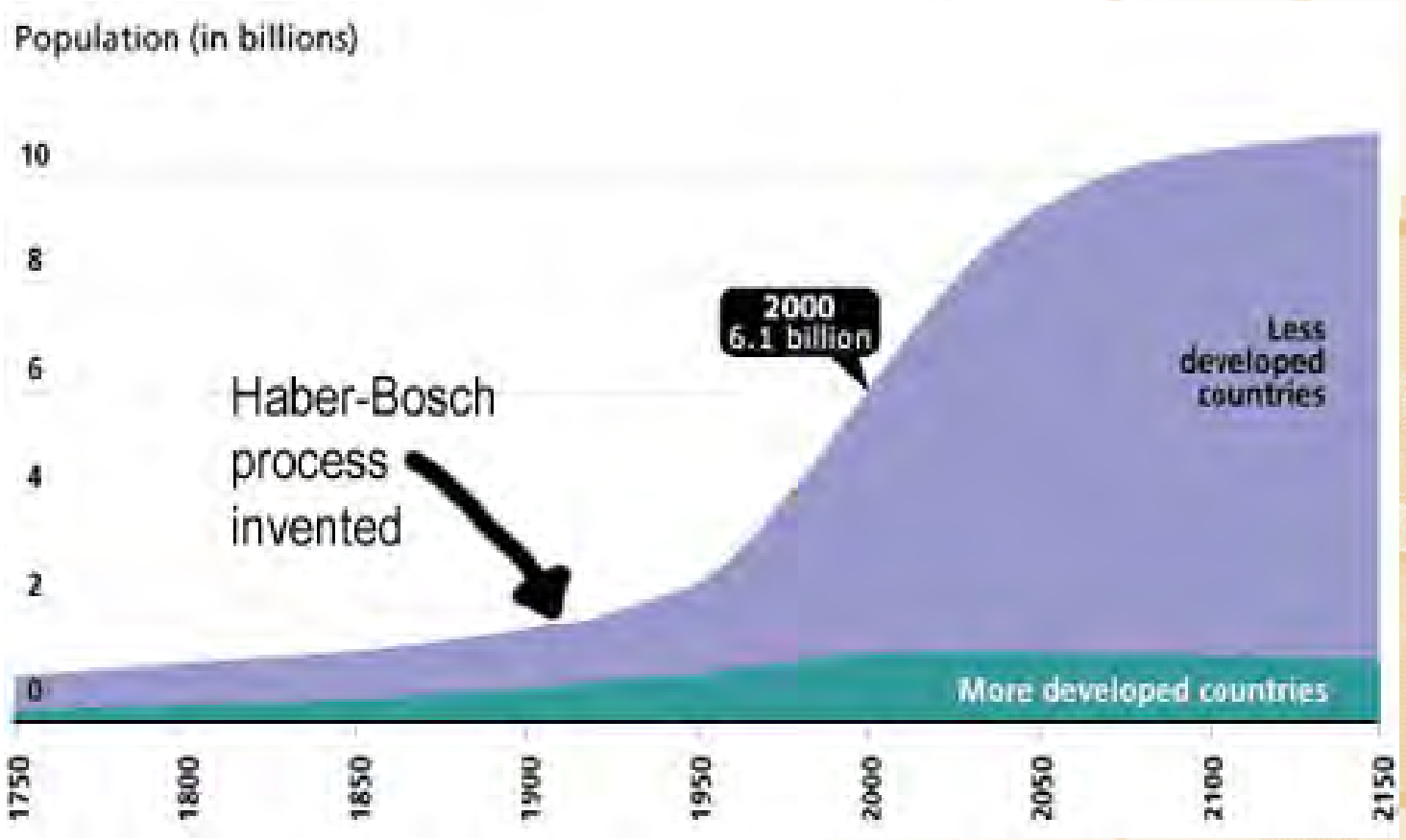
Haber-Bosch Process



https://upload.wikimedia.org/wikipedia/commons/thumb/d/db/Haber-Bosch-En.svg/450px-Haber-Bosch-En.svg.png
https://intothechemistry.files.wordpress.com/2016/02/129622b.jpg?w=624



"Fritz Haber and **Carl Bosch** *have probably had a greater impact than anyone in the past 100 years, including Hitler, Gandhi, Einstein, etc."*
http://people.idsia.ch/~juergen/haberbosch.html*)*



Recommended reading: Vaclav Smil: "Enriching the Earth" (MIT Press)

Forecasting Phosphorus Demand

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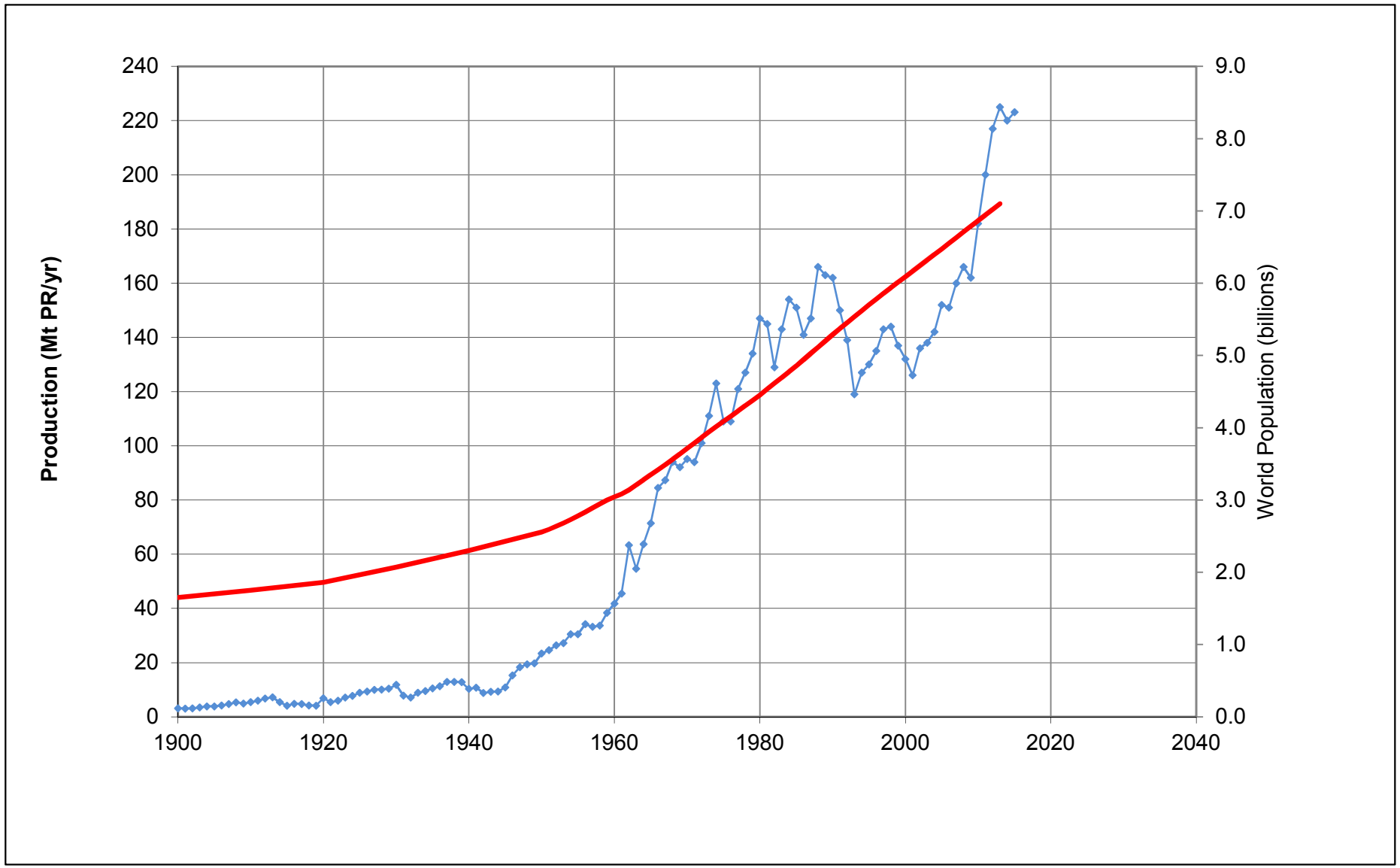

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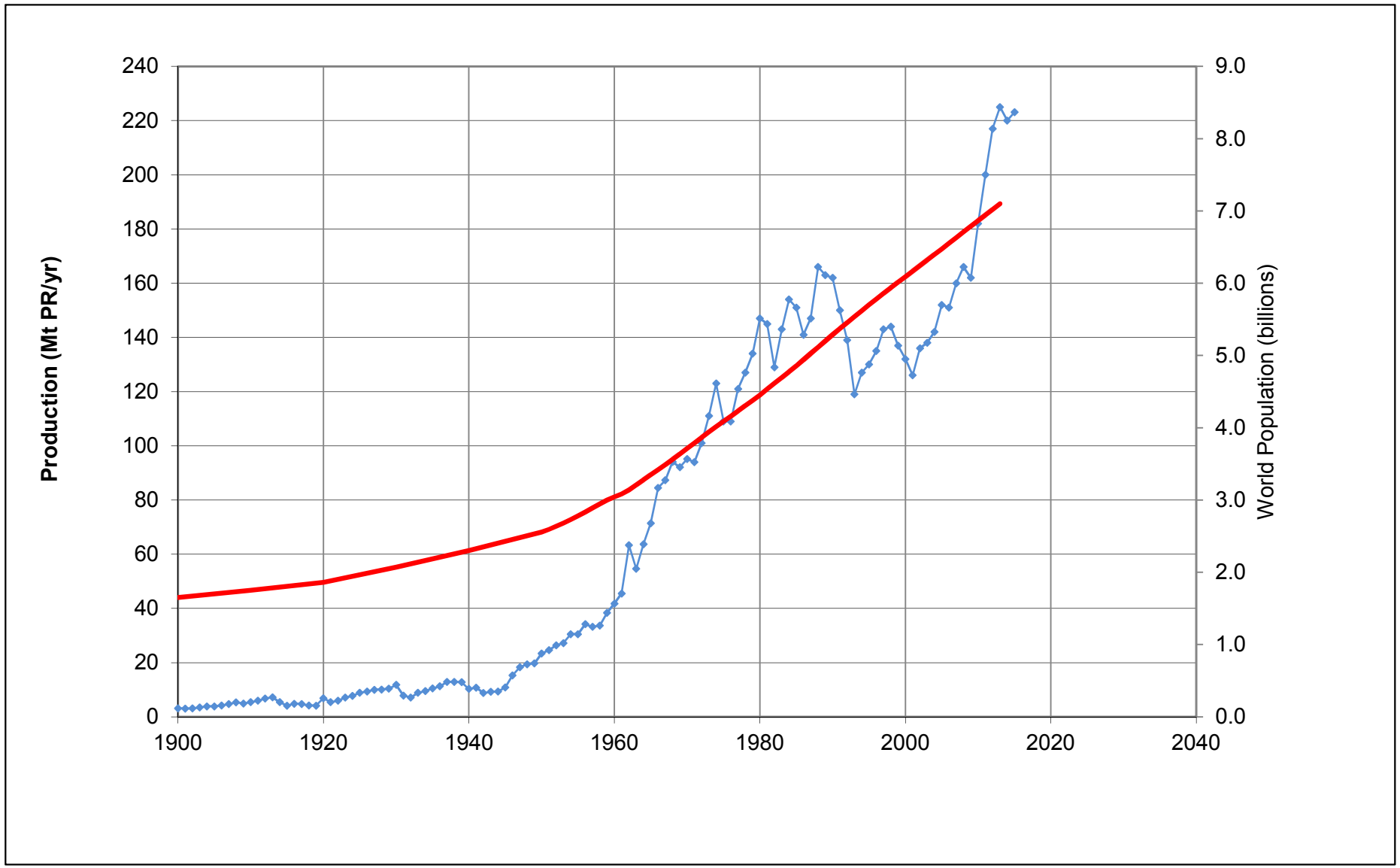
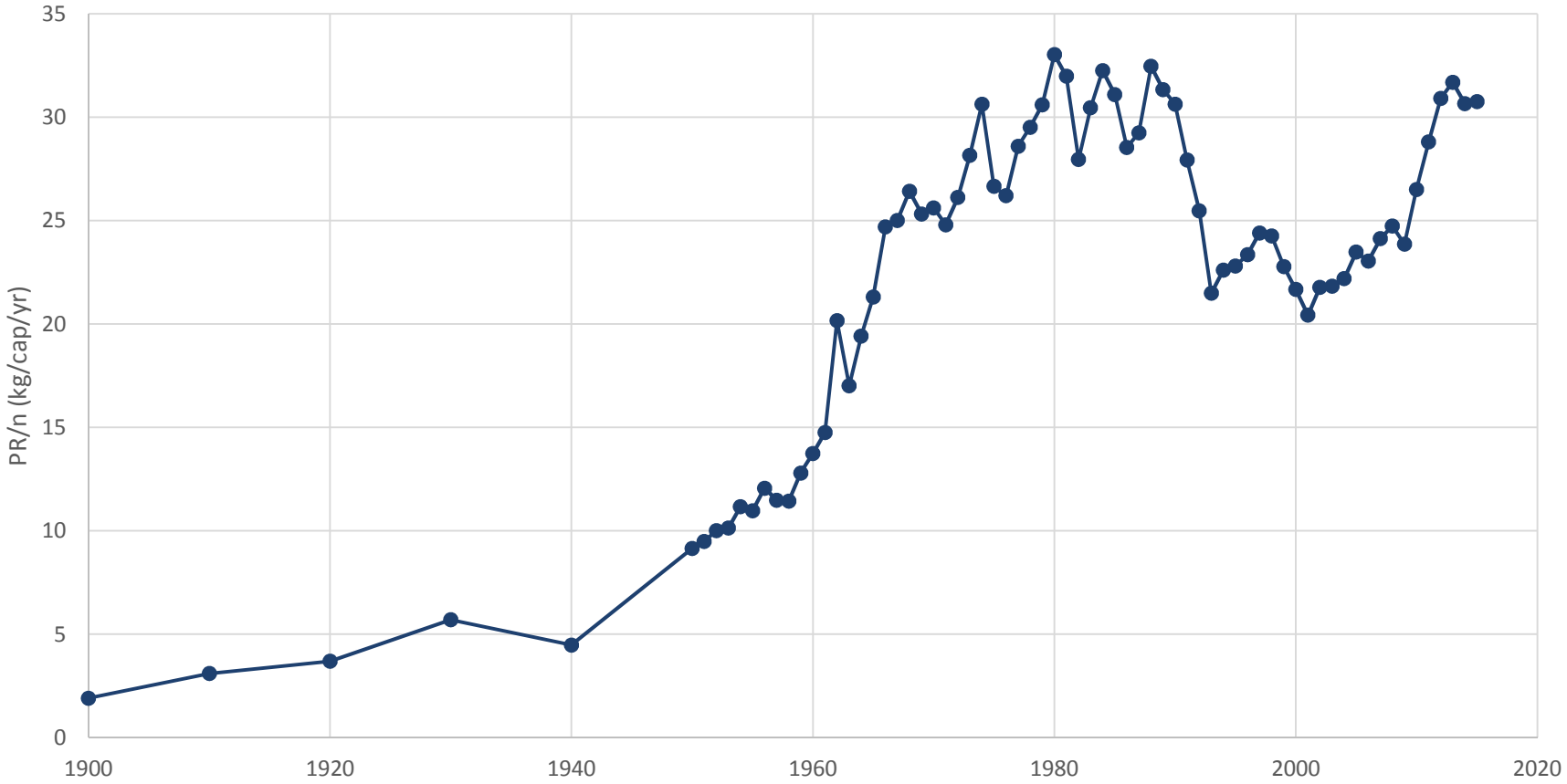
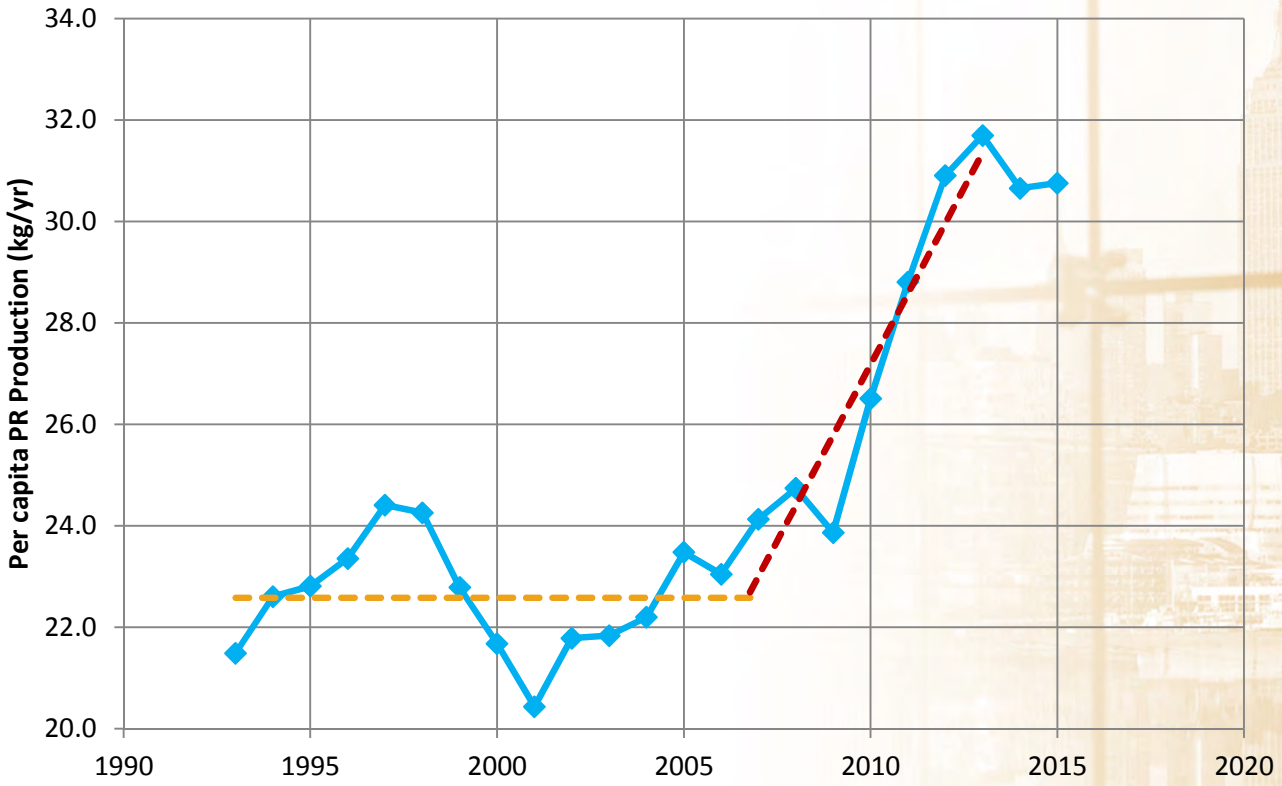


Per Capita Global PR Production

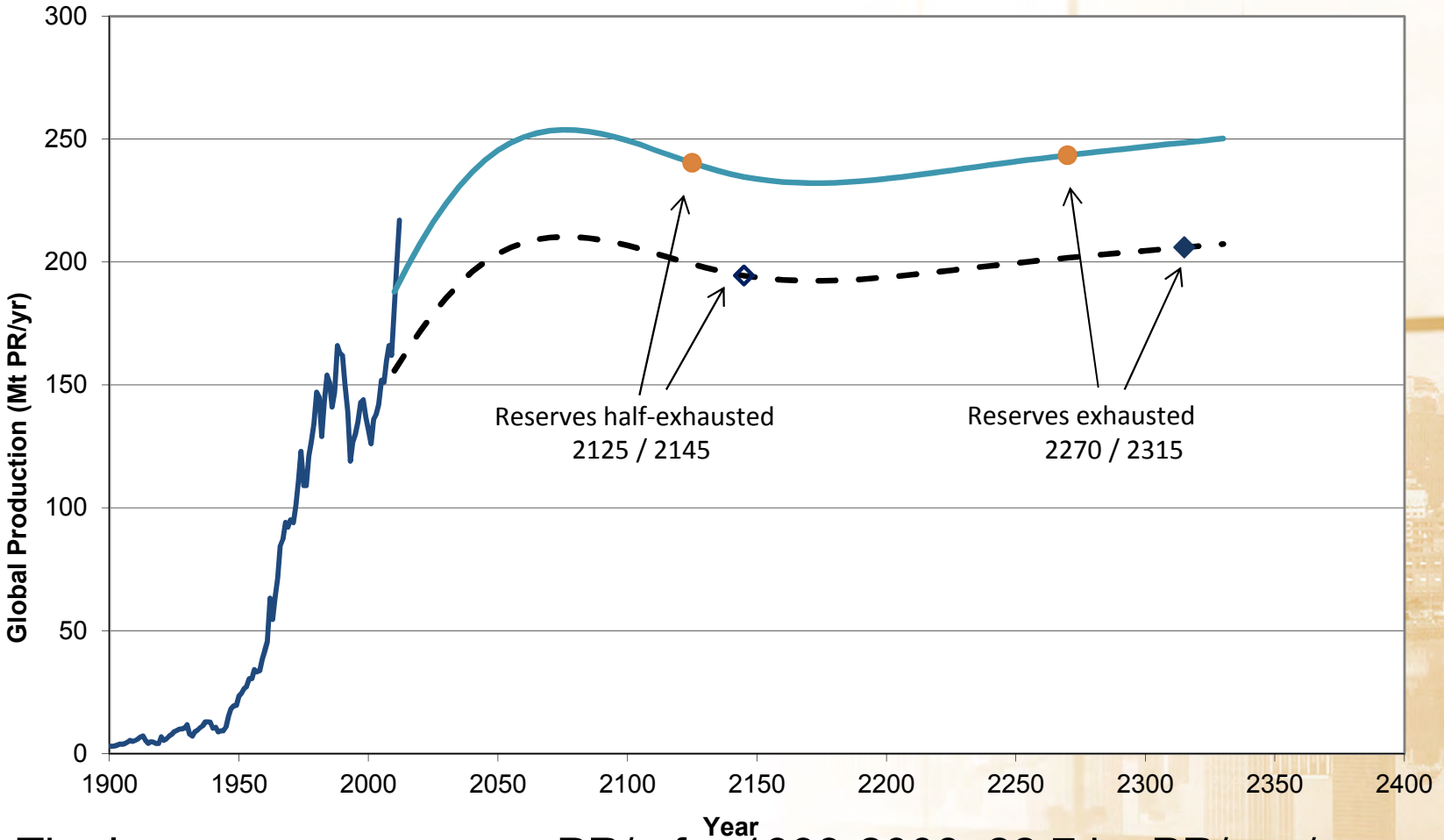


	Kg PR /cap/yr	g P /cap/d
Avg 1974-1990	30.1	10.8
Avg 1993-2008	22.7	8.15

Recent trend in per-capita production



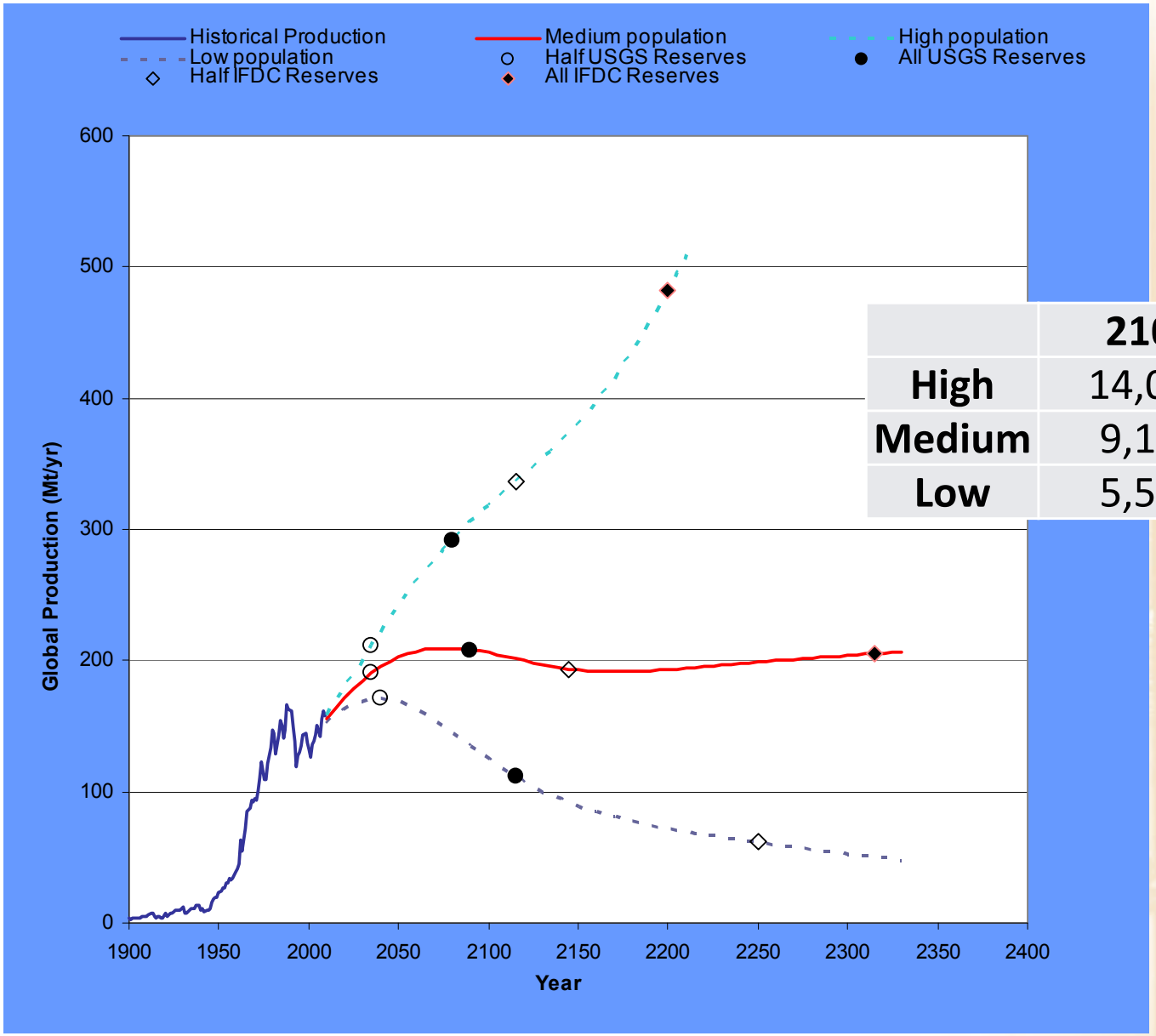
Extrapolation at constant PR/n



The lower curve uses avg PR/n for 1993-2008: 22.7 kg PR/cap/yr

The upper curve is uses avg PR/n for 2009-2012: 27.1 kg PR/cap/yr

Using a range of population estimates



	2100	2200
High	14,000	21,200
Medium	9,100	8,500
Low	5,500	3,165

Definitions of sustainability

- **Webster's New International Dictionary**
  "Sustain - to cause to continue (as in existence or a certain state, or in force or intensity); to keep up, especially without interruption diminution, flagging, etc.; to prolong."

- Sustainability is improving the quality of human life while living within the carrying capacity of supporting eco-systems

- Sustainability encompasses the simple principle of taking from the earth only what it can provide indefinitely, thus leaving future generations no less than we have access to ourselves

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http://www.sustainablemeasures.com/node/36

Proposed definition

- Sustainability is a condition of a steady-state or pseudo-steady-state society with respect to utilization of resources including materials, human resources and environmental services

What ought to be our planning horizon?

Sustainability means forever

Thank you

David A. Vaccari
Stevens Institute of Technology
Hoboken, NJ 07030 USA
dvaccari@stevens.edu

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