



# Nitrogen and Phosphorus Pathways and Sustainability

New York Marine Sciences Consortium  
SUNY Maritime College  
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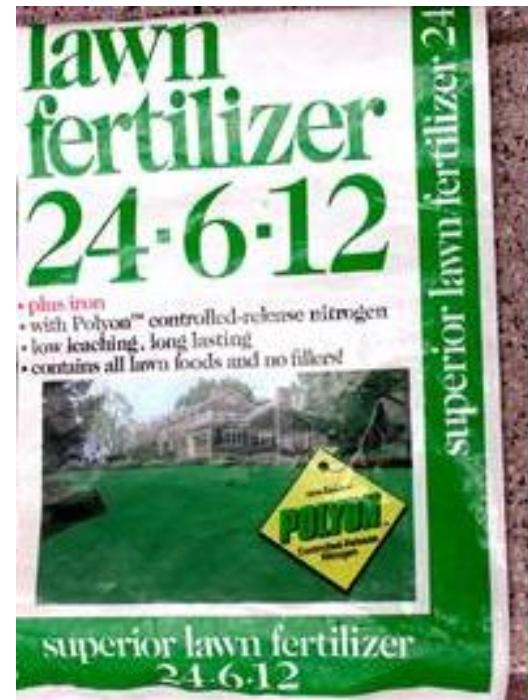


# Outline

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

# What do plants need to grow?

- Sunlight
- Soil/substrate
- $\text{CO}_2$  and  $\text{H}_2\text{O}$
- 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  $[\text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_2]$
  - DNA, RNA, ATP, Phospholipid membranes
  - 700 mg/d P reference dose; 1500 mg/d typical
  - Drinking water corrosion control – lead and copper



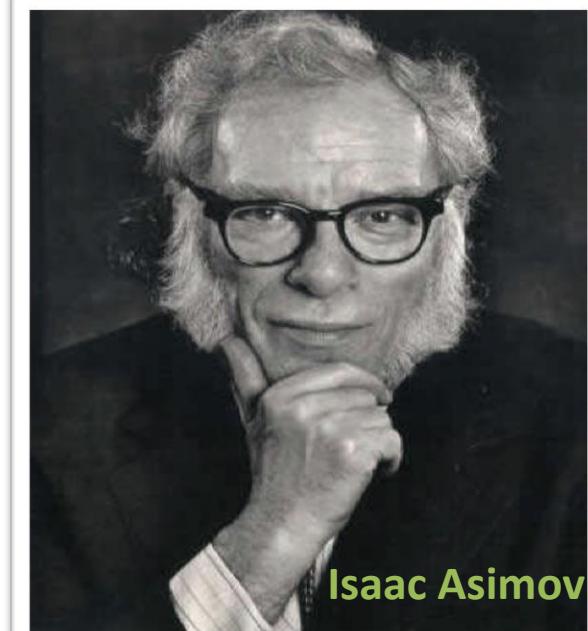
## Asimov on Chemistry

“Life’s Bottleneck”

The highest ratio of concentration in plant to that in soil:

P: 5.8; S: 2.0; Cl: 1.5;  
All others: <1.0

“We may be able to substitute nuclear power for coal power, and plastics for wood, and yeast for meat, and friendliness for isolation, but for phosphorus there is neither substitute of nor replacement.”



*Vlasta Klima*

*Balloun Lecture*



# Nitrogen and Phosphorus Pollution

- Nitrogen:
  - Eutrophication (marine environments)
  - Greenhouse gases –  $\text{NO}_2$
  - Acid rain ( $\text{NO}_x$ )
  - Smog ( $\text{NO}_x$ )
  - 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

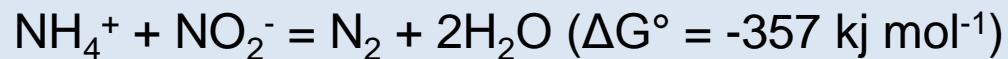
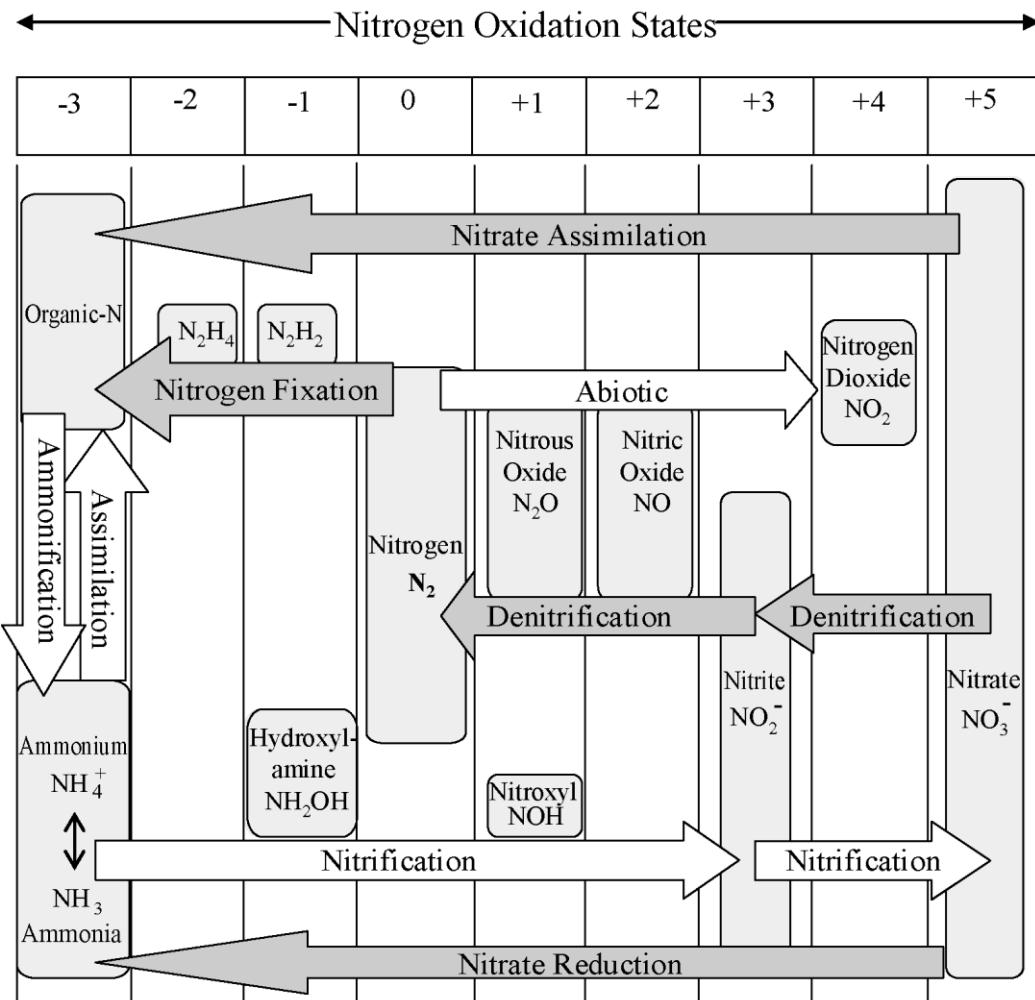




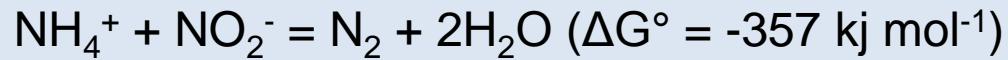
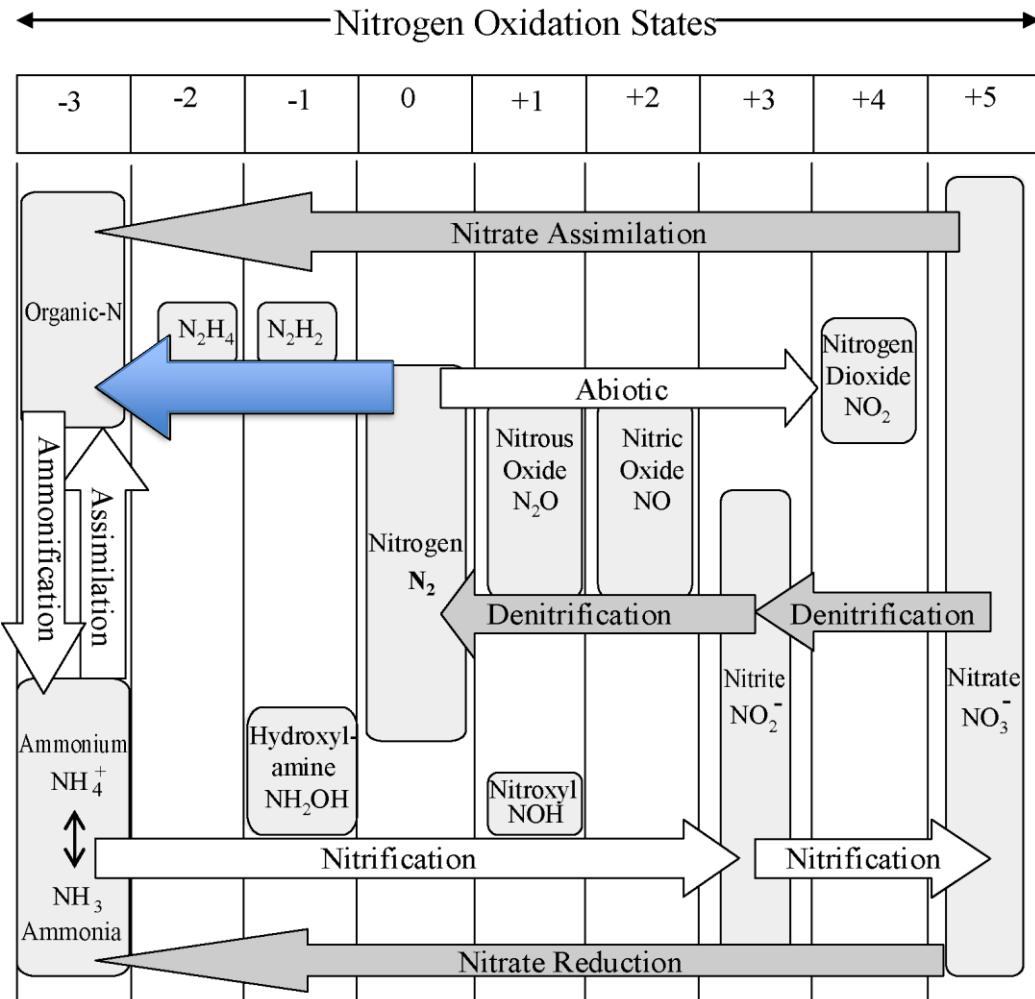
# Where Does Bioavailable Nitrogen Come From?

- **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

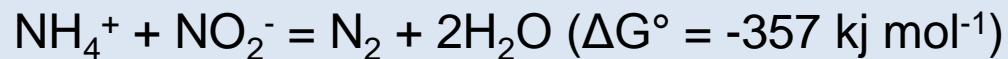
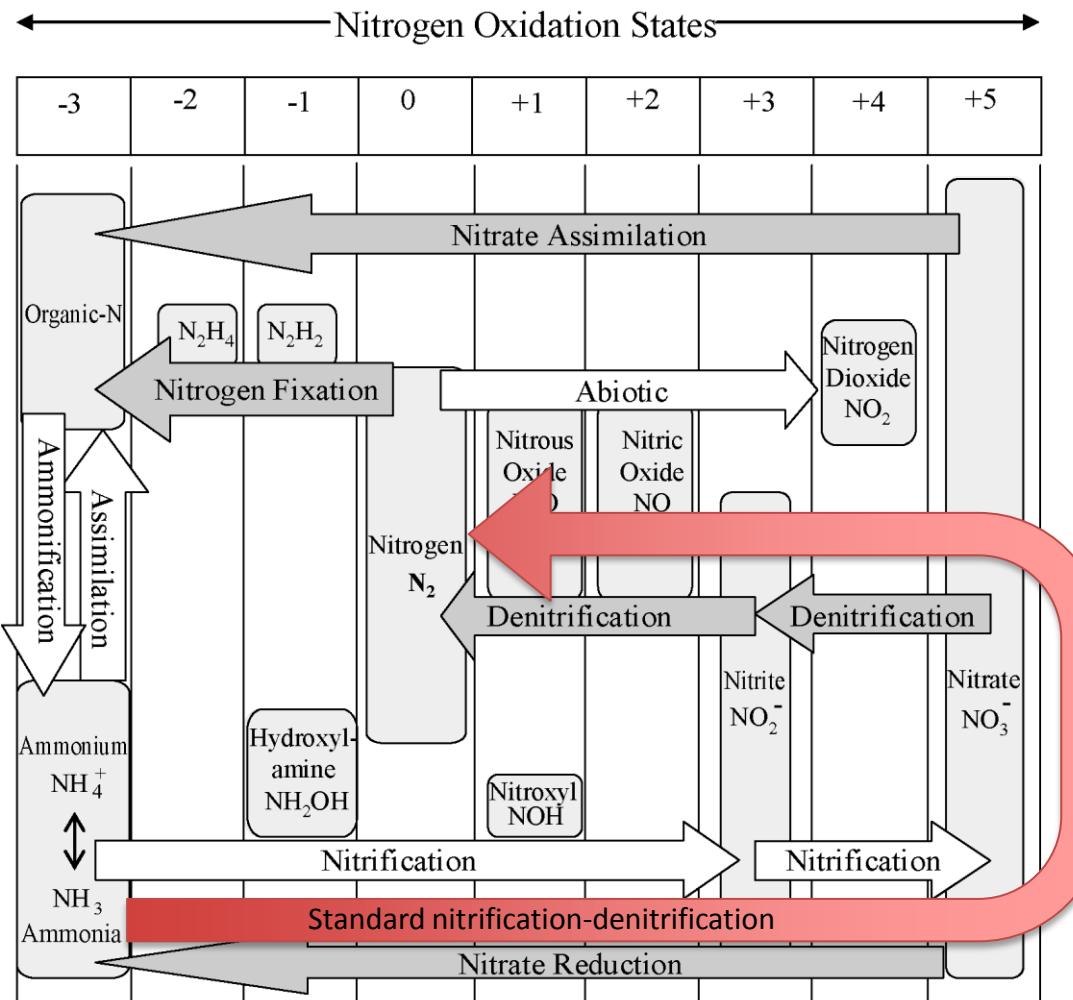
# Biological Nitrogen Transformations



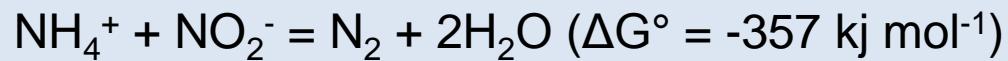
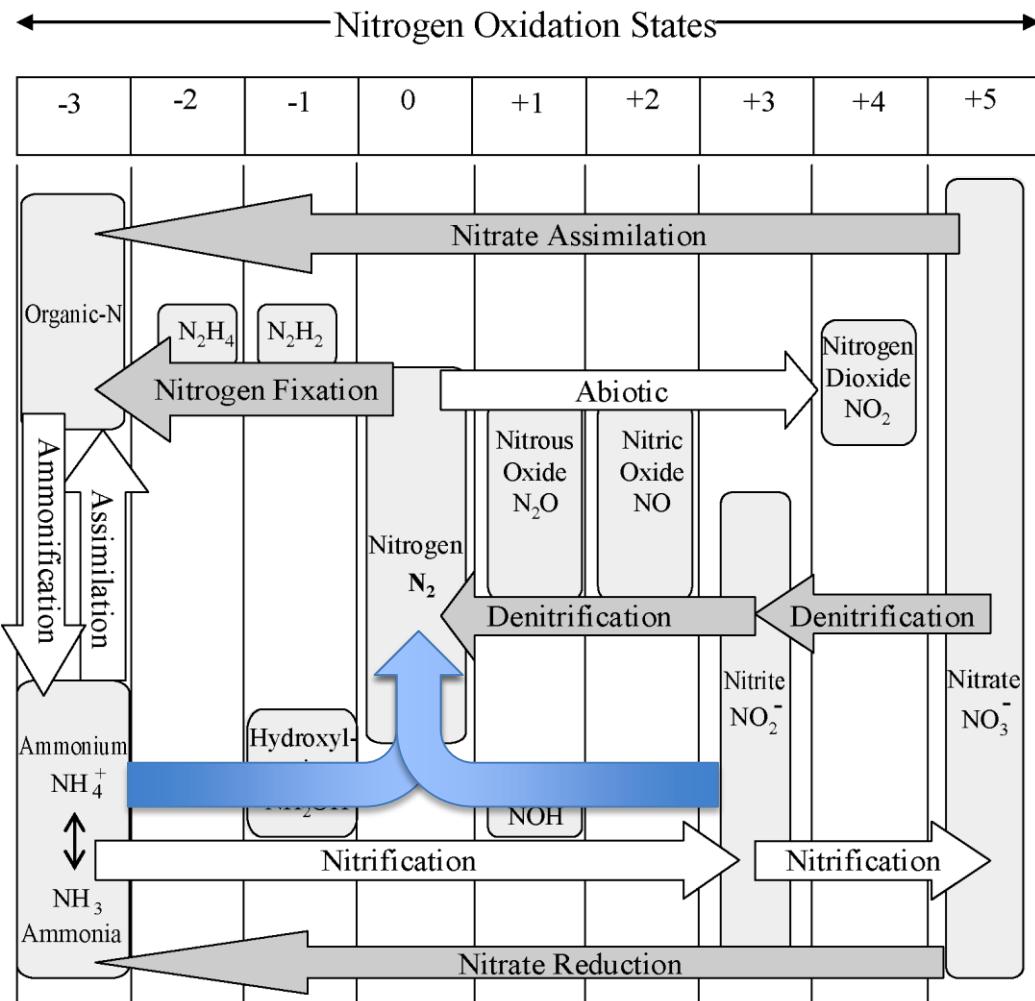
# Nitrogen Fixation



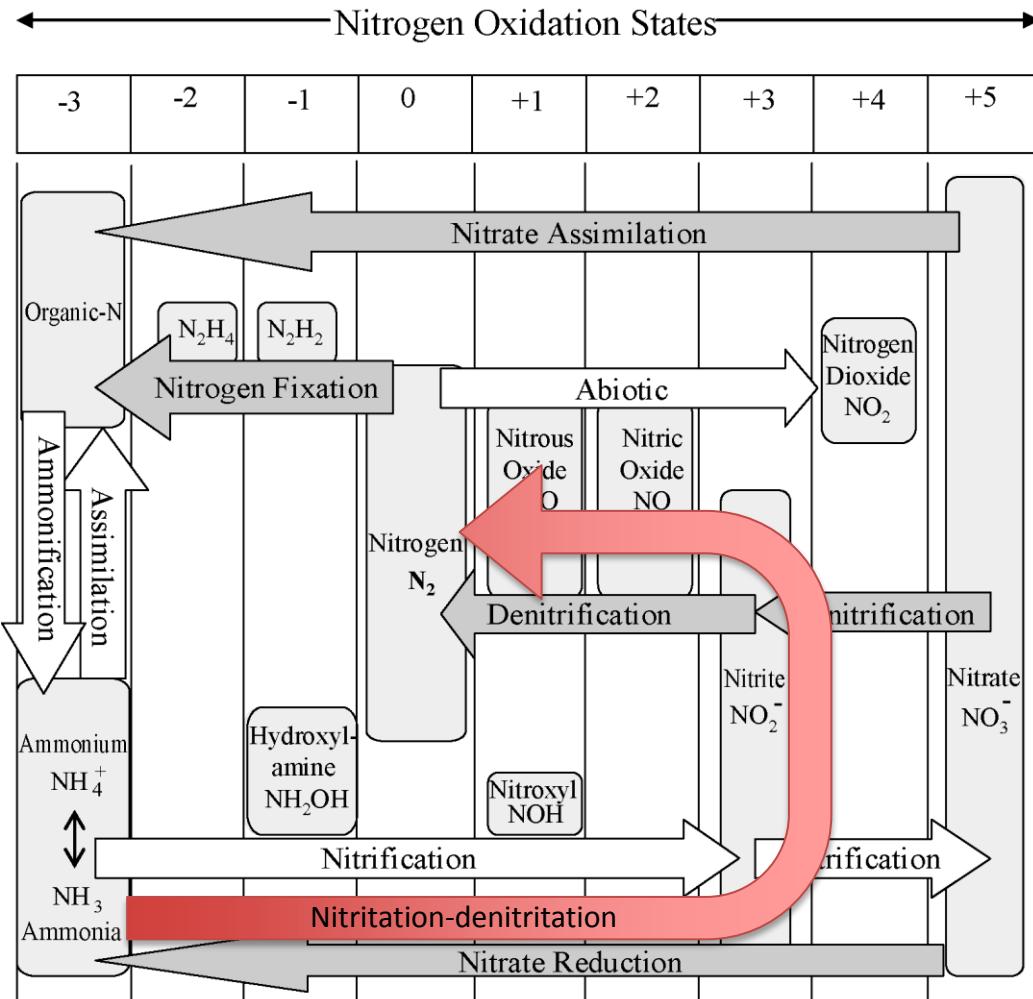
# Standard Nitrification-Denitrification



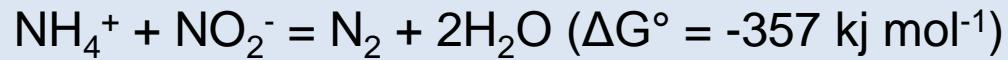
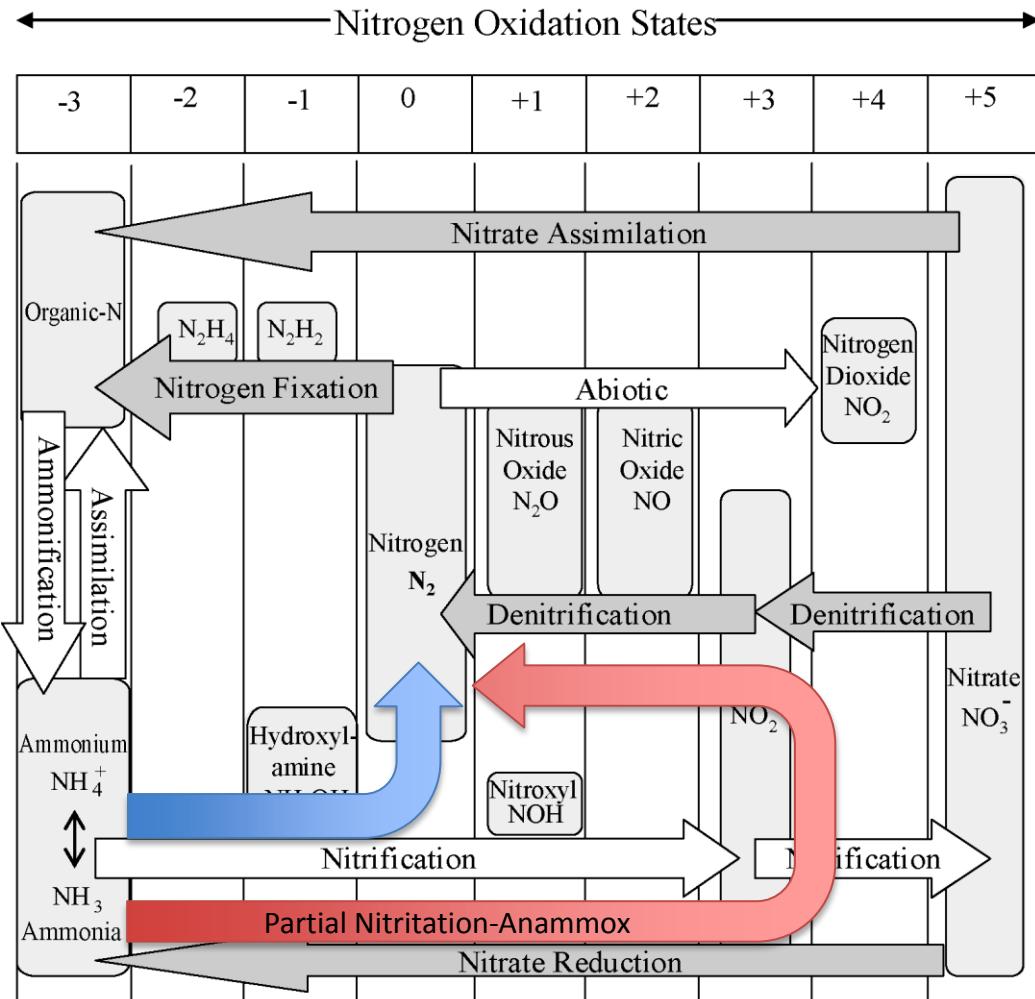
# Annamox – Anaerobic Ammonium Oxidation



# Nitrite Shunt – Anaerobic Ammonium Oxidation



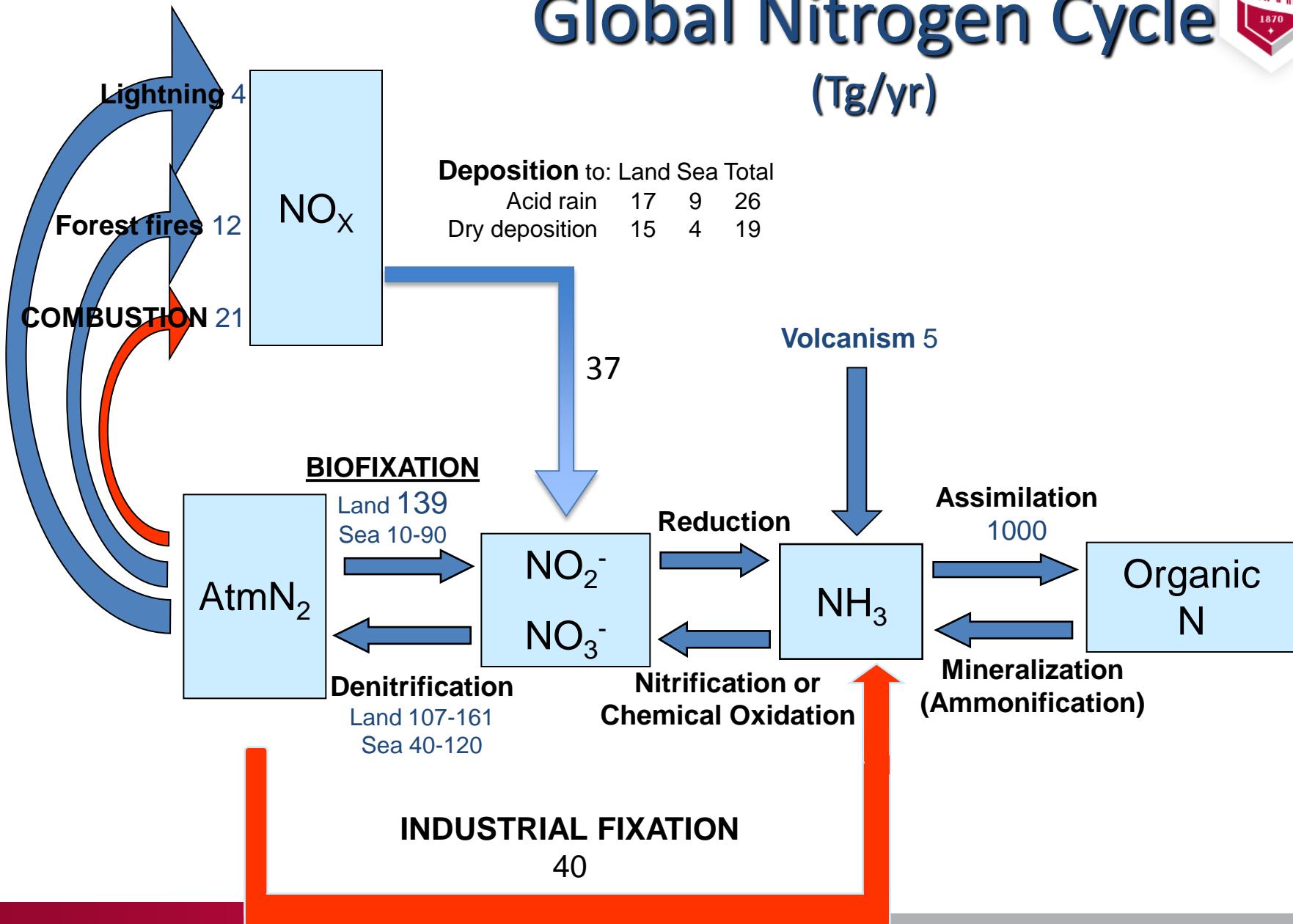
# Deammonification



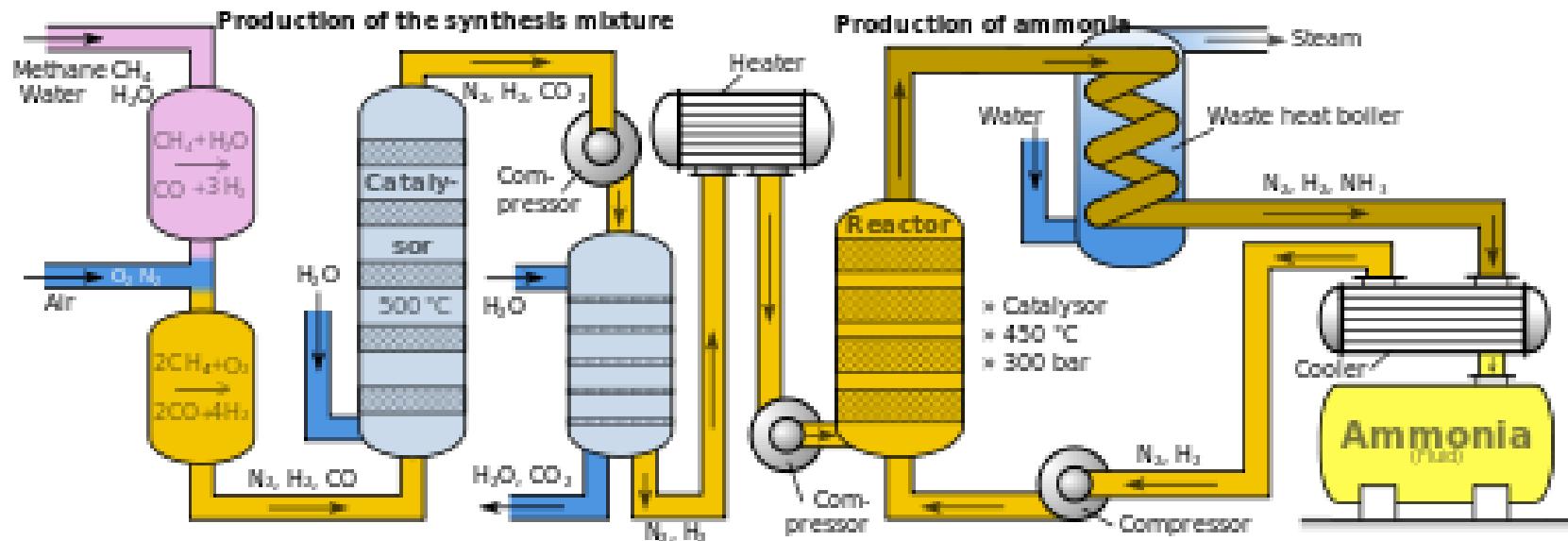


# Global Nitrogen Cycle

(Tg/yr)

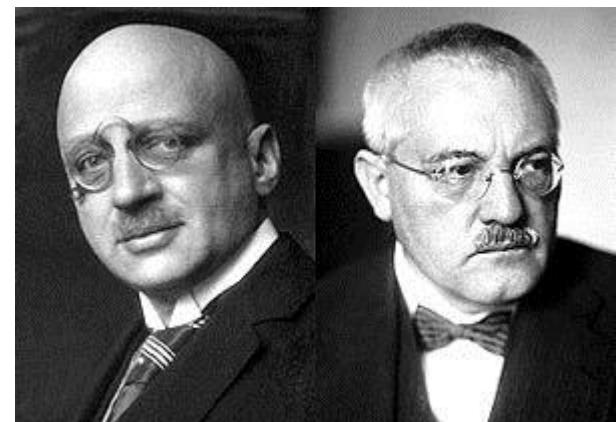


# Haber-Bosch Process

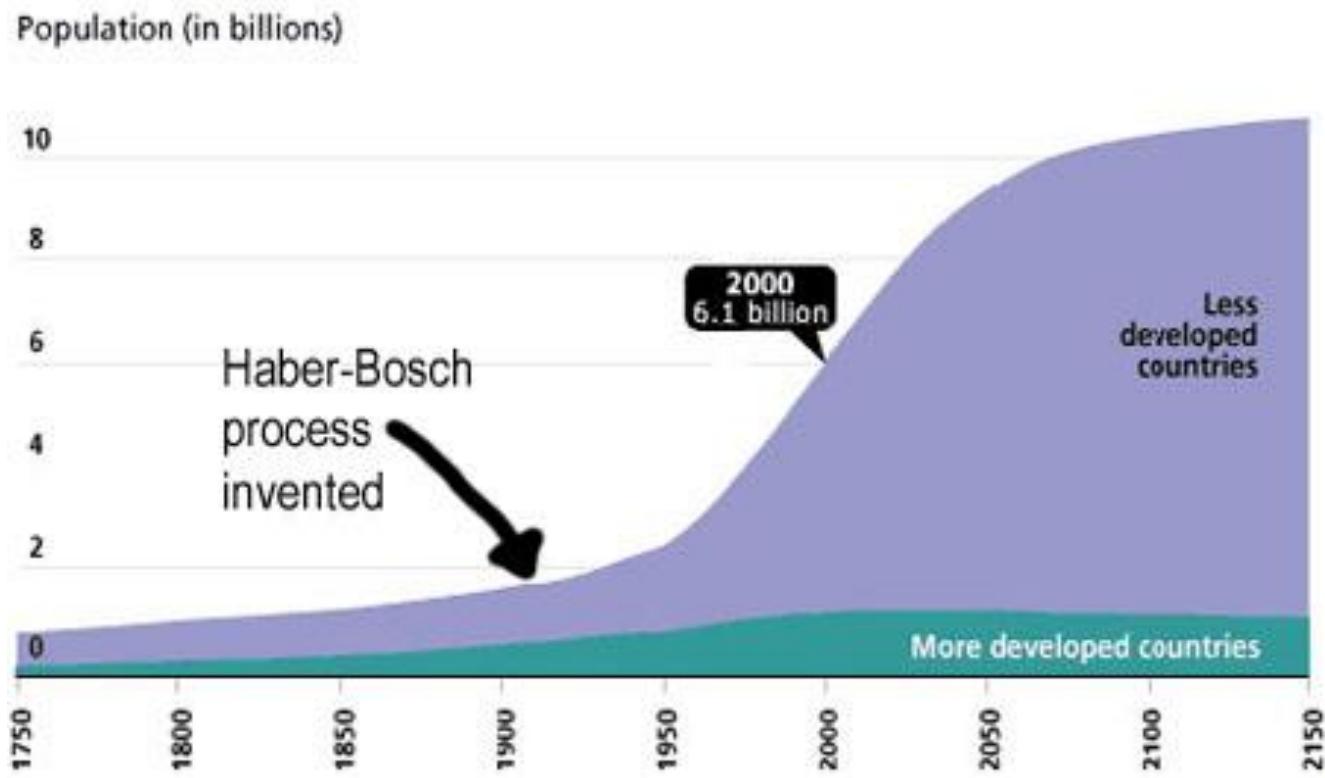


<https://upload.wikimedia.org/wikipedia/commons/thumb/d/db/Haber-Bosch-En.svg/450px-Haber-Bosch-En.svg.png>

<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)

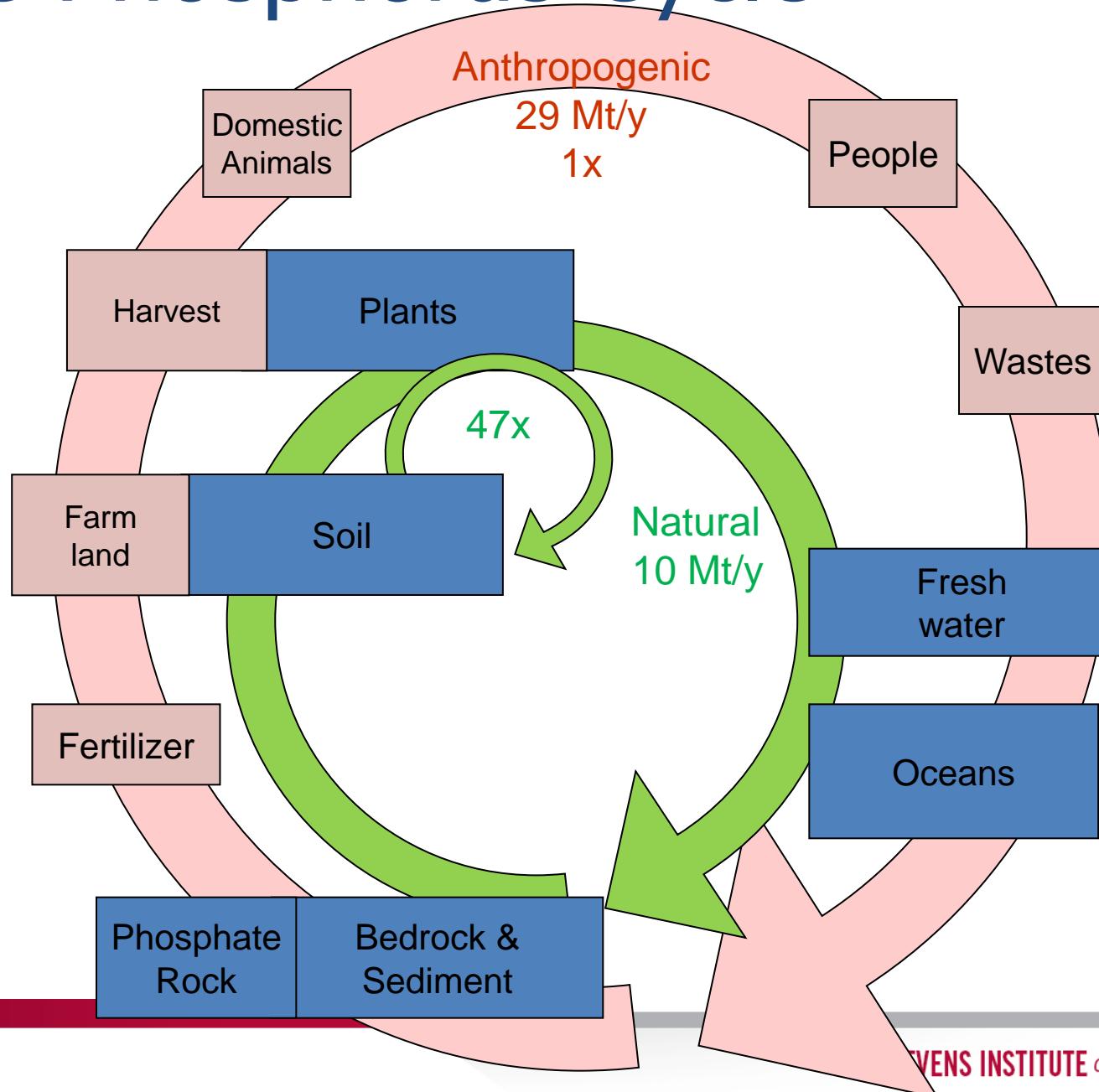
# Where do we get our phosphorus from?

How long will it last?

# Natural Sources: Erosion, Sedimentation, Flooding



# The Phosphorus Cycle



# 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 Adrienne Appel, New York Times, August 4, 2007



12,000 hp = 9 MW

# 2012 estimation of global reserves - USGS



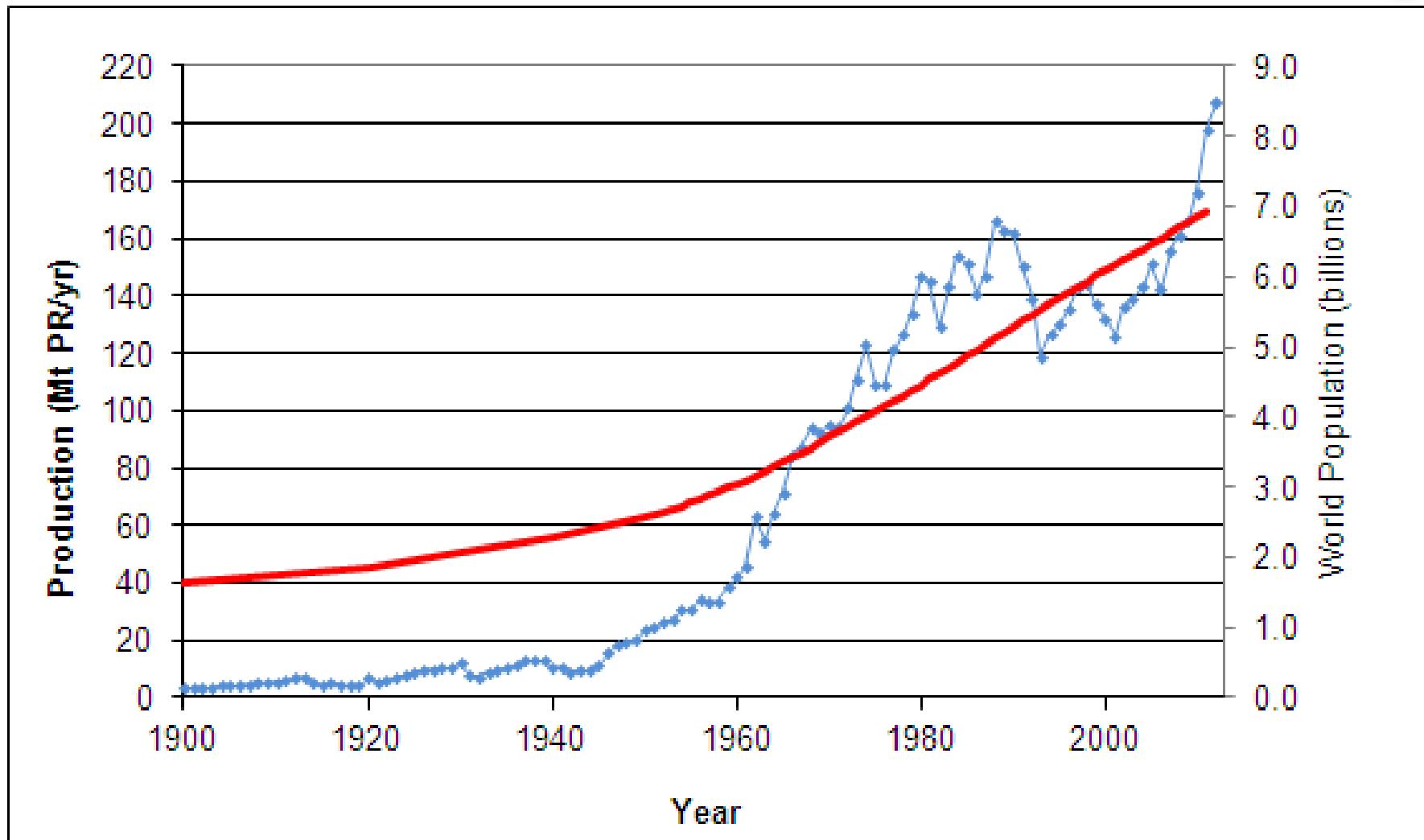
Mt or Mt/yr	Production	Reserves	Life	Production % of global	Reserves % of global
Morocco_and_Western_Sahara	28.00	50,000	1786	13.3%	74.4%
China	89.00	3,700	42	42.4%	5.5%
Algeria	1.50	2,200	1467	0.7%	3.3%
Syria	2.50	1,800	720	1.2%	2.7%
Jordan	6.50	1,500	231	3.1%	2.2%
South_Africa	2.50	1,500	600	1.2%	2.2%
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%
<b>World_total (rounded)</b>	<b>210</b>	<b>67,000</b>	<b>319</b>		



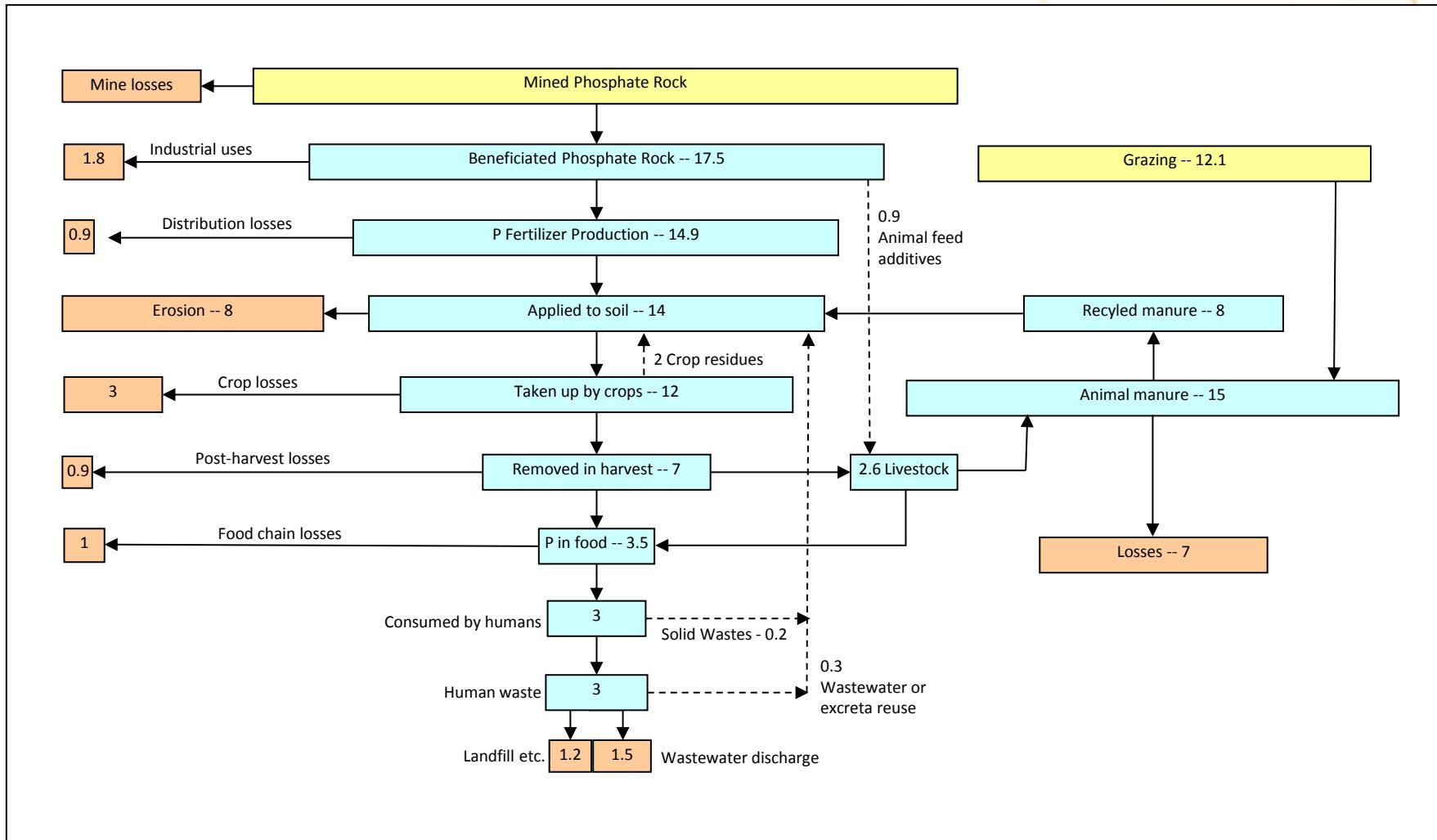
# Morocco and Western Sahara – The Saudi Arabia of Phosphorus



# Global Trend in Production and Population



# Flow of P in our Food System





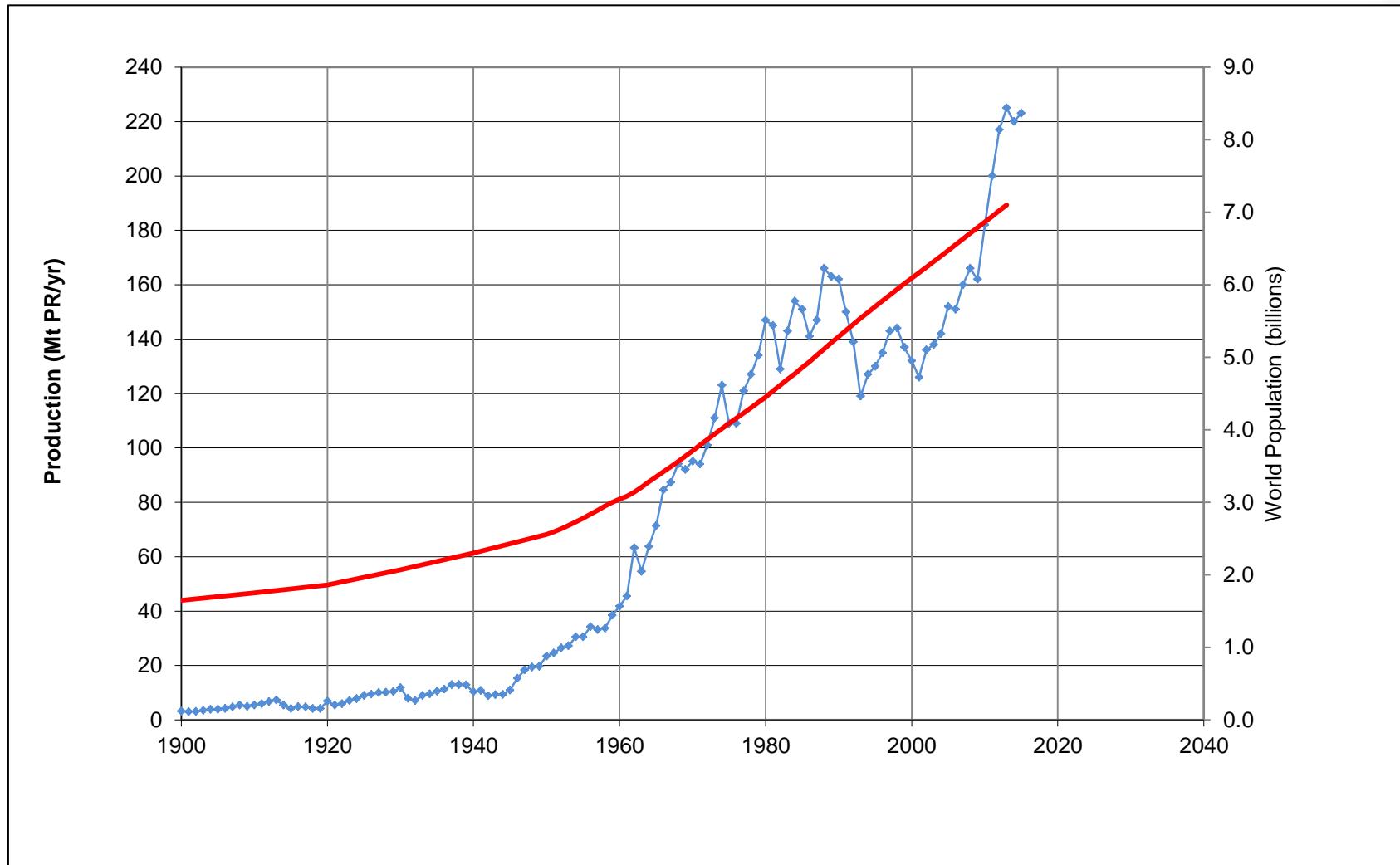
# Forecasting Phosphorus Demand

# 2012 estimation of global reserves – International Fert. Devel. Corp (IFDC) &

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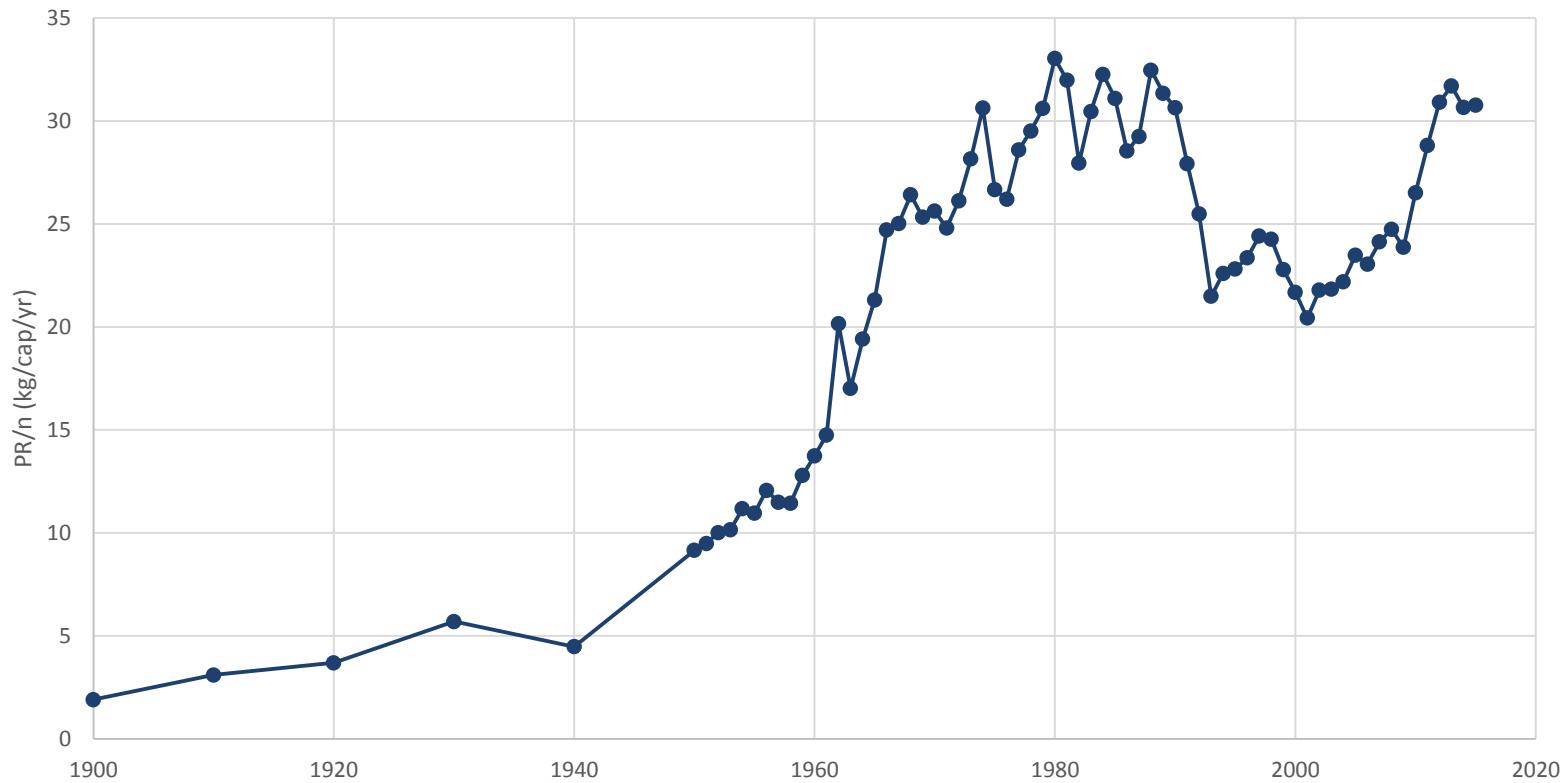


# Global Trend in Production and Population



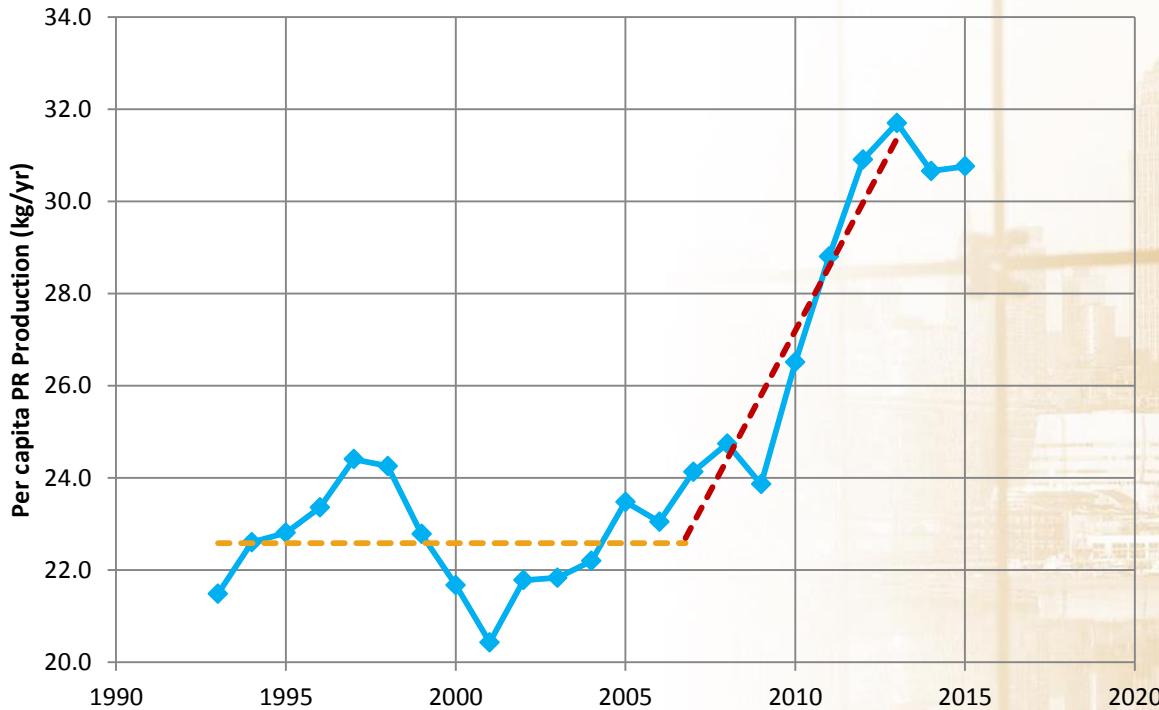


# Per Capita Global PR Production

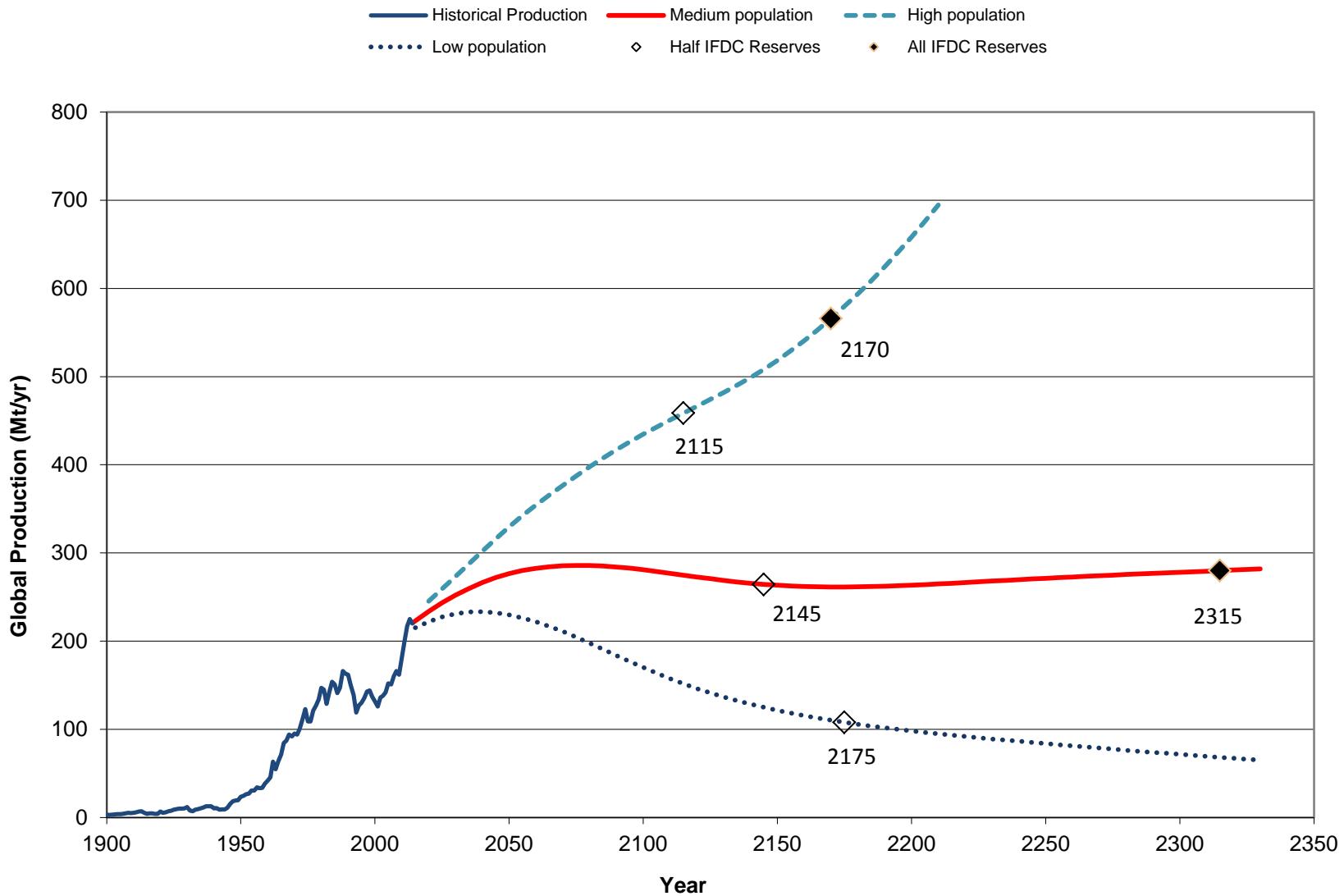


	Kg PR /cap/yr	g P /cap/d
Avg 1974-1990	30.1	10.8
Avg 1993-2008	22.7	8.15

# Recent trend in per-capita production

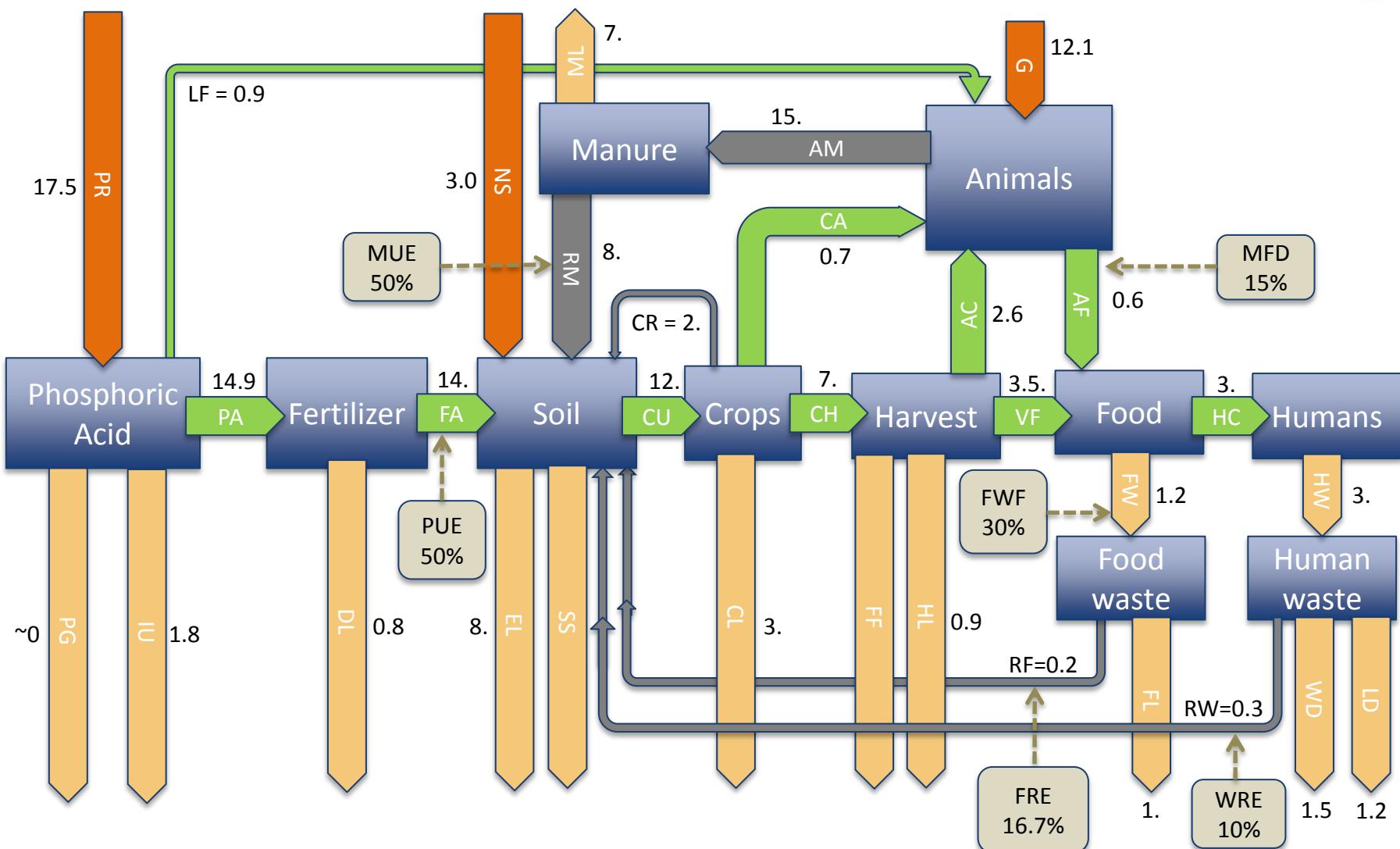


# Assume constant per-capita PR

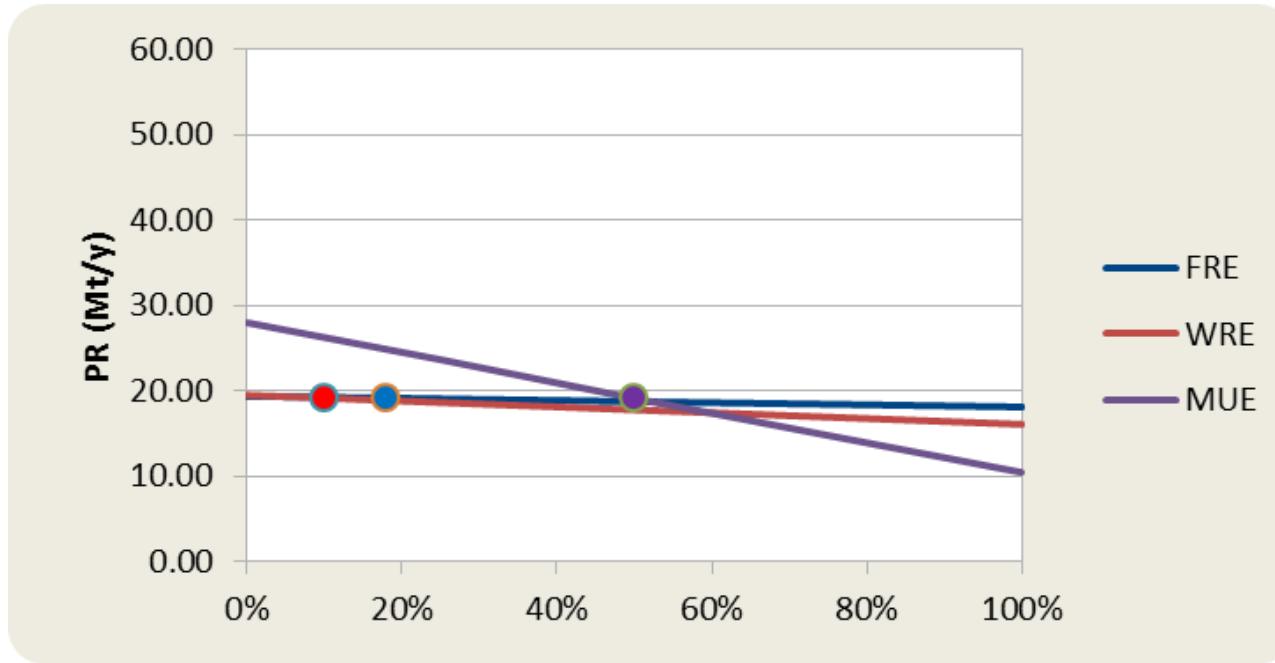


# Material Flow Analysis (MFA) of Global Phosphorus Flows

(based on Cordell, et al, 2009)



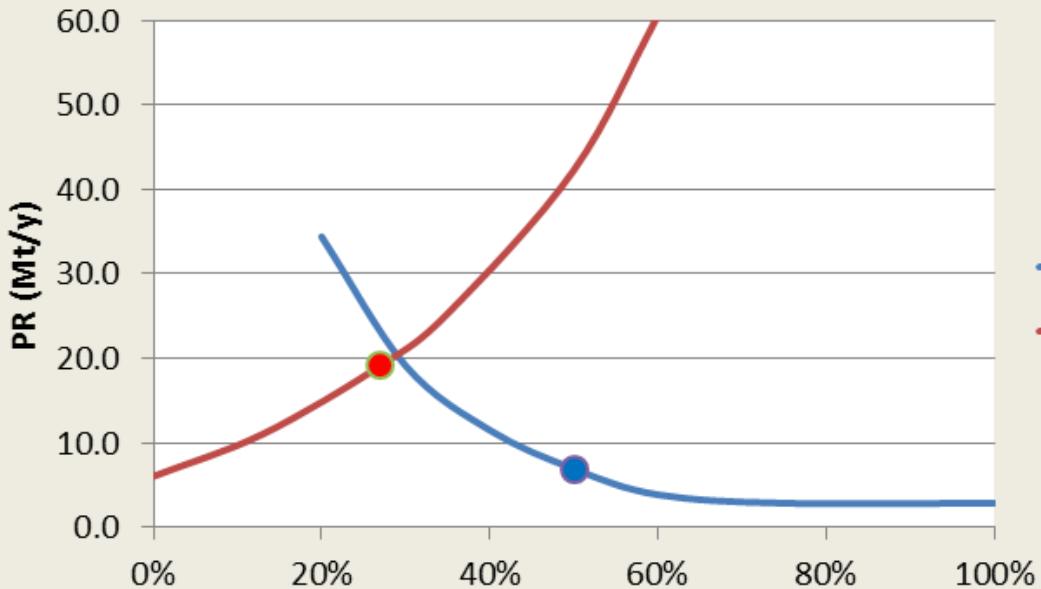
# Effects of Manure Recycling Efficiency (MUE), Food Waste Recycling Efficiency (FRE), and Human Waste Recycling Efficiency (WRE)



Relative sensitivity	
MUE	-0.92
<b>WRE</b>	<b>-0.18</b>
FRE	-0.066

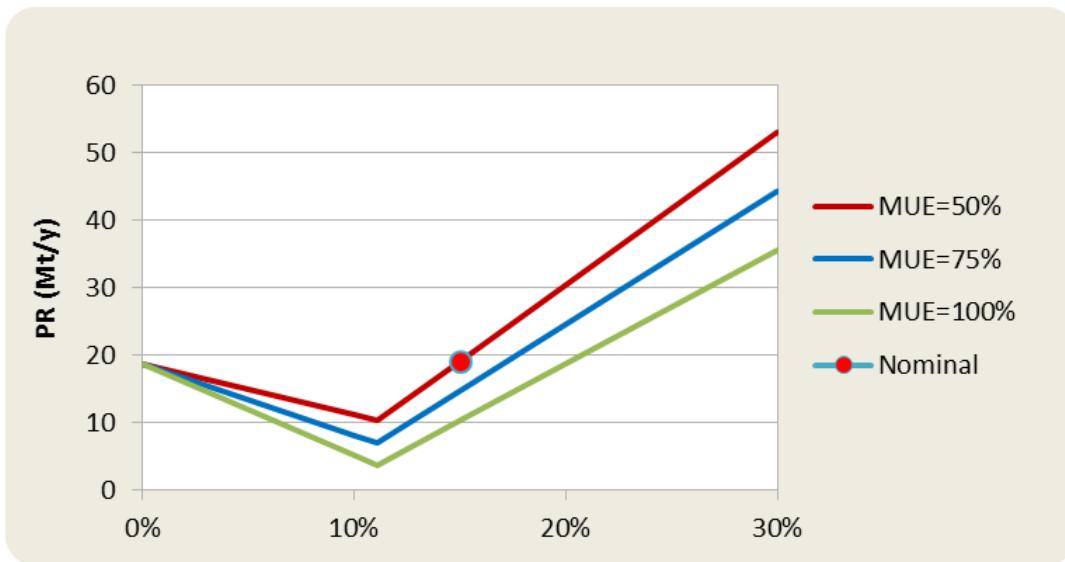
I.e.: Increasing WRE by 1% would decrease PR consumption by 0.18%

# Effects Ag P Use Efficiency (PUE) and Fraction of Food Wasted (FWF)



Relative sensitivity	
FWF	3.4
PUE	-6.0

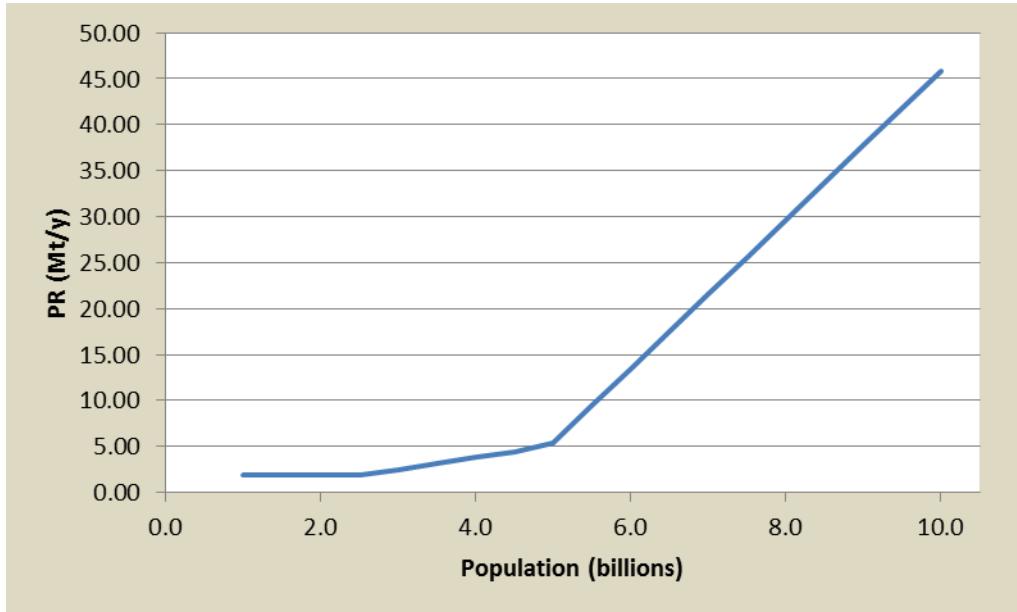
# Effects of Meat Fraction in Diet (MFD) Interacting with MUE



Optimize	% Impr.
MFD	46%
FWF	68%
PUE	85%
MUE	46%
WRE	16%
FRE	5.4%

Optimum does not take into account cost or feasibility of the intervention

# Effect of Population



Relative sensitivity	
MFD	11.9
PUE	-6.0
FWF	3.4
Population	2.4
MUE	-0.92
WRE	-0.18
FRE	-0.066

Relative sensitivity = 2.4

I.e.: Decreasing population by 1% decreases PR demand 2.4%



# Cycle interactions - Nutrients

- Phosphorus production requires sulfur
- Nitrogen production requires energy (natural gas)
- Natural gas production produces sulfur



# Cycle interactions - Food

- Food production requires energy
- Food production requires nitrogen
- Food production requires phosphorus
- Utilization of fertilizer requires irrigation
- Food production requires arable land
- Natural terrestrial ecosystems recycle nutrient and contribute OM for topsoil formation
- Harvesting removes nutrients and OM from land

# Using corn for bio-fuel production

(courtesy James Barnard)

**An estimated  
1.7 Mtons of  
phosphorus being  
used for making  
bio-fuels**

With 40% of the grain crop going to bio-fuels for no gain in energy and enormous subsidies

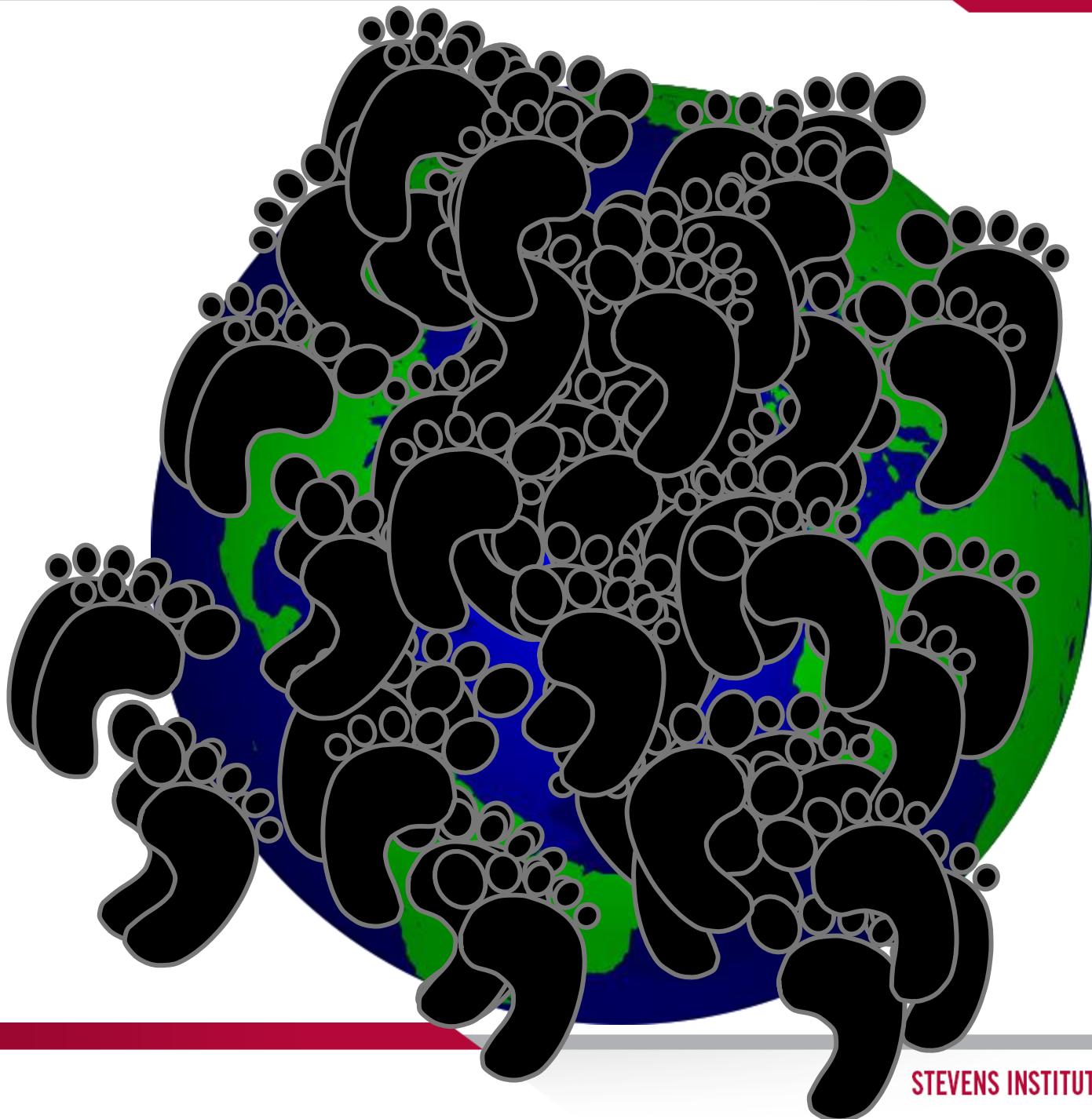




# What is needed

- Reduced “footprint”
- Population reduction

- Political will:
  - ❖ Long-term view
  - ❖ Resource sharing
  - ❖ Interest in others’ welfare
- Women’s rights and education



STEVENS INSTITUTE of TECHNOLOGY

The background image shows an aerial view of the New York City skyline across the Hudson River. In the foreground, the Stevens Institute of Technology campus is visible, featuring modern buildings, green lawns, and trees. The Hudson River flows through the center, and the Manhattan skyline with the One World Trade Center is prominent in the distance.

# Thank you

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