c2

NITROGEN BACKGROUNDER

Overview

The **Nitrogen Backgrounder** is a set of five presentations (or modules) and a depository of supporting documents on the subject of reactive nitrogen (rN). At the request of the Associate Administrator for the Office of Policy, Economics, and Innovation (OPEI), National Center for Environmental Economics in the Office of Policy, Economics and Innovation (NCEE) organized and led an agency-wide effort to assemble the information and produce the material. Scientists and experts from throughout EPA, with special assistance from the Office of Water (OW), Office of Research and Development (ORD), the Office of Air and Radiation (OAR), and the Office of International Activities (OIA), contributed through a series of workgroup teams that met for almost two years. Staff from OPEI, ORD, and OW presented the material to EPA senior management at an all-day retreat in Annapolis, Maryland on February 21, 2008.

The intent of the Backgrounder is to provide a basic understanding among EPA staff and others of a complex and persistent environmental problem--excess rN in the environment that is not bound up in long-term storage, such as soil complexes. The presentations explain not just the science of rN, but also the sources, the environmental and economic impacts, Federal regulatory and non-regulatory activity to mitigate its adverse impacts, and challenges to successful management.

As is true for most environmental issues, the science is dynamic, as research sheds new light on processes and relationships, and the economic drivers for the generation and removal of rN change over time. Management in response evolves. The Backgrounder thus represents a snapshot in time of what is known about rN and EPA and other federal agencies' actions regarding its origins and control.

EPA United States Environmental Protection Agency

Slide 1

c2 Draft presentation

ctsuser, 5/12/2009

NITROGEN BACKGROUNDER

1	**OVERVIEW**
2	**THE N-CYCLE IMPACTING HUMAN HEALTH AND THE ENVIRONMENT**
3	**INTERVENTIONS, CONTROL OPTIONS, AND ECONOMICS**
4	**CHALLENGES**
5	**INTEGRATION**

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NITROGEN BACKGROUNDER

Module 1: Overview

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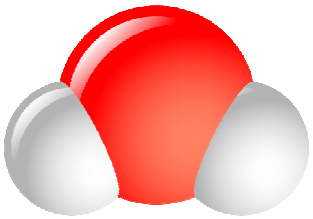
Slide 3

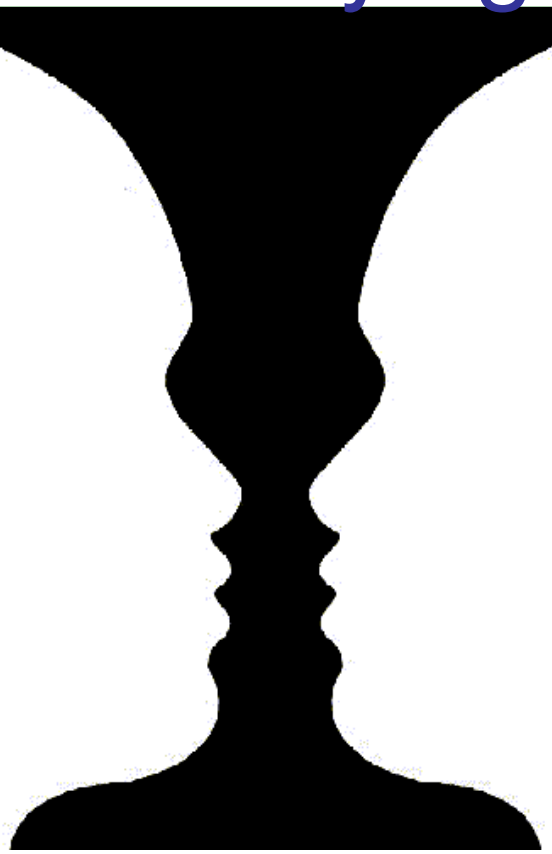
c1 Draft presentation
ctsuser, 5/12/2009

The ocean is 90% oxygen… but we'd suffocate trying to breathe it!

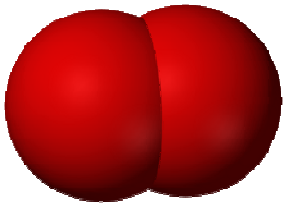
H_2O



Un-Breathable Oxygen

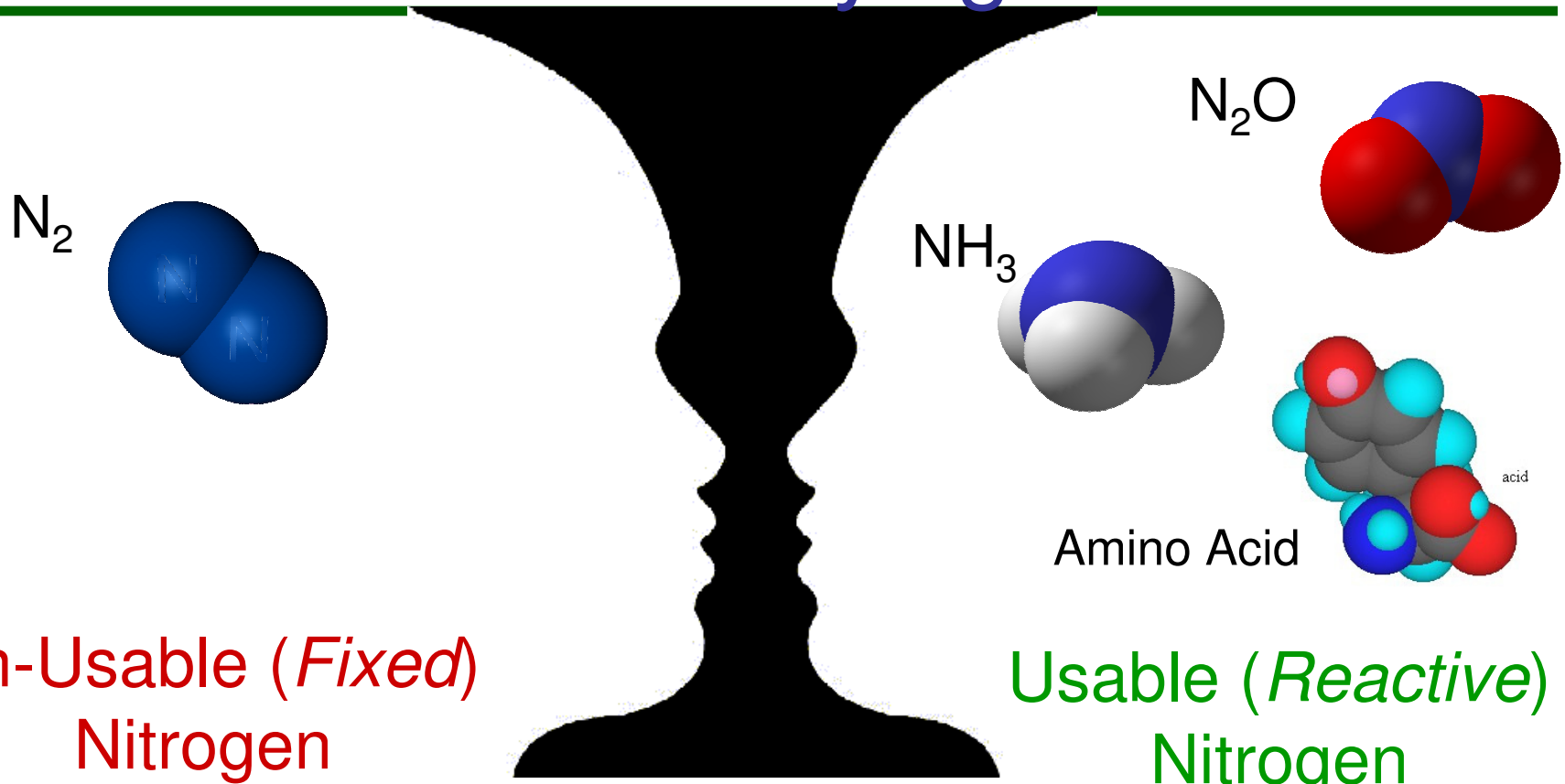


O_2



Breathable Oxygen

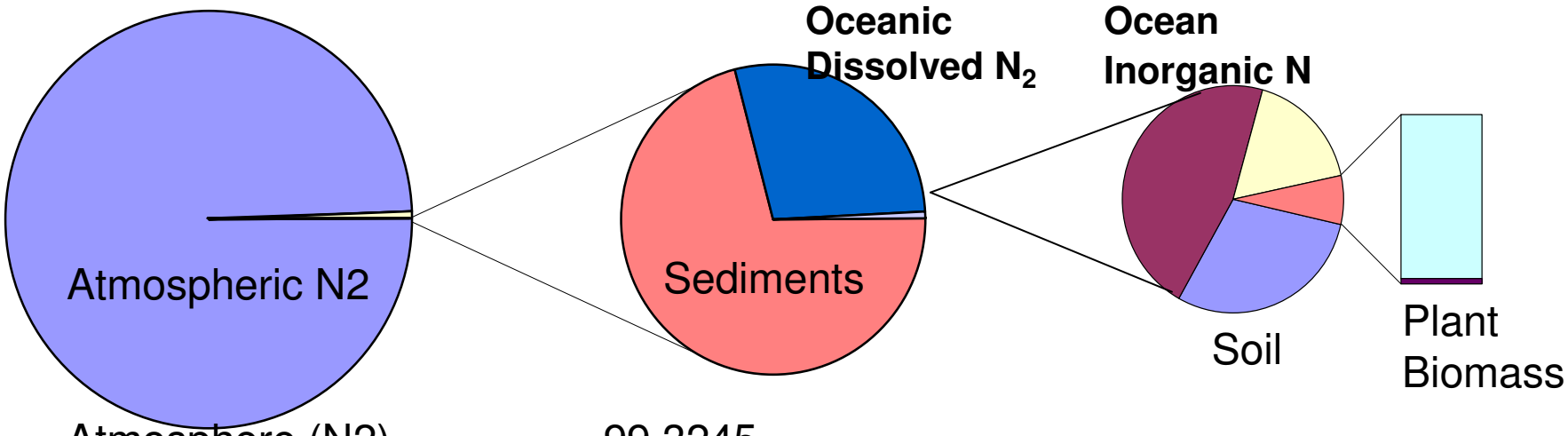
The atmosphere is 80% nitrogen… but we'd starve trying to eat it!



Un-Usable (*Fixed*) Nitrogen

Usable (*Reactive*) Nitrogen

Global Reservoirs of REACTIVE Nitrogen



~~Atmosphere (N2)~~	~~99.3245~~
~~Sediments~~	~~0.5468~~
~~Ocean (Dissolved (N2)~~	~~0.1242~~
Ocean Inorganic	0.0015
Soil	0.0024
Terrestrial Biomass	0.0009
Atmosphere (N_2O)	0.0003
Marine Biomass	0.0000

Only 0.001% is "available" for biological production.

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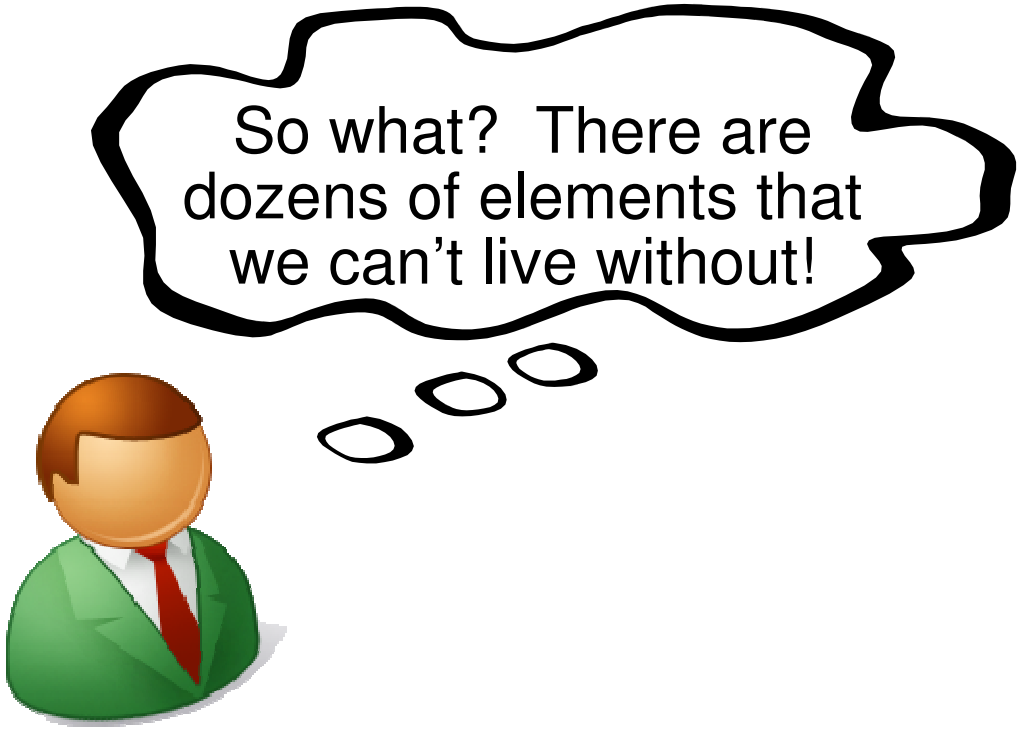
Definition of rN for the Purposes of the Nitrogen Backgrounder

- rN that is not locked up in organic complexes (soils with carbon to nitrogen ratios generally of 10 to 12)
- rN not in other long-term storage

Why Nitrogen?

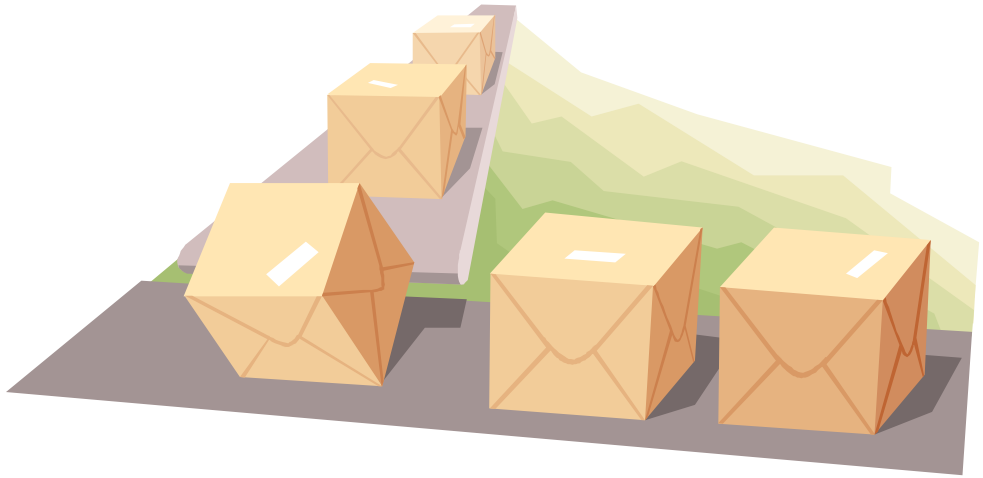
- Nitrogen is essential to all forms of life. Without it, nothing can live or grow.



Why Nitrogen?

- It is typically the “limiting nutrient” in growth…

in an assembly line, when you run out of one of the parts production stop… Nature usually runs out of r-N first

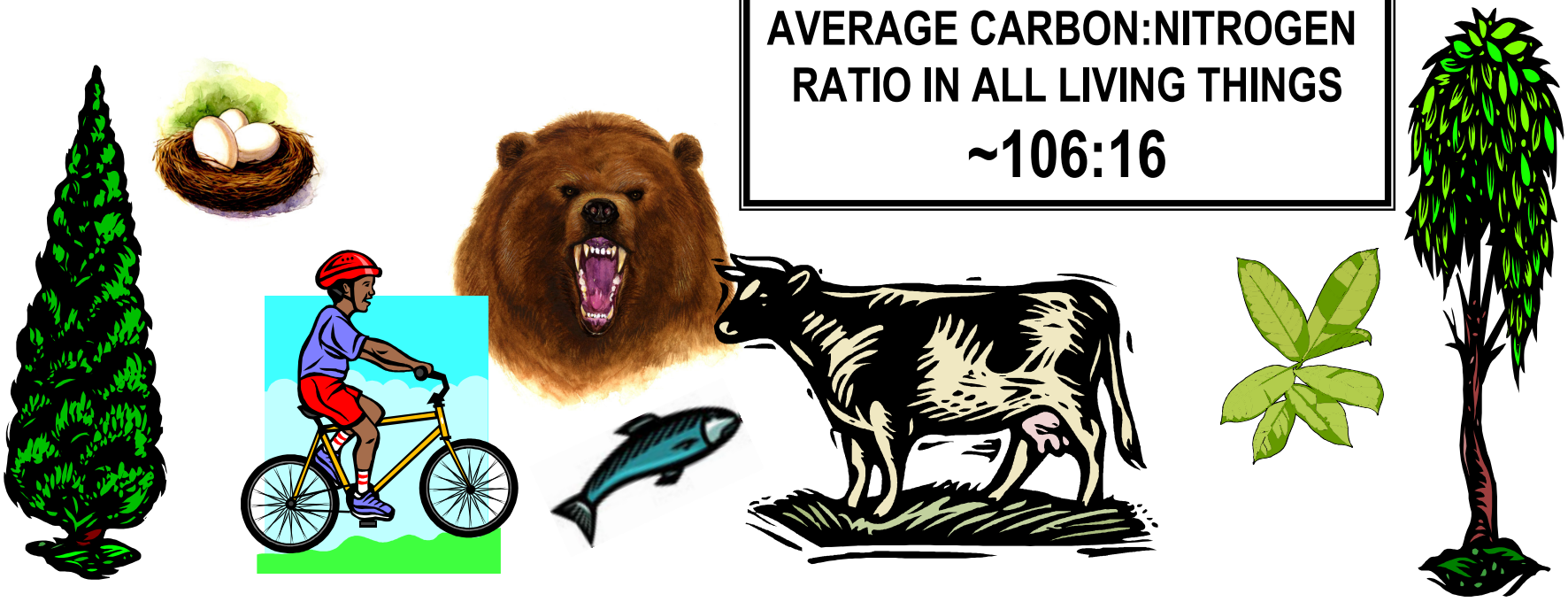


Why Nitrogen?

- Since it is so important in limiting, or promoting growth … it is the major nutrient in most fertilizer.

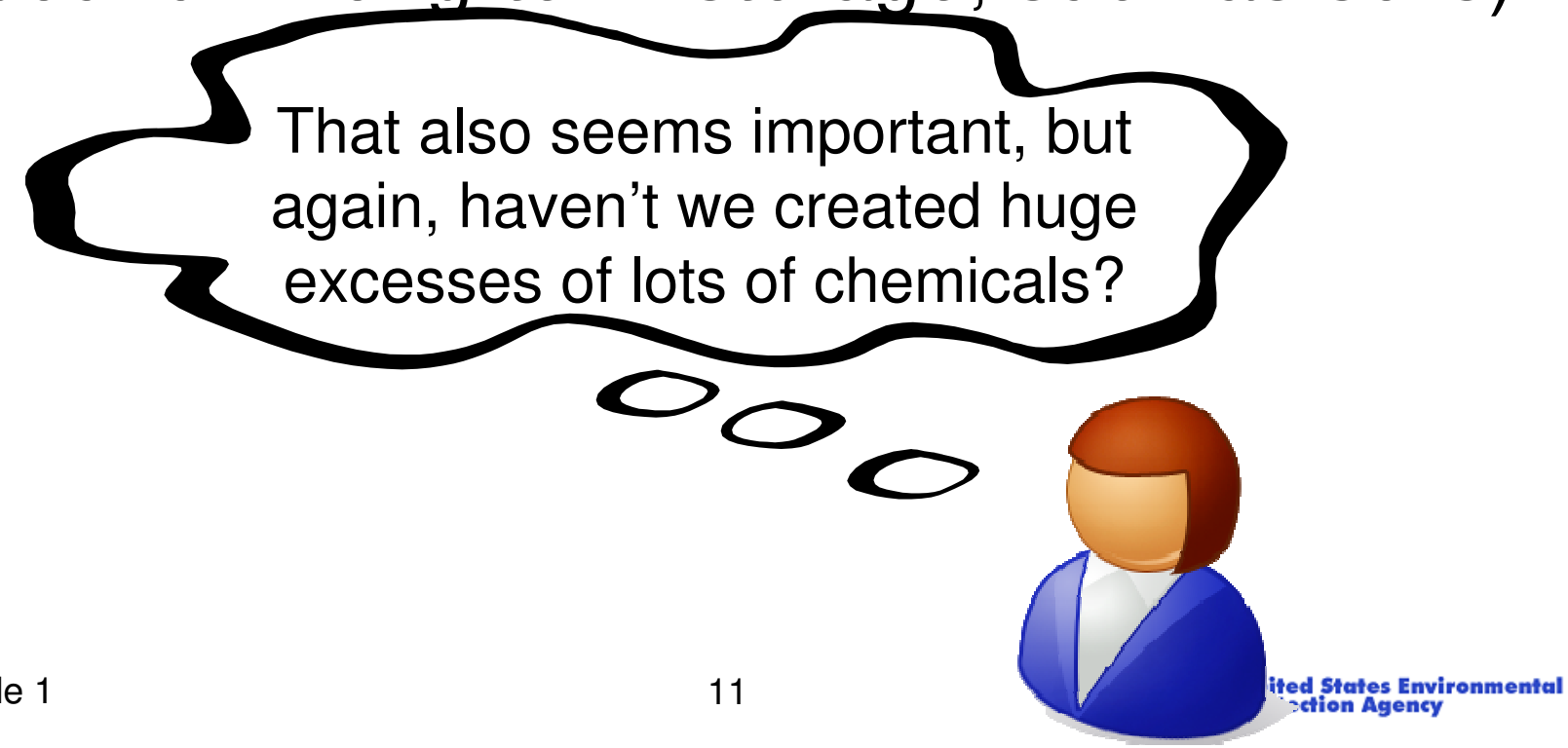
AVERAGE CARBON:NITROGEN RATIO IN ALL LIVING THINGS

~106:16



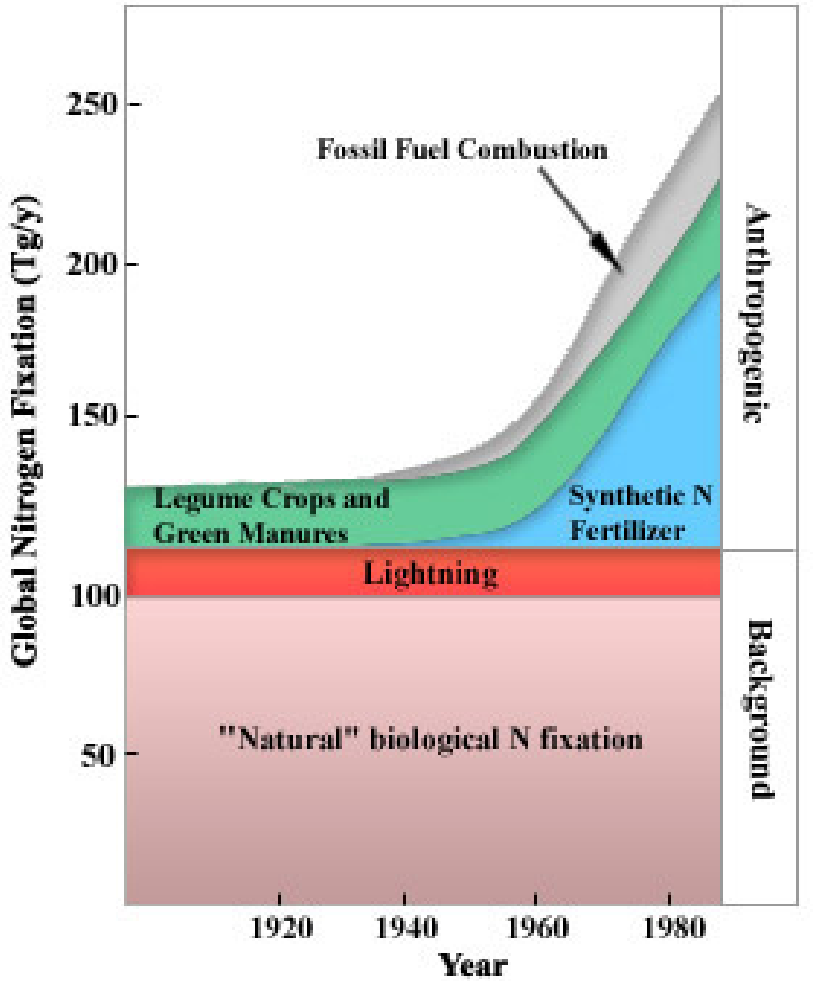
Why Nitrogen?

- Because of this humans have created a huge excess of reactive nitrogen (not bound in long-term storage, such as soils).



Why Nitrogen?
Nitrogen Excess Is Unique

- Humans have more than doubled the yearly production of new reactive nitrogen over natural levels.
- Most additional reactive nitrogen comes from synthetic fertilizer production.



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Why Nitrogen?
Nitrogen Excess Will Get Worse

- Limiting Nutrient – How much N is made?
  - Dictates limits on plant and animal growth

- Equilibrium – How much N accumulates?
  - Determined by natural forces and human actions

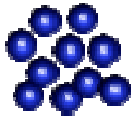
Why Nitrogen?
Understanding Equilibrium

- The next four slides illustrates how equilibrium would be reached in a simple system… wherein Nature produces 10 pounds of r-N from N_2 each year and the environment recycles 10% of that back into N_2 each year

DYNAMIC EQUILIBRIUM
Year 1

- 10%

+ 10 lbs.

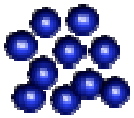


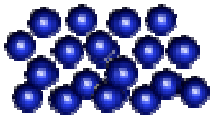
10 lbs -10% = 9 lbs

DYNAMIC EQUILIBRIUM
Year 2

- 10%

+ 10 lbs.



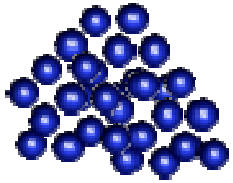


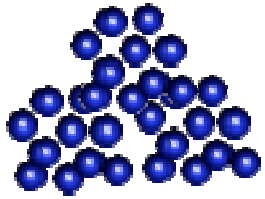
(9 + 10) lbs -10% = ~17 lbs

DYNAMIC EQUILIBRIUM
Year 3

- 10%

+ 10 lbs.





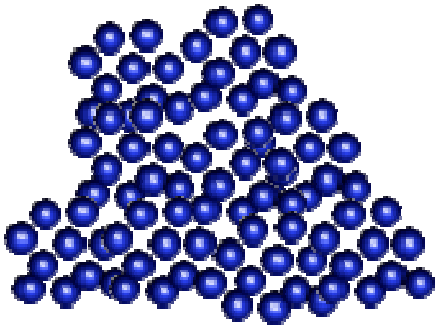
(17 + 10) lbs -10% = ~24 lbs

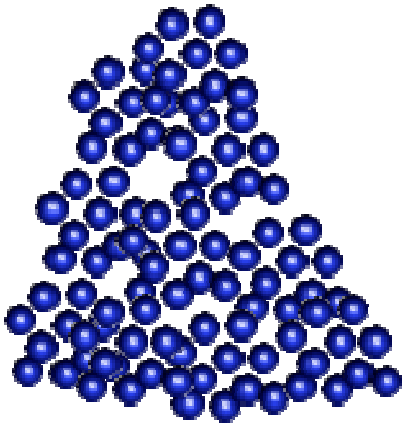
DYNAMIC EQUILIBRIUM Over Time…

- 10%

Equilibrium achieved!

+ 10 lbs.



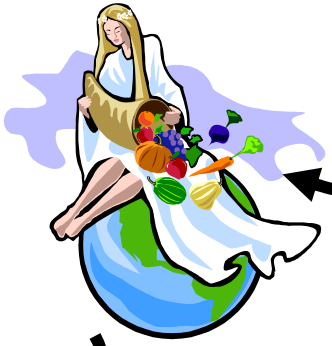


(90 + 10) lbs -10% = 90 lbs

. . . but what if man starts adding r-N as well?

- The next three slides show how the equilibrium shifts as a new source of r-N is added

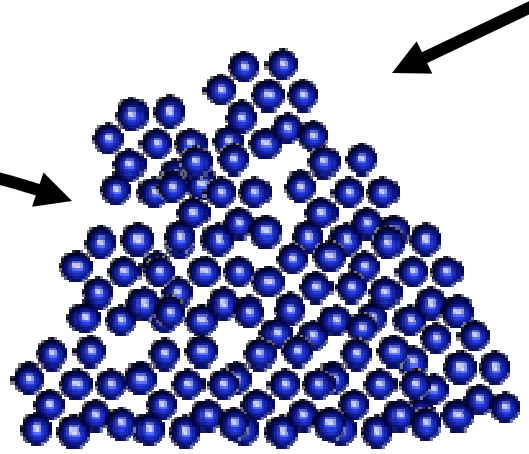
ACCUMULATION
Year 11

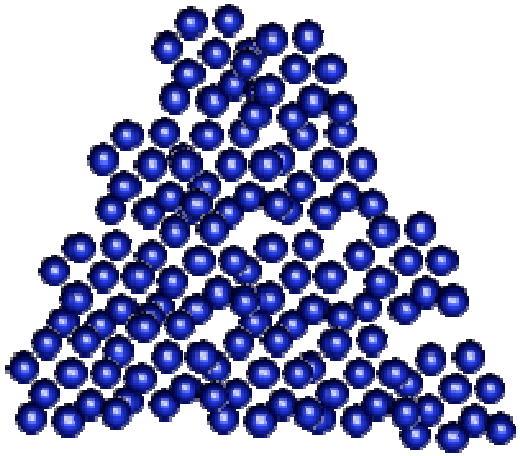


- 10%

+ 10 lbs.

+ 10 lbs.





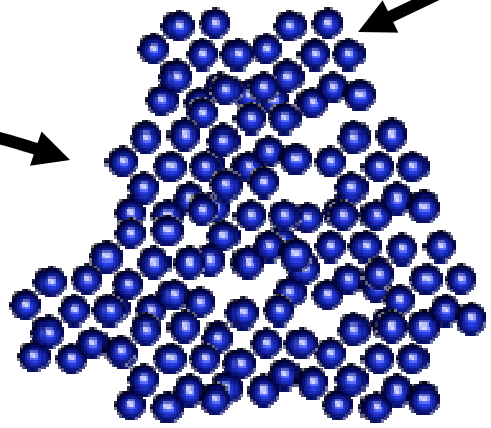
(90 + 20) lbs -10% = 99 lbs

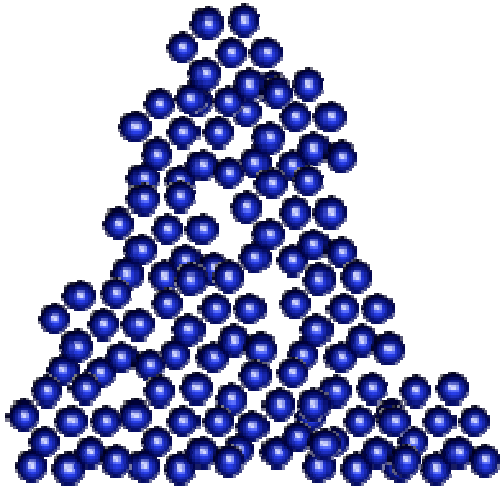
ACCUMULATION
Year 12

- 10%

+ 10 lbs.

+ 10 lbs.

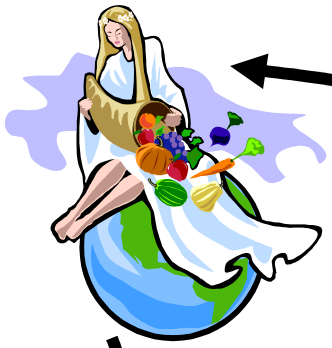




(99 + 20) lbs -10% = 107 lbs

ACCUMULATION…a new equilibrium

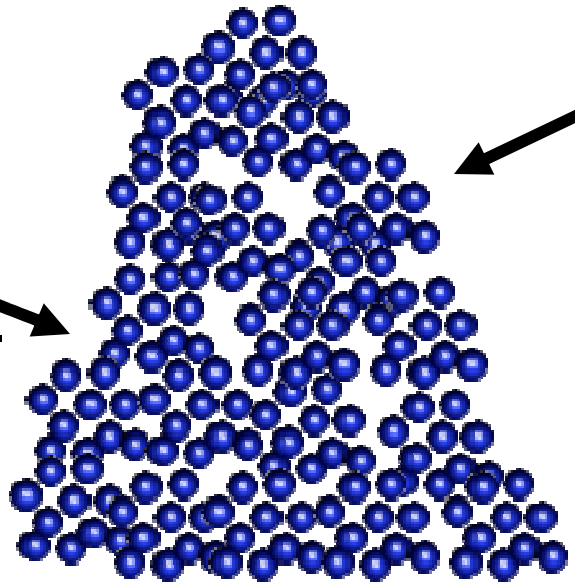
Year 20

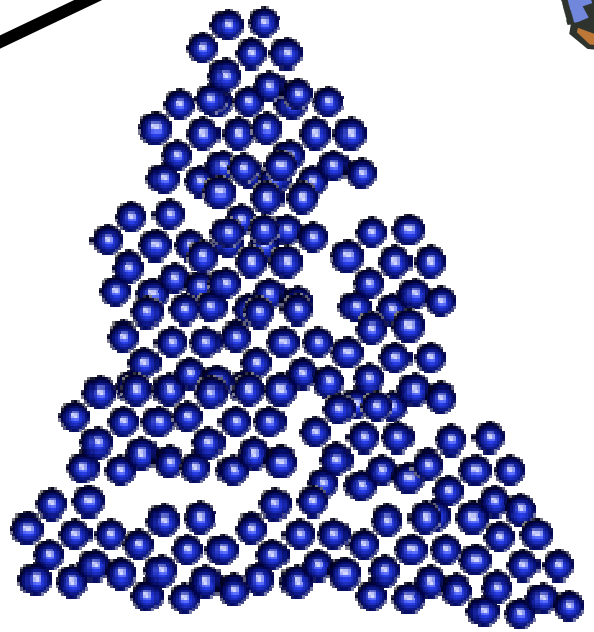


- 10%

+ 10 lbs.

+ 10 lbs.





(148 + 20) lbs -10% = 151 lbs

But it isn't that simple…man increases how much he adds each year…AND development decreases denitrification mechanisms (wetlands estuaries where this occurs are destroyed

Increased N Production (Fixation)

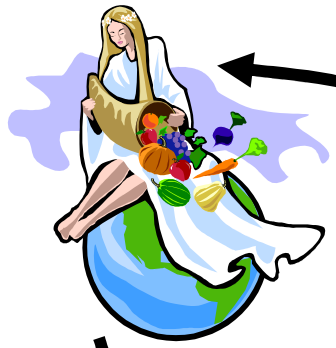
10lbs
11lbs
12lbs
etc.

Decreased Opportunity for Denitrification

10%
9.9%
9.8%
etc.

The next slide shows what effect this increased production, decreased recycling would have on accumulation

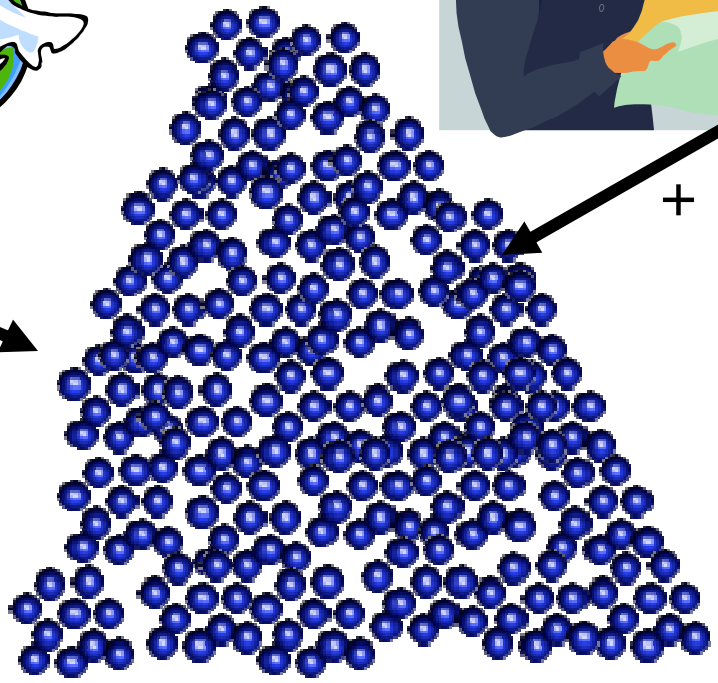
ACCUMULATION
Year 20

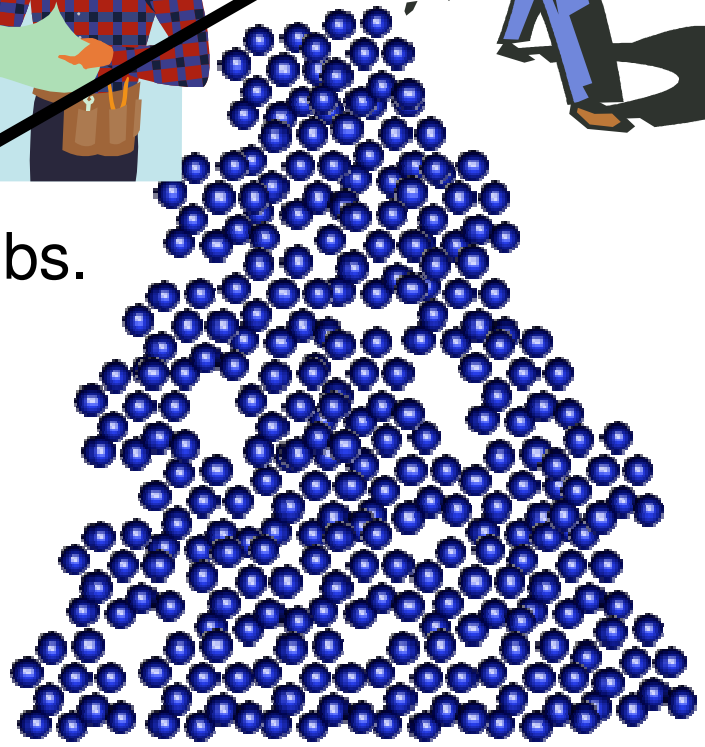


- 9%

+ 10 lbs.

+ 10 lbs.





(200 + 20) lbs - 9% = 208 lbs

Some of this accumulation is in long-term storage, such as soils or plants

This is good!

Top Four Ways To "Fix" Nitrogen
(i.e., Make Reactive Nitrogen)

1) Haber-Bosch Process

Hydrogen + Nitrogen → Ammonia → Nitrates, Nitrites
(from NG) (from air) (high T/P; Fe catalyst) (Fertilizer)

2) Biological Nitrogen Fixation (BNF): atmospheric nitrogen is converted to ammonia by a pair of bacterial enzymes called NITROGENASE

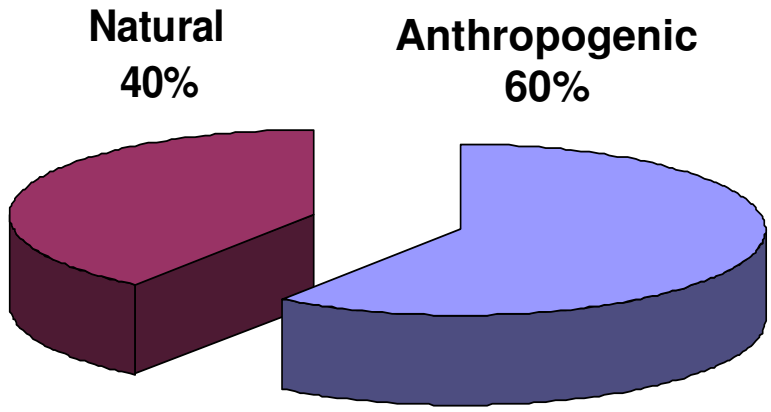
$$N2 + 8H+ + 8e- + 16\ ATP \rightarrow 2NH3 + H2 + 16 ADP + 16\ Pi$$

3) N_2 oxidized by Combustion

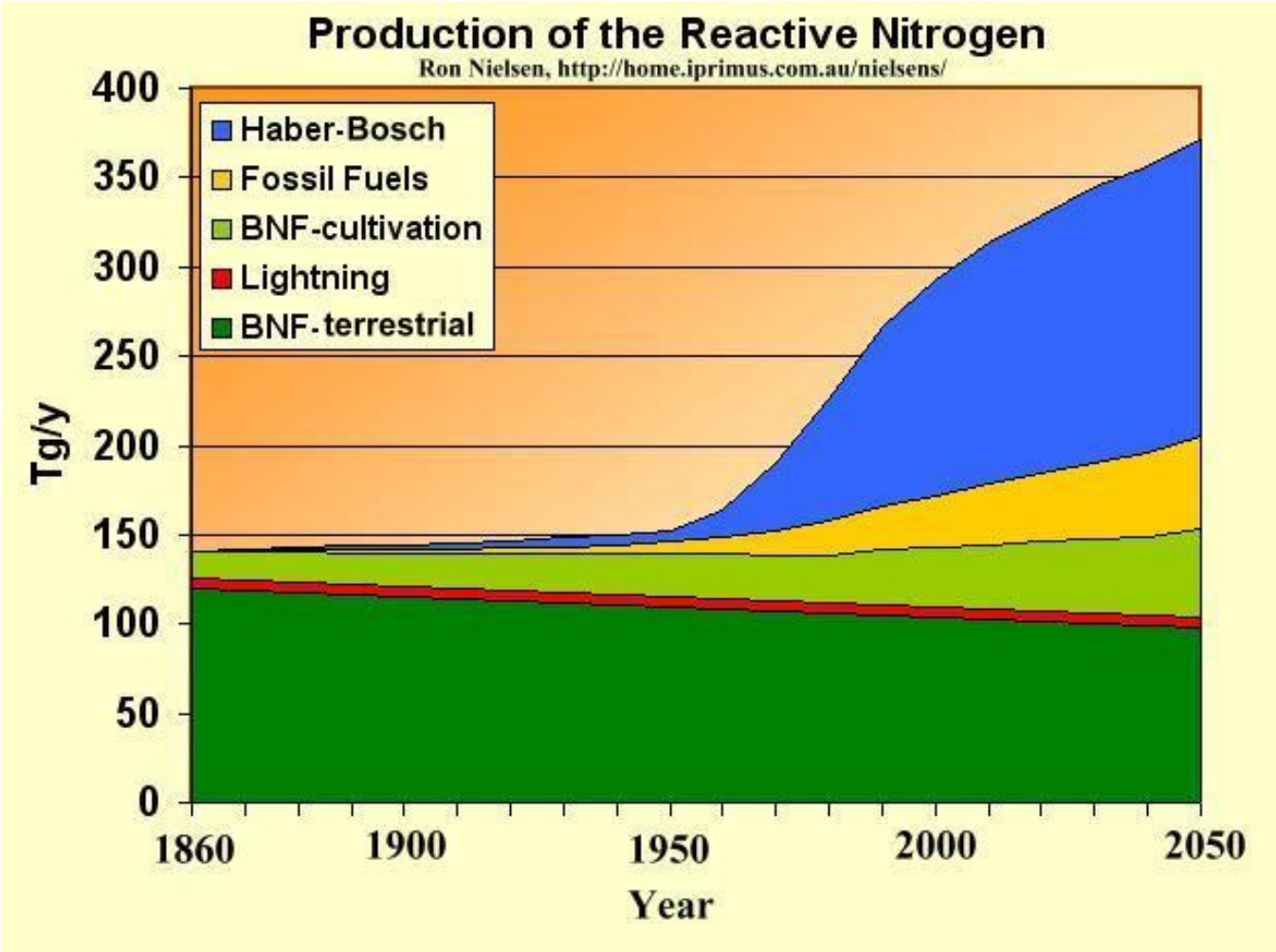
4) N_2 oxidized by Lightning

Anthropogenic Sources of Reactive N Now Exceed The Sum of All Natural Sources

ANTHROPOGENIC SOURCES	Global Annual Release Of Fixed Nitrogen (teragrams)
Fertilizer	80
Legumes and other plants	40
Fossil fuels	20
Biomass burning	40
Wetland draining	10
Land clearing	20
Total from human sources	**210**
NATURAL SOURCES	
Soil bacteria, algae, lightning, etc.	140

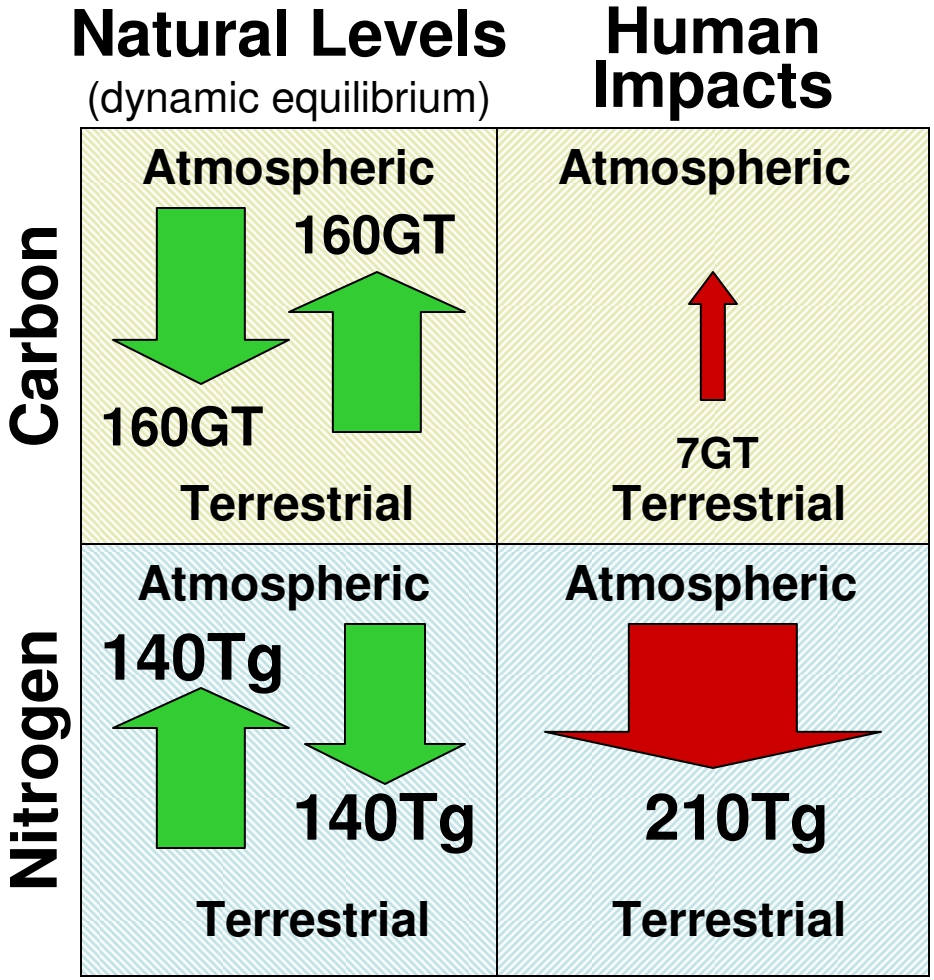


And It's Accelerating



The Scale of the Problem: Nitrogen vs. Carbon

- CO_2 production is a major driver for climate change: an urgent, global concern.
- In nature, both reactive N and CO_2 maintain a dynamic equilibrium.
- Compare human production of reactive N to human CO_2 production.
- Anthropogenic reactive nitrogen inputs dwarf the natural equilibrium.



*1 GT (gigaton) = 100 Tg (teragram)

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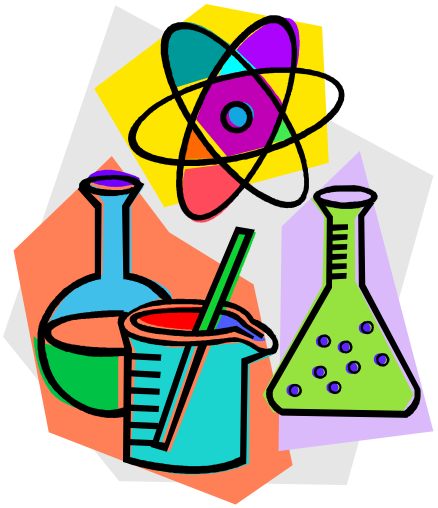
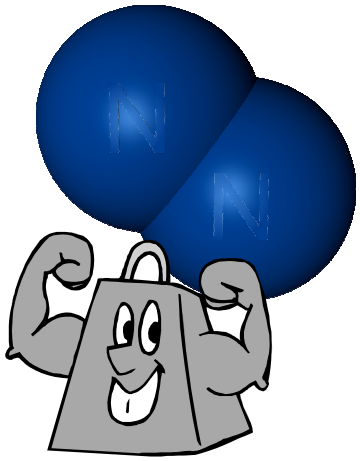
- The real reason N has become a problem is all because of chemistry…



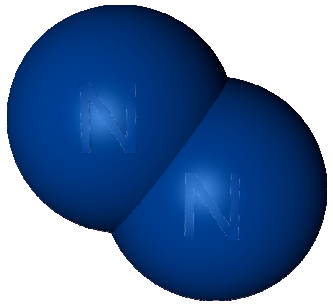
Two Kinds of Nitrogen

- Nitrogen (N) is a common chemical element.
- Most N is found in stable N_2 molecules.
- The N_2 triple bond is **<u>extremely strong</u>**, among the strongest in nature.
- N_2 cannot be used as a nutrient unless it somehow changes form...

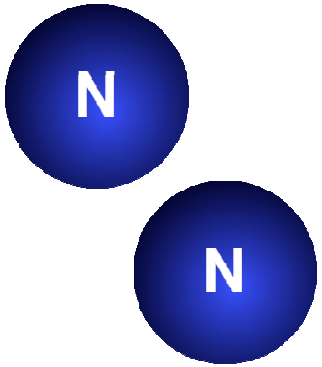


Two Kinds of Nitrogen

- When N_2's bond is broken, N becomes reactive.
  - **Definition**
    reactive – participating readily in chemical reactions

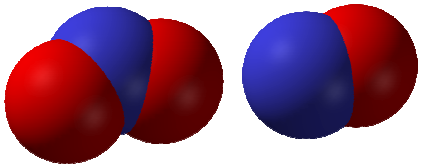


- Reactive nitrogen is highly labile: it bonds easily and often changes form, creating different molecules.

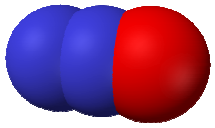


Many Forms, Many Reasons

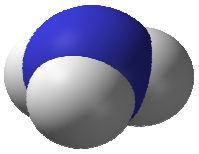
- Reactive nitrogen takes on many forms, including:



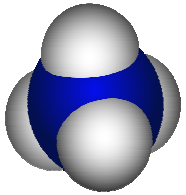
Nitrogen Oxides
NO_x



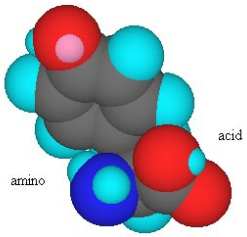
Nitrous Oxide
N_2O



Ammonia
NH_3



Ammonium
NH_4

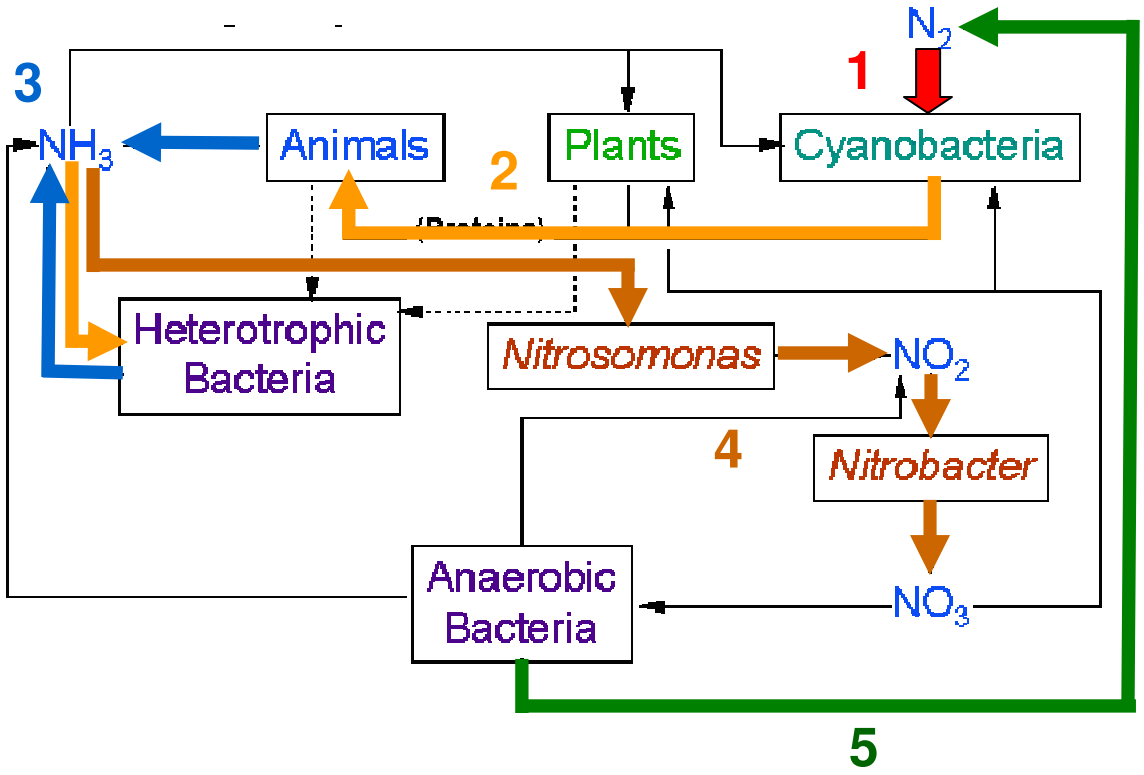


Amino
Acid

as well as bound in **organic complexes, such as soil**

- It changes form depending on conditions; it can provide energy by adding oxygen ("oxidized"), or in anaerobic conditions it can be a source of oxygen ("reduced")
- Unlike the stable N_2 molecule, reactive N can be used by living things, and can provide both benefits, and harmful effects

The Natural N-Cycle Involves Five Major Microbial Processes



1. Nitrogen Fixation

2. Uptake and Immobilization

3. Ammonification

4. Nitrification

5. Denitrification

Why is Reactive Nitrogen Doubling in the Environment?

- r-N is a limiting nutrient for growth. This is why r-N is a major component of fertilizer.
- Farmers have an economic incentive to use fertilizer—N fertilizer is necessary for growing populations--and even to overfertilize as insurance for yields
- Farmers have an economic incentive to grow crops that cause seasonal soil nitrogen imbalances, i.e., excess nitrogen that is not taken up by plants or bound in soil complexes.
- Excess nitrogen exported offsite to contaminate soil, air, and water.
- Component of fossil fuel. Combustion of fuel can release reactive nitrogen from long-term sinks or turn N_2 into reactive nitrogen.

All This Extra Nitrogen Is Not Good!

- There are no economic drivers for denitrification! Current economic drivers only promote formation of reactive N, never conversion back to N_2.
- In fact, there is evidence that **economic development decreases denitrification opportunities**!
- As population and growth increase, the balance is constantly shifted *toward* reactive nitrogen (not bound in long-term storage) and *away* from N_2.

Damages from Reactive Nitrogen

Reactive Nitrogen:

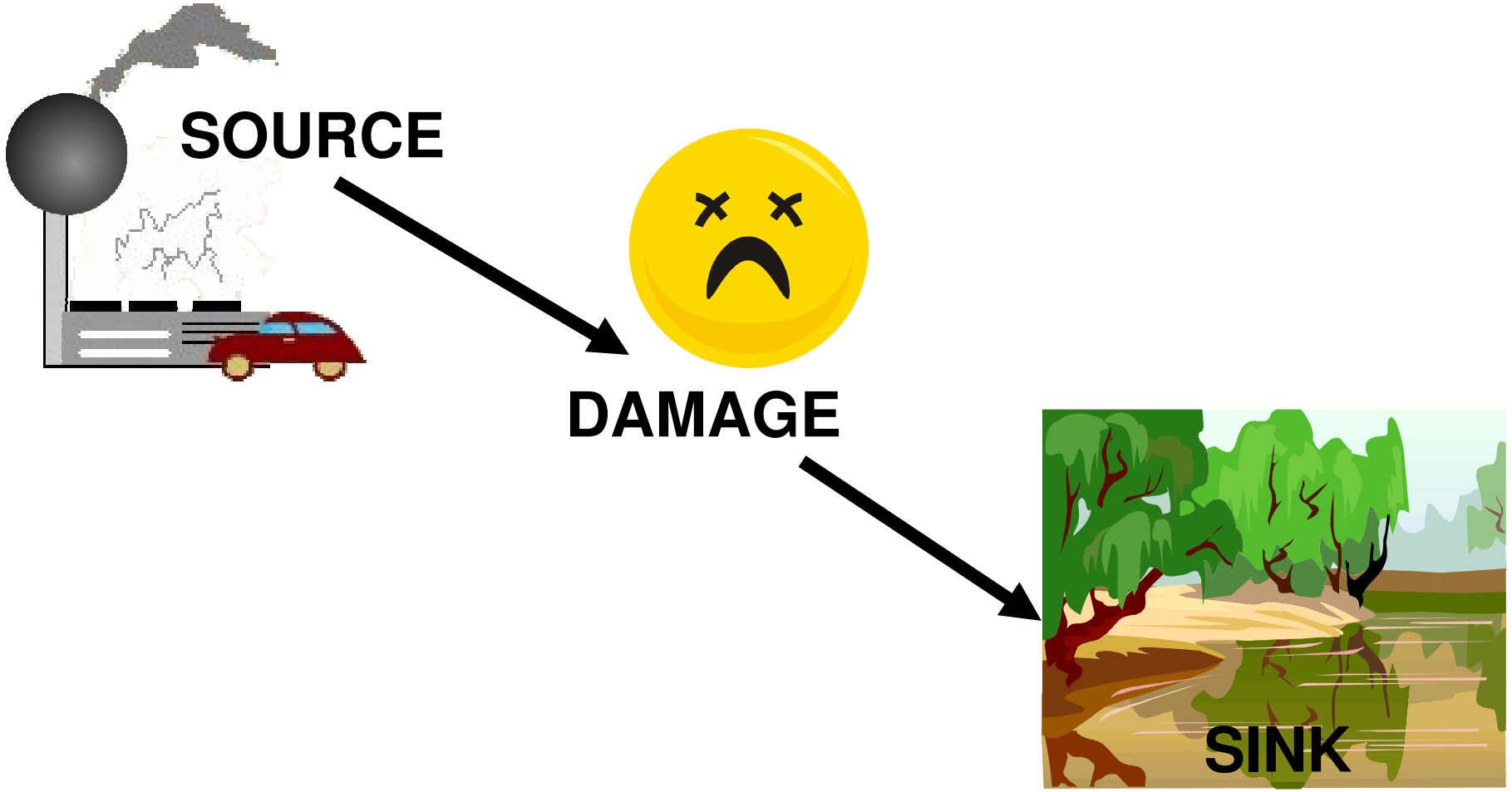
- Contributes to particulate matter formation
- Contributes to ozone formation
- Causes eutrophication and hypoxia in water bodies
- Acidifies waters and soils, damaging crops
- Forms N_2O, a greenhouse gas, with 300 times more warming potential than CO_2

Why Nitrogen? Because It's Different

- Most big-risk toxic pollutants tend to be long-lived. They do their damage, then find a place (a sink) to hang out.
  - Think of dioxins, lead, mercury, PCBs, etc.
- But N is different: it is labile. It changes forms easily.
- Each successive form can do additional damage. Nitrogen is a **serial offender**! What we have is:

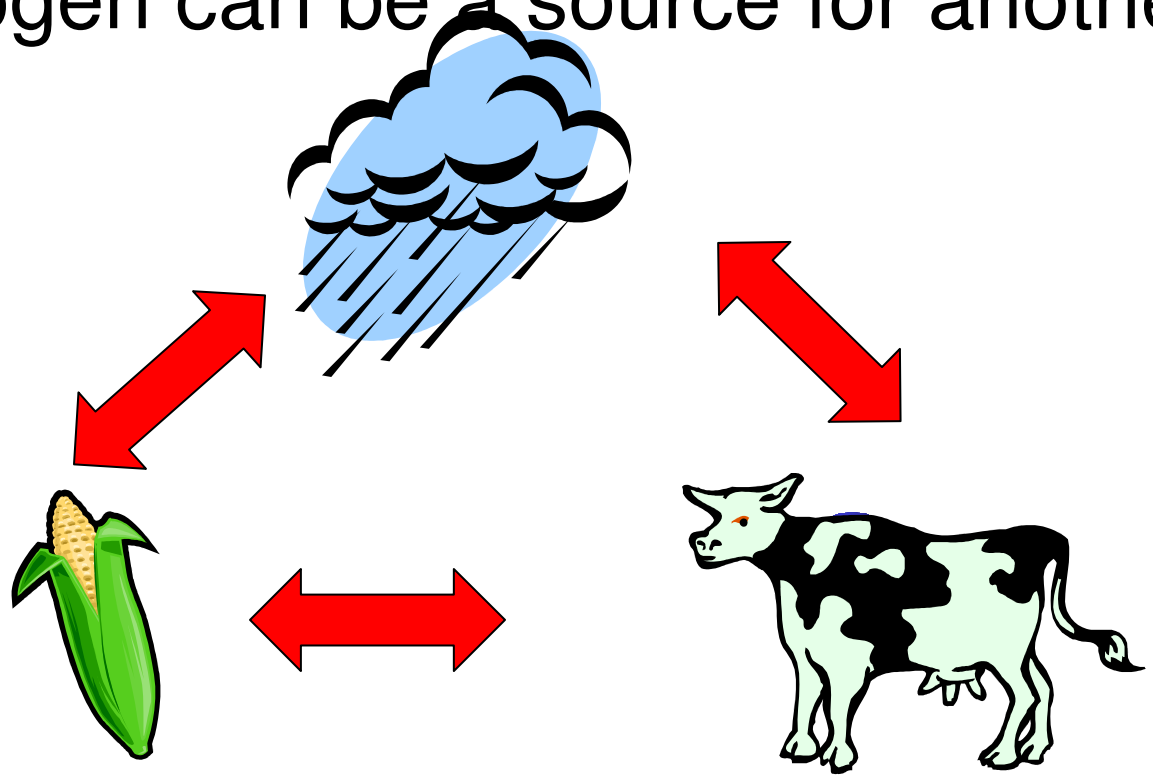
CHEMICAL RECIDIVISM!

A Typical Pollutant's Path

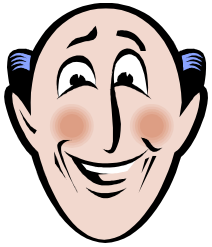


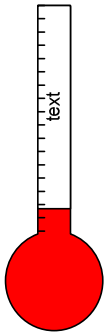
Sources and Sinks

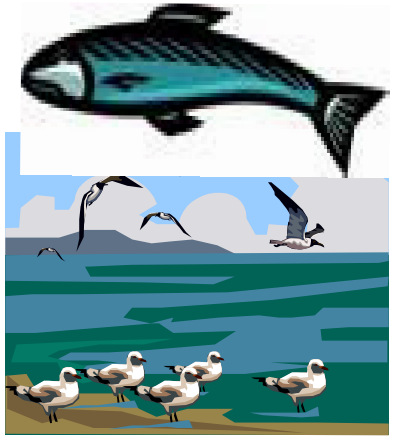
- Unlike most pollutants, a sink for one form of nitrogen can be a source for another.



In fact, r-N travels the enviroment like a pinball
As the next 4 slides demonstrate…
1) r-N is released from a corn field

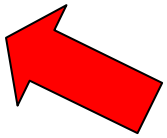


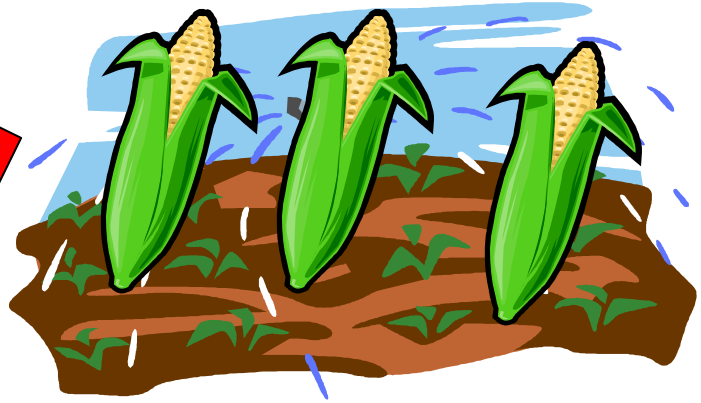




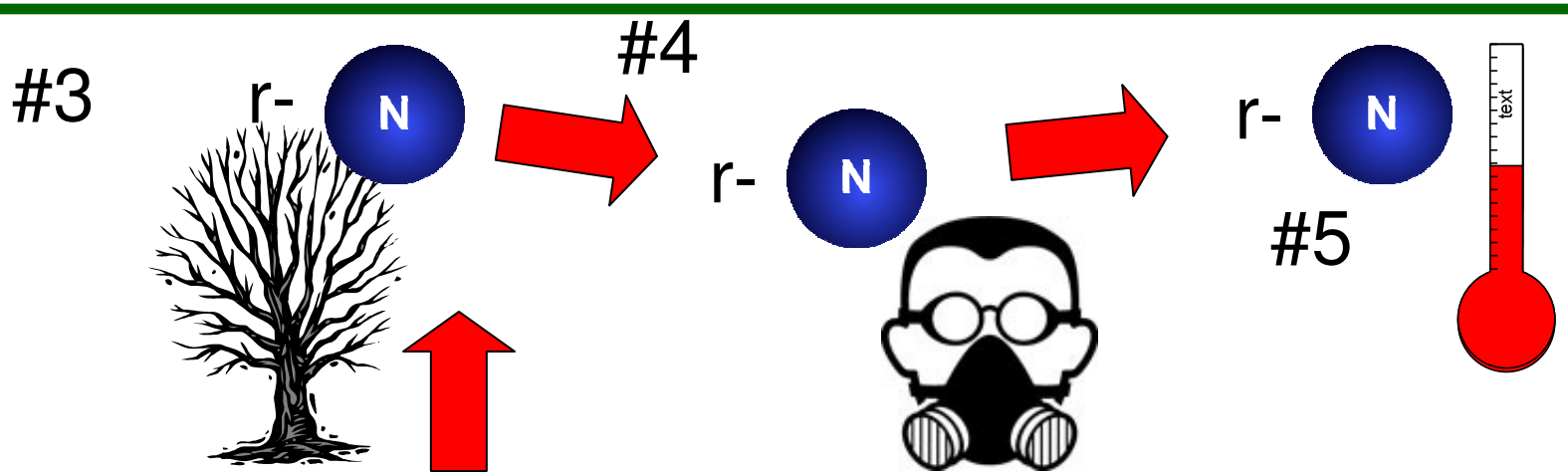
#1

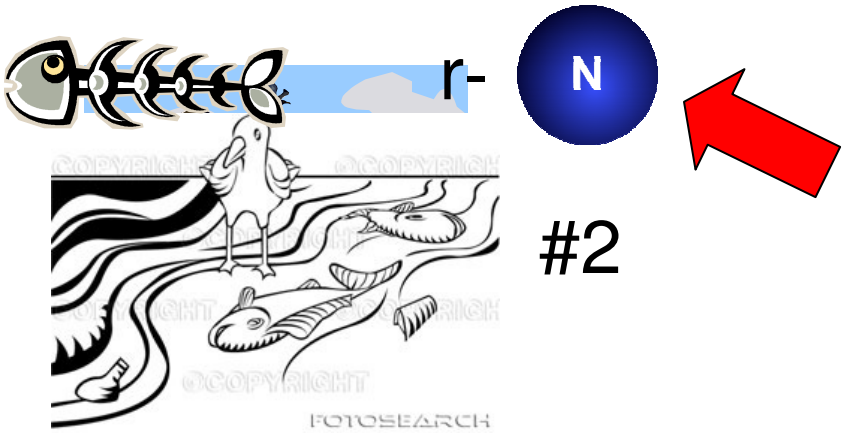
r- N

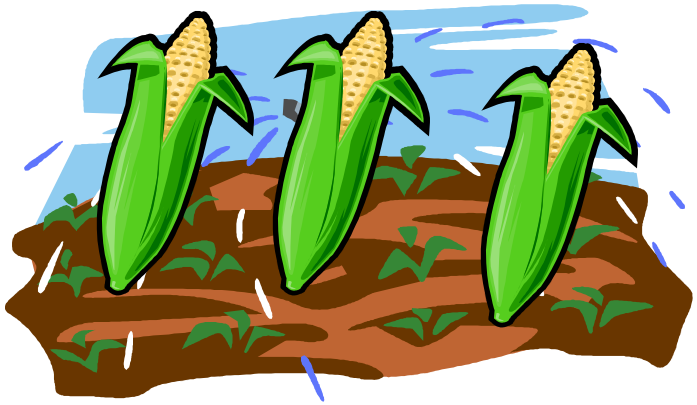




…after leaving the cornfield, it can result in 2) aquatic damage3) ecological damage, 4) air quality degradation and climate effects

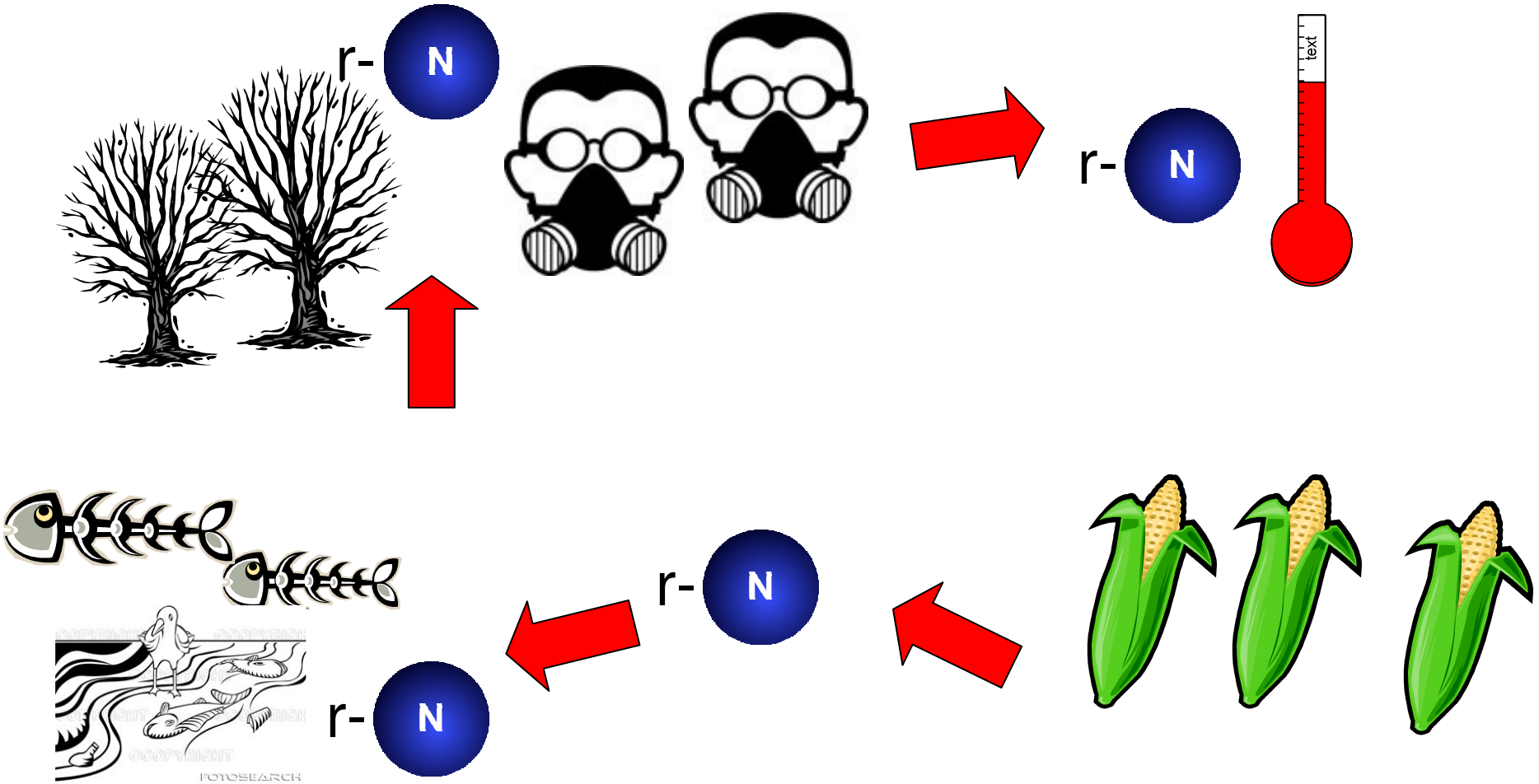




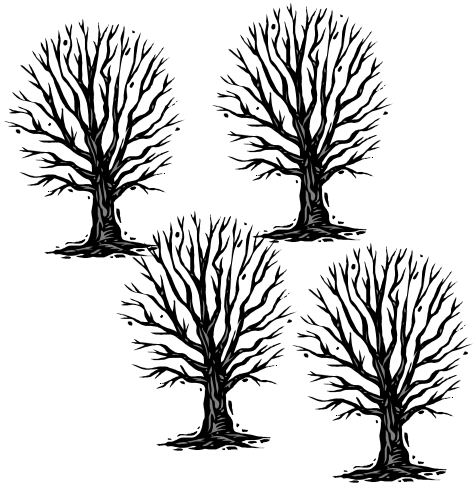


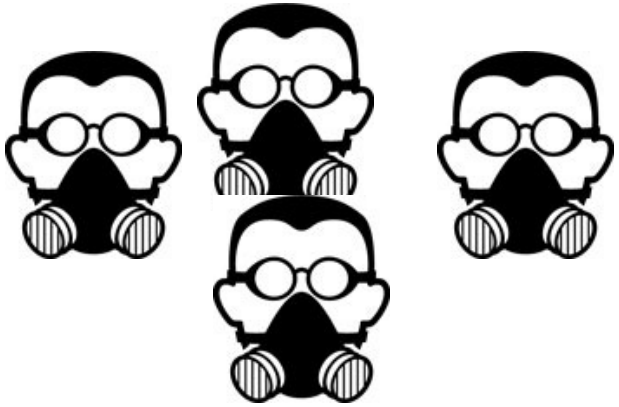
EPA United States Environmental Protection Agency

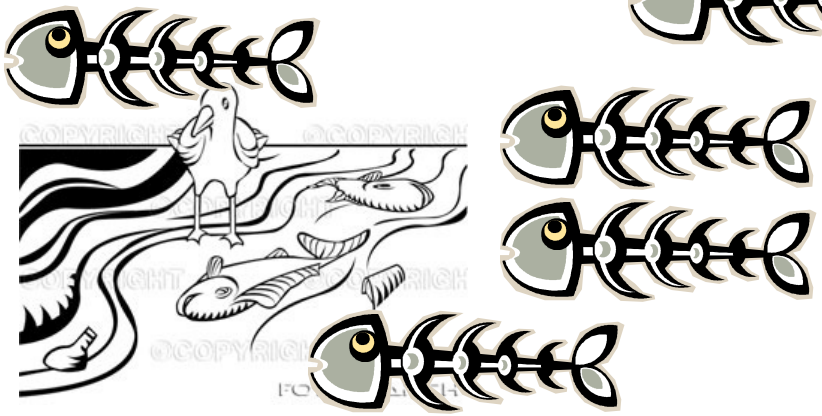
…the next year, more r-N is released with the opportunity to have impacts as well

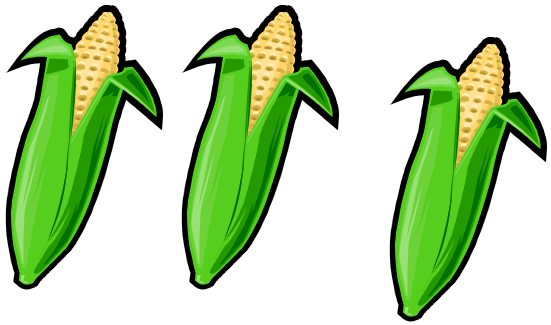


…and since some of the r-N travels around year after year, it's like a pinball machine where the balls only occasionally drop off the table, and effects can multiply…this is called the Nitrogen Cascade

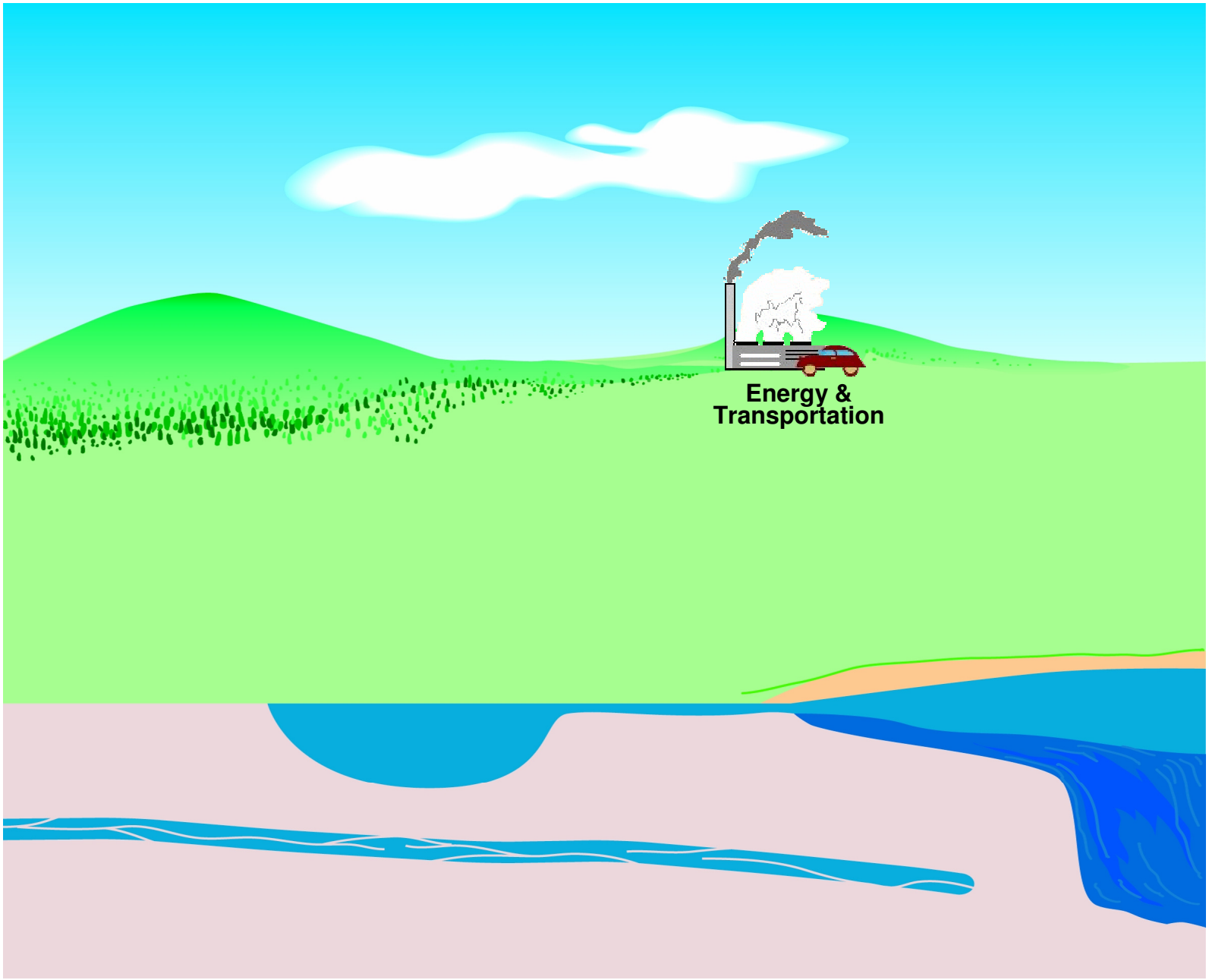






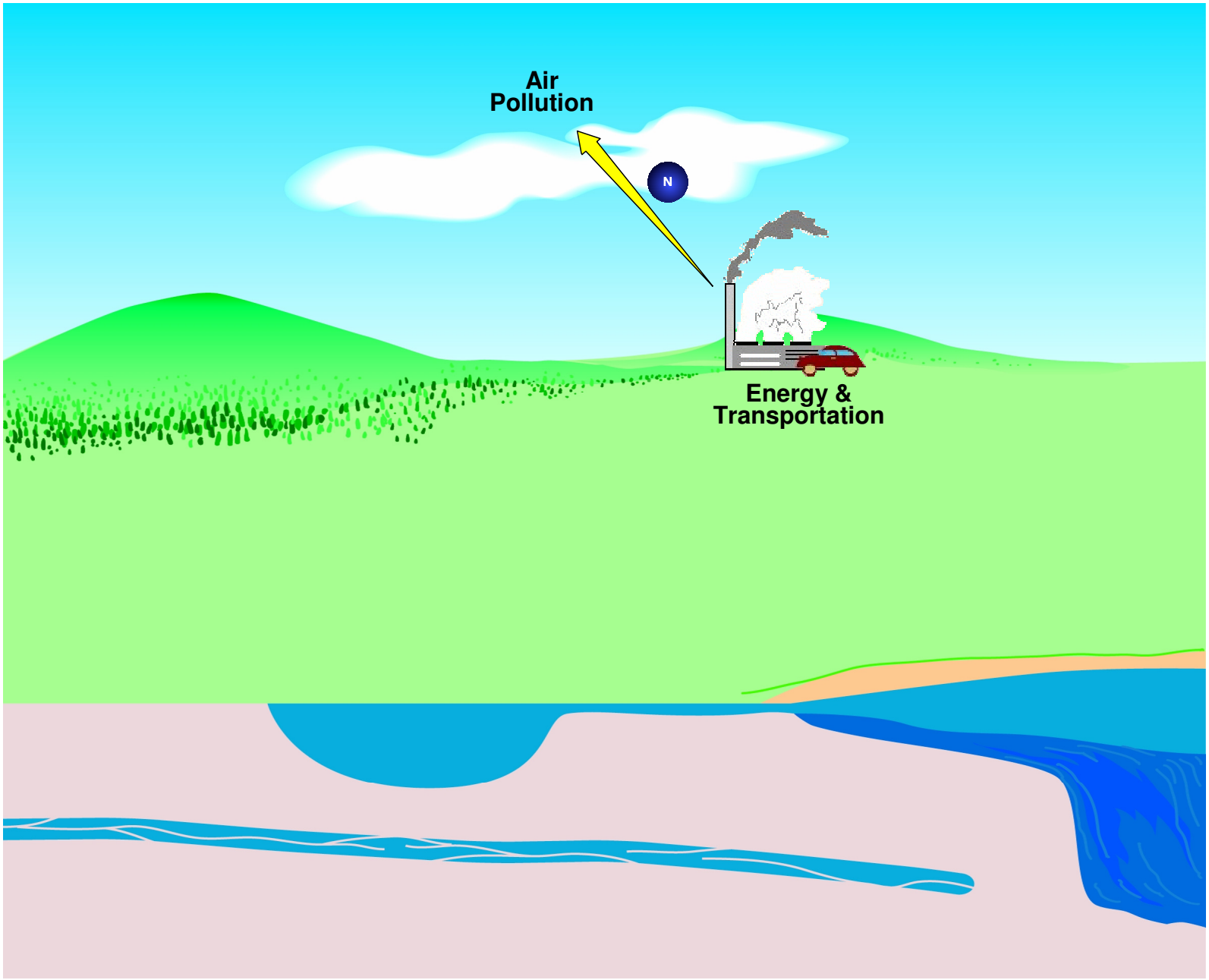


Example of Effect Cascade: R-N of Combustion



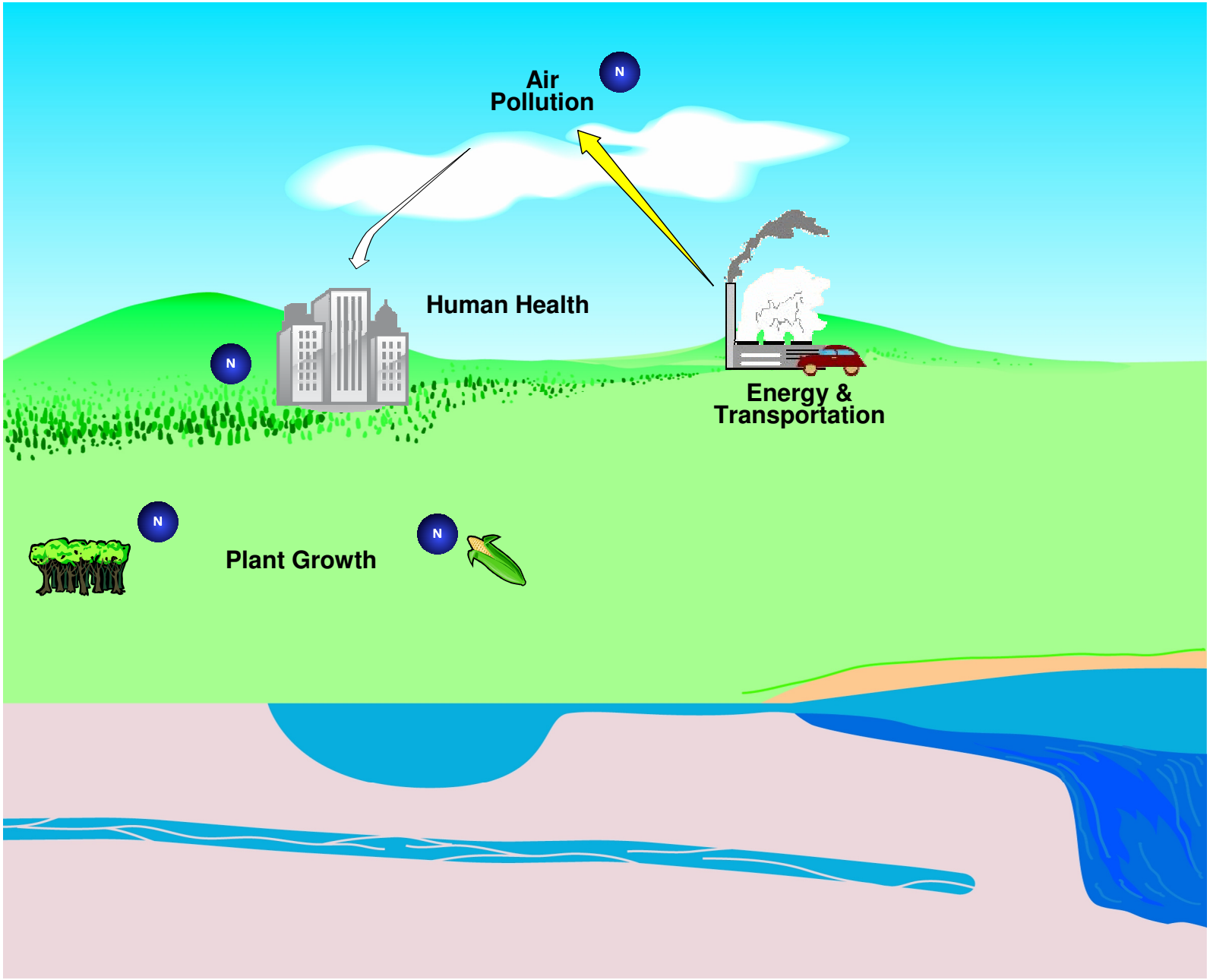
Based on Galloway et al., 2003

Particulate Matter & Ozone Formed with R-N



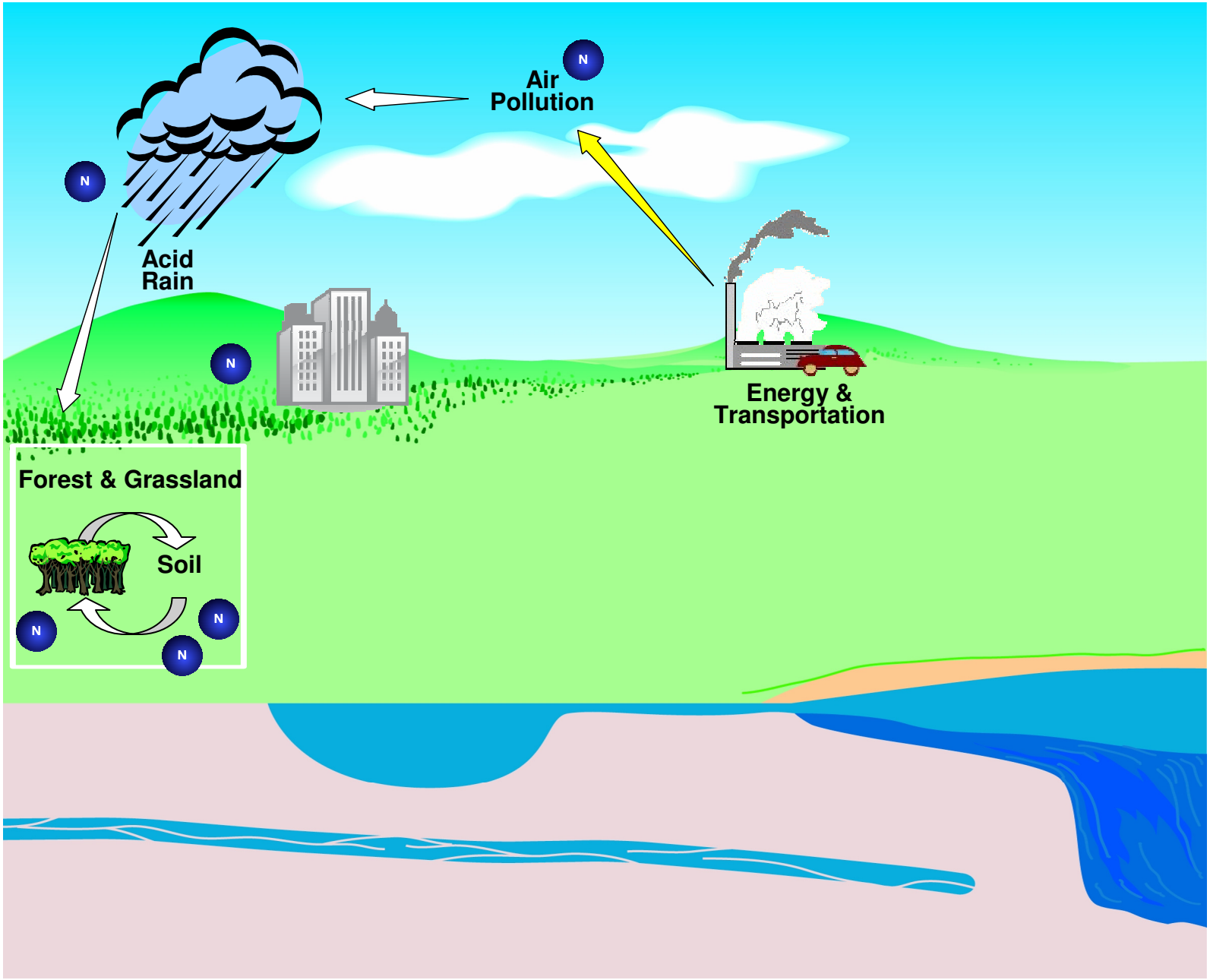
Based on Galloway et al., 2003

Air Pollution Affects Humans & Plants



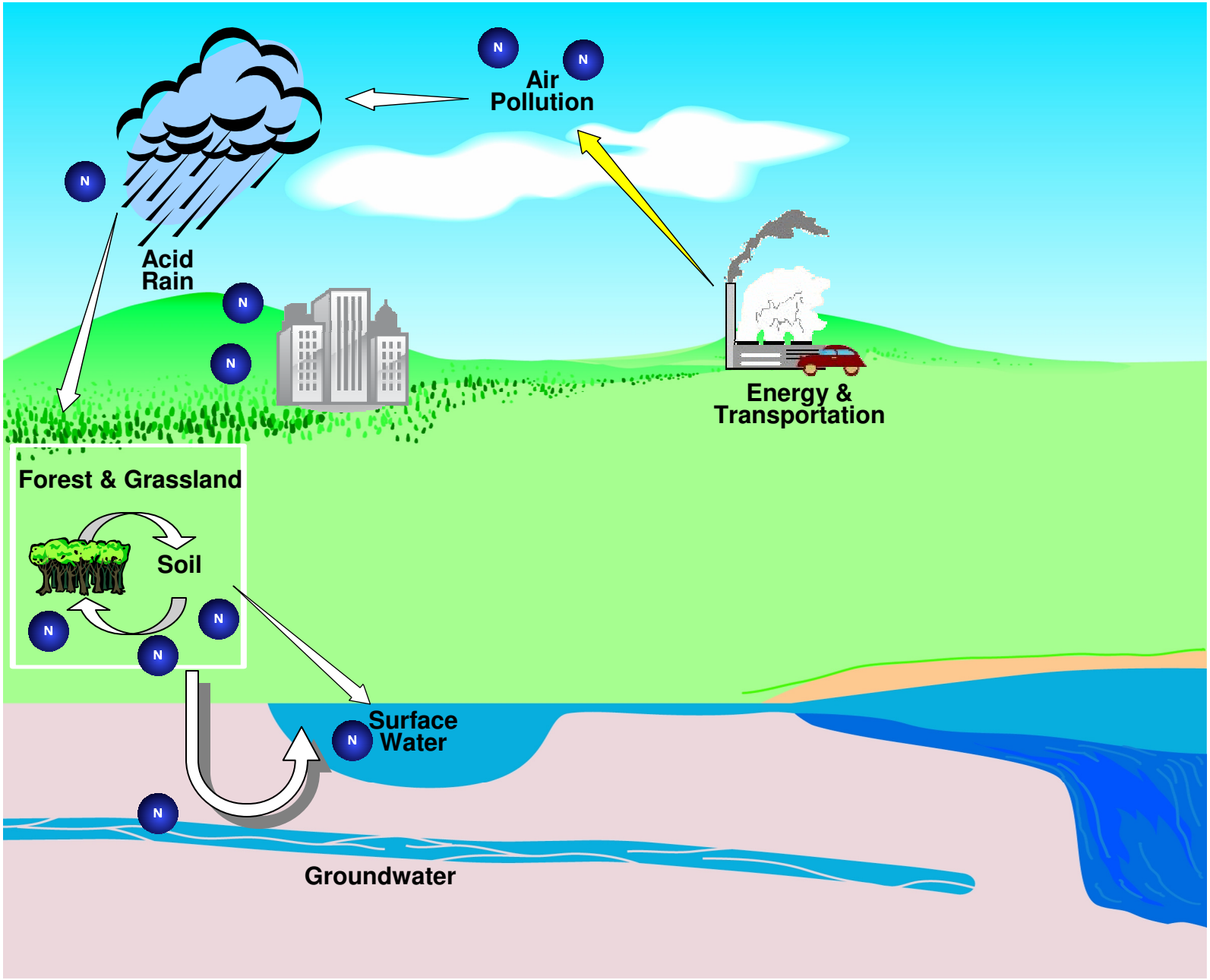
Based on Galloway et al., 2003

R-N Falls as Acid Rain on Forest/Grassland



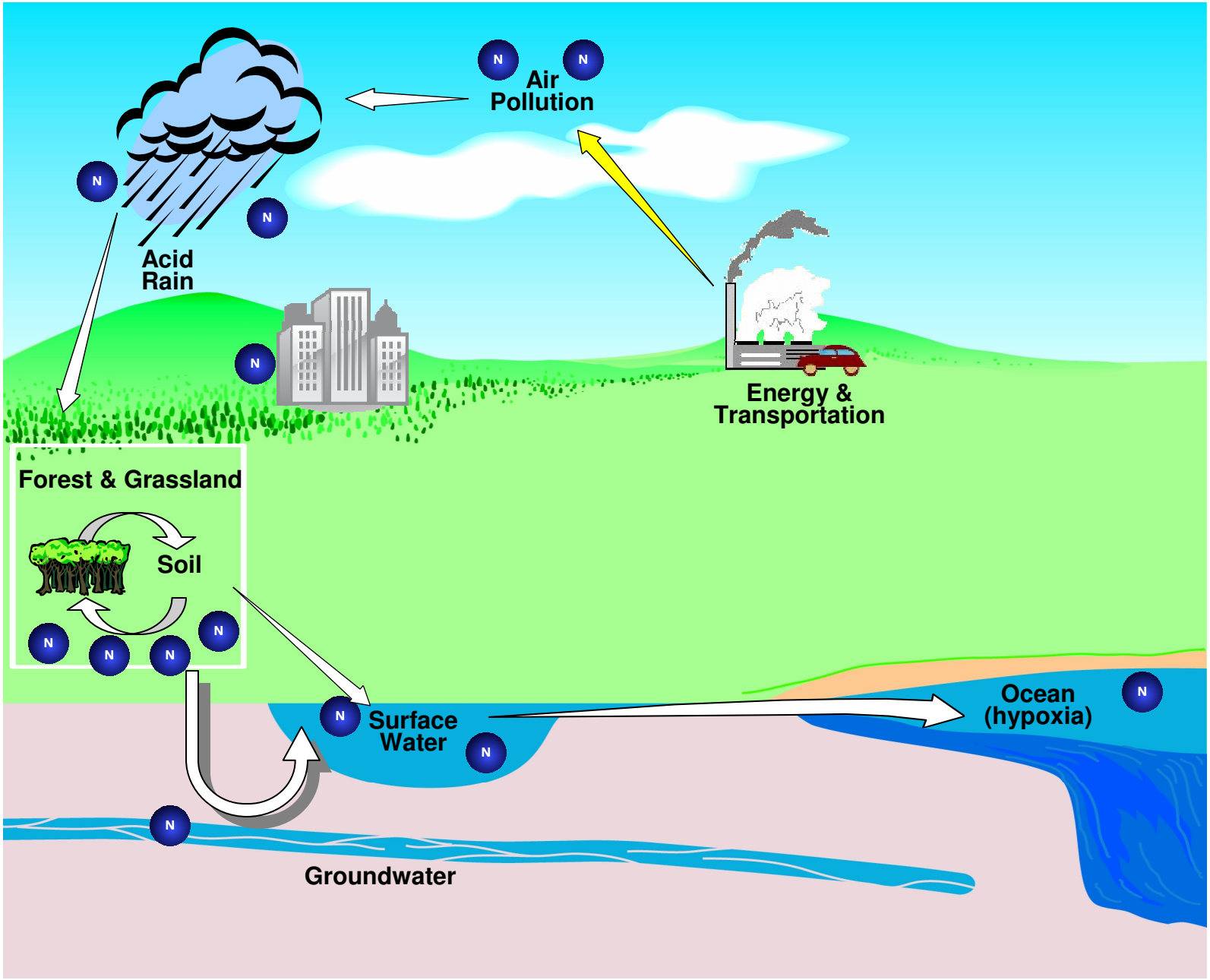
Based on Galloway et al., 2003

Ground & Surface Water Effects



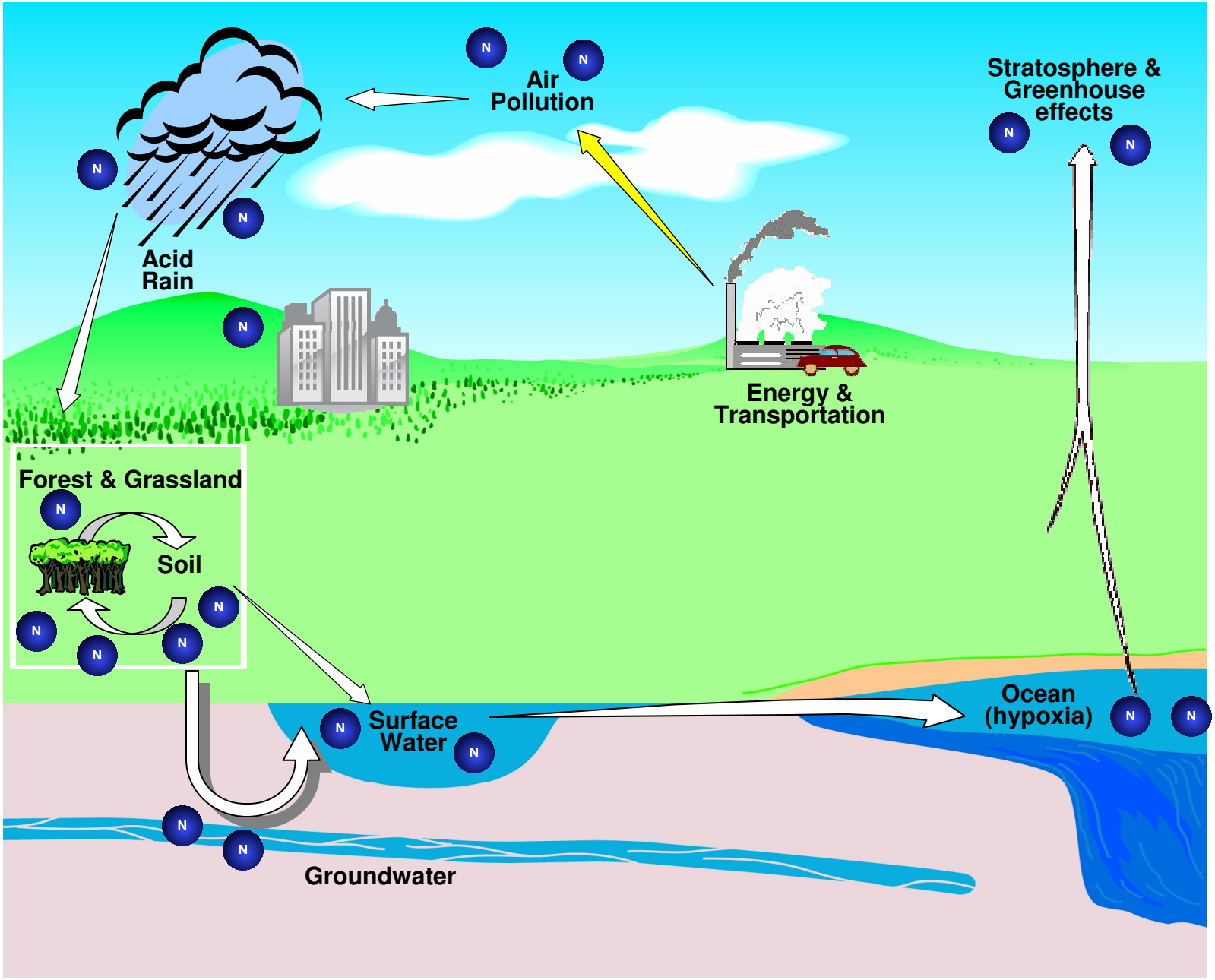
Based on Galloway et al., 2003

Ocean Effects



Based on Galloway et al., 2003

Stratospheric & Greenhouse Effects

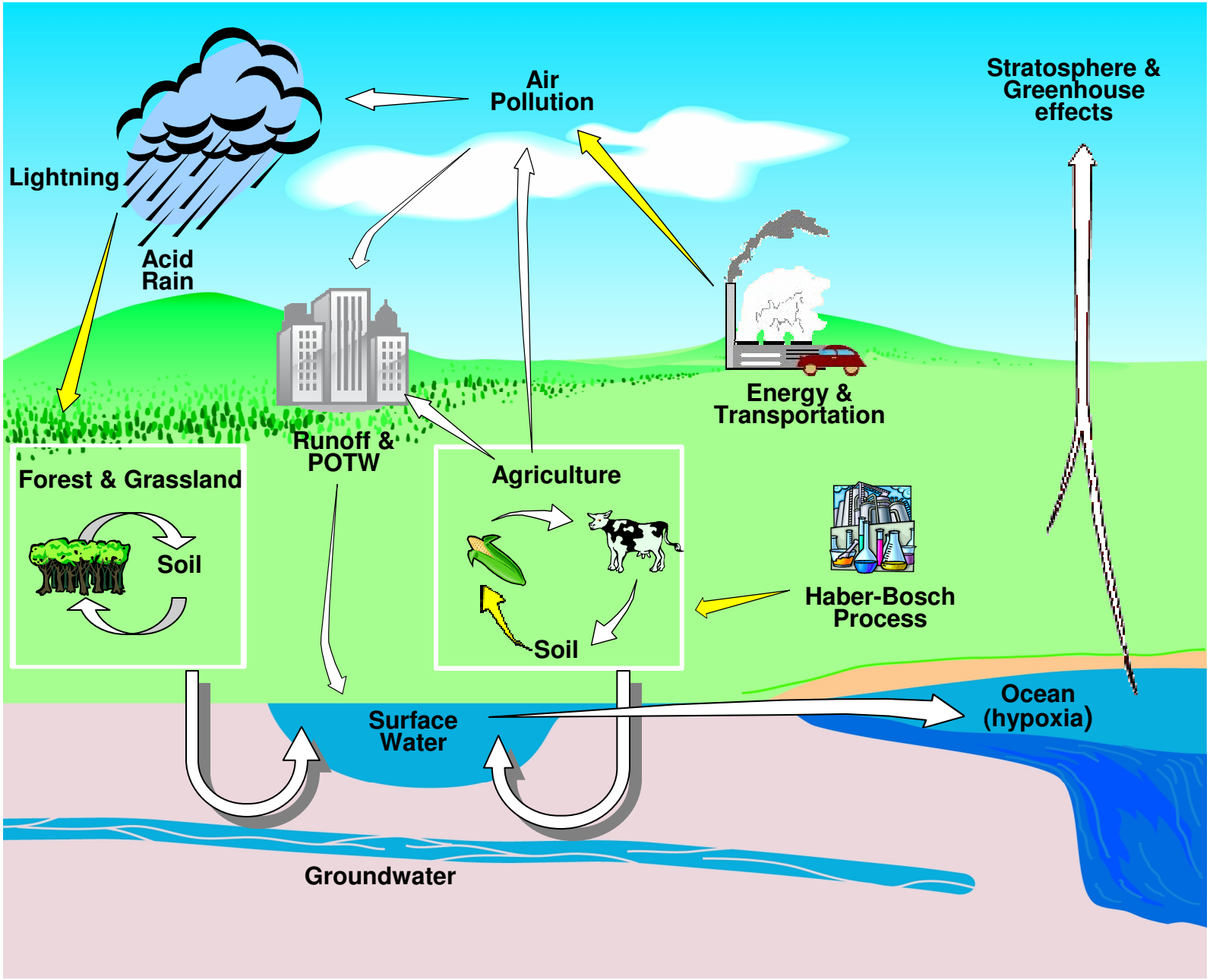


Based on Galloway et al., 2003

The Nitrogen Cascade

- Together, the paths of nitrogen between these sources and sinks form a complex system.
- This system is known as the Nitrogen Cascade.
- The Cascade allows us to visualize the widespread effects of nitrogen.

Multiple Pathways in Nitrogen Cascade



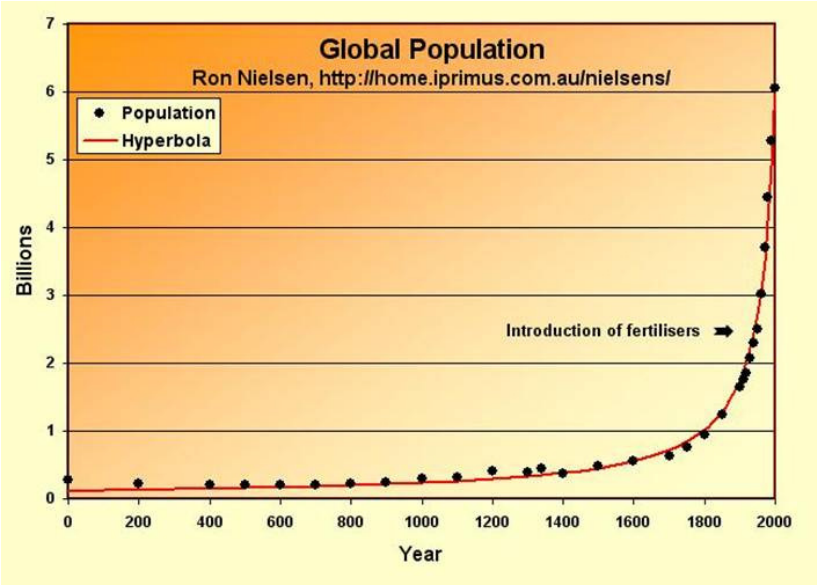
Based on Galloway et al., 2003

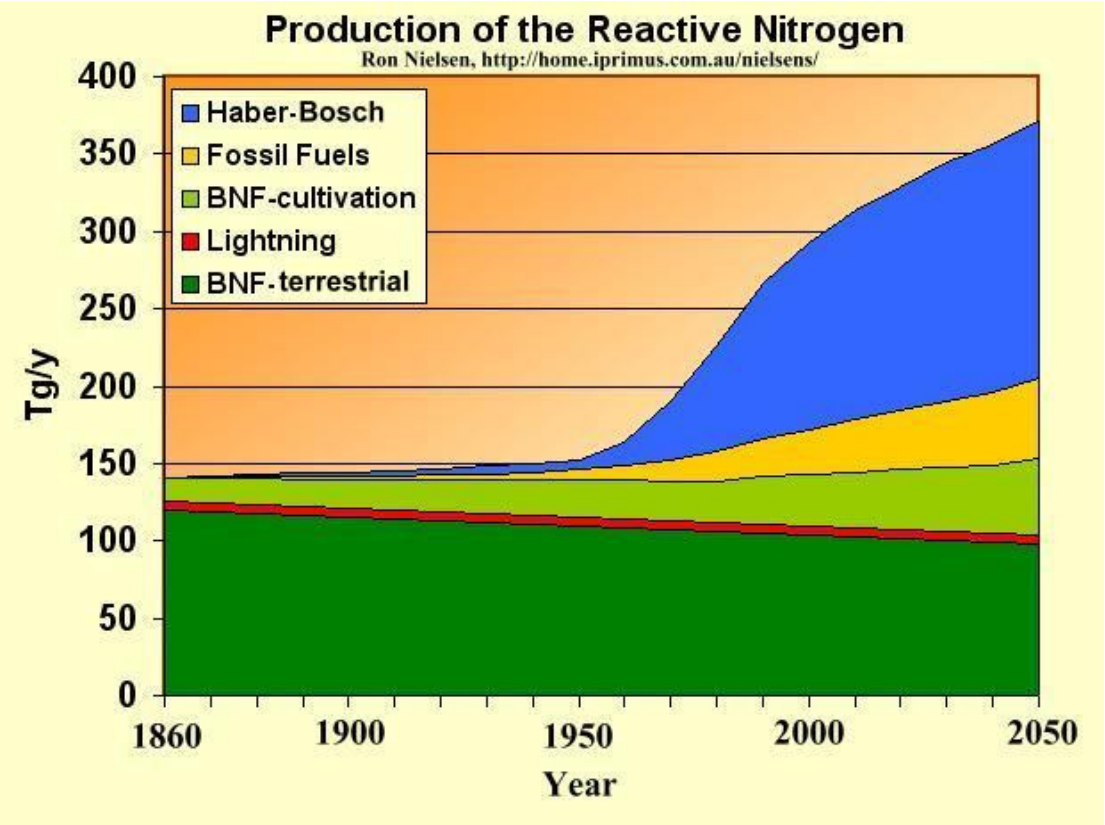
Nitrogen's Effects Are Dramatic

Haber-Bosch Process

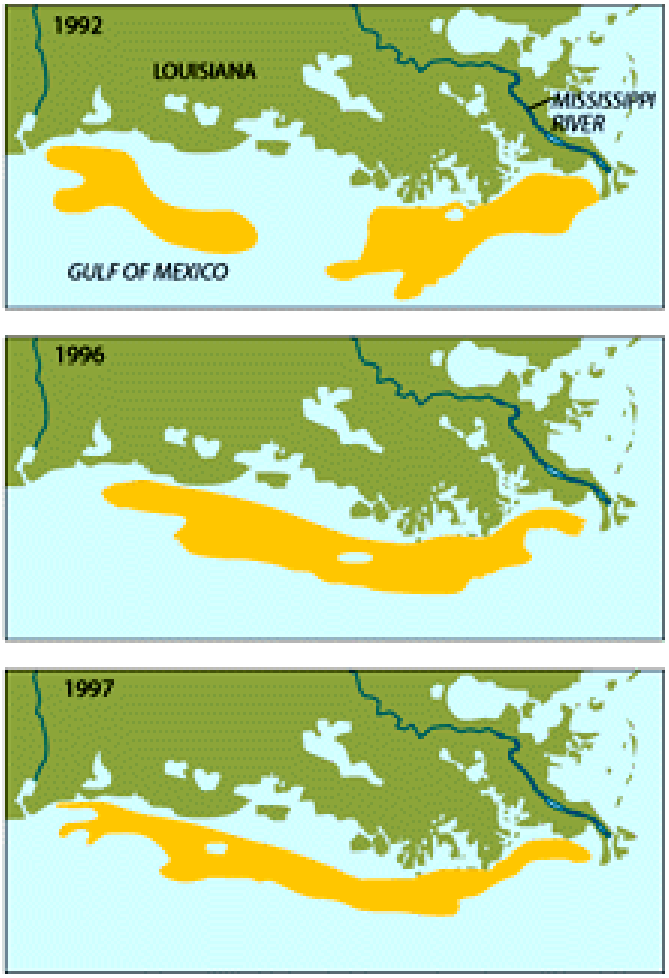
Hydrogen + Nitrogen → Ammonia → Nitrates,Nitrites

(from NG) (from air) (high T/P; Fe catalyst) (Fertilizer)



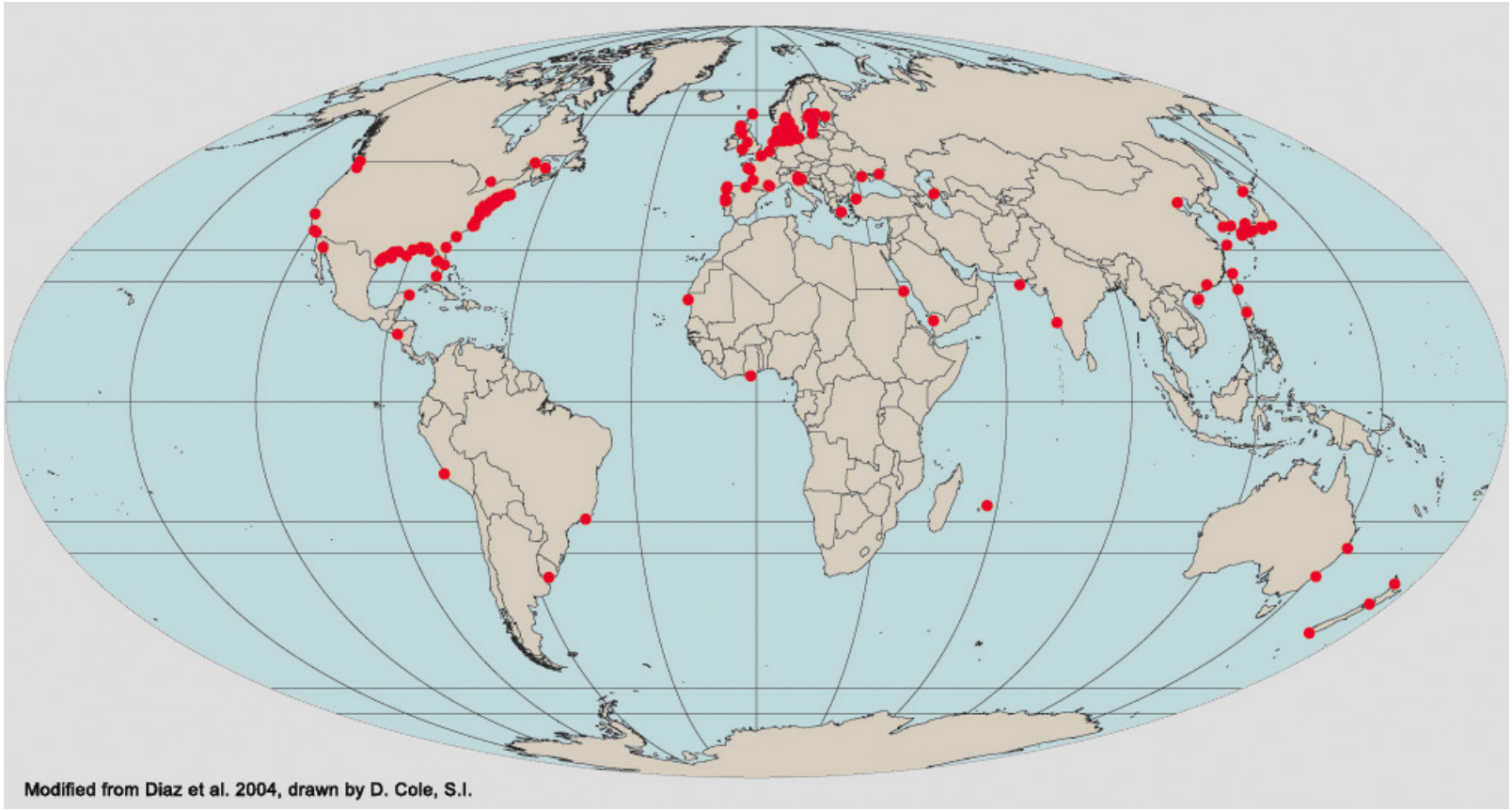


The Effects Are Worsening



The effects Are Widespread

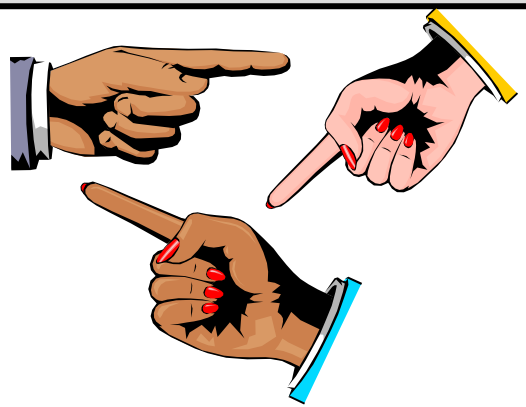
Dead zones in coastal waters from nitrogen-induced hypoxia have doubled in the last decade.



Reactive N Does Not Respect Program Office Boundaries!

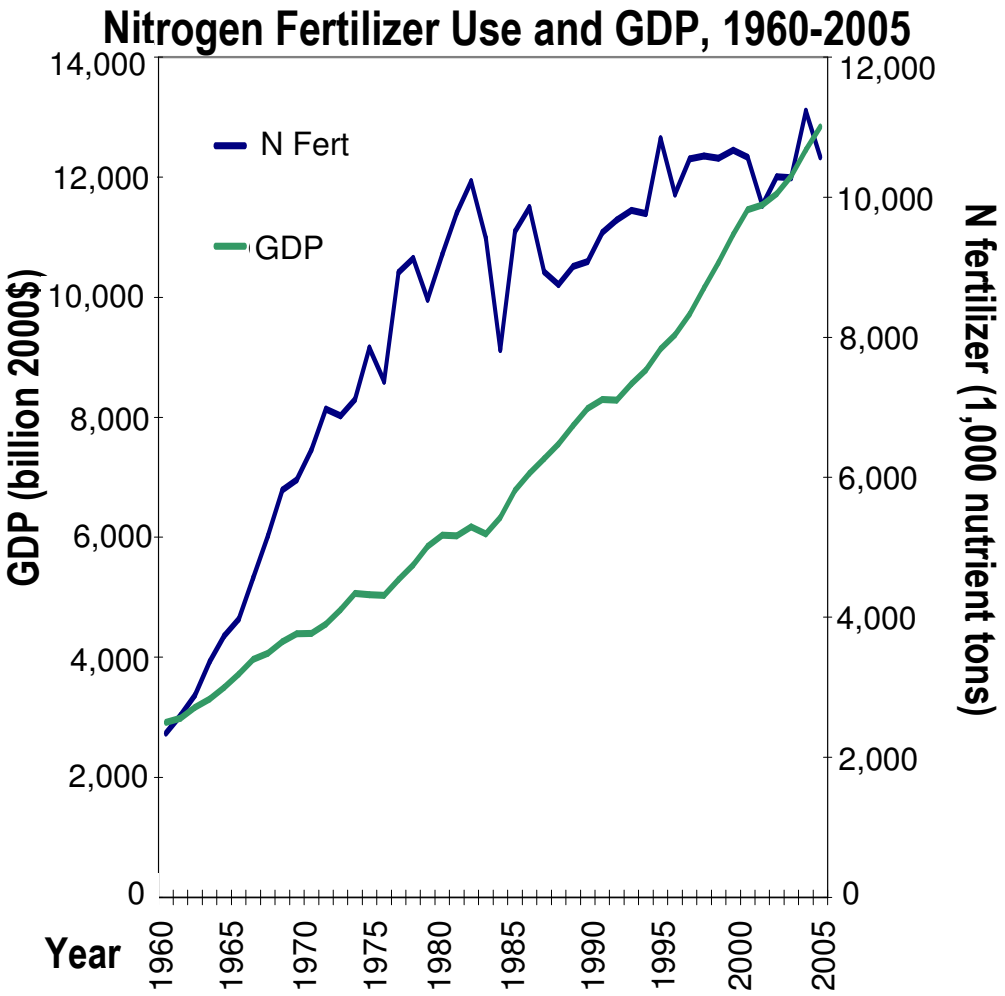
A decision about…	**…may also affect:**
Tailpipe/smokestack NO_x	Climate, water, and ecological impacts
Ammonia	Climate, air quality, and water quality impacts
Biofuel and land use	Climate and ecological impacts

As a serial polluter, a single N emission may affect multiple media and cross EPA program boundaries.

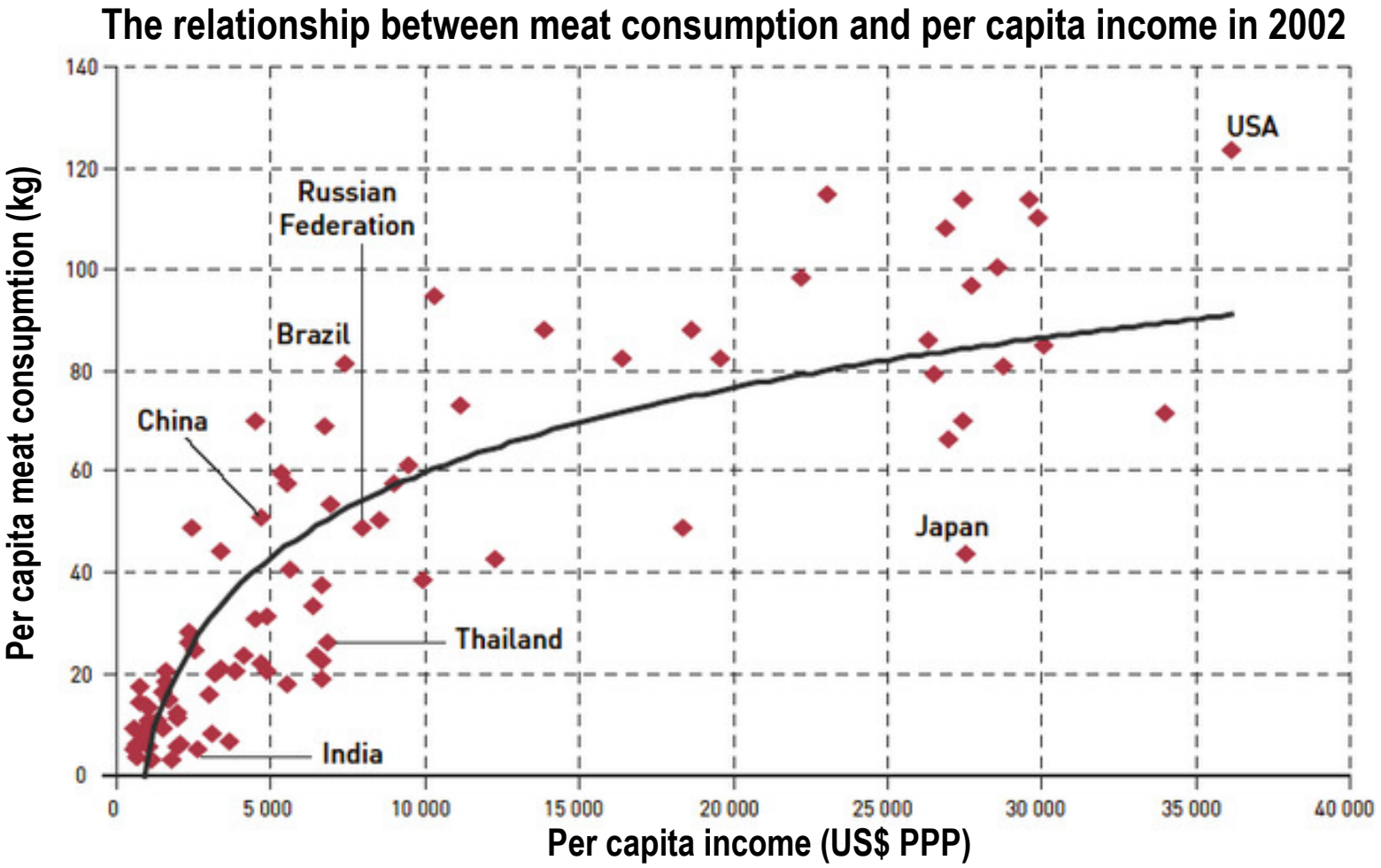


Where Will It End?

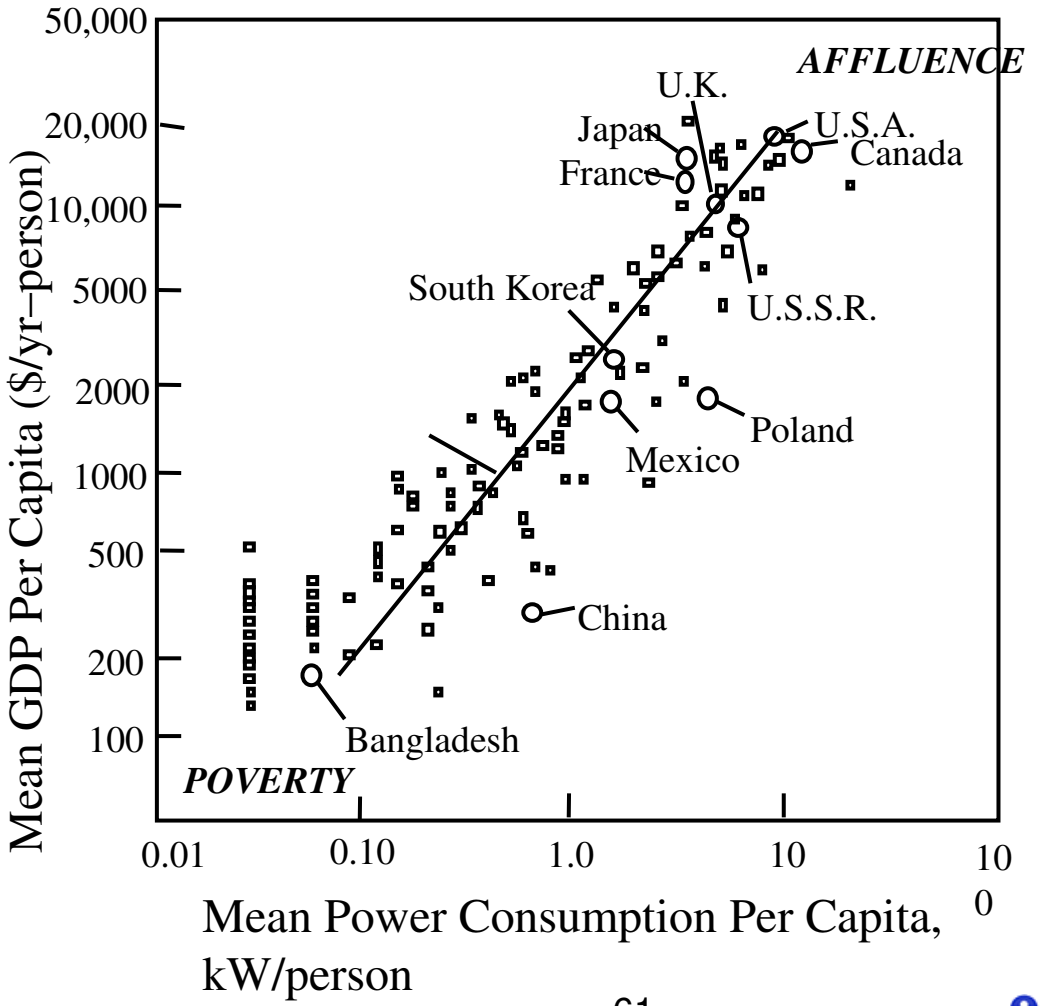
- Anthropogenic reactive nitrogen is driven by population and standard of living, including energy use and animal protein consumption.
- Unless we change our practices, reactive nitrogen growth (not bound up in long-term storage) will continue to accelerate…



…and accelerate



…and accelerate



Where We Go From Here

In the remaining modules, we will:

- Learn more about how N interacts with the environment
- Explore interventions to decrease N pollution
- Consider the effect of economics on N use
- Delve into the implications of energy and economic policy for nitrogen.

Learning Objectives

- Nitrogen is a nutrient with great benefits, but its overuse or mismanagement carries great risks.
- Nitrogen pollution is a systems issue.
- Reactive nitrogen moves among multiple media and takes on multiple forms, doing repeated damage to the environment, if not bound in long-term storage.
- Humans are causing the growth of reactive nitrogen (not in long-term storage) to accelerate rapidly.