WELCOME
TO THE MAY EDITION
OF THE 2017
M&R SEMINAR SERIES

BEFORE WE BEGIN

- SAFETY PRECAUTIONS
  - PLEASE FOLLOW EXIT SIGN IN CASE OF EMERGENCY EVALUATION
  - AUTOMATED EXTERNAL DEFIBRILLATOR (AED) LOCATED OUTSIDE
- PLEASE SILENCE CELL PHONES OR SMART PHONES
- QUESTION AND ANSWER SESSION WILL FOLLOW PRESENTATION
- PLEASE FILL EVALUATION FORM
- SEMINAR SLIDES WILL BE POSTED ON MWRD WEBSITE (www. MWRD.org: Home Page ⇒ Reports ⇒ M&R Data and Reports ⇒ M&R Seminar Series ⇒ 2017 Seminar Series)
- STREAM VIDEO WILL BE AVAILABLE ON MWRD WEBSITE (www.MWRD.org: Home Page ⇒ MWRDGC RSS Feeds)

Thomas L. Theis, Ph.D., PE, DEE

Current: Director of Institute for Environmental Science and Policy, University of Illinois at Chicago, Chicago, Illinois

Experience: He was the Bayard D. Clarkson Professor and Director of the Center for Environmental Management at Clarkson University. His areas of expertise include life cycle assessment, industrial ecology, the mathematical modeling and systems analysis of environmental processes, environmental policy; pollution prevention, and hazardous waste management. He has published over 130 peer-reviewed articles, and is the co-author of book: *Sustainability: A Comprehensive Foundation.* He was co-chair (with James Galloway and Otto Doering) of the Integrated Nitrogen Committee of the USEPA.

Education: Ph.D. (Environmental Engineering), M.S. (Environmental Health Engineering), and B.S (Civil Engineering), University of Notre Dame

Professional: USEPA Congressionally Chartered Science Advisory Board,

USEPA Science Advisory Board, Environmental Engineering Committee

Keynote speaker at the NitroEurope Conference in Gothenburg, Sweden

Member of the US delegation to the US-Japan Workshop on Life Cycle Assessment and Infrastructure Materials in Sapporo, Japan

Founding Principal Investigator of the Environmental Manufacturing Management Program

Reactive Nitrogen in the Environment: Perspectives on Integrated Management Approaches

James N. Galloway

Environmental Sciences Department, University of Virginia, Charlottesville, VA

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Institute for Environmental Science and Policy, University of Illinois at Chicago, Chicago, IL

Otto C. Doering

Department of Agricultural Economics, Purdue University, West Lafayette , IN

MWRD 19 May 2017

USEPA Science Advisory Board Integrated Nitrogen Committee

Viney Aneja	NC State University
Elizabeth Boyer	Penn State University
Kenneth Cassman	University of Nebraska
Ellis Cowling	NC State University
Russell Dickerson	University of Maryland
William Herz	The Fertilizer Institute
Donald Hey	Wetlands Research, Inc.
Richard Kohn	University of Maryland
JoAnn Lighty	University of Utah
William Mitsch	Ohio State University
William Moomaw	Tufts University
Arvin Mosier	University of Florida
Hans Paerl	University of North Carolina
Bryan Shaw	Texas Commission on Environmental Quality
Paul Stacey	State of Connecticut

An SAB Original Study

- Undertaken to provide advice to EPA, from a scientific perspective, on managing problems caused by excess reactive nitrogen (Nr) in the environment.
- Analyzes the inputs and flows of reactive nitrogen in the U.S.
- Recommends new risk reduction strategies to improve upon traditional media-specific regulatory and nonregulatory approaches.
- Recommends using the movement of nitrogen among environmental reservoirs in multiple ecosystems and media (the Nitrogen Cascade) as a framework for understanding and more effectively managing reactive nitrogen.

http://yosemite.epa.gov/sab/sabproduct.nsf/WebBOARD/INCSupplemental?OpenDocument

EPA
United States
Environmental Protection
Agency

SAB

Reactive Nitrogen in the United States: An Analysis of Inputs, Flows, Consequences, and Management Options

A REPORT OF THE EPA SCIENCE ADVISORY BOARD

Science Advisory Board
Office of the Administrator

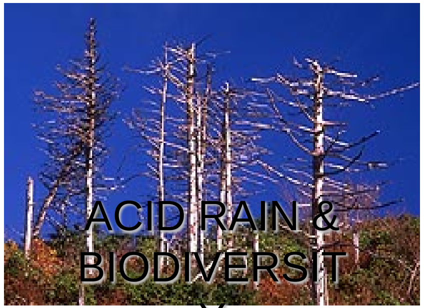
What is Reactive Nitrogen (Nr)?

All chemical forms of nitrogen, except N_2

Examples: NH_3-NH_4^+, N_2O, NO, NO2, NO_2^-, NO_3^-

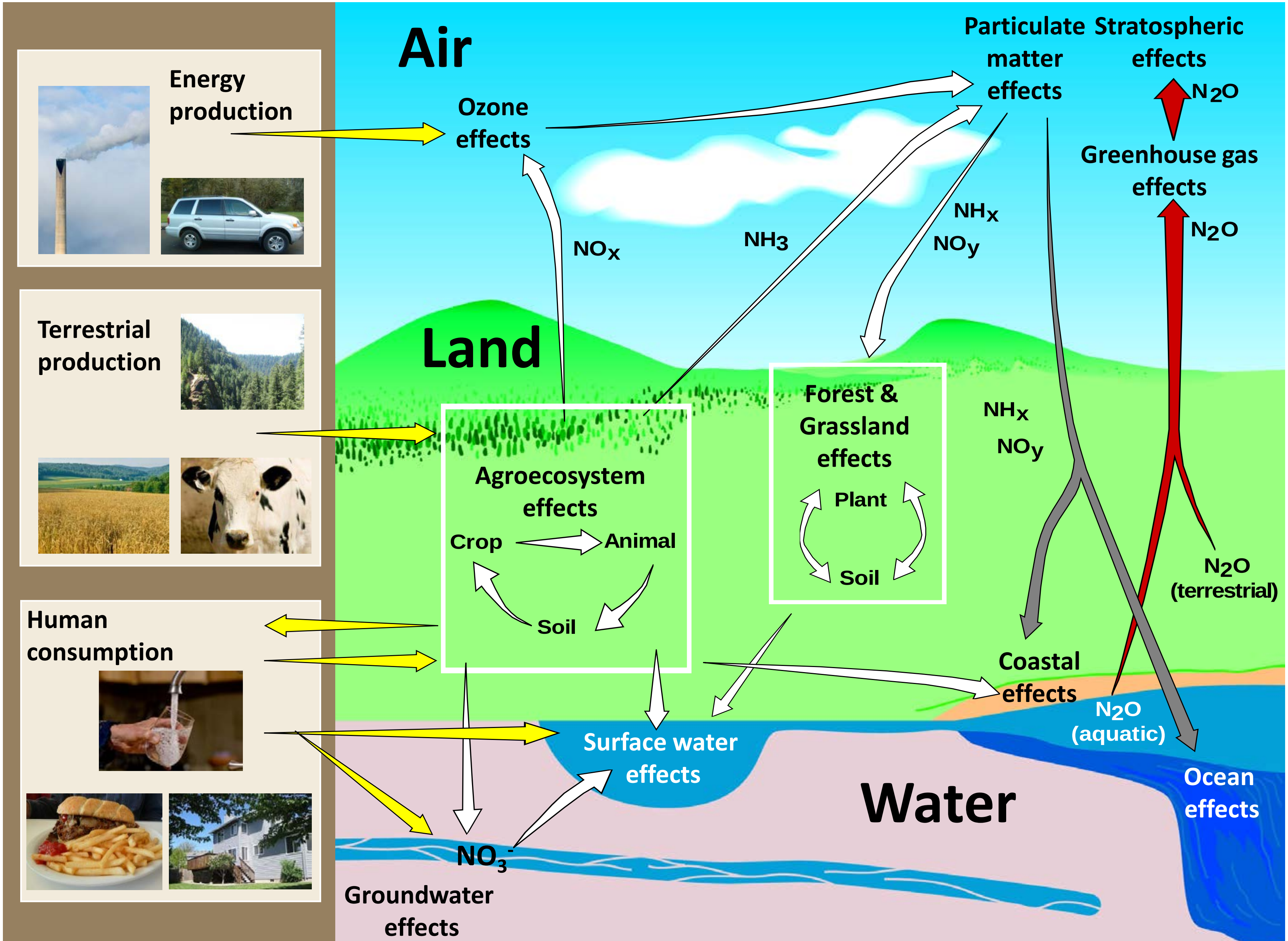
Organic-N

Nitrogen problems



N

The nitrogen cascade



Visibility/Smog-Ozone Formation

Grand Canyon, AZ

Los Angeles, CA

Coastal Hypoxia/Pollution of Fresh Waters

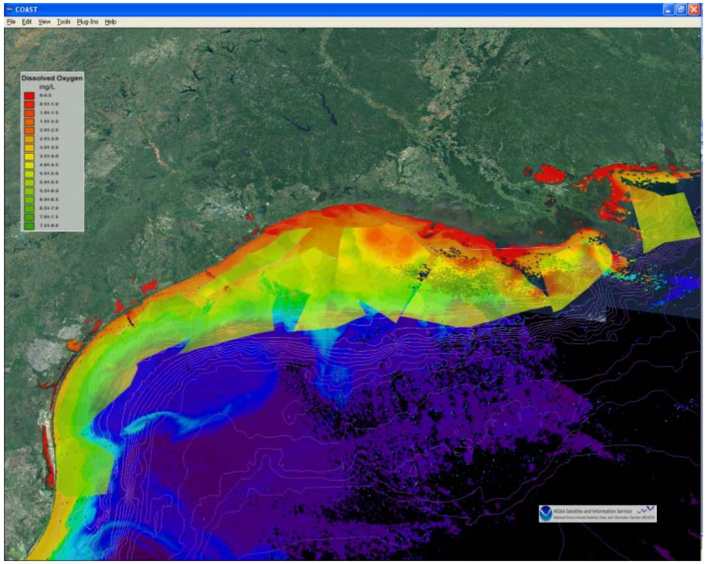
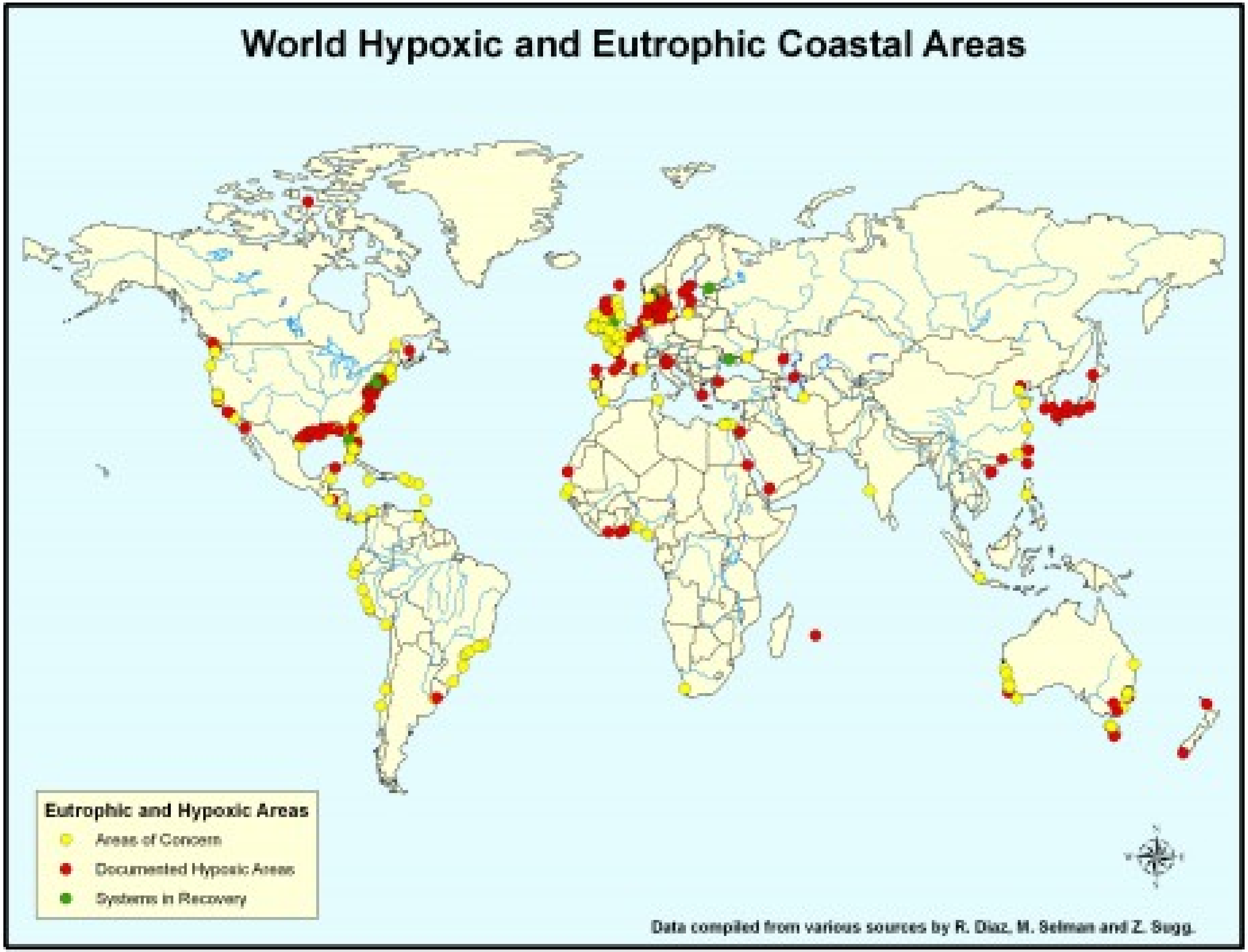


Photo: Nancy Rabalais, Louisiana Universities Marine Consortium

Algal Mat, Lake Erie



~ 415 Hypoxic Regions Globally

www.wri.org/.../Global_nolakes.preview.jpg

Recommendations…

- 24 Recommendations
  - 4 overarching recommendations
  - 20 specific findings & recommendations addressing air, water, and land use issues, monitoring, research, and education
- 5 Management goals

Overarching SAB Recommendations

- The nitrogen cascade should be used as a framework to understand the environmental impacts of reactive nitrogen as it moves through multiple ecosystems and media.
- Integrated cross-media management approaches and regulatory structures are needed to recognize tradeoffs and focus management efforts at points of the nitrogen cascade where they are most efficient and cost effective.
- EPA should form an intra-Agency Nr management task force to build on the existing breadth of Nr research and management capabilities within the Agency.
- EPA should convene an inter-Agency Nr management task force to coordinate federal programs that address Nr monitoring, modeling, research, and management.

Near Term Goals for Management Action

- The SAB estimates that a 25% reduction in Nr introduced into the U.S. environment might be achieved with existing technology in the coming 10-20 years through actions that could be taken by EPA and other management authorities.
  - Expanded efforts to control emissions of NO_x from mobile sources and power plants could decrease the generation of Nr by 2.0 Tg/yr.
  - Increased crop uptake efficiencies (through advances in fertilizer technology) could further decrease Nr releases by 2.4.Tg/yr.
  - Livestock-derived NH_3 emissions could be decreased by 0.5 Tg/yr through a combination of BMPs and engineered solutions, and NH_3 emissions from fertilizer application could be decreased by 0.2 Tg/yr through BMPs related to application rate and timing.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

MAR 2 3 2012

THE ADMINISTRATOR

Otto C. Doering III, Ph.D.
Chairman, Integrated Nitrogen Committee
Science Advisory Board
U.S. Environmental Protection Agency
1200 Pennsylvania Avenue, NW
Washington, D.C. 20460

Dear Dr. Doering:

I offer my sincerest thanks to you and the other members of the U.S. Environmental Protection Agency Science Advisory Board's Integrated Nitrogen Committee for your excellent work as reflected in the report, *Reactive Nitrogen in the United States: An Analysis of Inputs, Flows, Consequences and Management Options,* dated August 2011.

I praise the committee on the thoroughness and rigor of its analysis. The report provides a comprehensive summary of the current state of science with respect to nitrogen sources, uses, losses and impacts on human health and the nation's ecosystems. I also commend the committee for its comprehensive overview of the regulatory and nonregulatory approaches we currently use for reactive nitrogen, which, while effective, could benefit from an innovative and integrated overall nitrogen-management program.

N. B.

We are also reviewing the committee's proposal to establish a nationwide 25-percent reduction in reactive-nitrogen releases to the environment during the next 10 to 20 years. Without careful analysis and further discussion, I cannot commit the agency to a specific policy goal of this magnitude. However, I will ask that the proposal be discussed in the context of future intra-agency and interagency efforts.

In the meantime, I thank you and the committee once again for your excellent work and your dedicated service.

Sincerely,

Lisa P. Jackson

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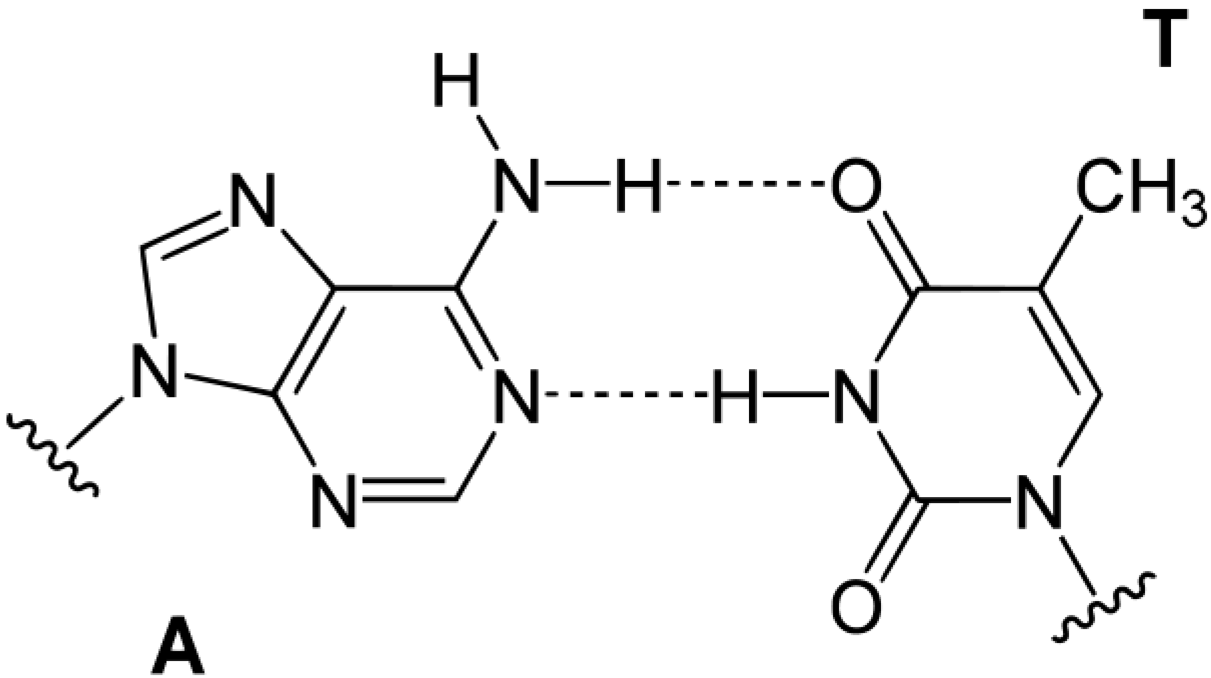
Why do we need reactive nitrogen?

- Human Nr requirement = 4.3 kg/cap/yr
- US = 1.4 Tg/yr
- World = 28 Tg/yr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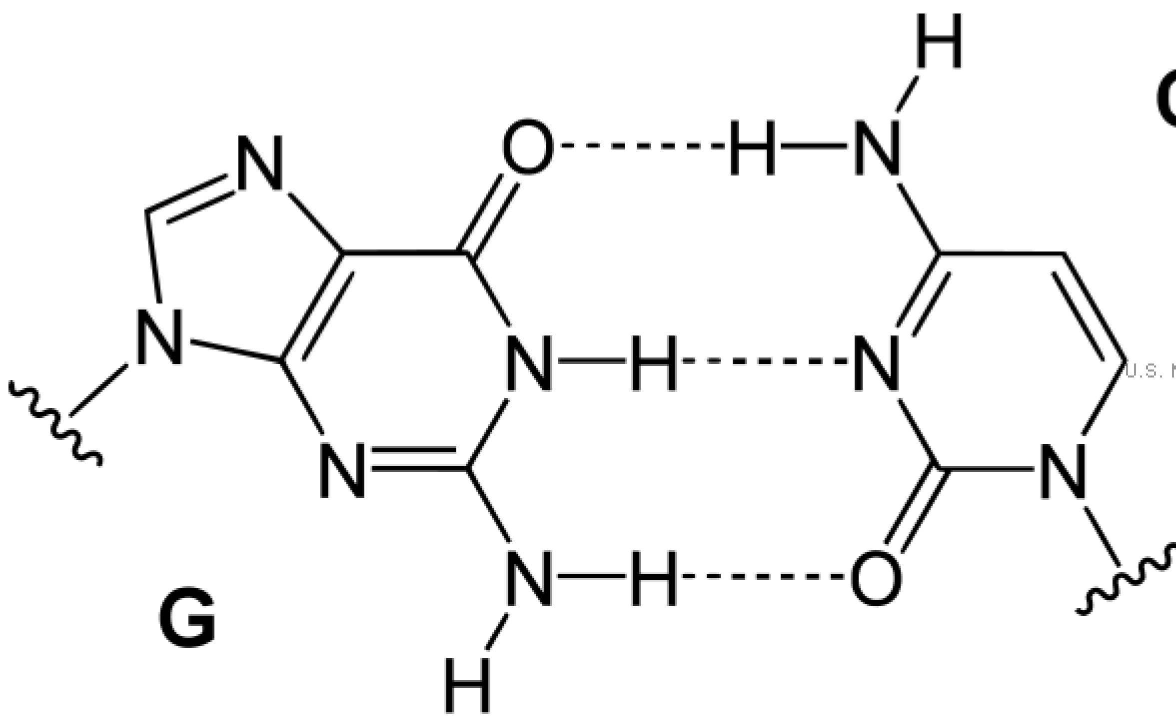
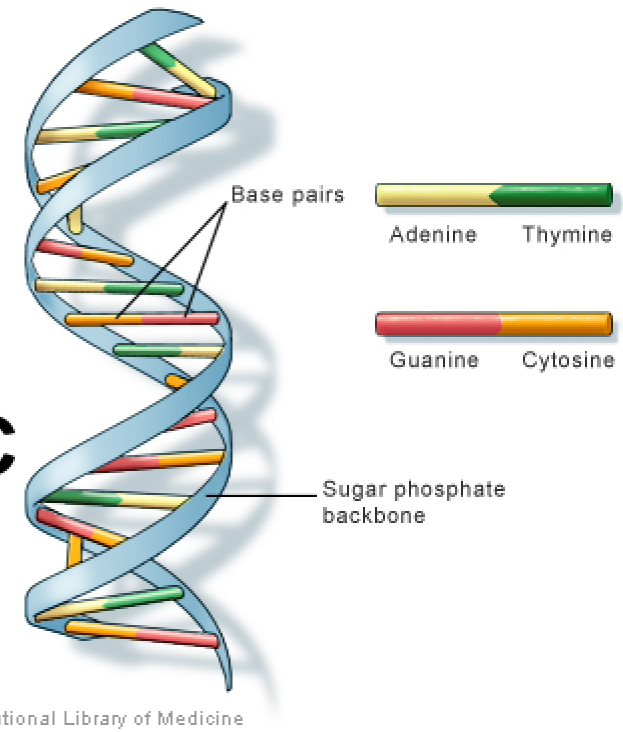
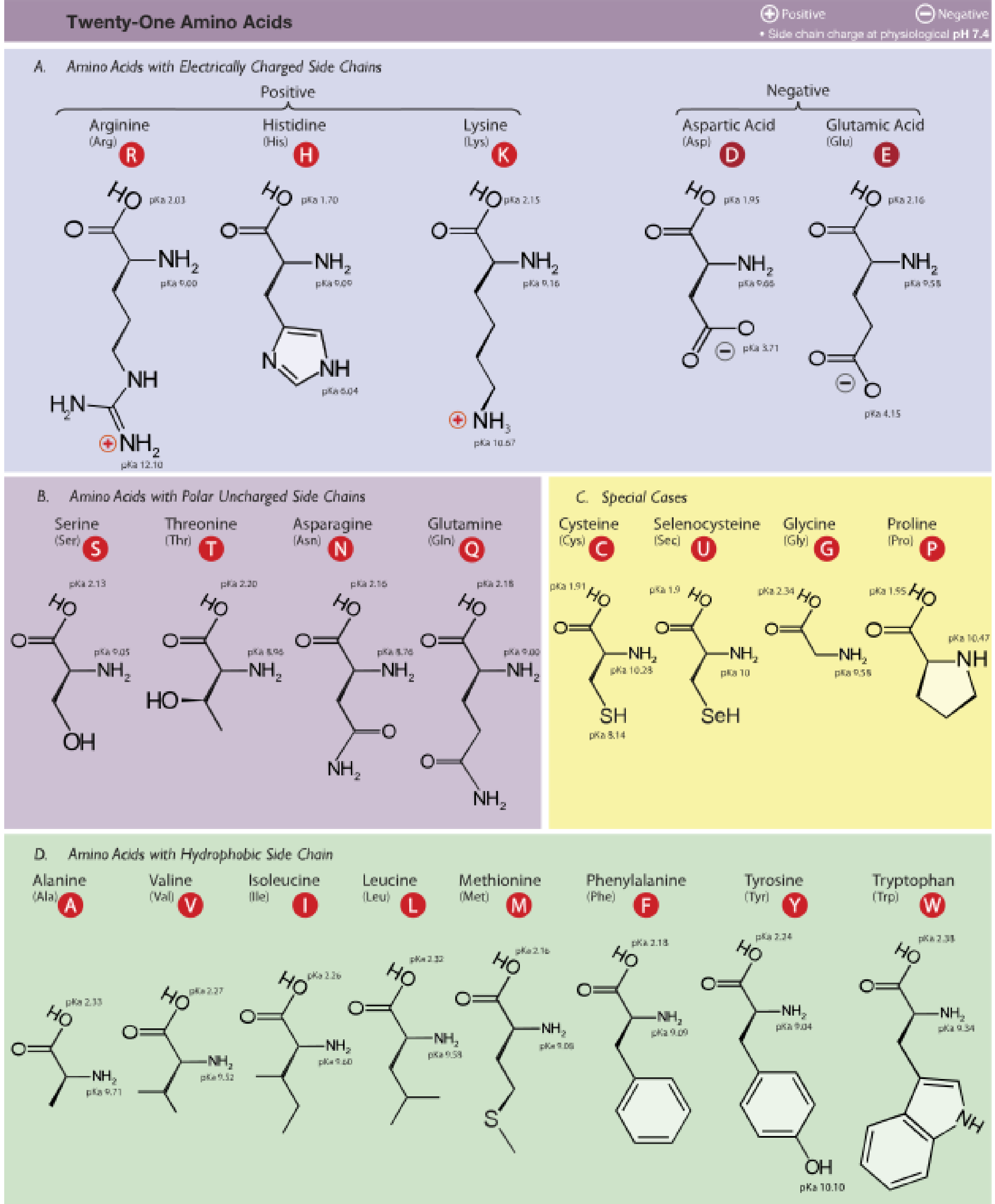
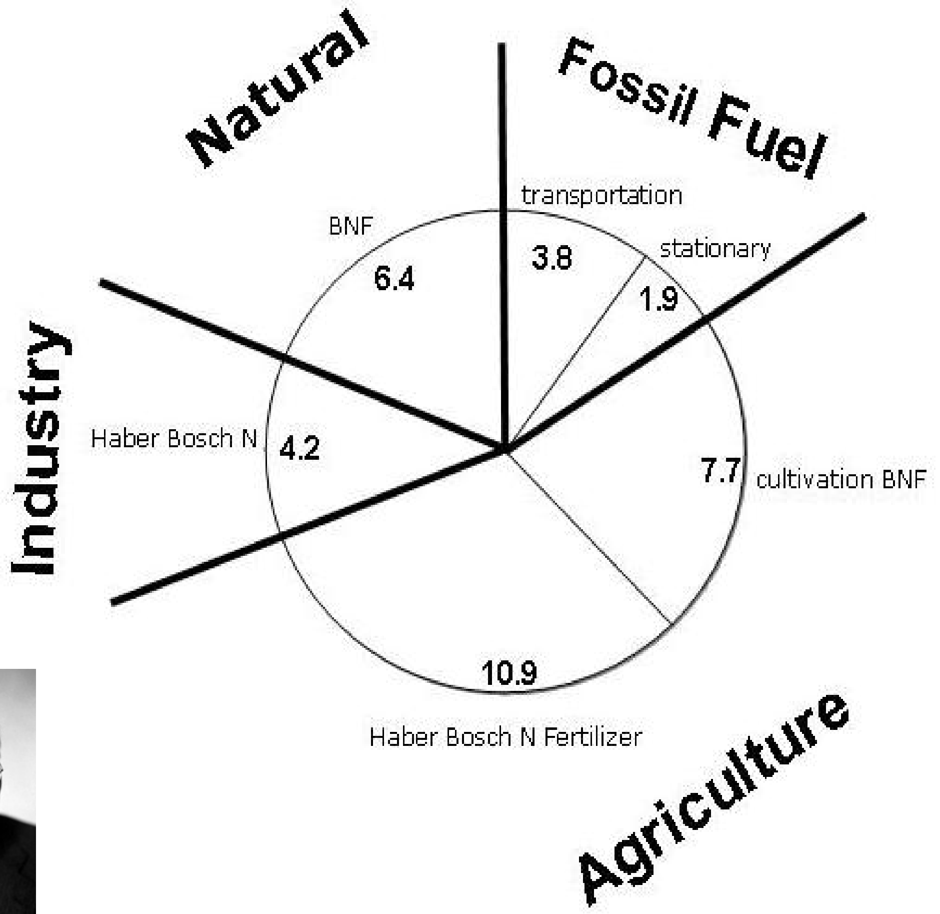

C
G


Base pairs
Adenine
Thymine
Guanine
Cytosine
Sugar phosphate backbone
U.S. National Library of Medicine



Twenty-One Amino Acids
Positive
Negative
• Side chain charge at physiological pH 7.4
A. Amino Acids with Electrically Charged Side Chains
Positive
Negative
Arginine (Arg) R
Histidine (His) H
Lysine (Lys) K
Aspartic Acid (Asp) D
Glutamic Acid (Glu) E
B. Amino Acids with Polar Uncharged Side Chains
Serine (Ser) S
Threonine (Thr) T
Asparagine (Asn) N
Glutamine (Gln) Q
C. Special Cases
Cysteine (Cys) C
Selenocysteine (Sec) U
Glycine (Gly) G
Proline (Pro) P
D. Amino Acids with Hydrophobic Side Chain
Alanine (Ala) A
Valine (Val) V
Isoleucine (Ile) I
Leucine (Leu) L
Methionine (Met) M
Phenylalanine (Phe) F
Tyrosine (Tyr) Y
Tryptophan (Trp) W

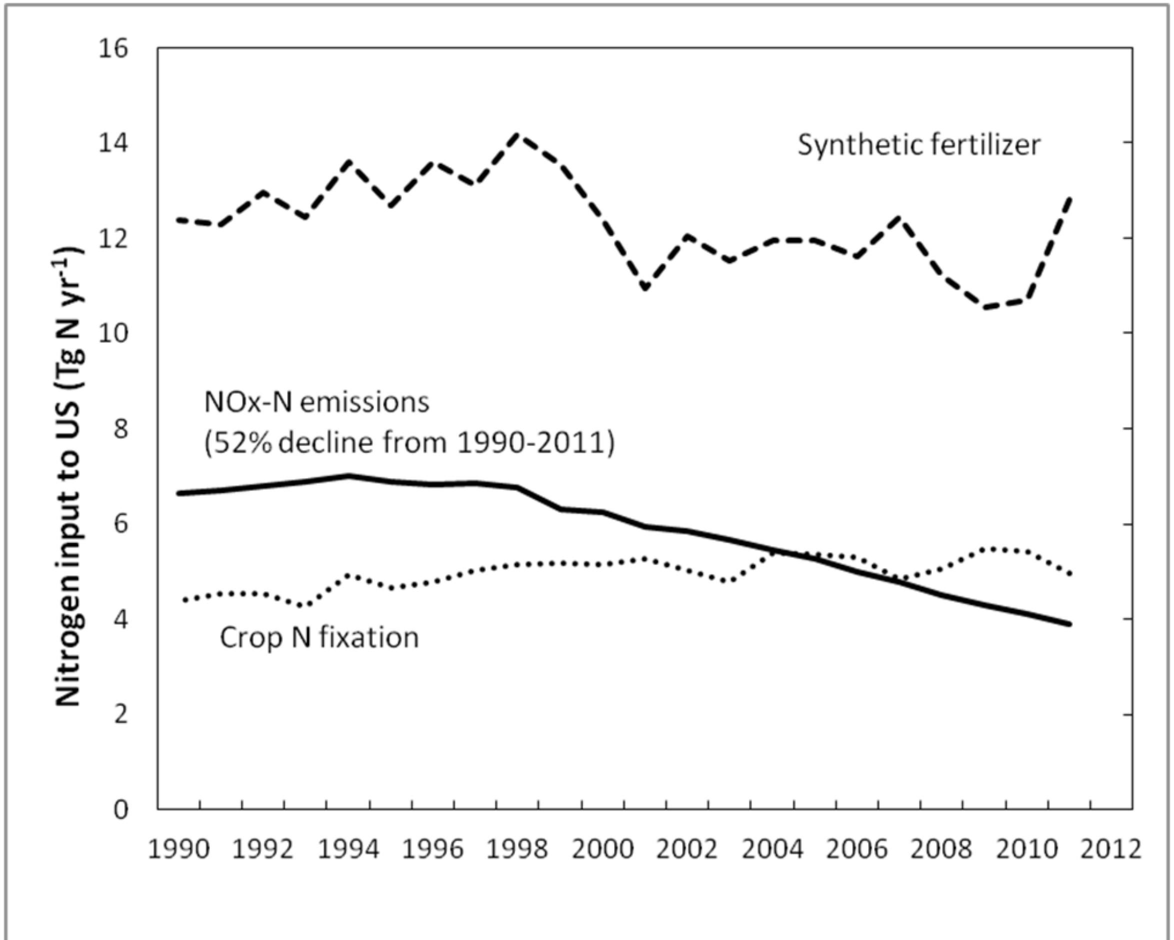
Sources of reactive nitrogen introduced into the US in 2002 (Tg N/yr)

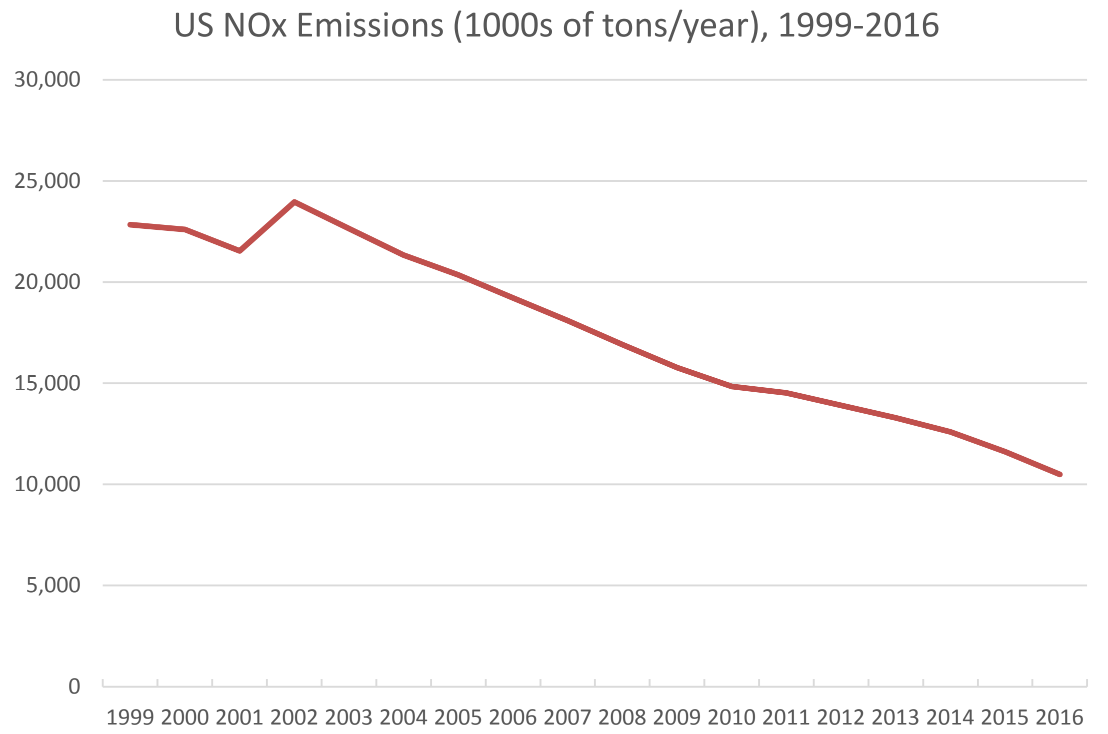



Haber


Bosch

Long Term Trends…

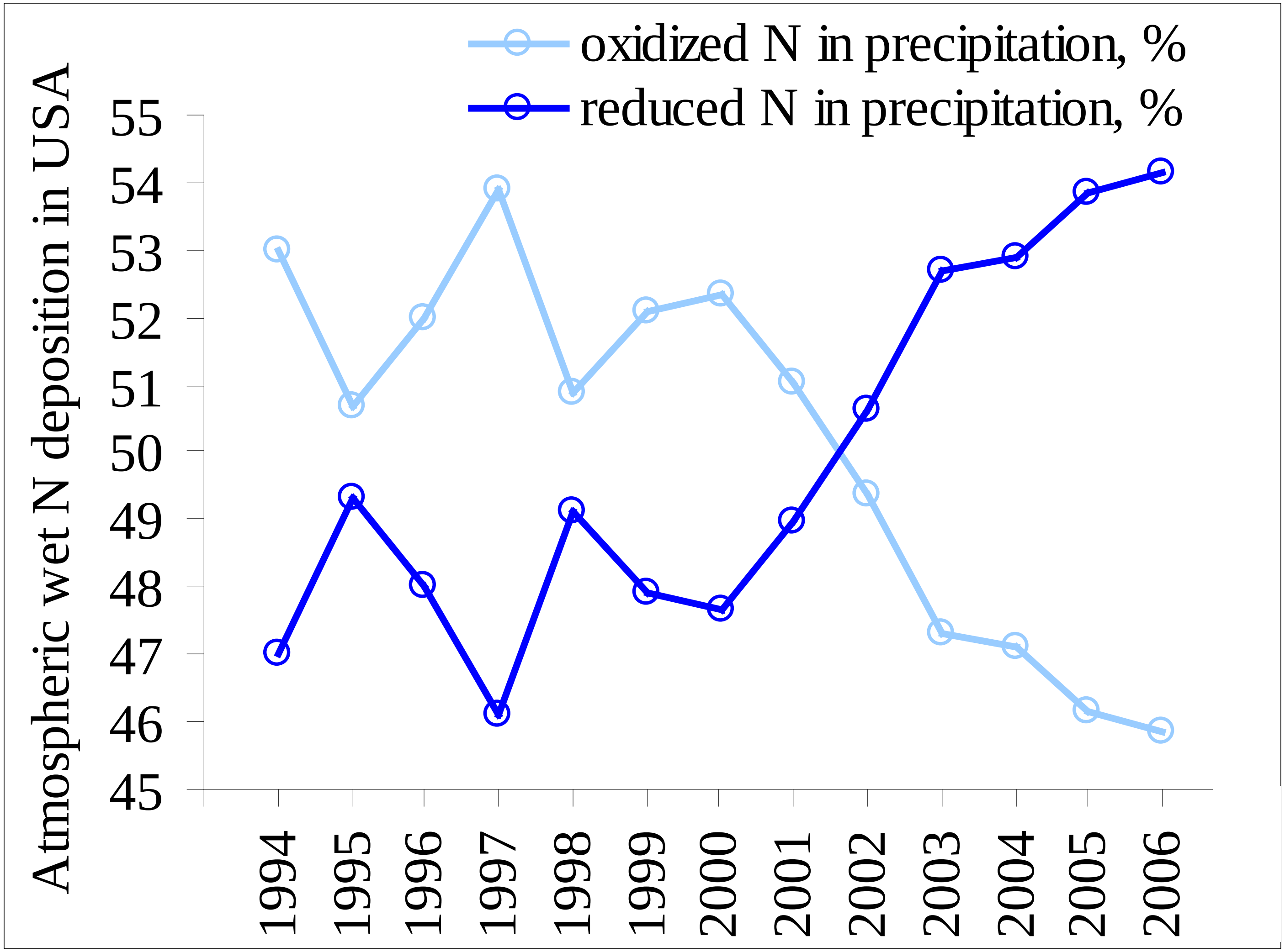



US NOx Emissions (1000s of tons/year), 1999-2016
30,000
25,000
20,000
15,000
10,000
5,000
0
1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016

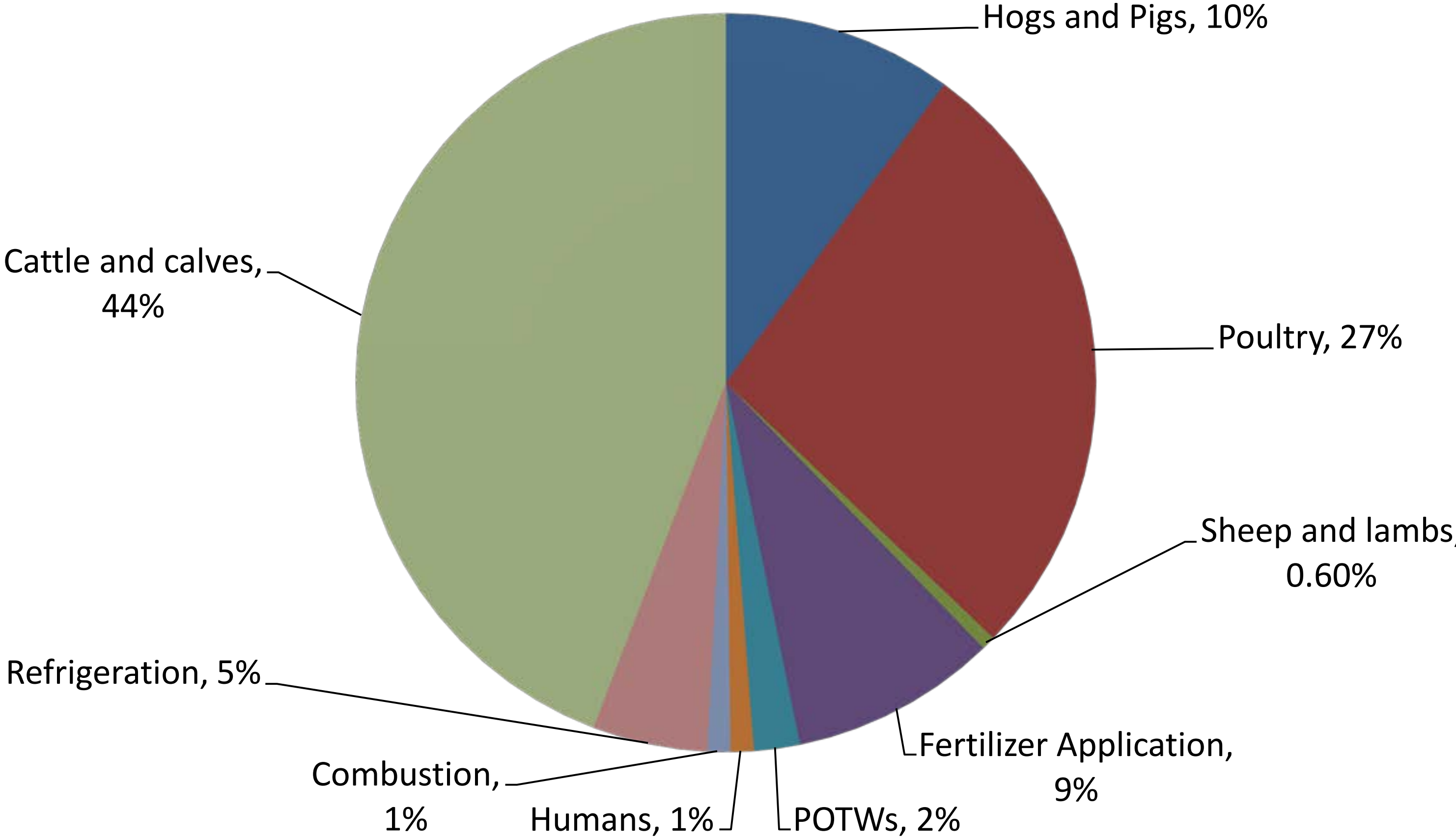
Major (US) federal laws for managing nitrogen

- **CAA** (1990) regulates NO_x emitted into atmospheric systems, but not NH_3
- **CWA** (1977) regulates NH_3 and total Nr released into aquatic systems
- **SDWA** (1996) regulates NO_3^- and NO_2^- in potable waters
- **EISA** (2007) requires the setting of biofuel standards based on *life cycle assessment*

Changes in N wet deposition, 1994-2006

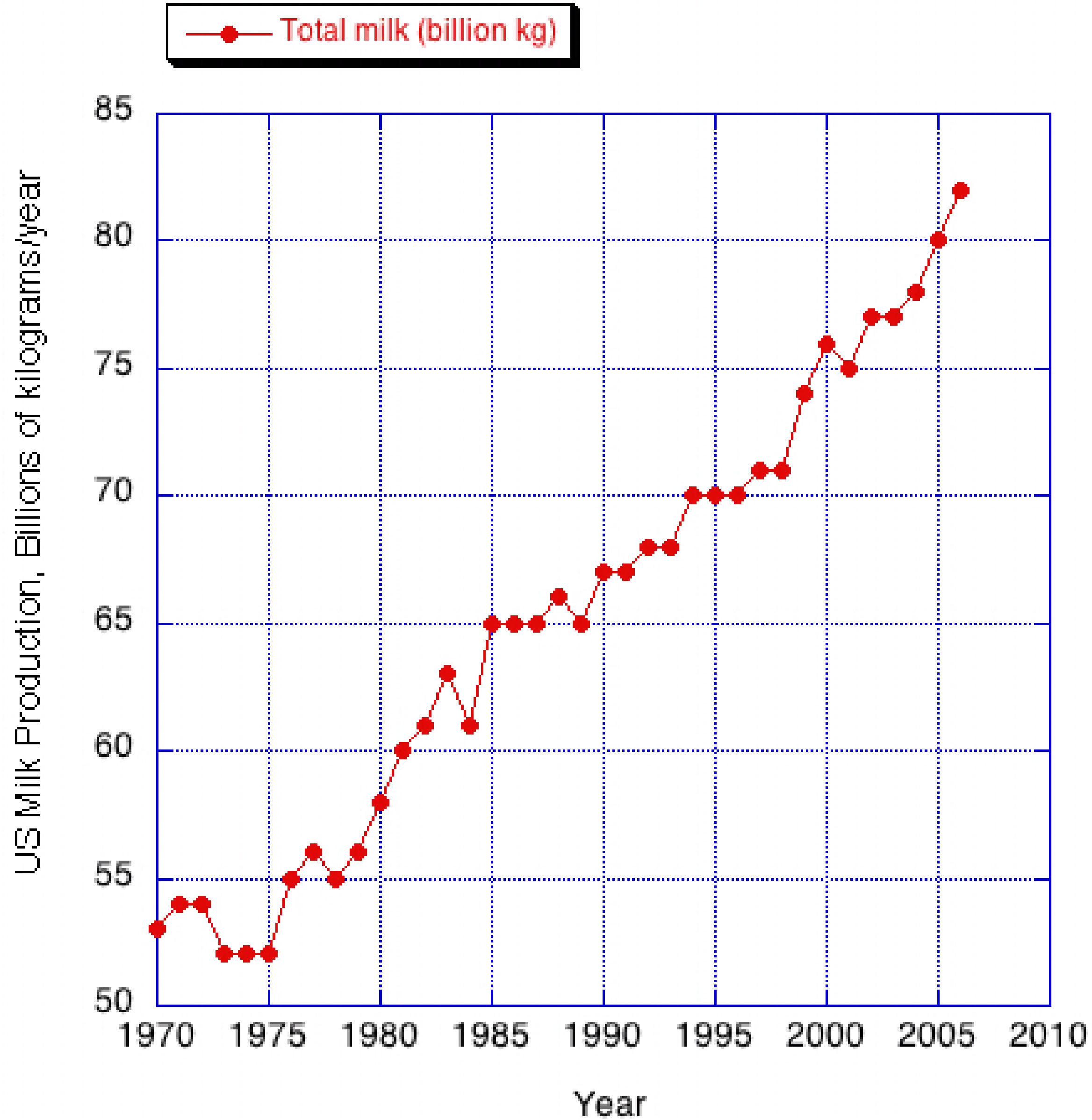


US ammonia emissions

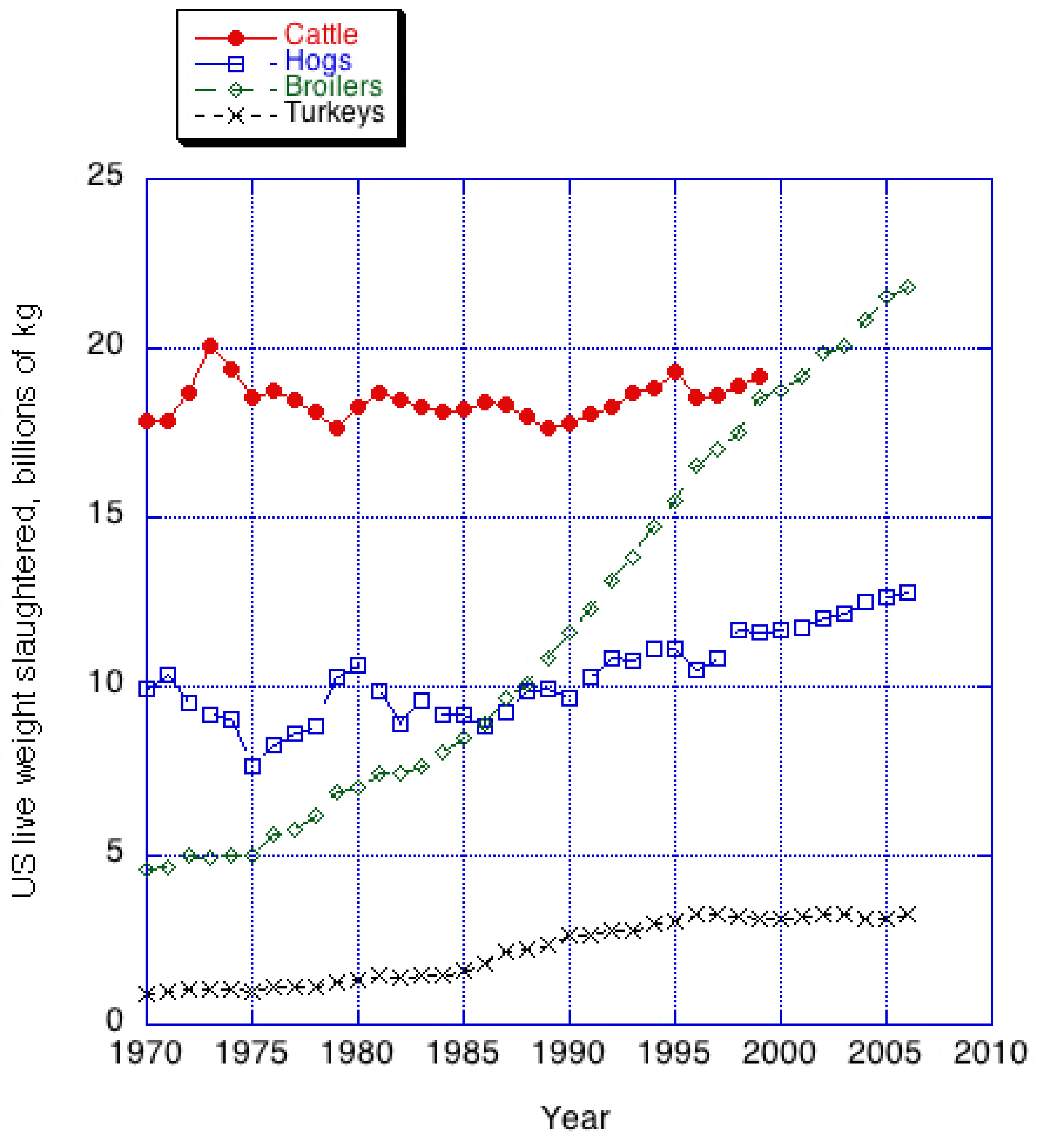


Source: Battye et al. 1994

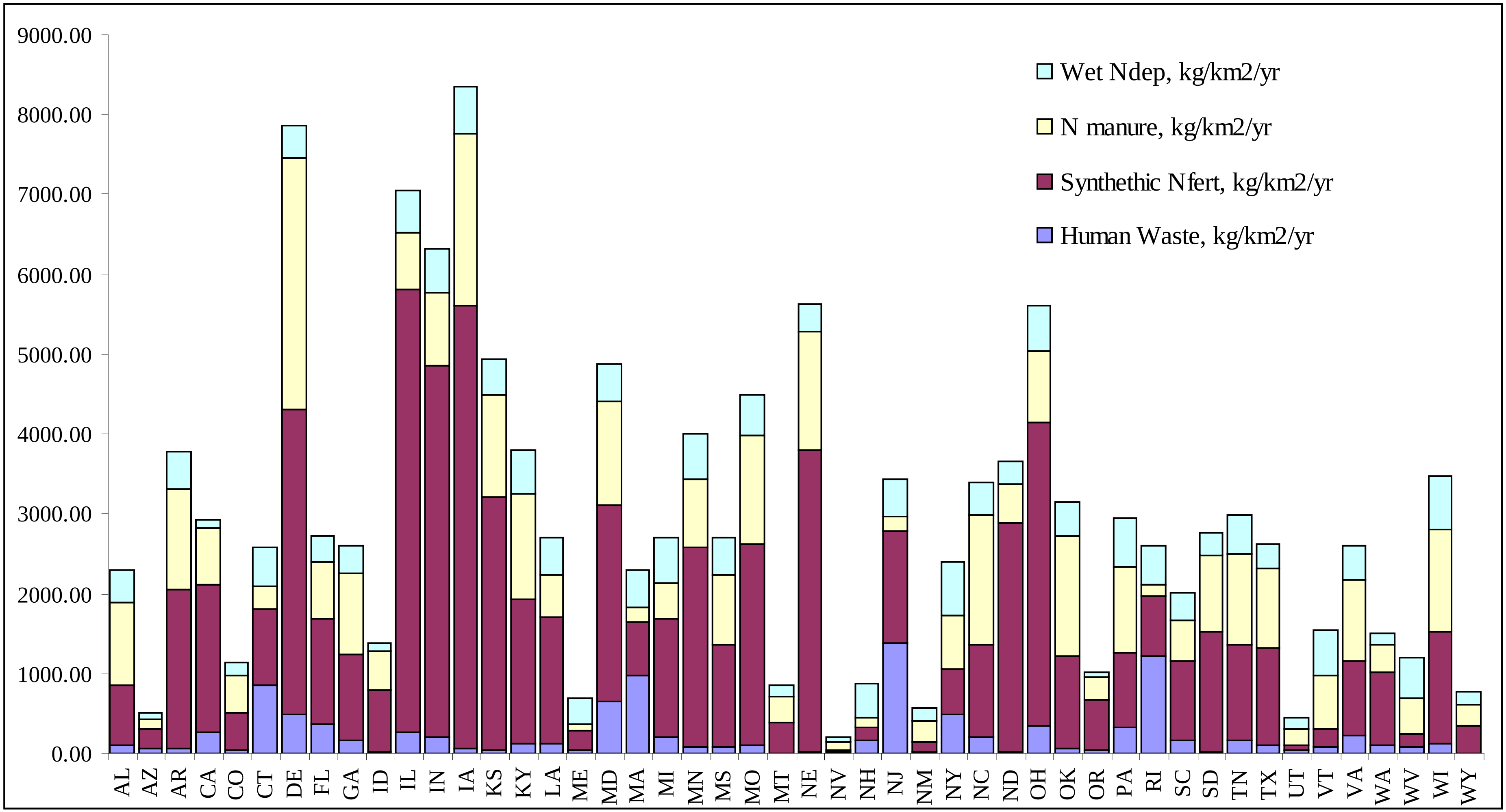
US Milk Production, 1970-2006



US Meat Production, 1970-2006

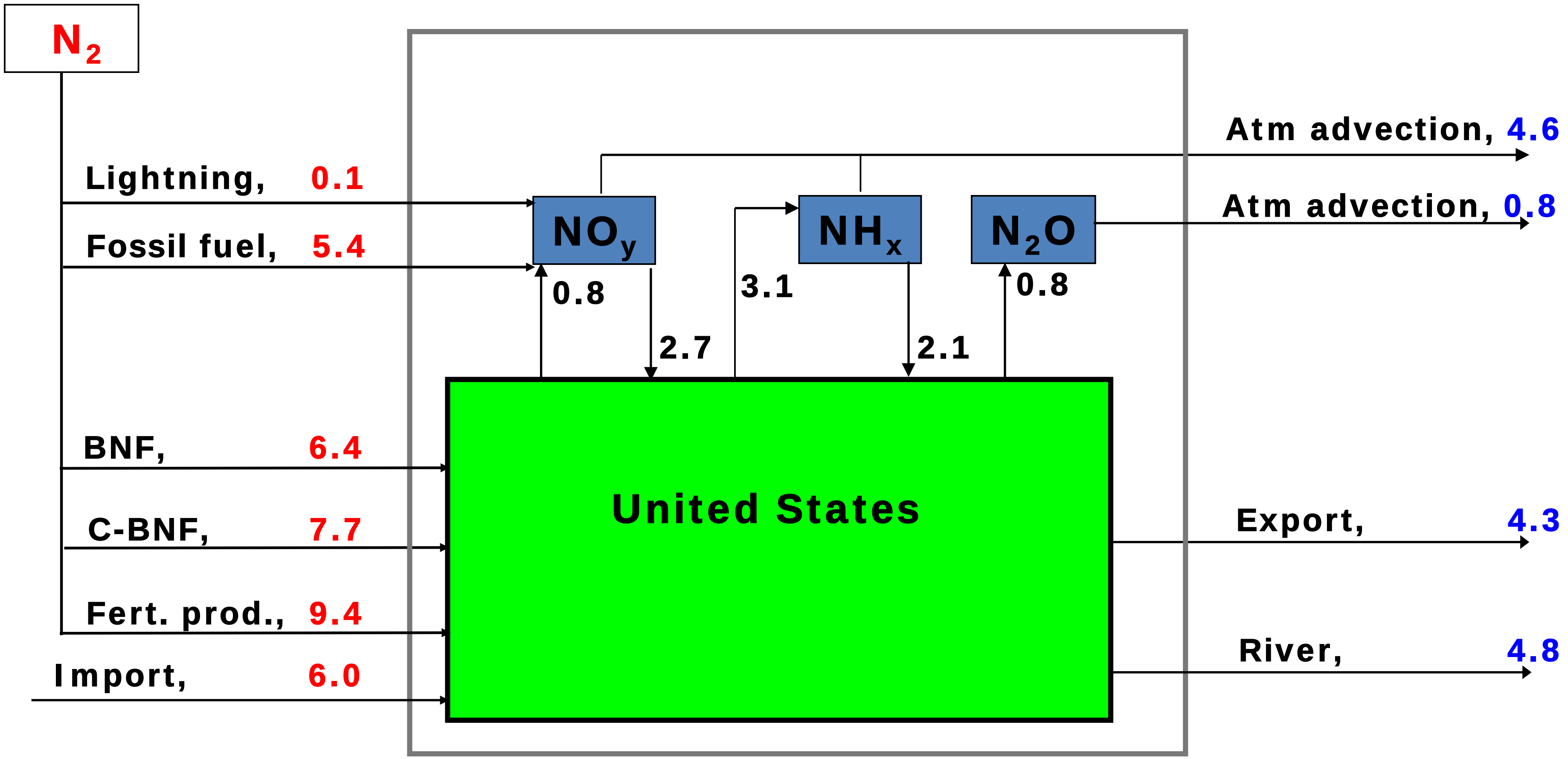


State subtotals → surface balance



US Nitrogen Budget

Tg N yr^{-1}



Nr Inputs: 35 Tg N
Nr Outputs: 14 Tg N

Nr "Missing": 21 Tg N

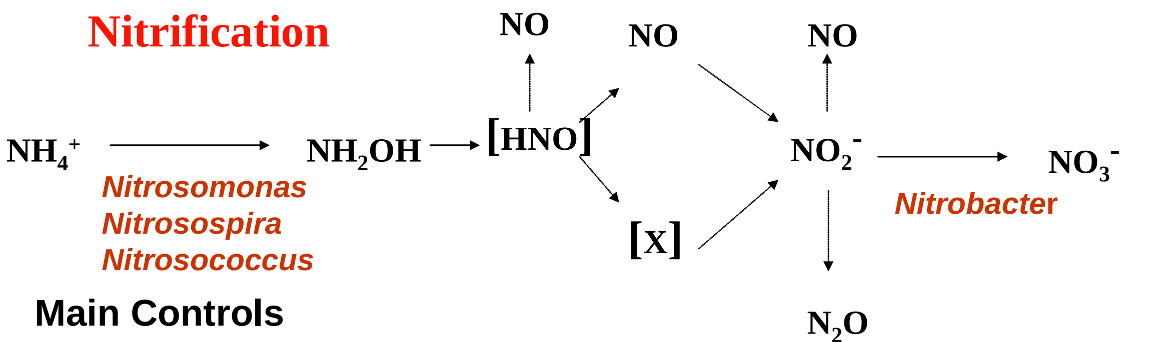
Nr Storage: 5 Tg N
~ 2 Tg soils&vegetation
~ 3 Tg groundwater

Nr Denitrified to N_2:
21 Tg N - 5 Tg N = 16 Tg N

Nitrification and denitrification processes

(from Mosier and Parkin 2007)

Nitrification



Main Controls

Substrate, O_2, H_2O, T

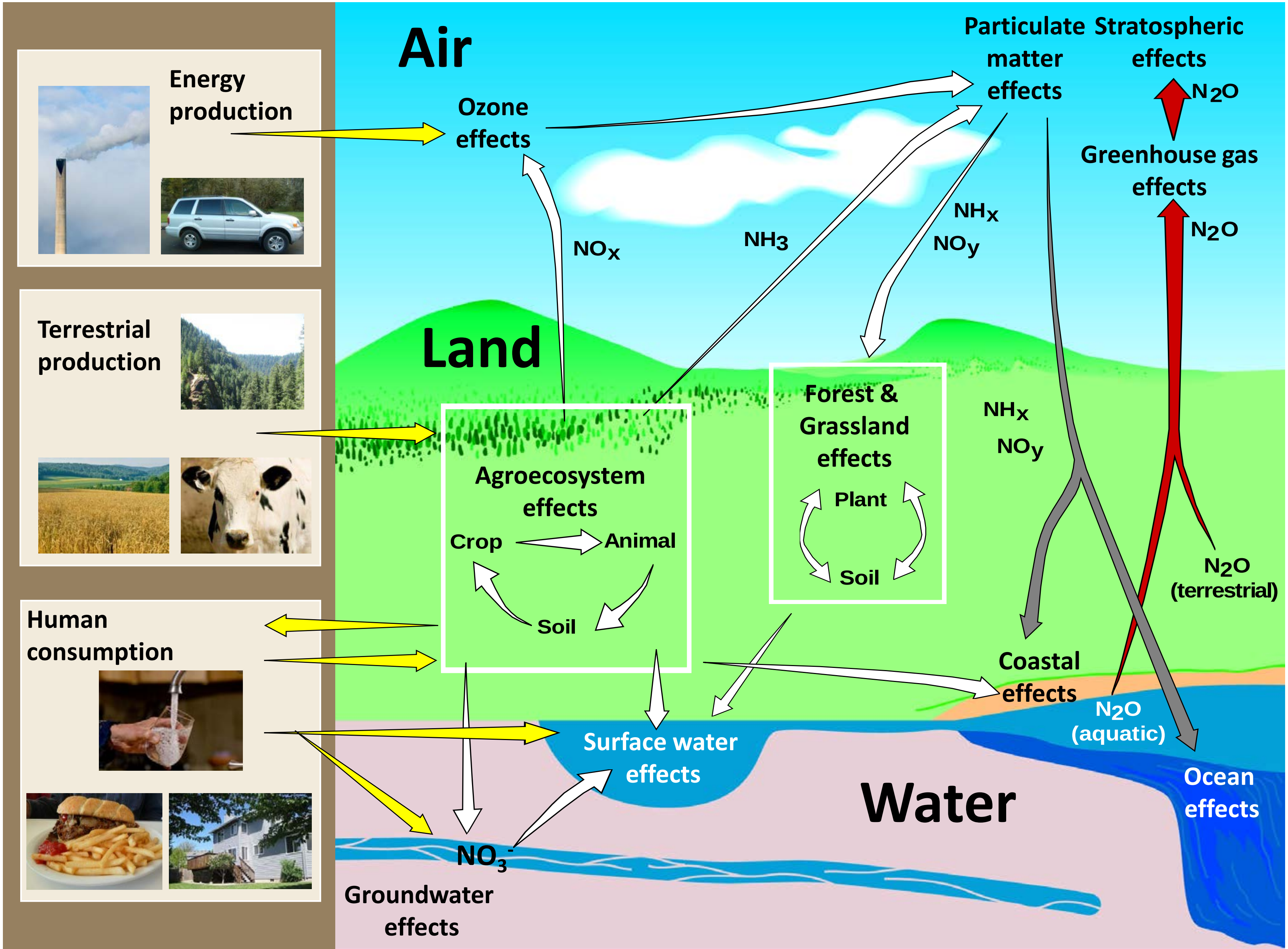
Denitrification

Facultative Anaerobic Bacteria

Main Controls

Substrate, available C, O_2 , H_2O, T

The nitrogen cascade



Metrics Case Study: Chesapeake Bay

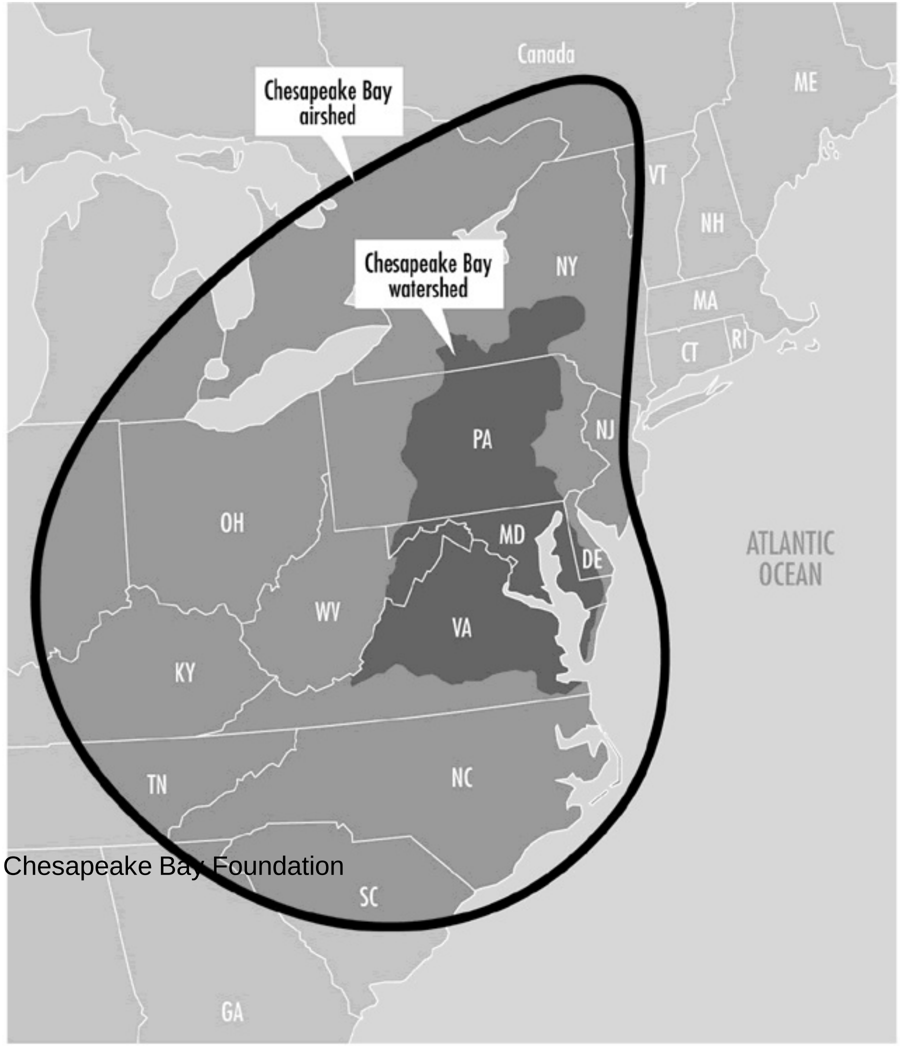
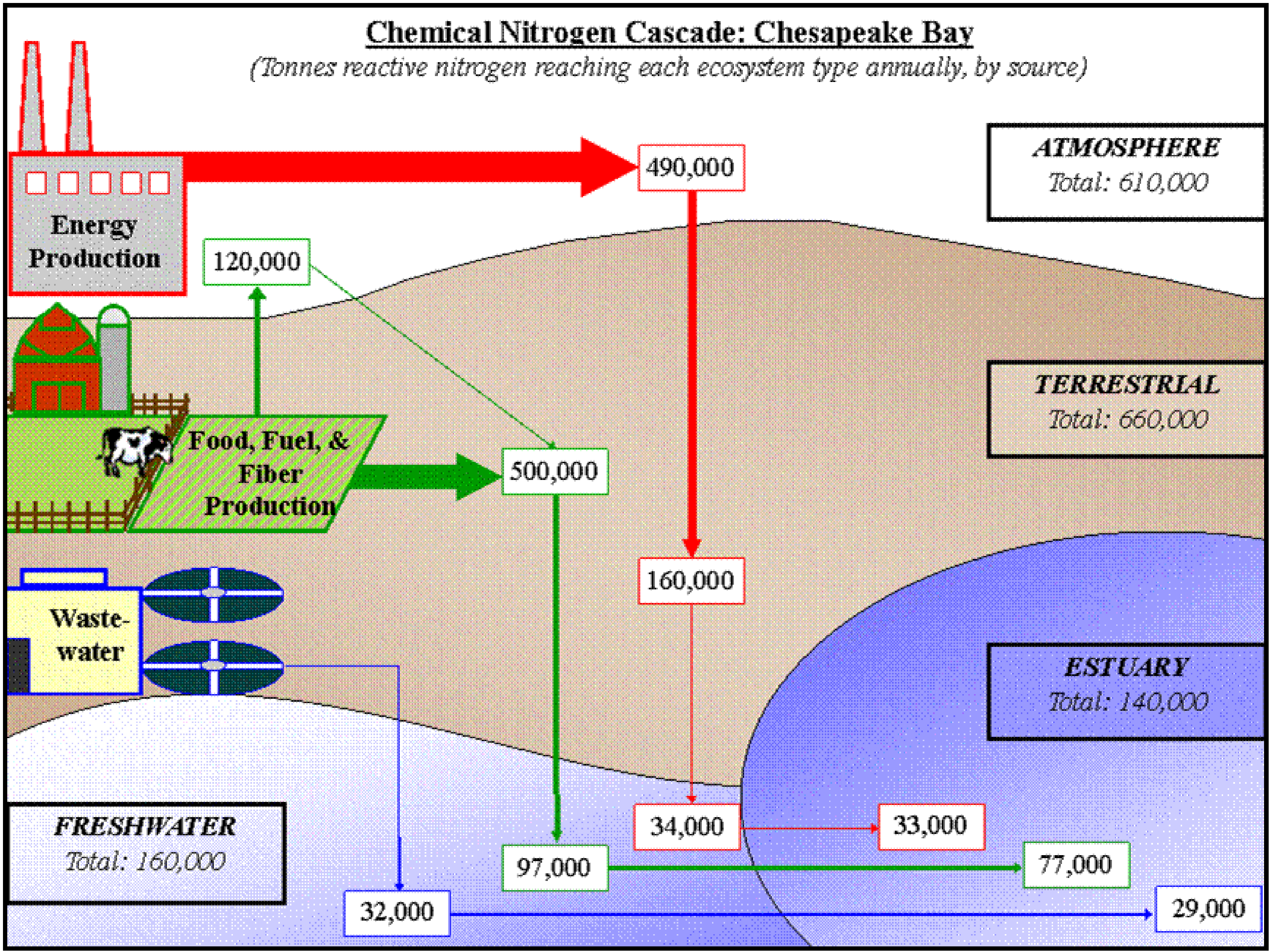
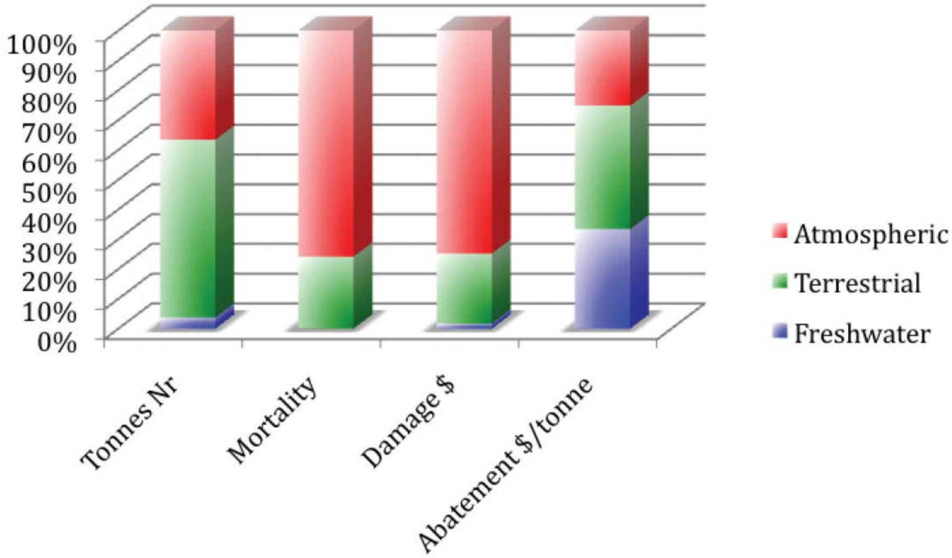


Image from Chesapeake Bay Foundation


Chemical Nitrogen Cascade: Chesapeake Bay
(Tonnes reactive nitrogen reaching each ecosystem type annually, by source)
Energy Production
490,000
ATMOSPHERE
Total: 610,000
120,000
Food, Fuel, & Fiber Production
500,000
TERRESTRIAL
Total: 660,000
160,000
Waste-water
ESTUARY
Total: 140,000
FRESHWATER
Total: 160,000
34,000
33,000
97,000
77,000
32,000
29,000

The Nitrogen Cascade in Chesapeake Bay – Implications for Nr Management

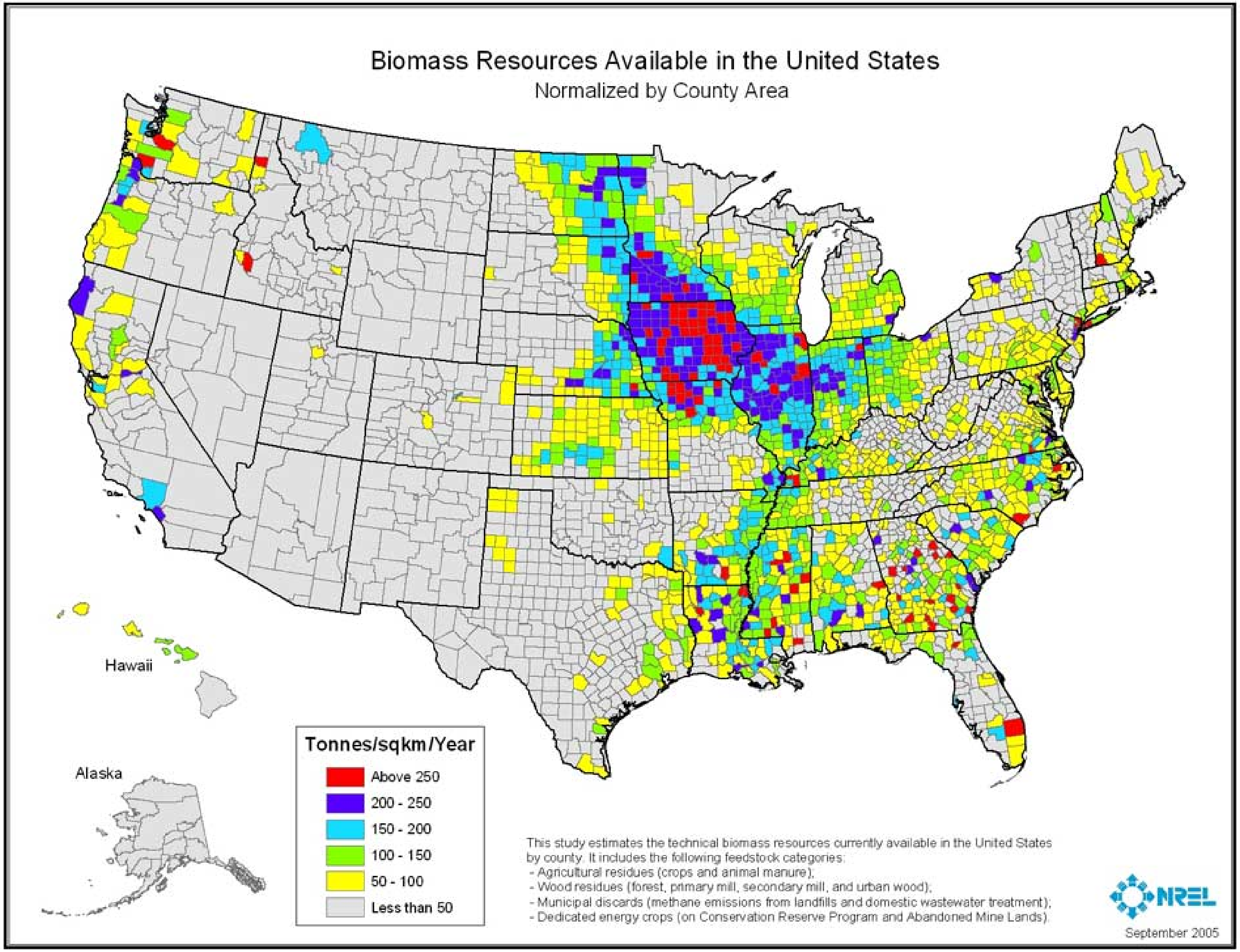
- Damage costs and marginal abatement costs per metric ton of Nr by source (atmospheric, terrestrial, freshwater) indicate that the least costly abatement and greatest gain comes from atmospheric emission controls.



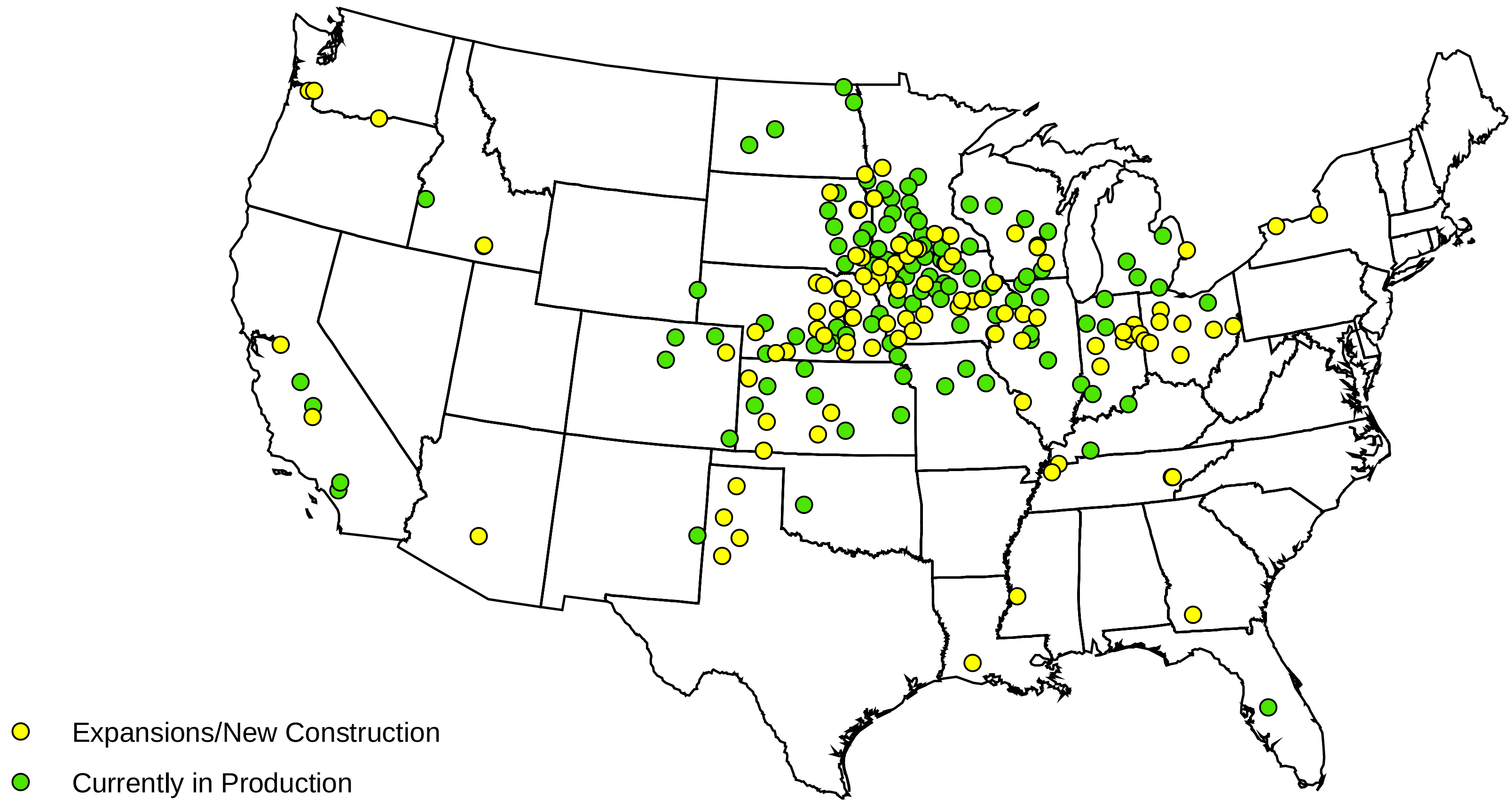
Relative importance of all reactive nitrogen sources released into atmospheric, terrestrial, and freshwater media within the Chesapeake Bay Watershed (Birch et al., 2011)

Mississippi River Basin

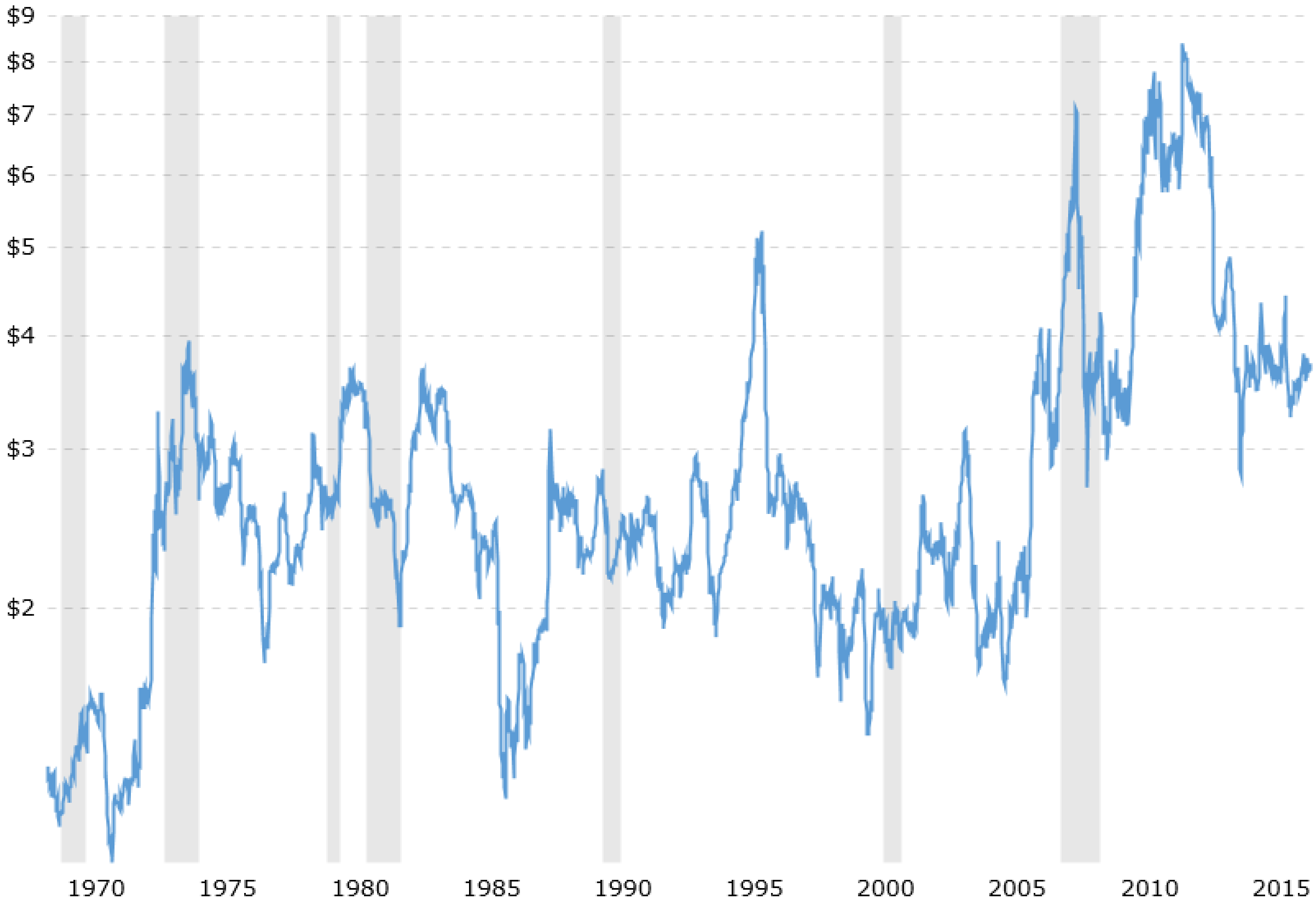
U.S. Biomass Resources



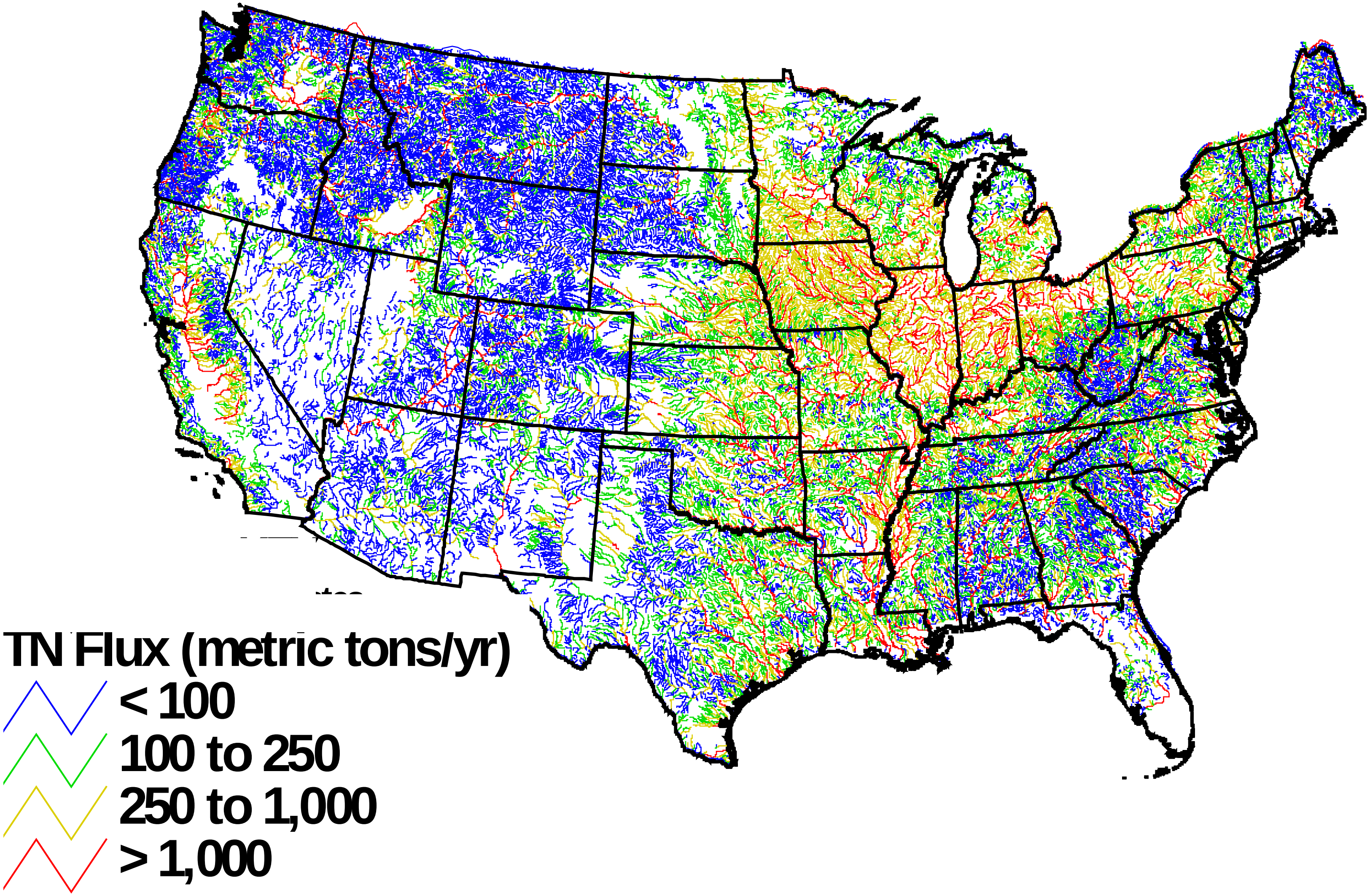
U.S. Ethanol Plants



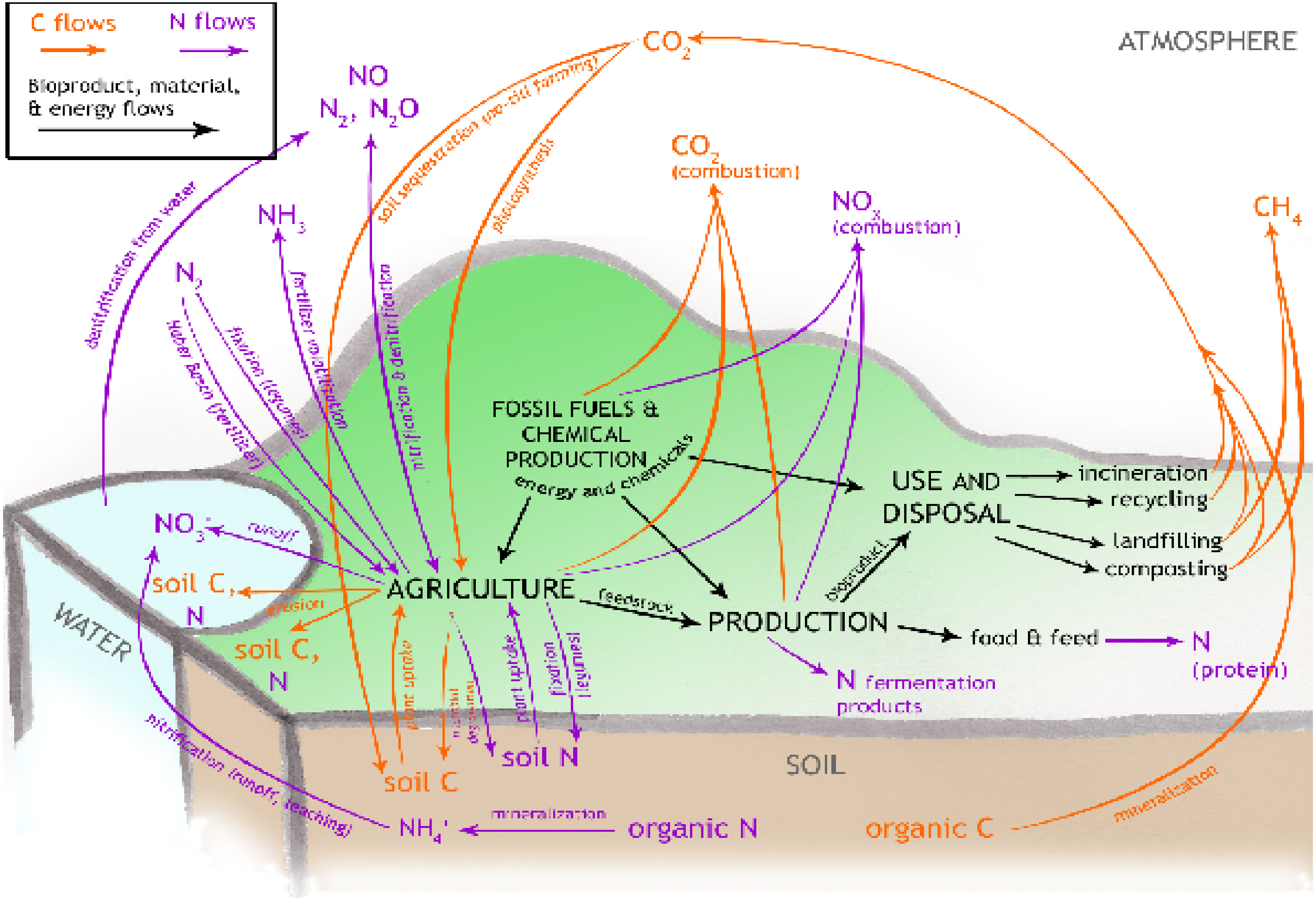
45 Year History: Price of Corn (U.S. $$/bushel)



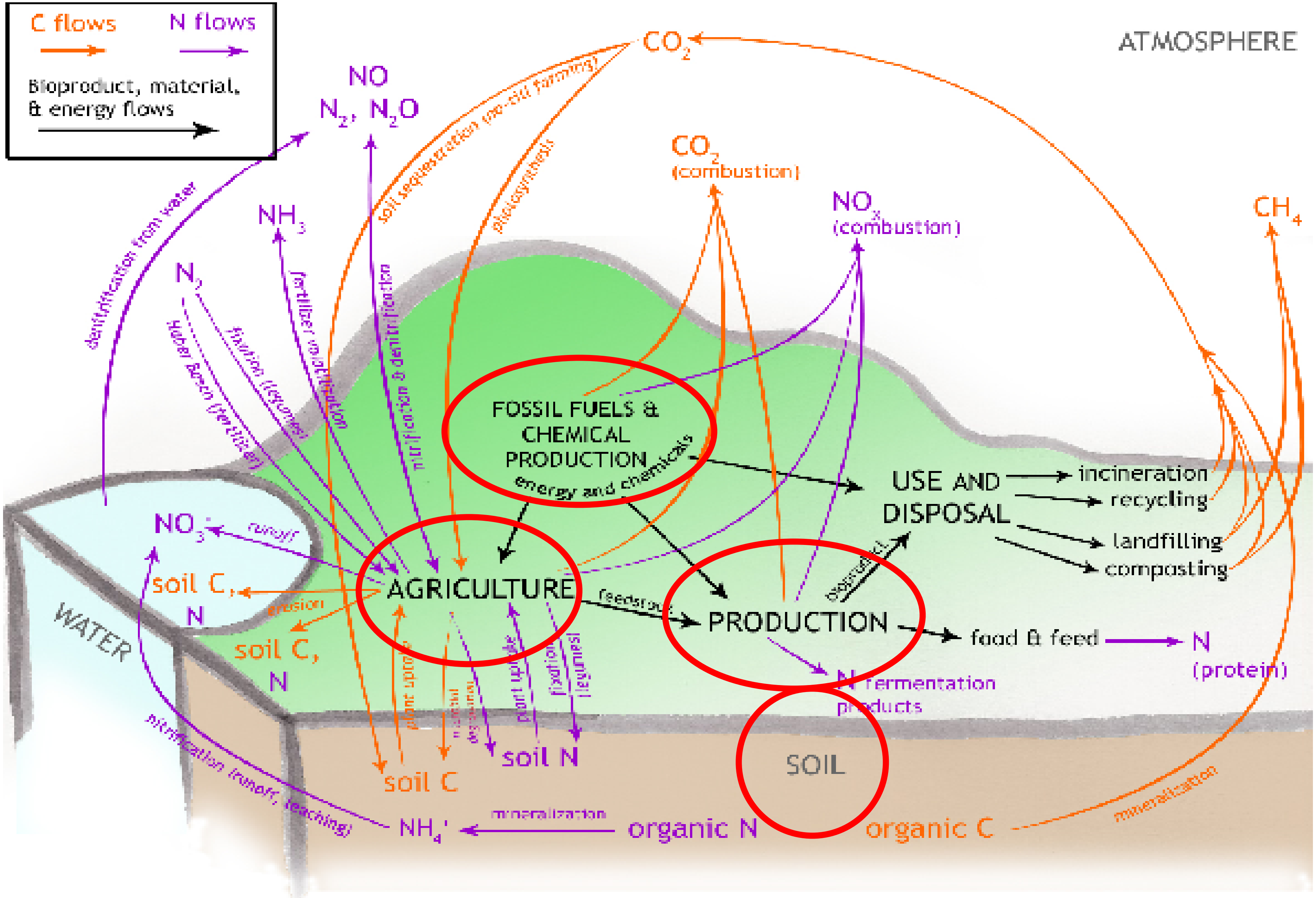
SPARROW simulated N fluxes in stream reaches



Carbon and Nitrogen Global Cycles



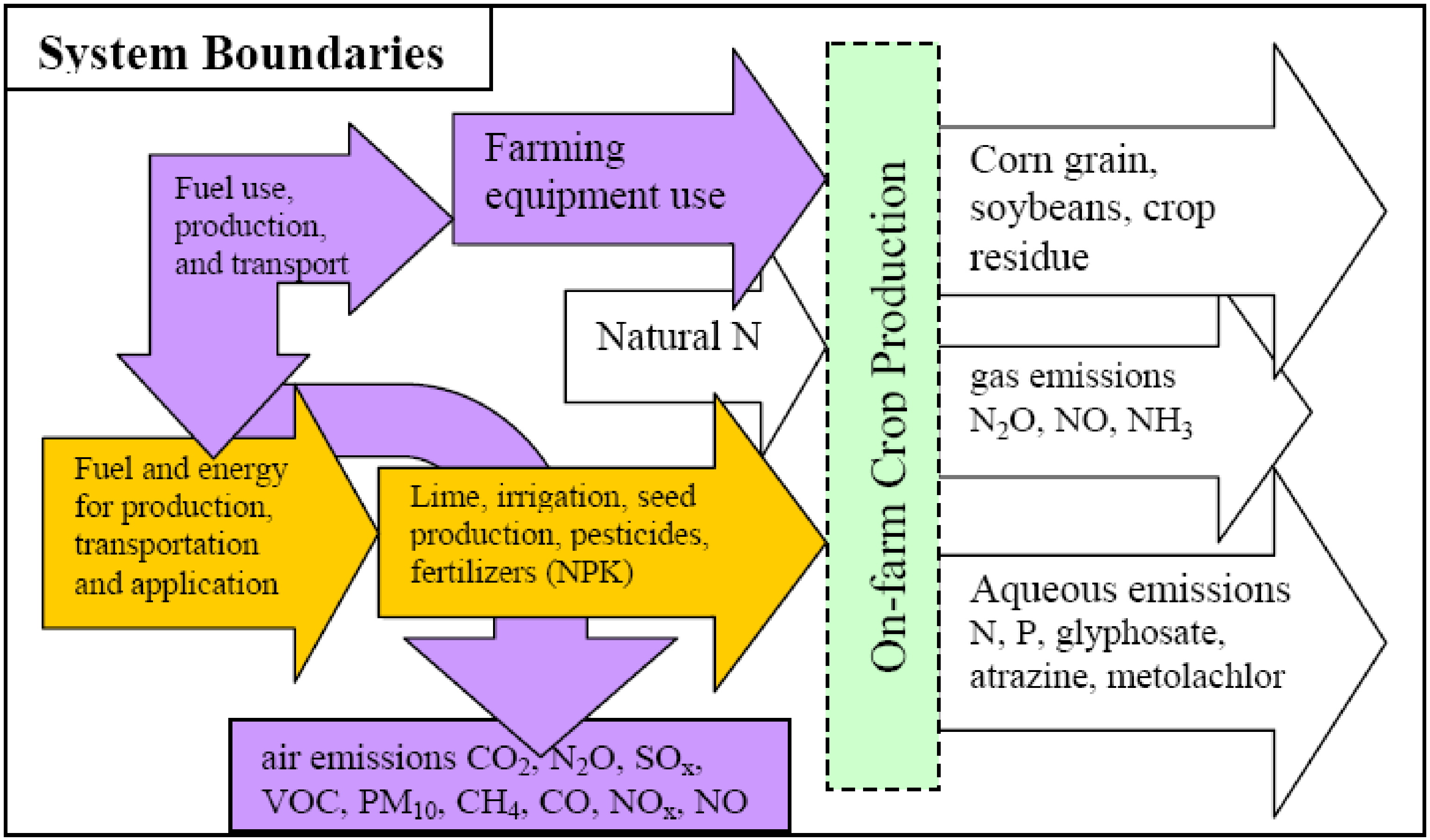
Carbon and Nitrogen Global Cycles



Major Environmental Impact Categories: N and C

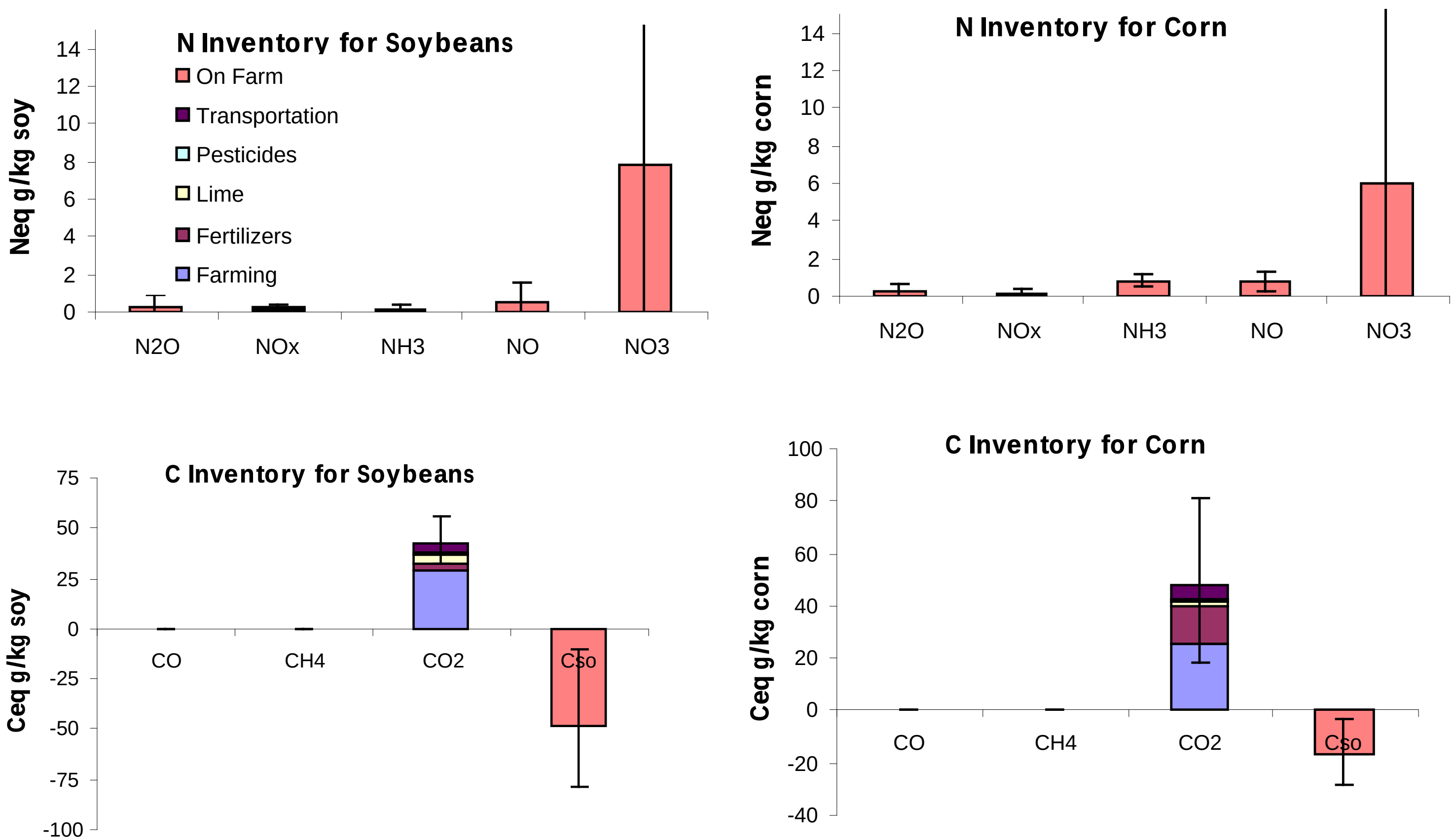
Impact	*Reference Unit* (TRACI)	*Carbon*	*Nitrogen*
Climate Change	$CO_{2\ eq}$	CO_2, CH_4	N_2O
Eutro/Hypoxia	N_{eq}	indirect	NO_3^-, NH_3, NO_x
Ecotoxicity	2,4-D_{eq}	compound specific	NH_3
Human Health (Criteria)	$PM2.5_{eq}$	substance specific	NO_x
Non-Cancer	$Toluene_{eq}$		NH_3
Acidification	H^+	H_2CO_3	HNO_3, NH_4^+
Smog Formation	NO_{xeq}	CH_4, CO, VOC	NO_x

Corn-Soybean Agrosystem for LCI

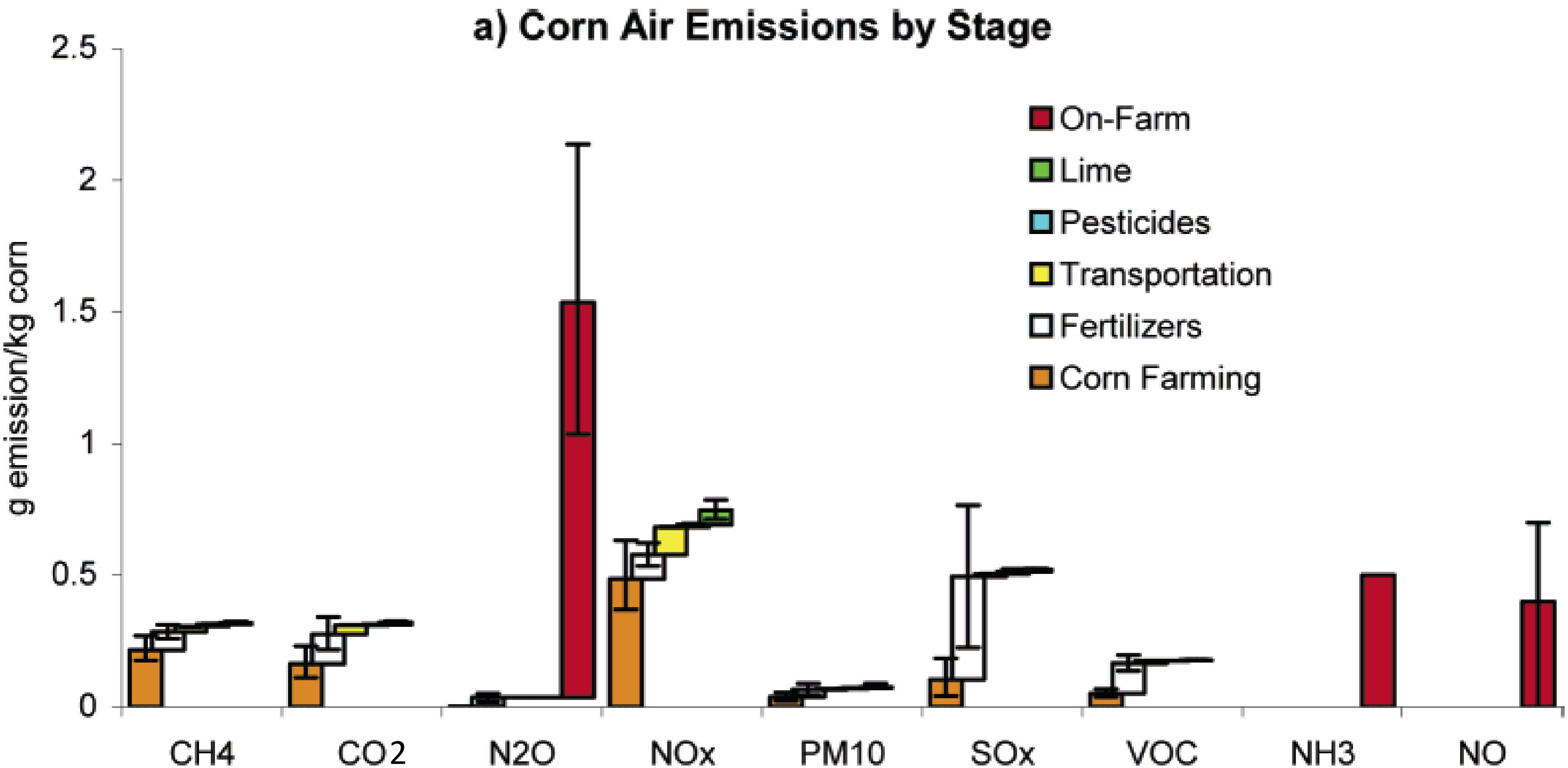


Landis et al, ES&T 41:1457-1464 (2007)

C and N Inventories/Corn & Soybean (grown in rotation)

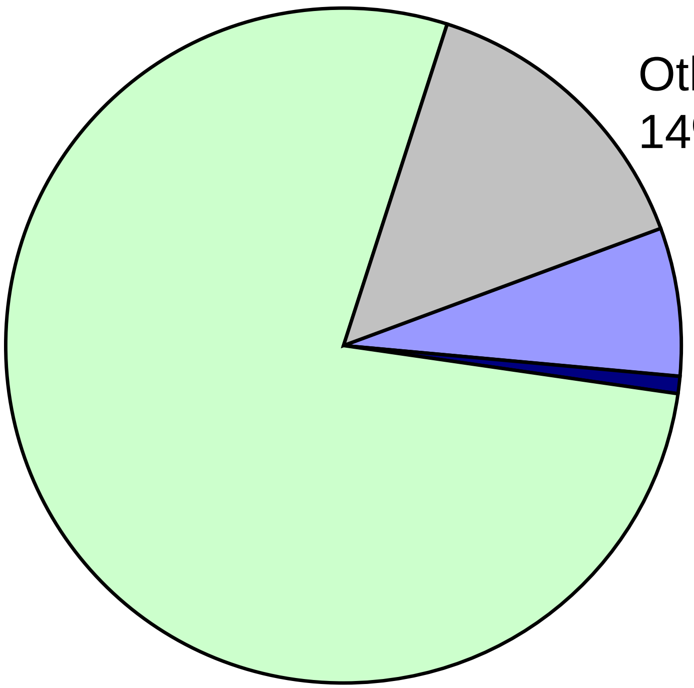


Agricultural Inventory



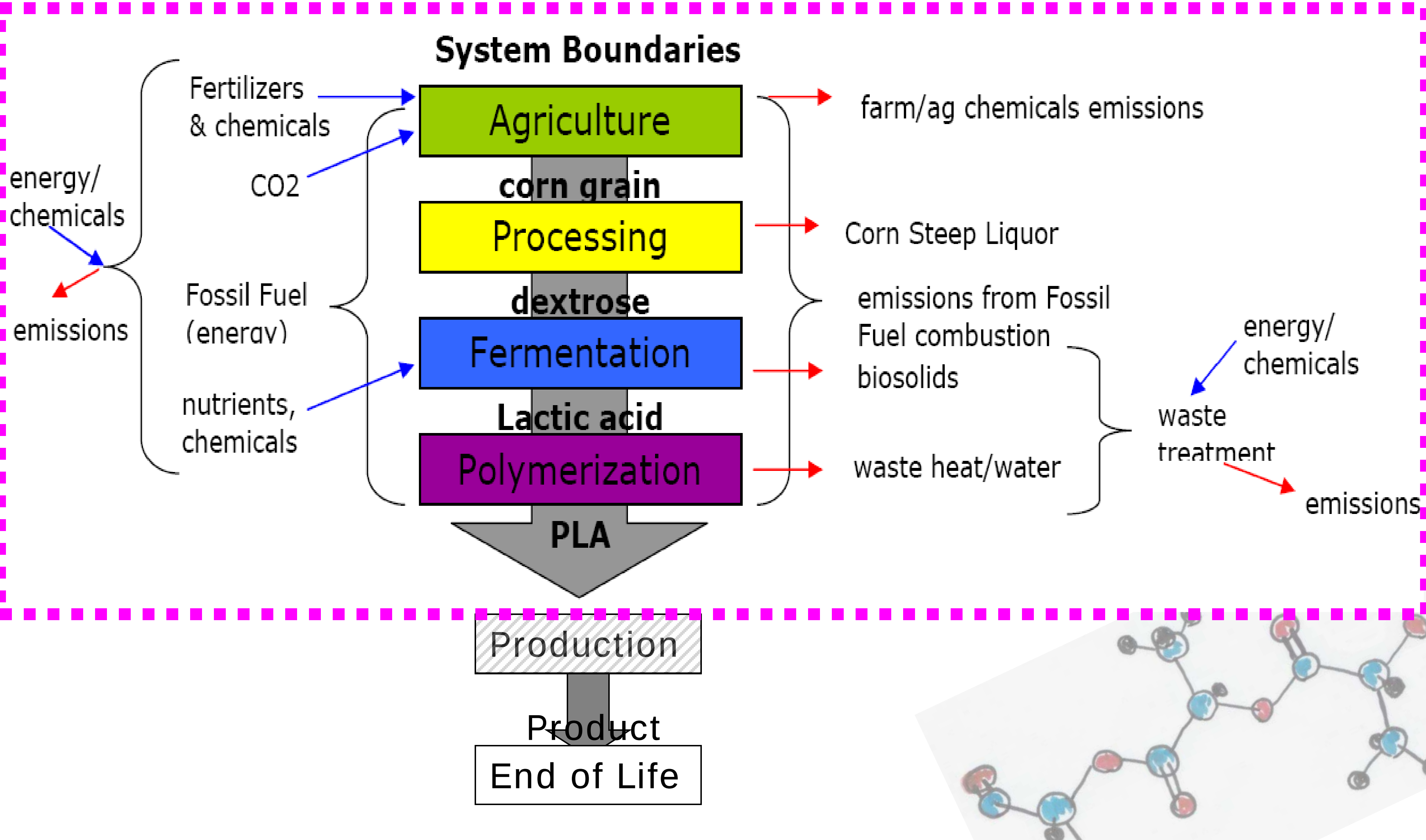
Landis, et al. *ES&T* **2007**, *41*, 1457-1464

U.S. N_2O Emissions in 2005

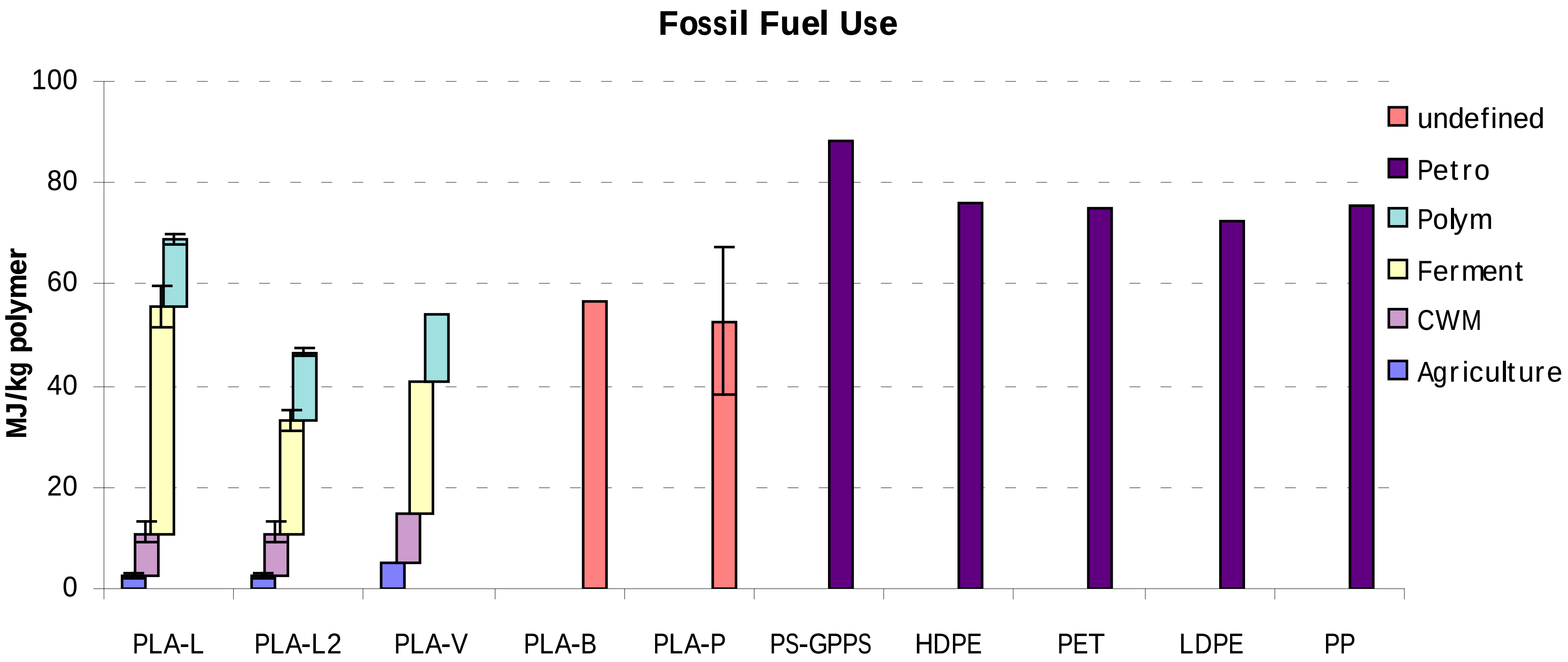


Source: Inventory of U.S. Greenhouse Gas Emissions and Sinks, 1990-2005

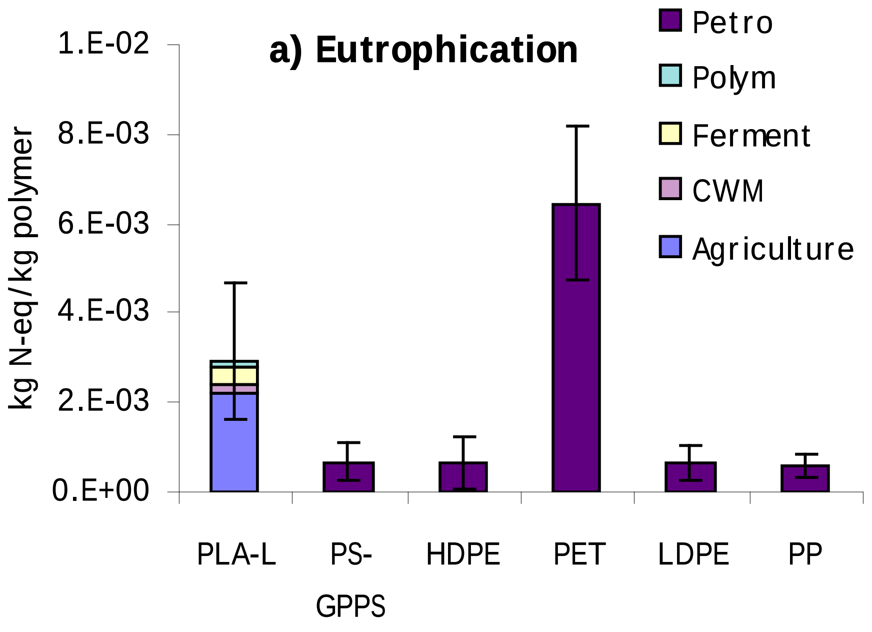
Case Study: Polylactic Acid (PLA)



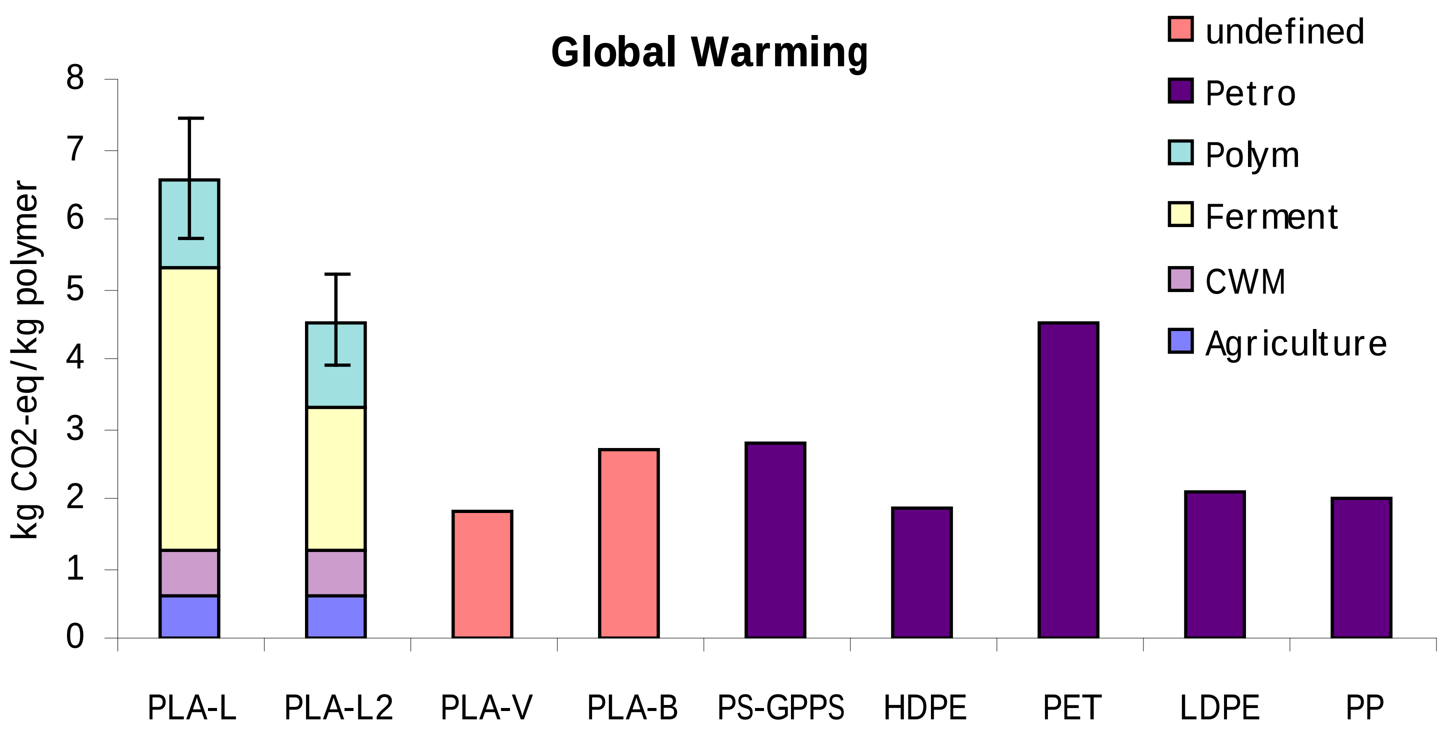
Comparative Results



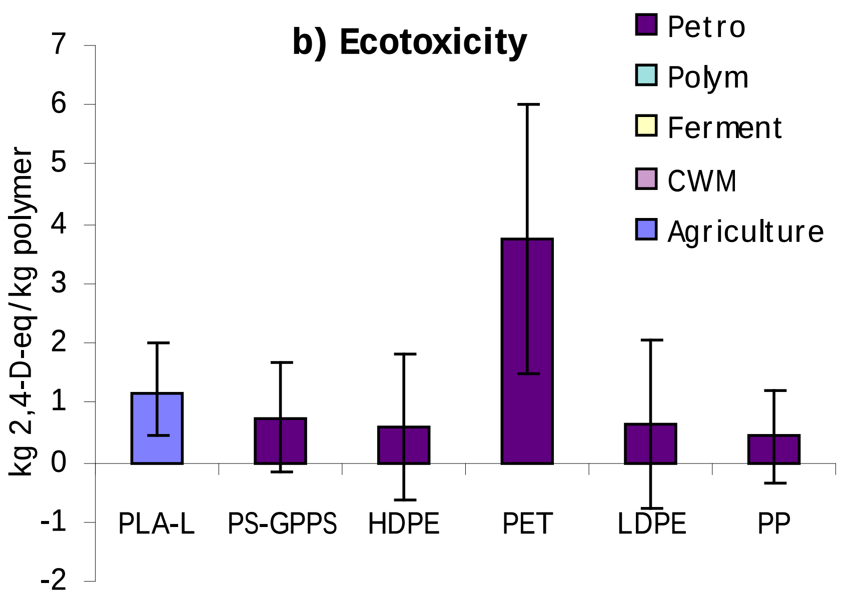
Comparative Results

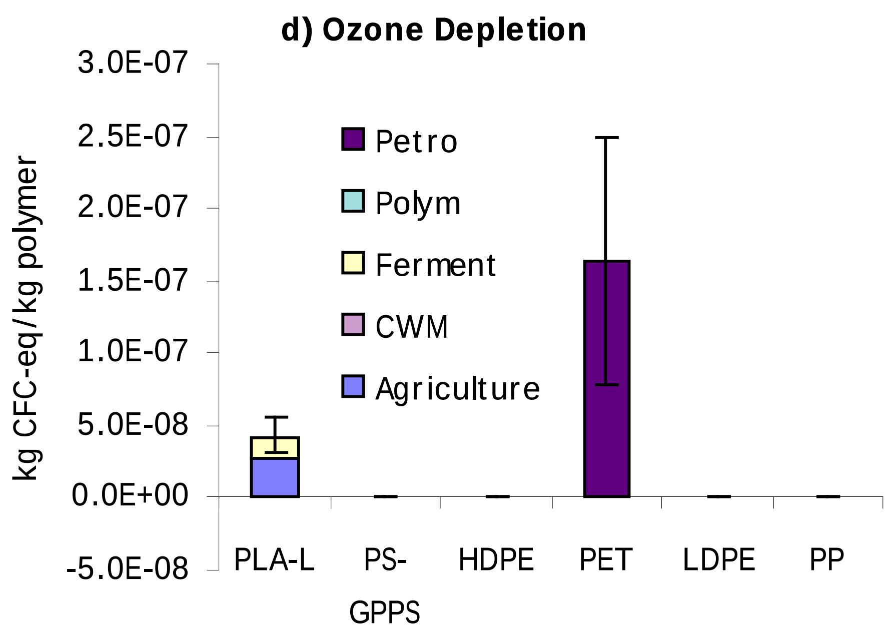


Comparative Results

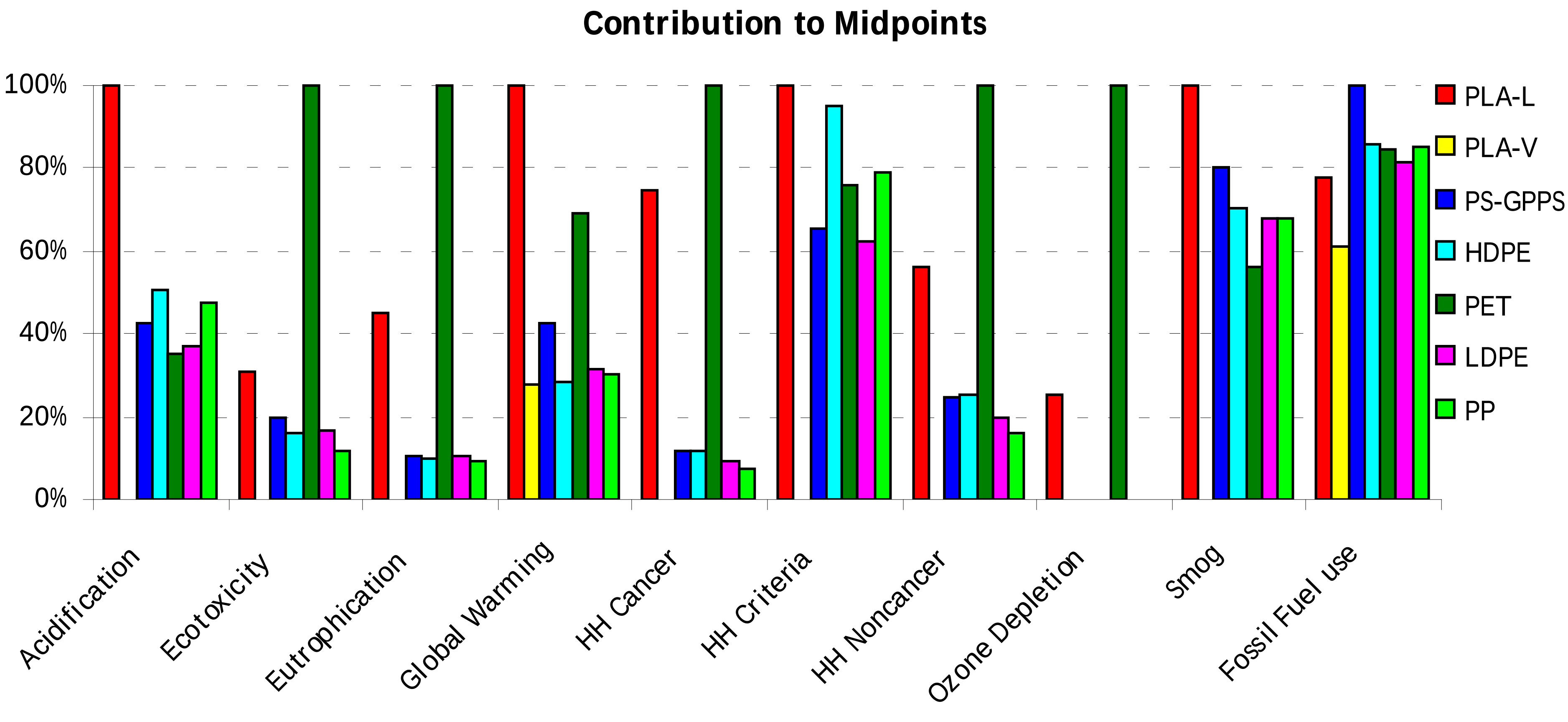


Comparative Results

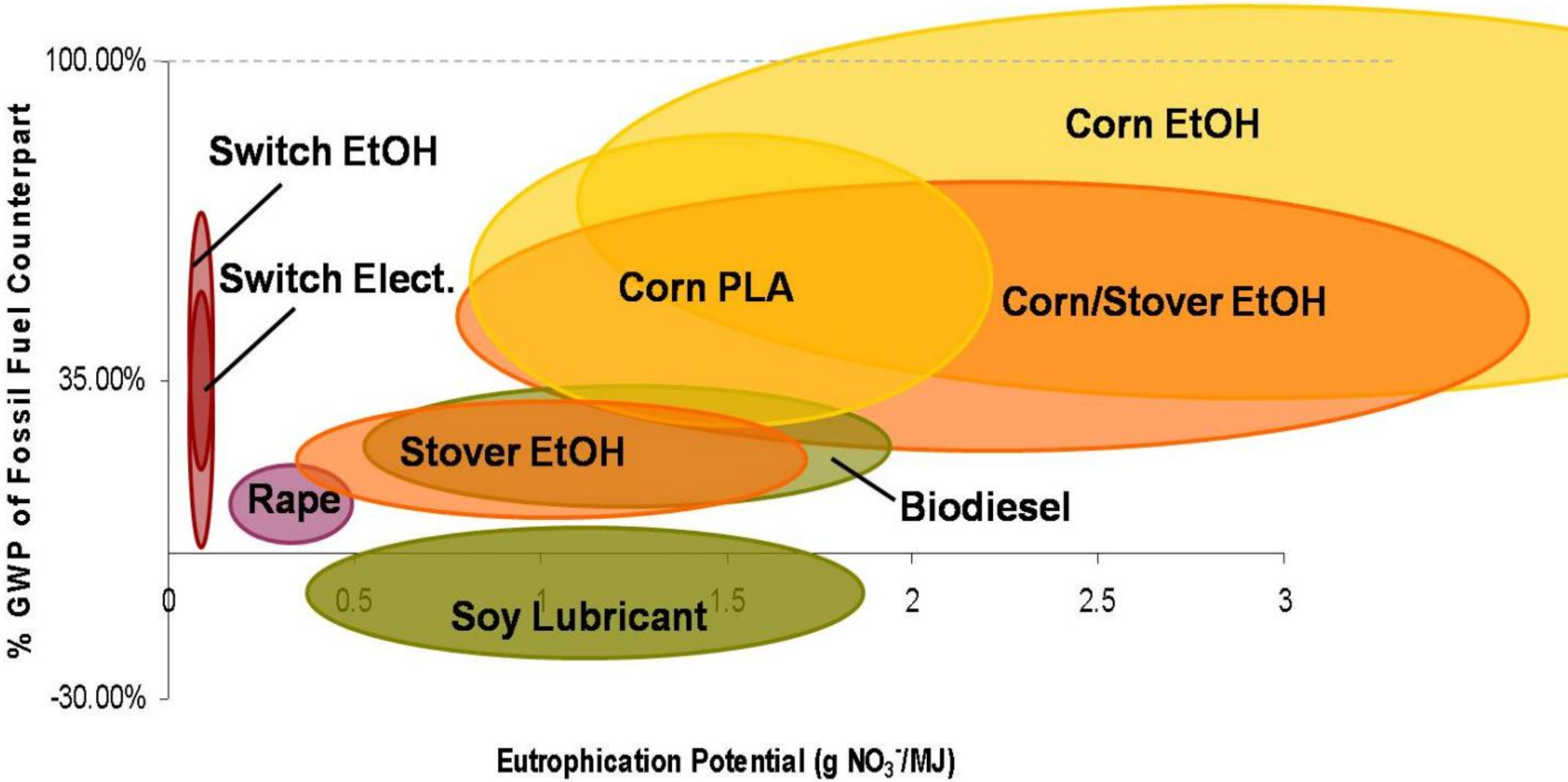




Comparative LCA Results



Relative C/N Profiles



Concluding thoughts…[1]

Life Cycle Approach

- By following the flow of materials (and energy), life cycle analysis compels us to couple related subsystems, for example material acquisition to product development and use, nitrogen cycling to carbon cycling, demand to impacts, impacts to control measures to policy
- Helps in making holistic comparisons among options, policies, and designs
- Clarifies the nature of tradeoffs, helping to avoid unintended consequences
- Illuminates those points where intervention works best
- Helps to identify critical research and data needs

Concluding thoughts…[2]

Is the nitrogen problem a lost cause?

- Total NO_x emissions dropping
- NH_3 emissions rising
- Nr needs vs impacts
- Complex interactions (cascade/coupling w/ C)
- Ongoing research needs
- Relative indifference
- Limited regulatory approach (TMDL)
- Conflicting policies (food vs fuel)