Perspectives on Reactive Nitrogen and the Environment

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NitroEurope IP Kick Off Meeting

13 March, 2006

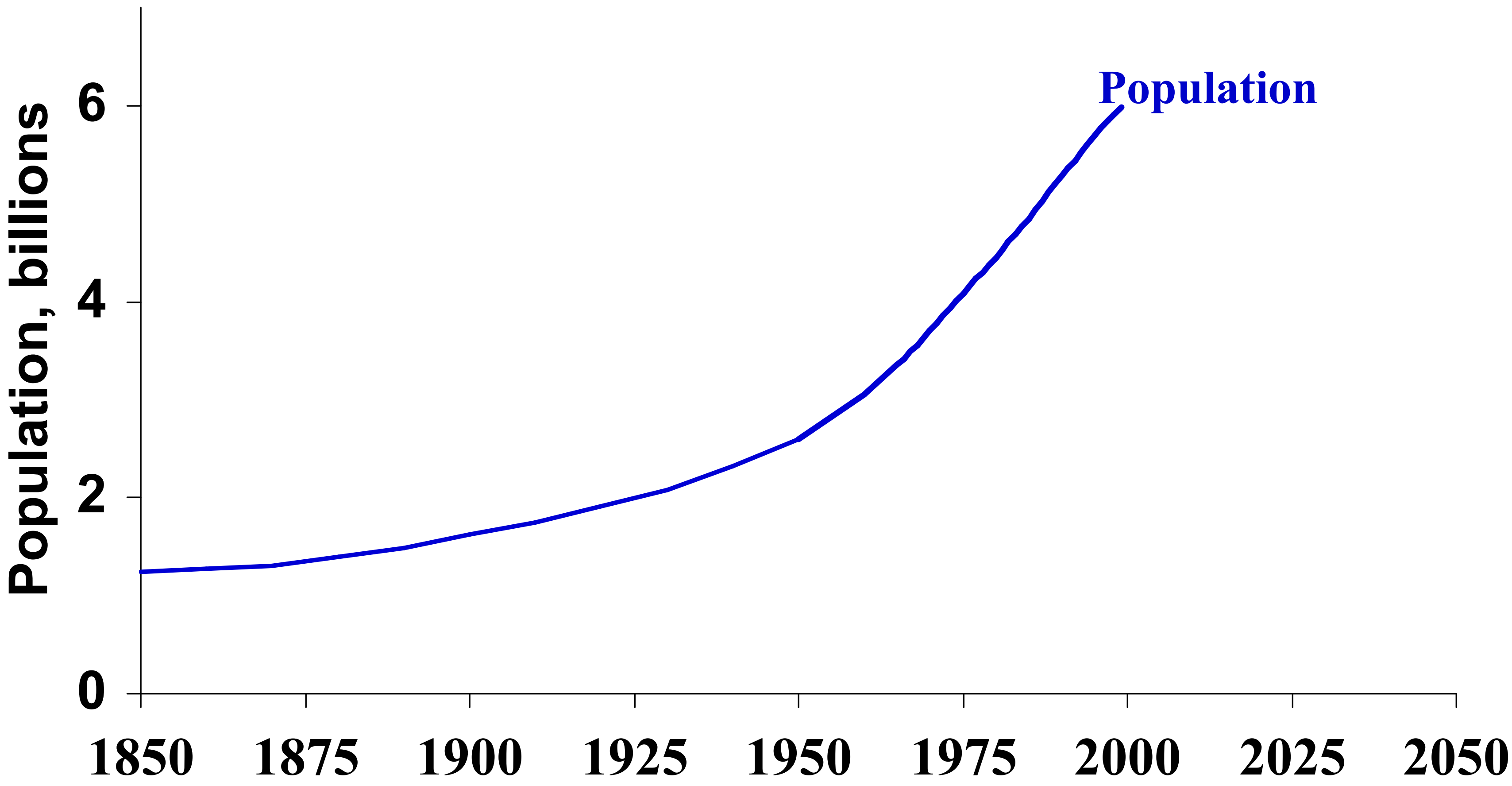
Garmisch-Partenkirchen, Germany

Outline

- Historical trends in reactive N (N_r) creation
- N research priorities 30-40 years ago
- What have we learned about N_r?
- Trends in NH_3, NO_x, & greenhouse gases in Europe
- Societial Responses for addressing N_r needs
- Perspectives on N_r, 1960s-2000s

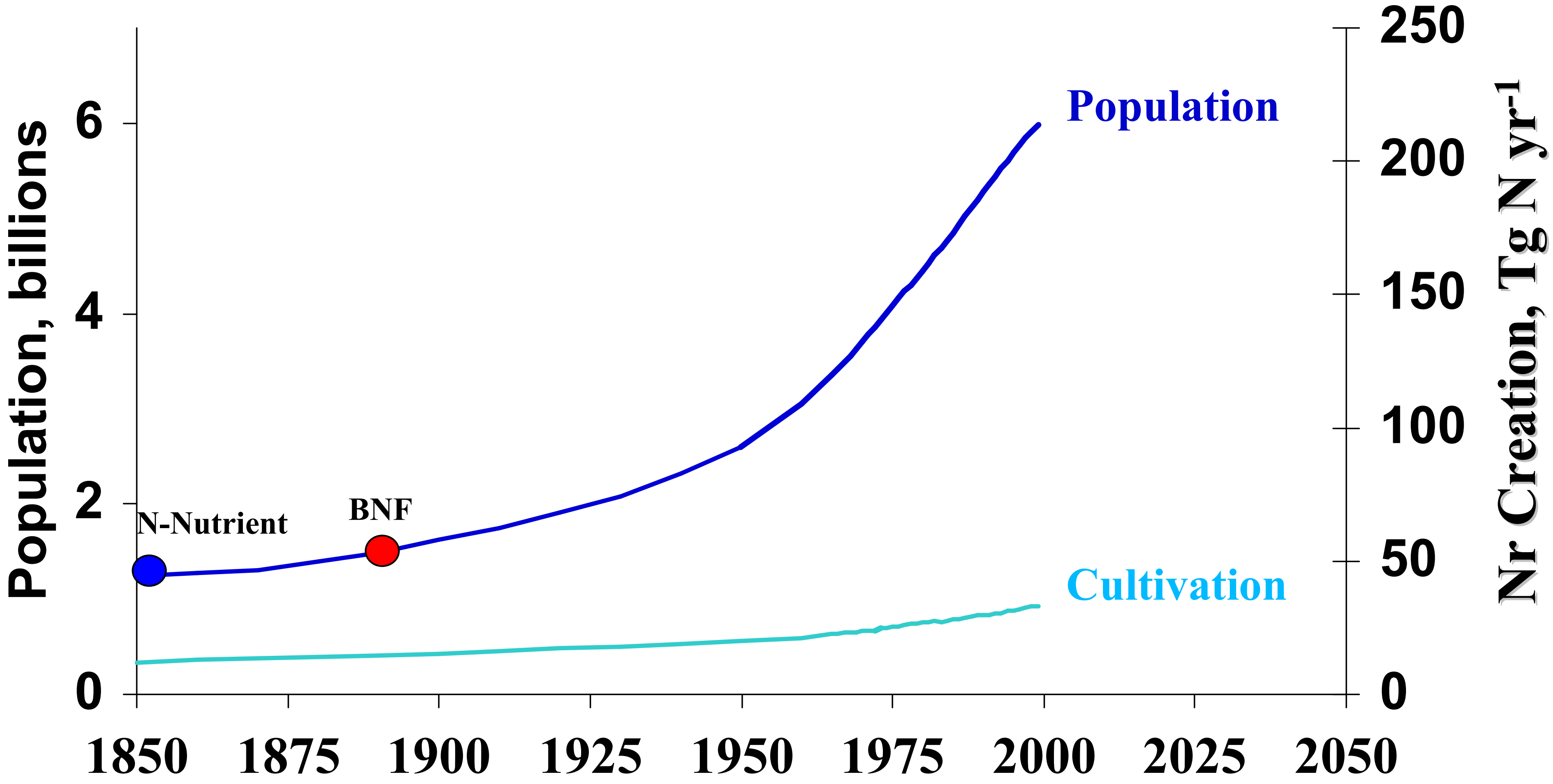
Historical Trends in Reactive N (N_r) Creation

Timeline of Global Reactive N Creation by Human Activity 1850 to 2000



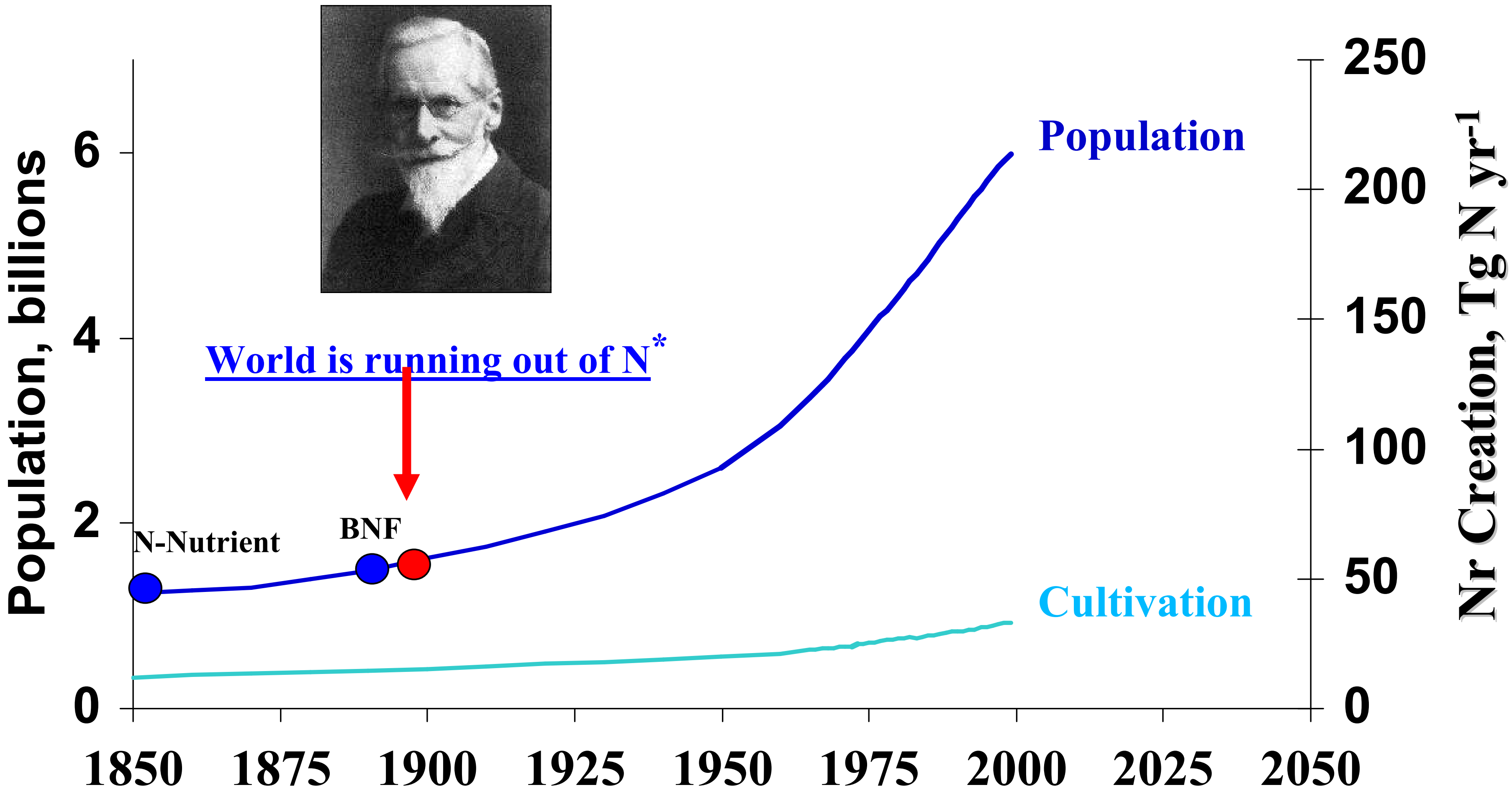
Galloway et al., 2003

Timeline of Global Reactive N Creation by Human Activity
1850 to 2000



Galloway et al., 2003

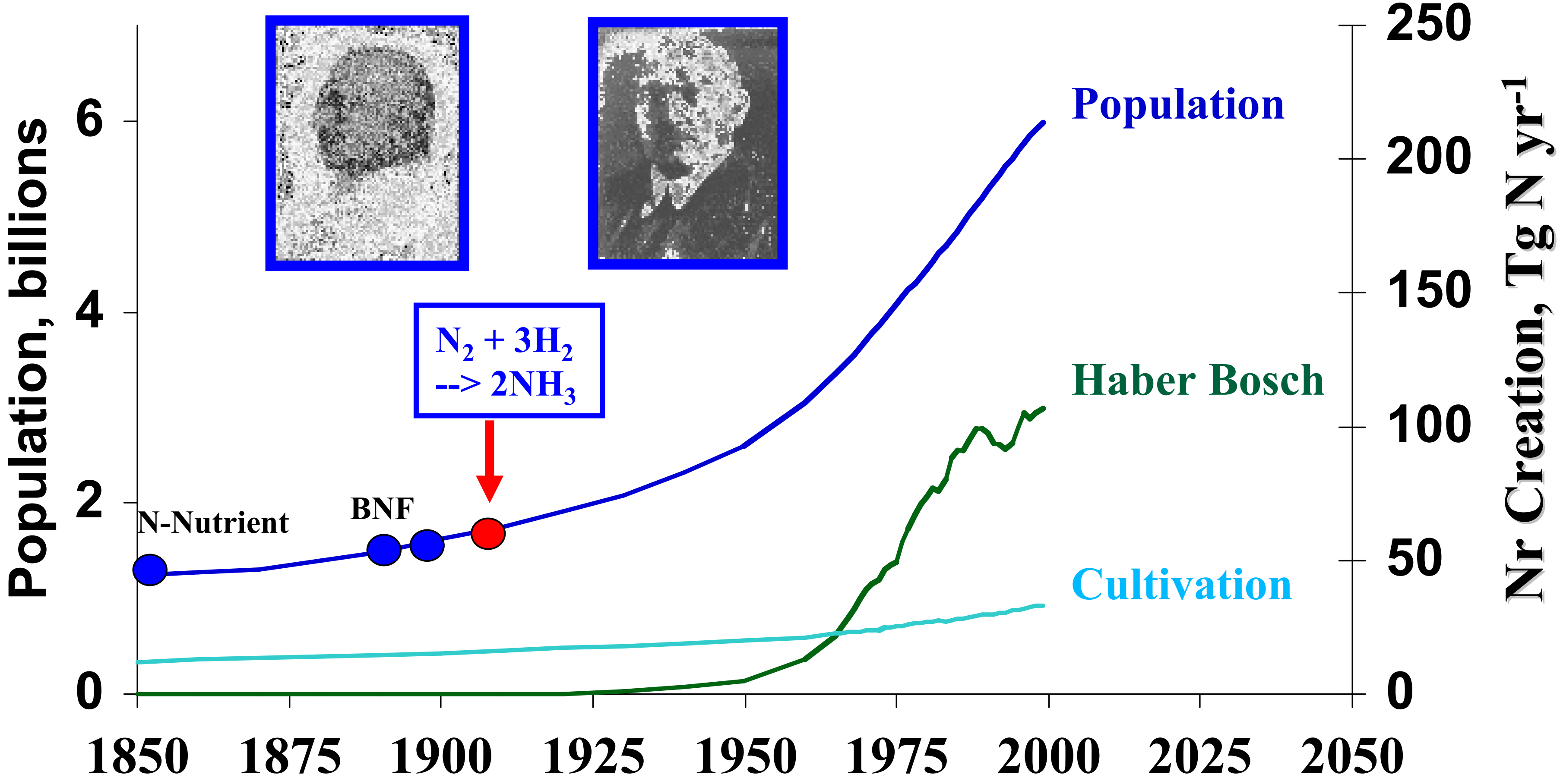
Timeline of Global Reactive N Creation by Human Activity 1850 to 2000



*1898, Sir William Crookes, president of the British Association for the Advancement of Science

Galloway et al., 2003

Timeline of Global Reactive N Creation by Human Activity 1850 to 2000



Galloway et al., 2003

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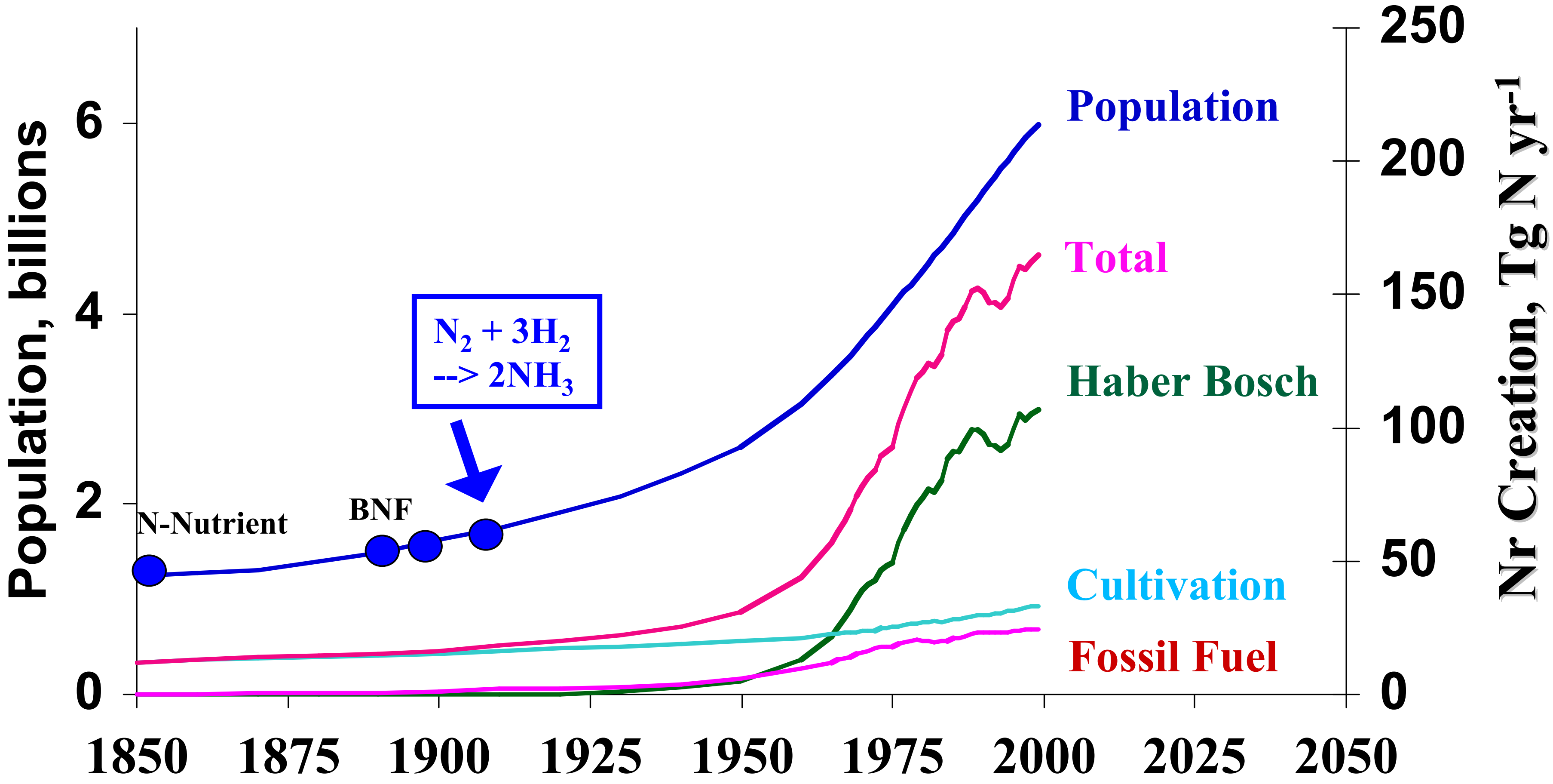
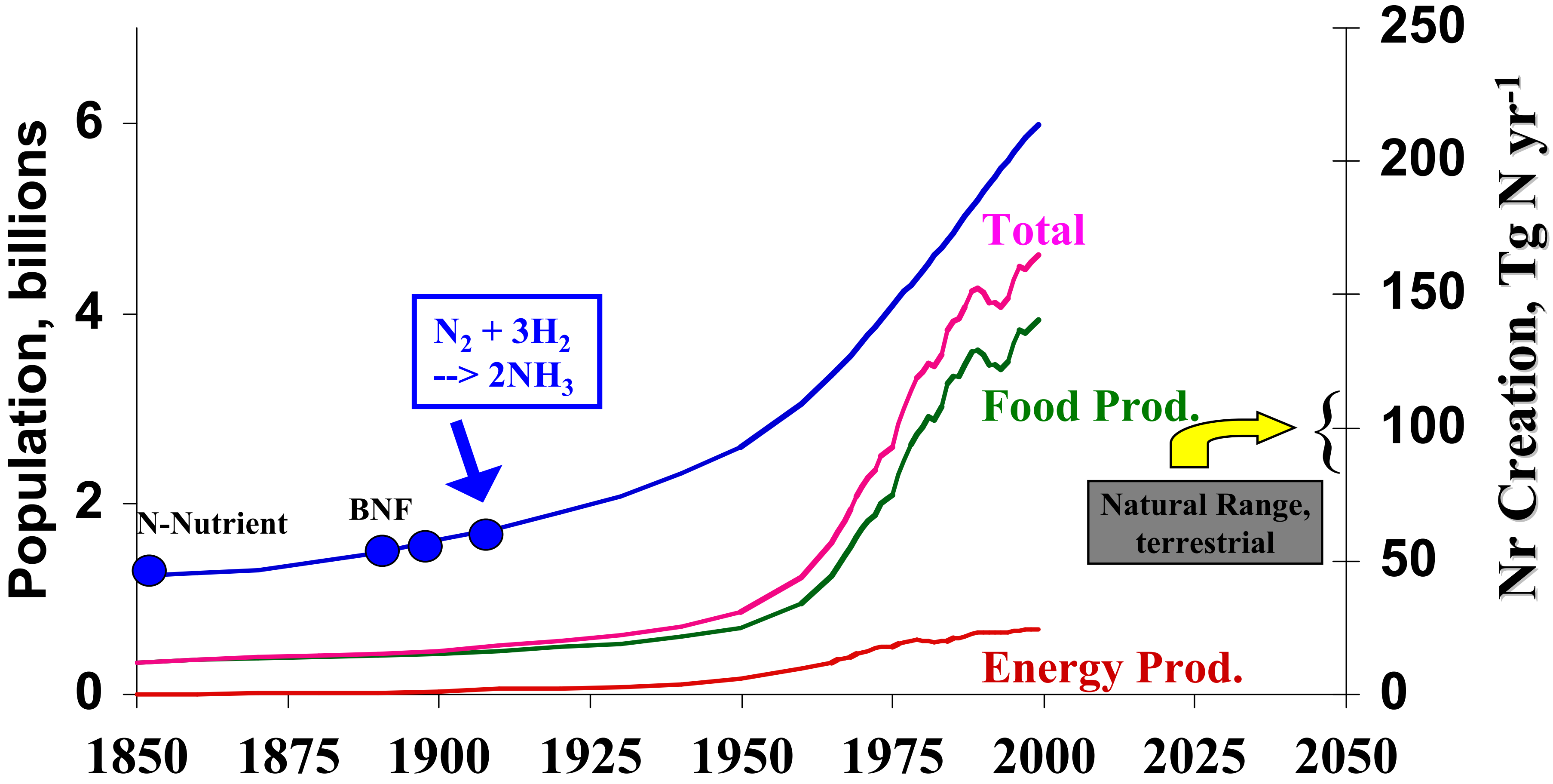


Galloway et al., 2003

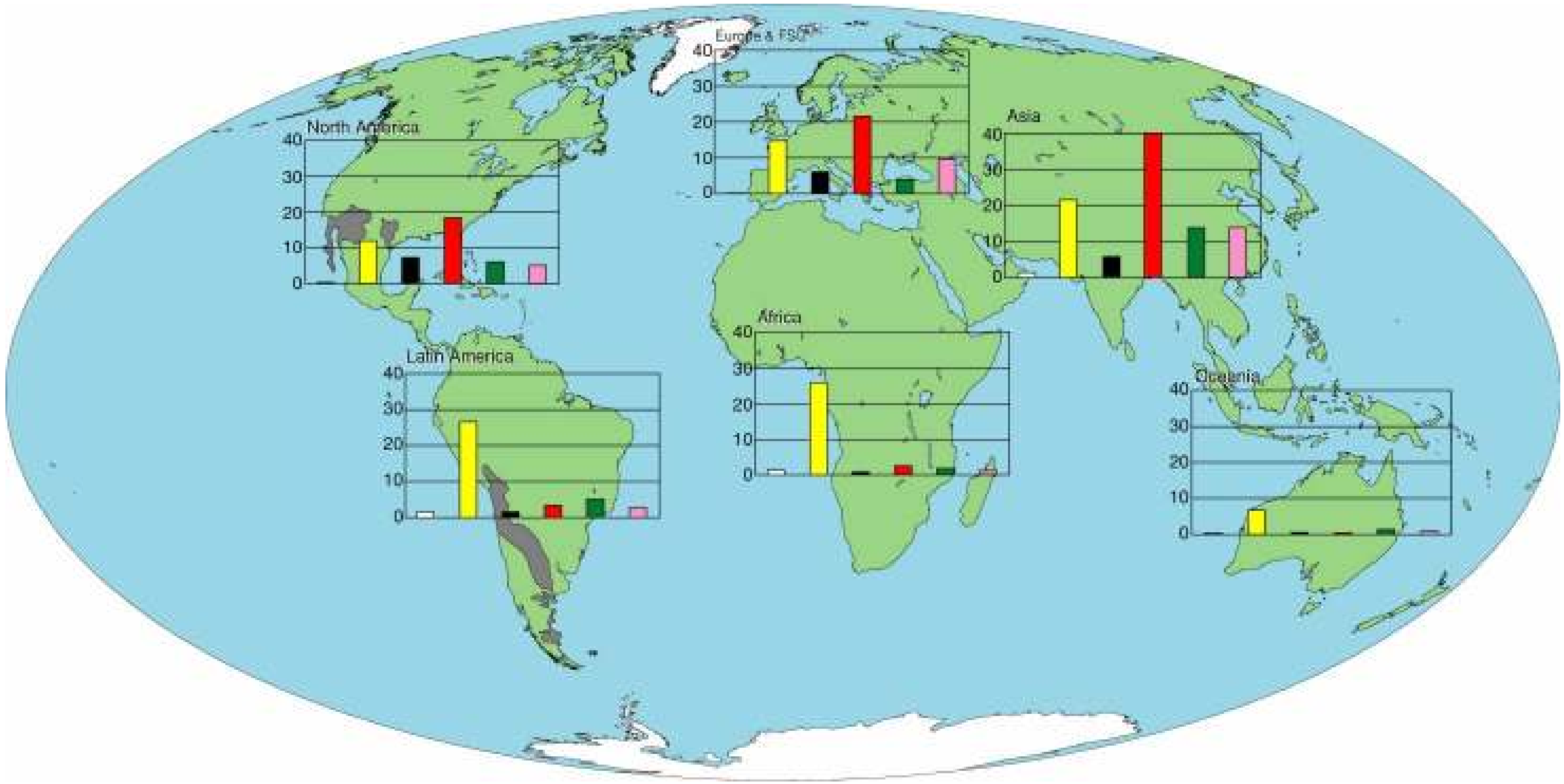
Timeline of Global Reactive N Creation by Human Activity 1850 to 2000



Galloway et al., 2003

Nr Creation by Region

Tg N yr^{-1}



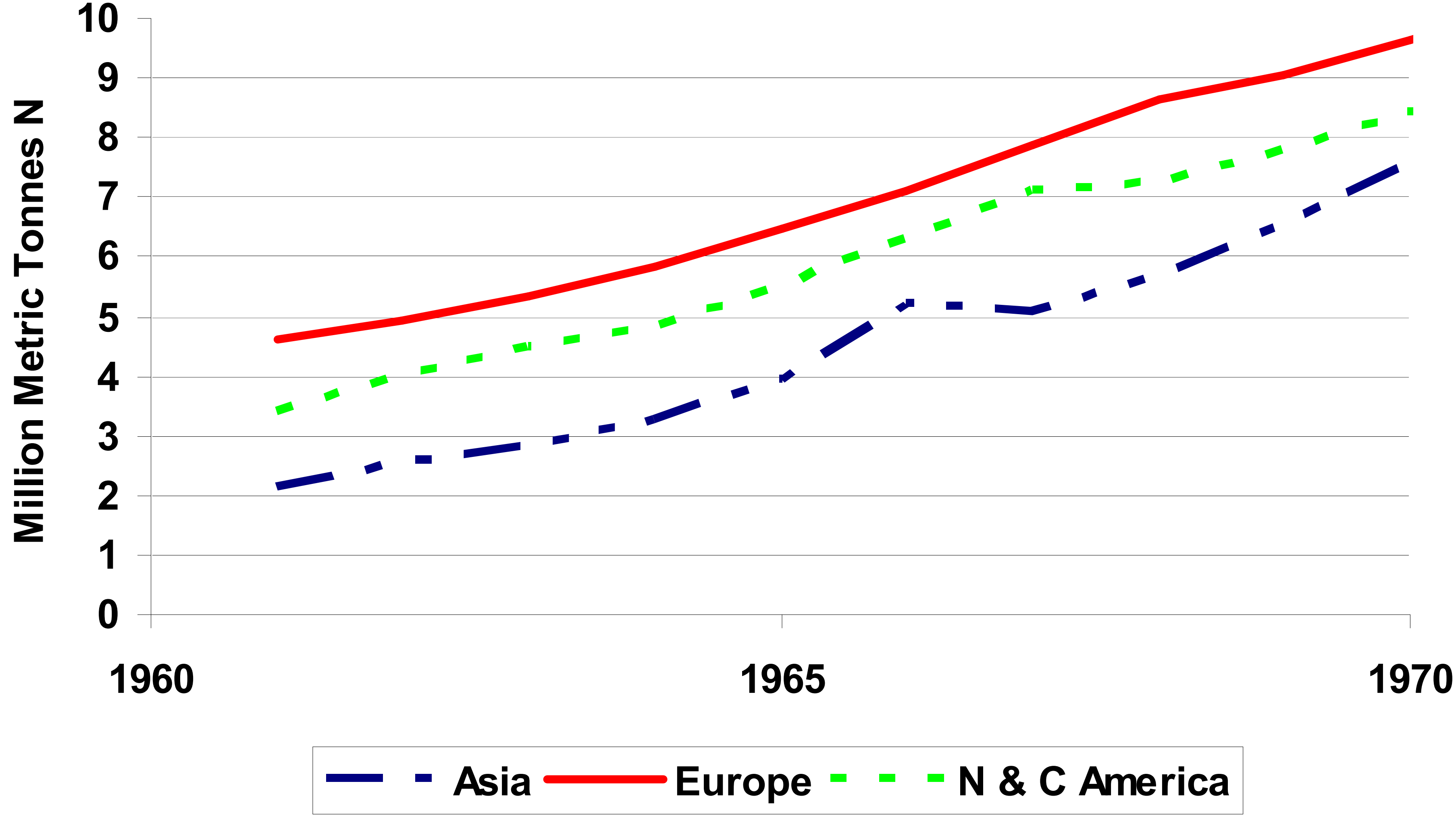
Galloway et al., 2004

Lighting BNF Fossil Fuel Fertilizer Prod. C-BNF Imports

N Priorities 30-40 Years Ago

1960s & 70s----Increasing N Fertilizer Use

N Fertilizer Consumption



N Priorities 30-40 Years Ago

- Allison (1955,1965, 1966) –Enigma of soil N balance sheets and recovery of N from Inorganic fertilizers and manures

—N in harvested crops will more often be less than 50% rather than greater than 50% of N applied or mineralized from organic matter. Even when leaching was accounted for, 15% of the fertilizer N added or mineralized from soil organic matter could not be found—presumably lost by denitrification.

N Priorities 30-40 Years Ago

G.W. Cooke. 1971. Fertilisers & Society (7th Francis New Memorial Lecture)
The Fertiliser Society of London, March 1971

"……. fertiliser use has developed, especially during the past 15 years….Society has rewarded us financially for our services in providing cheap food. ….. accusations that we pollute the environment and have taken some part in destroying the soil. ……. our present duties to Society, particularly that we must make fertilisers more efficient."

"Although we have within sight a basis for using P and K efficiently, we do not for nitrogen. "…….with arable crops we are fortunate if half of the applied nitrogen is recovered". I see no reason to modify this, except to say I now think half is an over-estimate."

N Priorities 30-40 Years Ago

- Commoner, 1968— called for elimination of fertilizer N use for 10 years—estimated that 15% of fertilizer N is lost by leaching to surface waters, and that an equal fraction is lost to air.
- Viets and Hageman. 1971. Factors Affecting the Accumulation of Nitrate in Soil, Water, and Plants, Agriculture Handbook No. 413/Agricultural Research Service-USDA

"One of the problems confronting the commercial N fertilizer enthusiast, and the organic N enthusiasts too, in these days of concern about eutrophication and possible nitrate accumulation, is to explain why the recovery of supplemental N by crops is so low. What happens to the rest of it? How can recovery be improved? The same problem is presented in explaining where all of the N went that has been lost from our former grassland and forested soils placed under cultivation."

N Priorities 30-40 Years Ago

Viets & Hageman:

- "Since much of our farmland has already lost much of its native organic N, thereby impairing its capacity to produce unless fertilized, we must use increasing amounts of fertilizer to utilize the full potential of our better varieties and water resources. The "balance of nature" can be better restored by using higher rates of N fertilizer than using less."
- "… almost every facet of the nitrate problem needs further investigation from the nitrate standards in water that will avoid methemoglobinemia to determination if there is any form of fertilizer N that can be used that will not yield some nitrate to the water table, and yet be economic and permit near maximum yields.

N Priorities 30-40 Years Ago

Viets & Hageman (1971)

“Agronomists and soil scientists have been interested in response of crops to various rates of N application with the objective of attaining good yields and good recovery of the fertilizer. They have not, however, had much concern for N that was lost in runoff or leached below the root zone, except that it was not available for plant use. So in spite of the perhaps hundred thousand experiments that have been conducted, we have little information on how much and how fast nitrate percolates, and whether it reaches the water table.”

Atmospheric Trace Gas Priorities 30-40 Years Ago

P.J. Crutzen, Ambio, 1972 ; Crutzen and Ehhalt, Ambio, 1977

Effects of Nitrogen Fertilizers and Combustion on the Stratospheric Ozone Layer

The Possibility that increasing use of fixed nitrogen in agriculture might lead to significant ozone reductions in the future because of increased N_2O emissions from the soil was mentioned first by Crutzen in 1972.

Projections that 200 Tg N/year of fertilizer and biologically fixed N in agriculture would be needed by 2010.

Atmospheric N Priorities 30-40 Years Ago

McElroy et al 1976:

"Nitrous oxide plays an important role in the chemistry of atmospheric ozone." "…..enhanced agricultural productivity, stimulated for the most part by the rapidly growing use of chemical fertilizers, might lead to an increase in the production of N_2O, with consequently serious effects on the equilibrium concentration of atmospheric O_3."

Atmospheric N Priorities 30-40 Years Ago

CAST 1976 (Council for Agricultural Science & Technology)

Nitrous oxide-nitrogen production on land is estimated as 5 to 10 MT/yr; estimates from oceans range from less than 1 to 100 Mt/yr

"In spite of the uncertainties in the predictions of the effects of increased fixation of nitrogen on stratospheric ozone, the potential hazard is sufficiently serious that, in addition to research on the various phases of the global nitrogen cycle that impinge upon the nitrous oxide-ozone question, research on the efficiency of use of all fixed forms of nitrogen should be worthwhile."

What have we learned about N_r in the past 40 years?

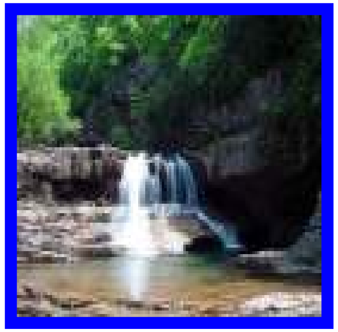
There are significant effects of Nr accumulation within the atmosphere, geosphere and biosphere

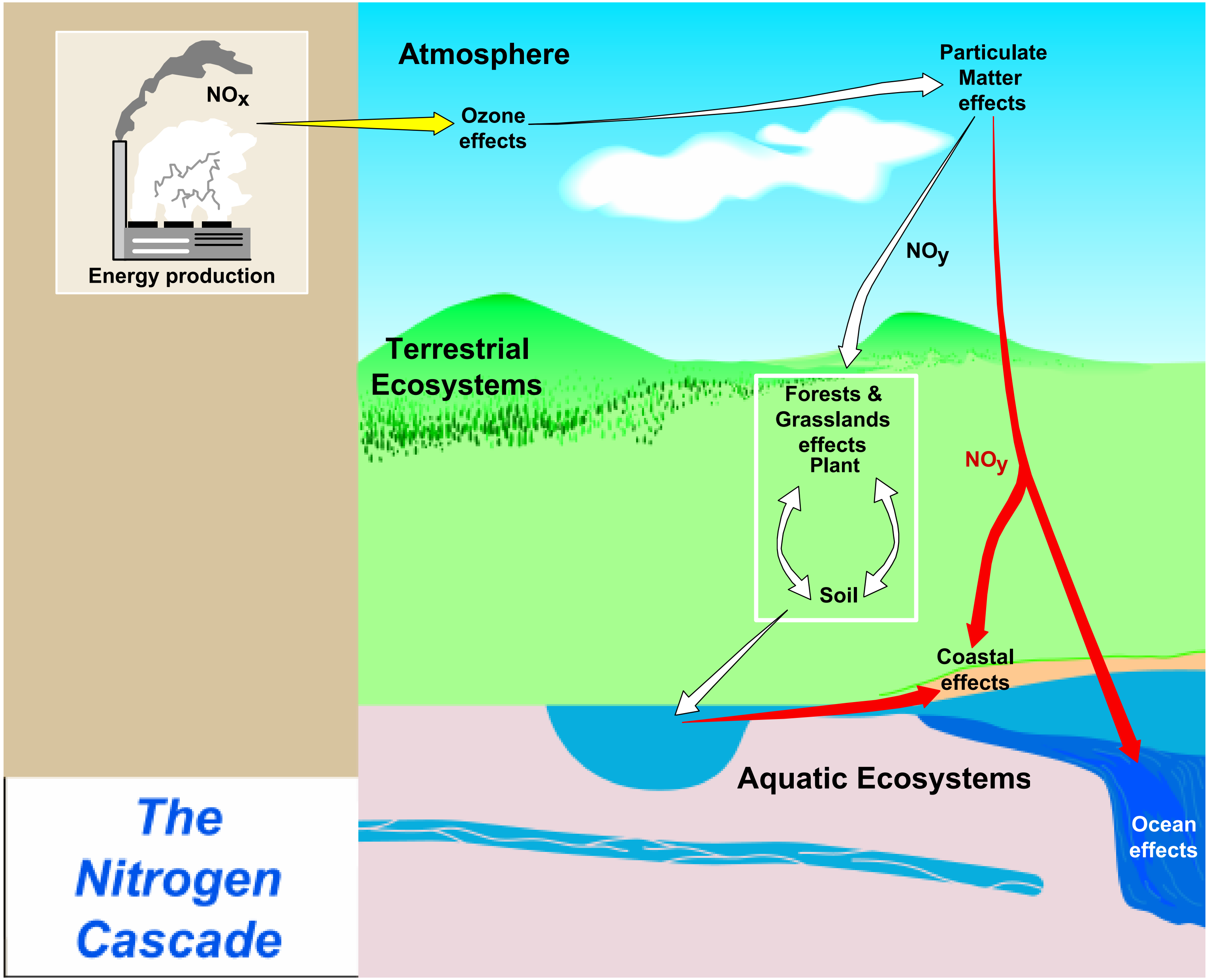
Increases in:
- **tropospheric O_3, N_2O & PM2.5**
- **soil acidity and N concentrations**
- **coastal water N concentrations**

Decreases in:
- **stratospheric O_3**

Lead to:
- **loss of biodiversity in terrestrial and aquatic ecosystems**
- **human health effects**
- **changes in earth's radiation balance**

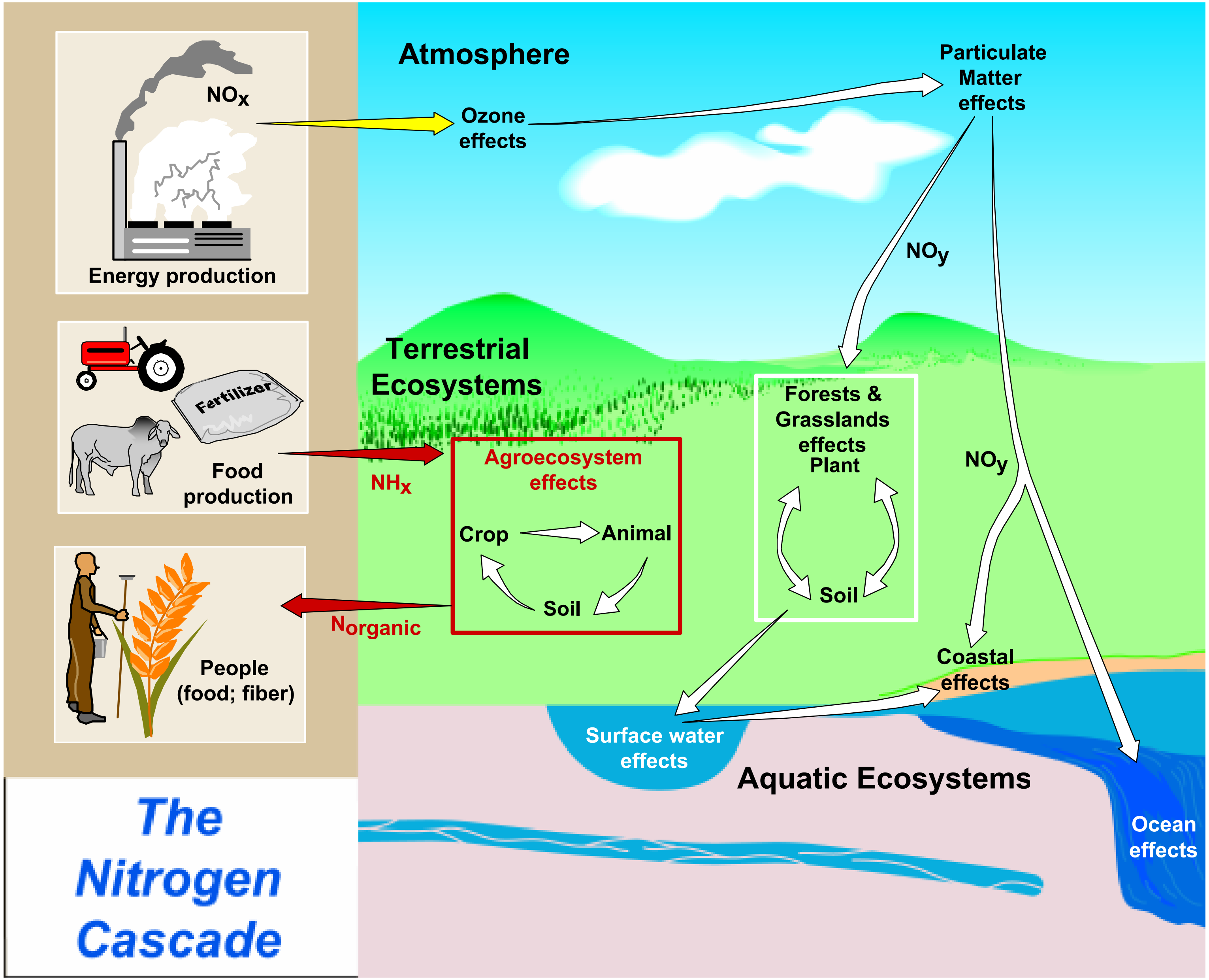
These effects can be sequential, such that a single atom of nitrogen could contribute to them all, over time and space.





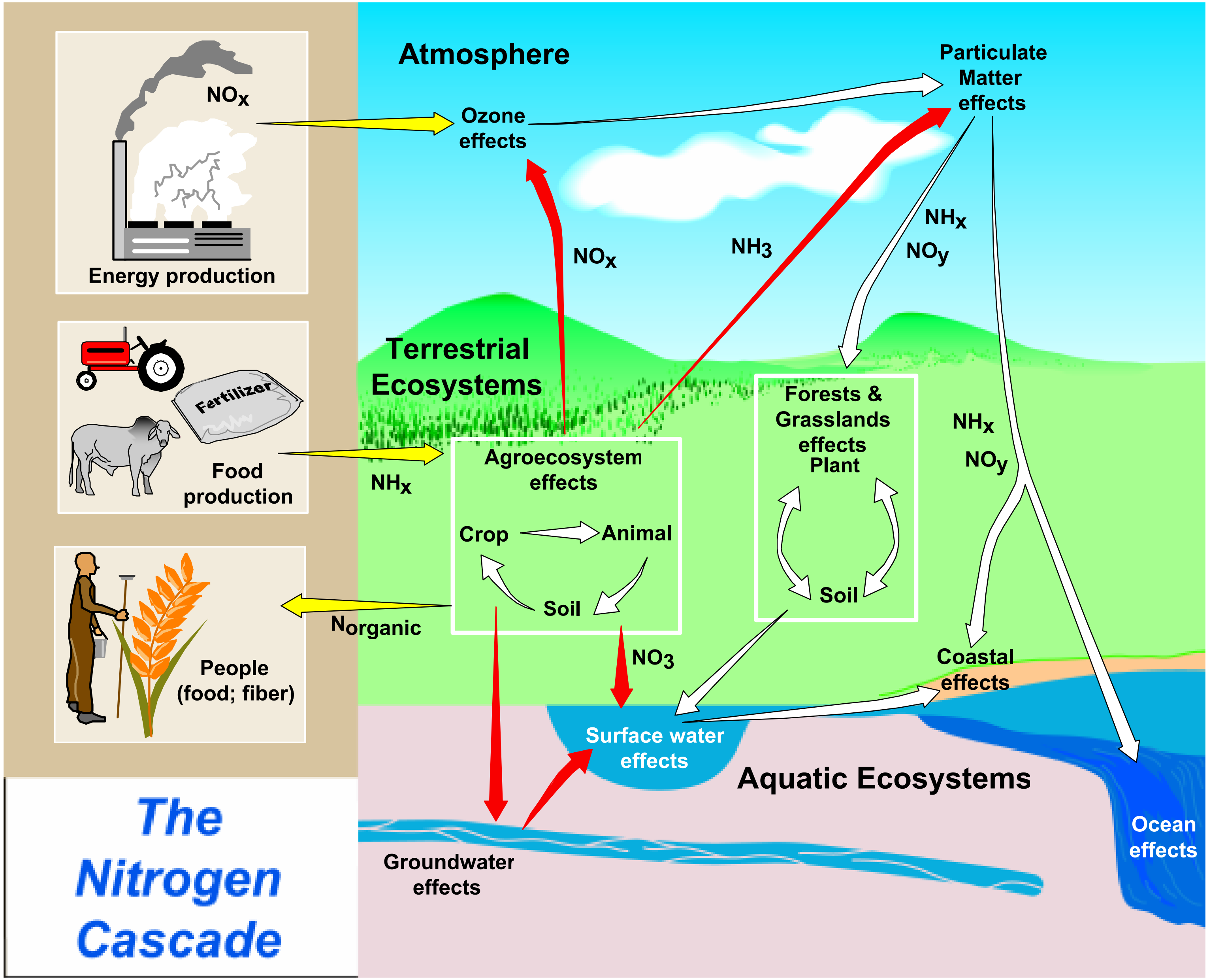
Nitrogen oxides cause contribute to smog, acid rain, loss of biodiversity in ecosystems

Galloway et al., 2003



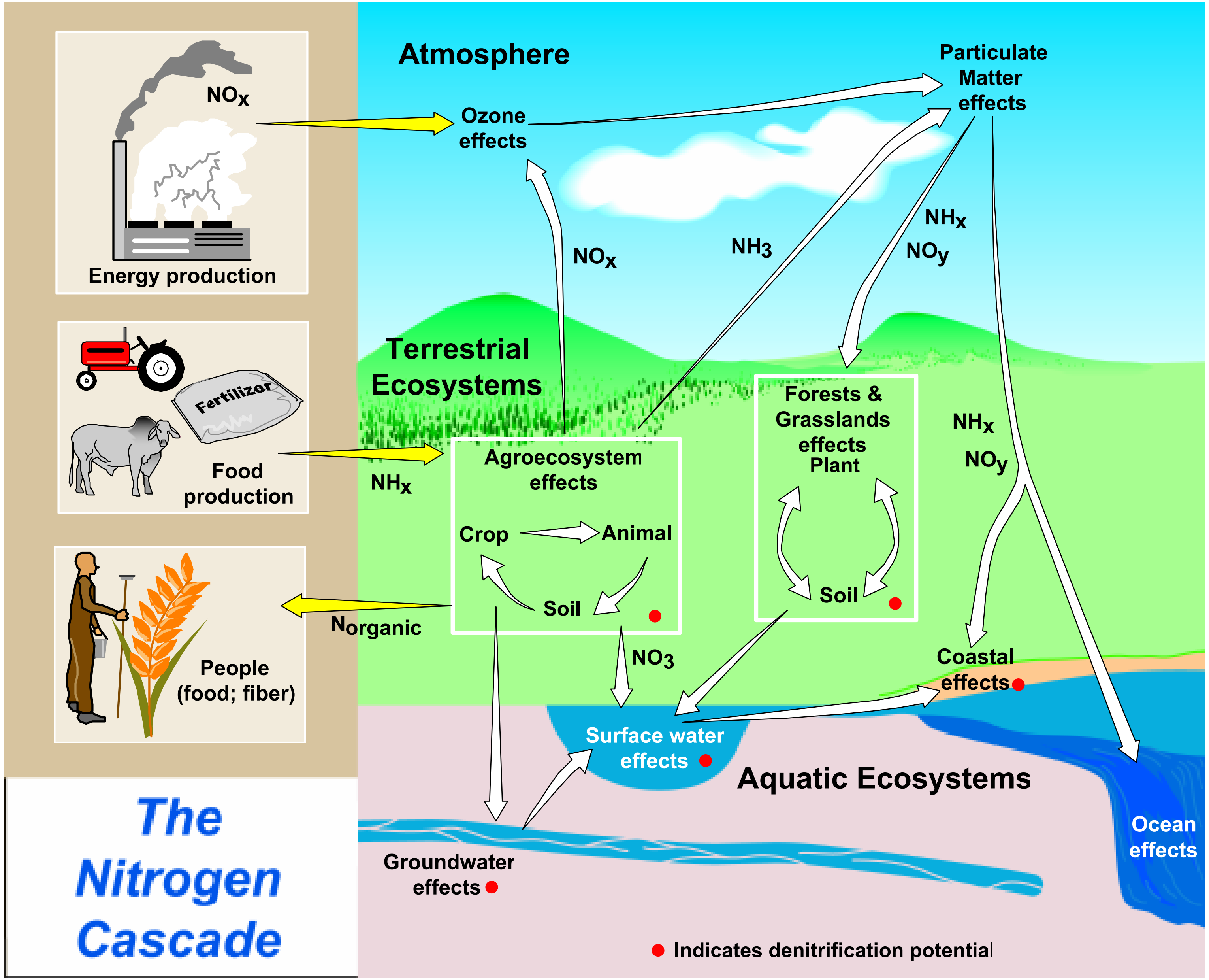
Galloway et al., 2003

Agroecosystems feed and clothe the world's peoples



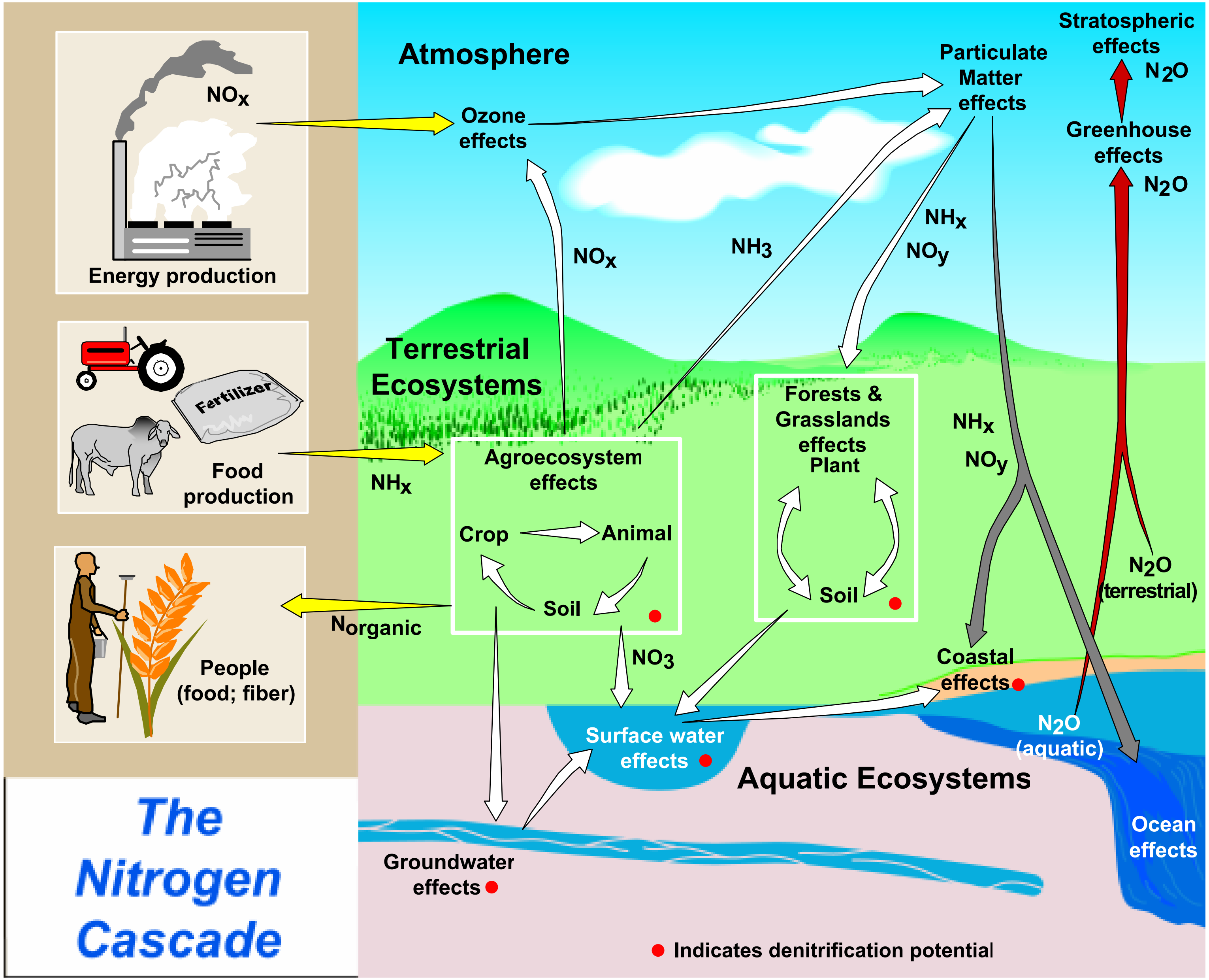
Agroecosystems do not retain N very efficiently

Galloway et al., 2003



Denitrification=When reactive N gets converted back to N_2

Galloway et al., 2003



But denitrification also produced N_2O.

Galloway et al., 2003

Balance Between Nr Creation and Denitrification

- Terrestrial system
  - 270 TgN/yr of Nr introduced into continents in mid-1990s.
  - ~40% lost from continents
    - 12 TgN via N_2O formation
    - 48 TgN into coastal systems via rivers
    - 8 TgN into coastal systems via atmosphere
    - 33 TgN into open ocean via atmosphere
  - What about the other ~60% (~170 TgN)?
- About 110 TgN/yr are denitrified to N_2, mostly in rivers and coastal systems.
  - Good news and bad news
- About 60 TgN/yr accumulate in mostly terrestrial ecosystems.
  - Mostly bad news

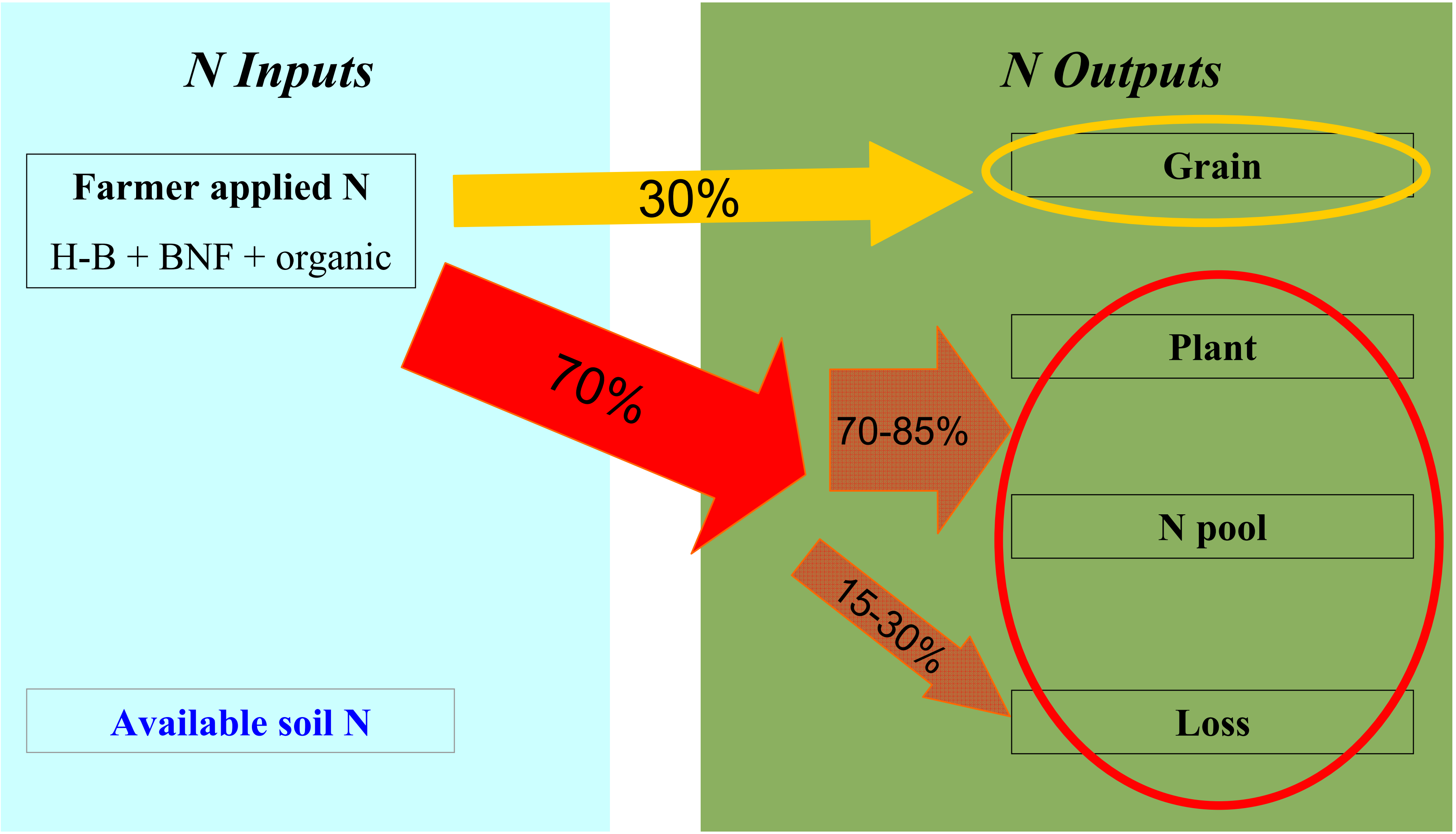
Galloway, 2006

Summary

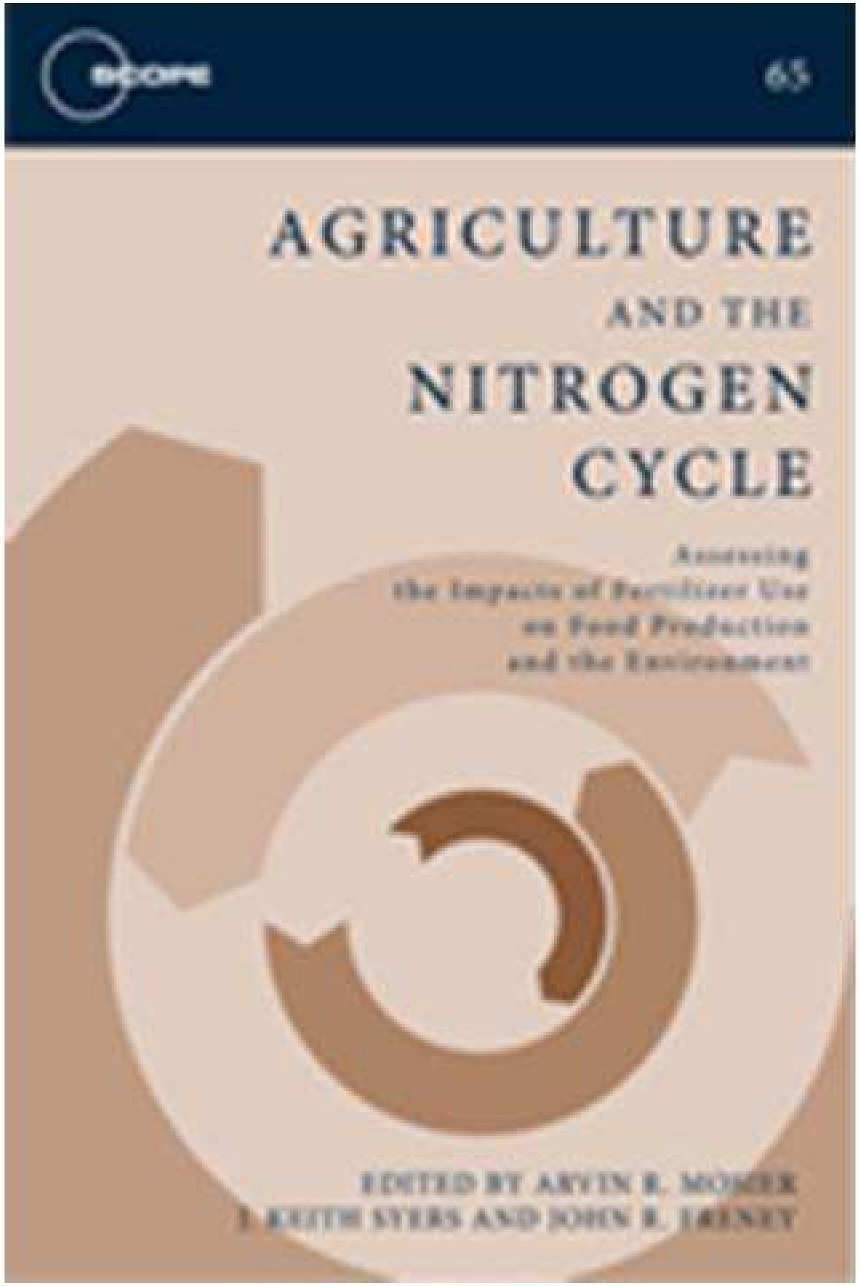
- Humans mobilize ~50% more Nr than natural terrestrial ecosystems.
  - *Food production accounts for 75%*
- Nr is widely dispersed
  - *Atmospheric Nr emissions have increased 3-fold since 1860; NH_3 twice as important as NO_x; Riverine fluxes have more than doubled in many regions; Nr is accumulating in environmental systems.*
- Nr has cascading, negative consequences on a large number of systems on local, regional and global scale.
  - *but don't forget about food!*
- Nr management should focus on optimizing the benefits of nitrogen, while minimizing its problems

Galloway, 2006

Crop N cycling



Burke et al. 2005. Consequences of Industrialized Animal Production



SCOPE Volume 65

September, 2004

Agriculture and the Nitrogen Cycle

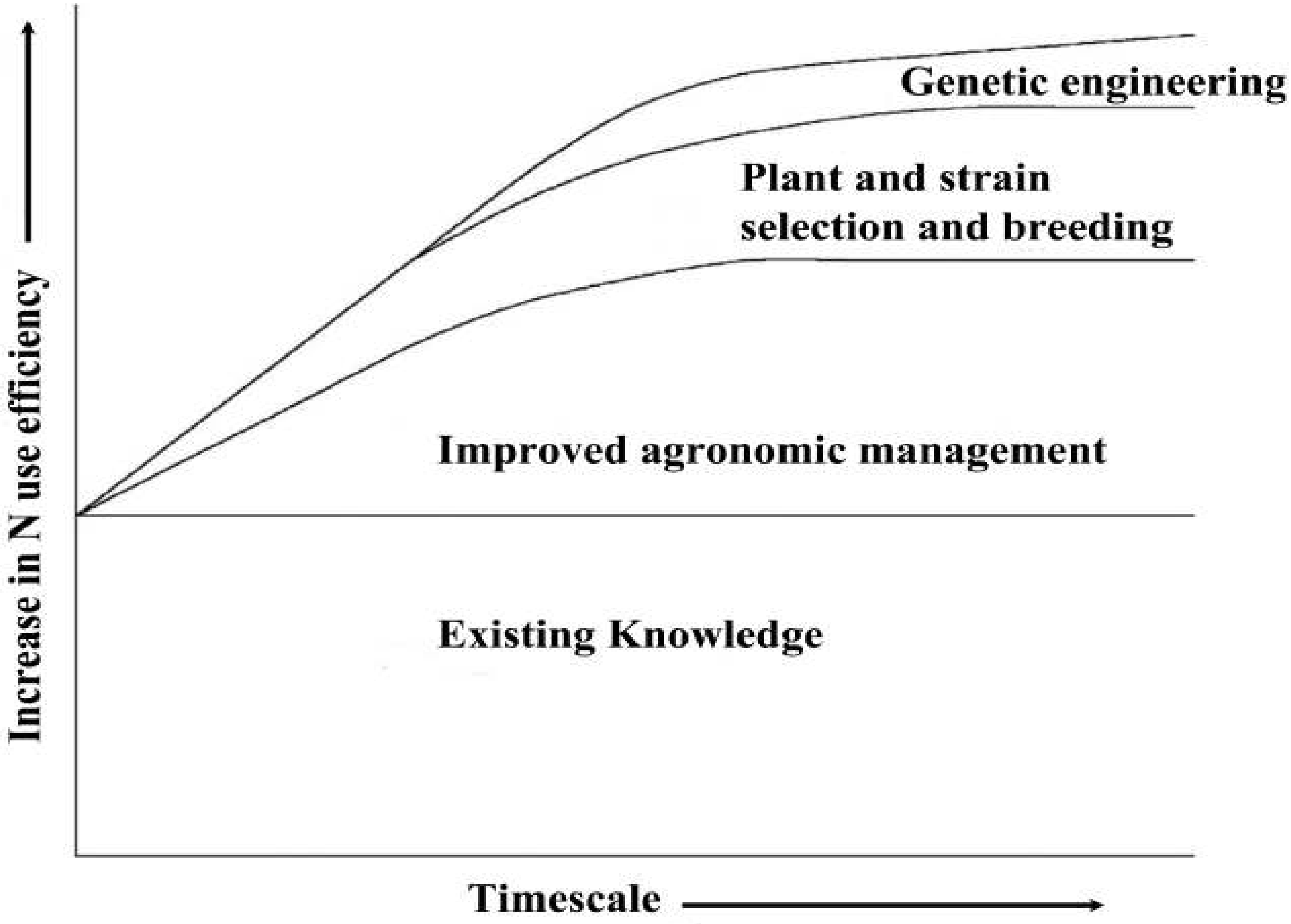
Assessing the Impacts Of Fertilizer Use on Food Production and The Environment

Improving Nitrogen Use Efficiency (NUE)
Key to Environment and Food Security Concerns

NUE Values (Table 2.1, SCOPE 65)

Crops	Mean NUE under current farming practice, %	Mean NUE in research plots, %	Maximum NUE of research plots, %
Rice – irrigated	31 (Asia)	49	88
Rice - rainfed	20	45	55
Wheat - irrigated	33 (India)	45	96
Wheat rainfed	17 (USA)	25	65
Maize – irrigated	37	42	88
Maize – rainfed	30	40	65
Vegetables	30	50	80

Prospects for Improving N Use Efficiency (SCOPE 65, Fig. 3.2)



Scientific Activities that Impacted Terrestrial Trace Gas Research in the past 20 Years

1989—Dahlem Conference: Exchange of Trace Gases Between Terrestrial Ecosystems and the Atmosphere

1989—Conference on Soils and the Greenhouse Effect

1989---Steudler et al. Nature—link of N fertilization and CH_4

1990—IPCC First Report

1996--- 1997 IPCC National Inventory Methodologies for CH_4 and N_2O

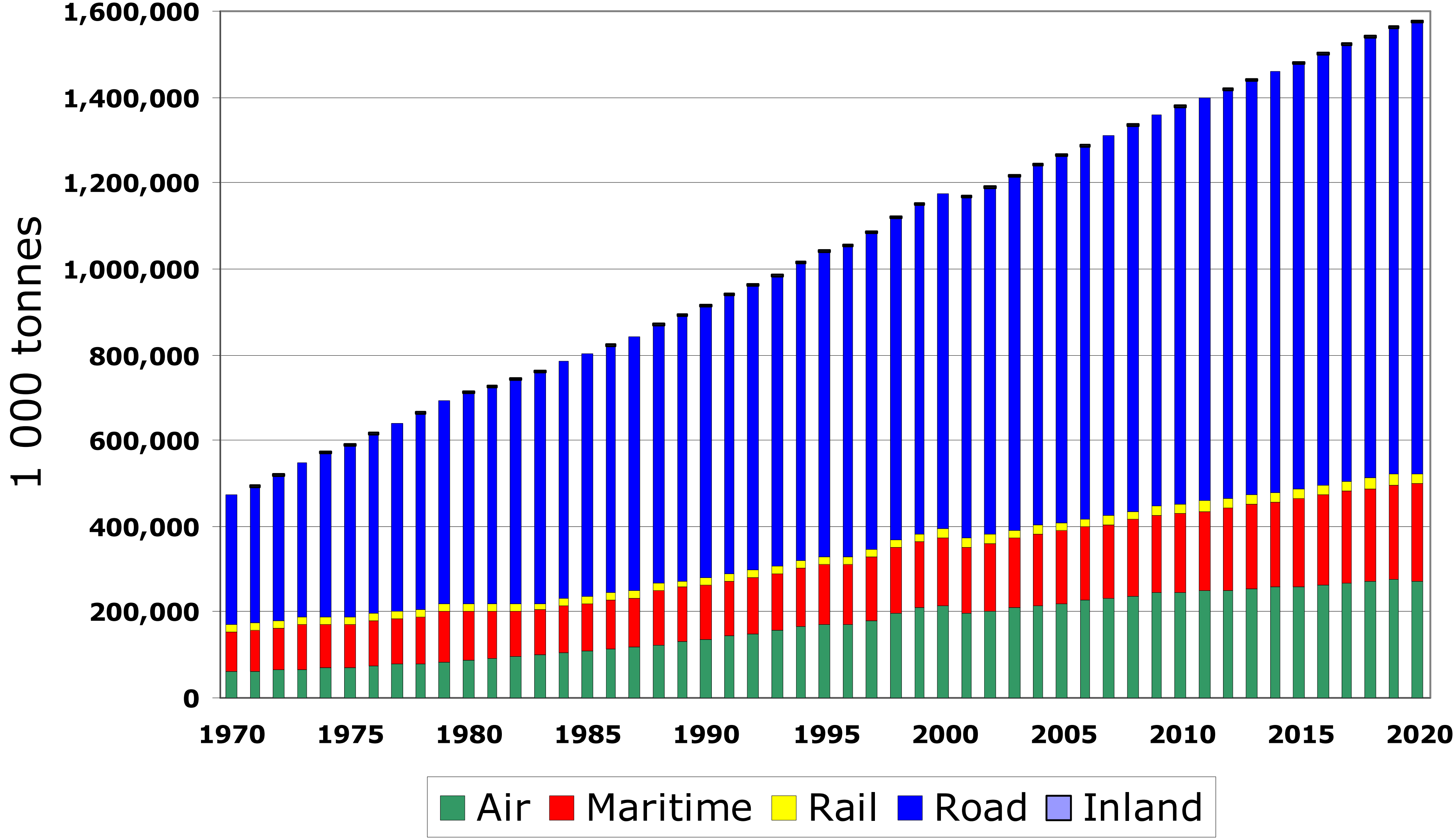
1997---Kyoto Protocol

2004—Ratification of the Kyoto Protocol

Current trends in NH_3, NO_x & greenhouse gases emissions in Europe

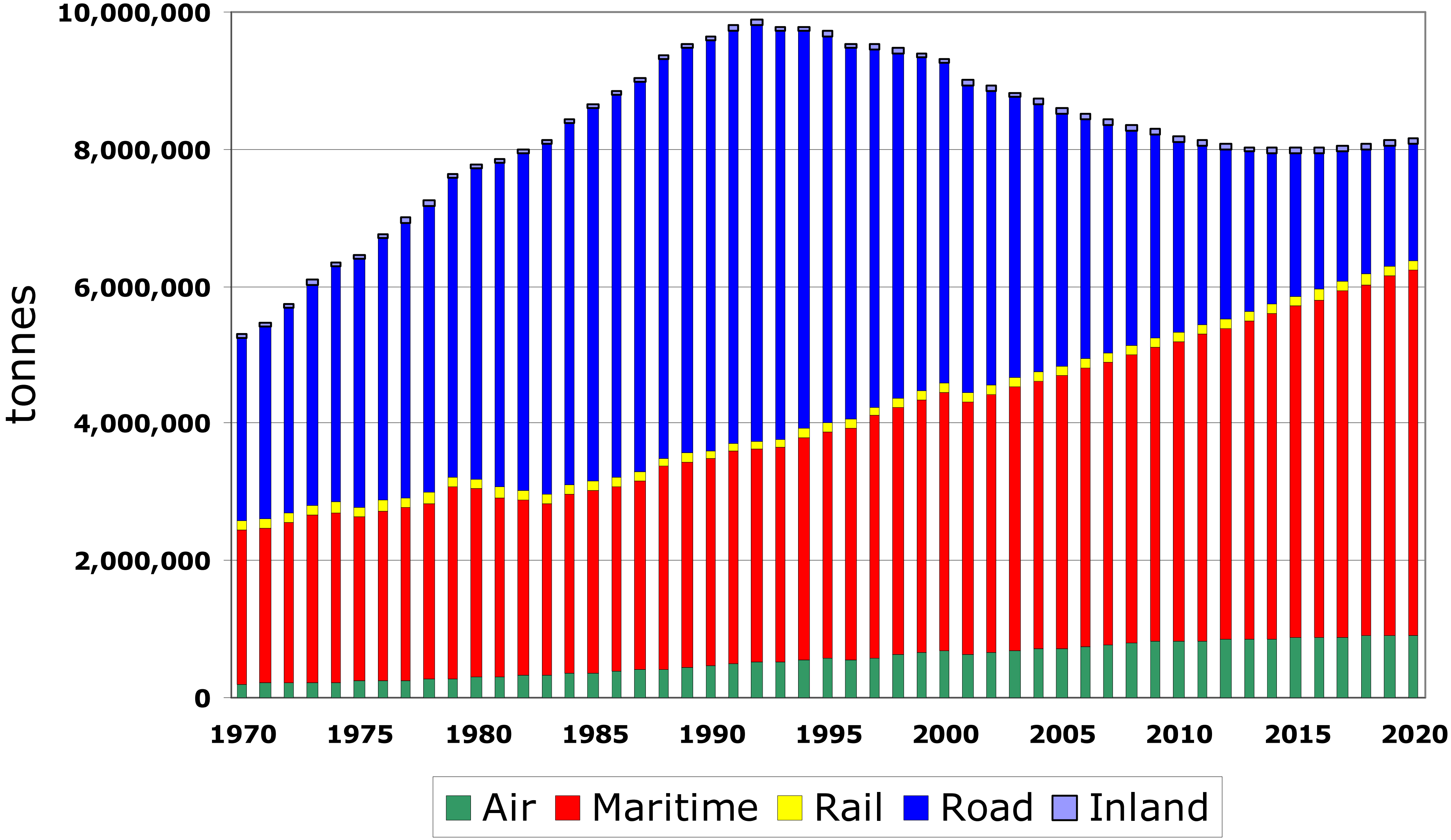
- Ammonia, NO_x, nitrate leaching, CH_4, CO_2 & N_2O
- Trends in Fertilizer Use, Livestock Production

Evolution of CO_2 emissions in the EU15



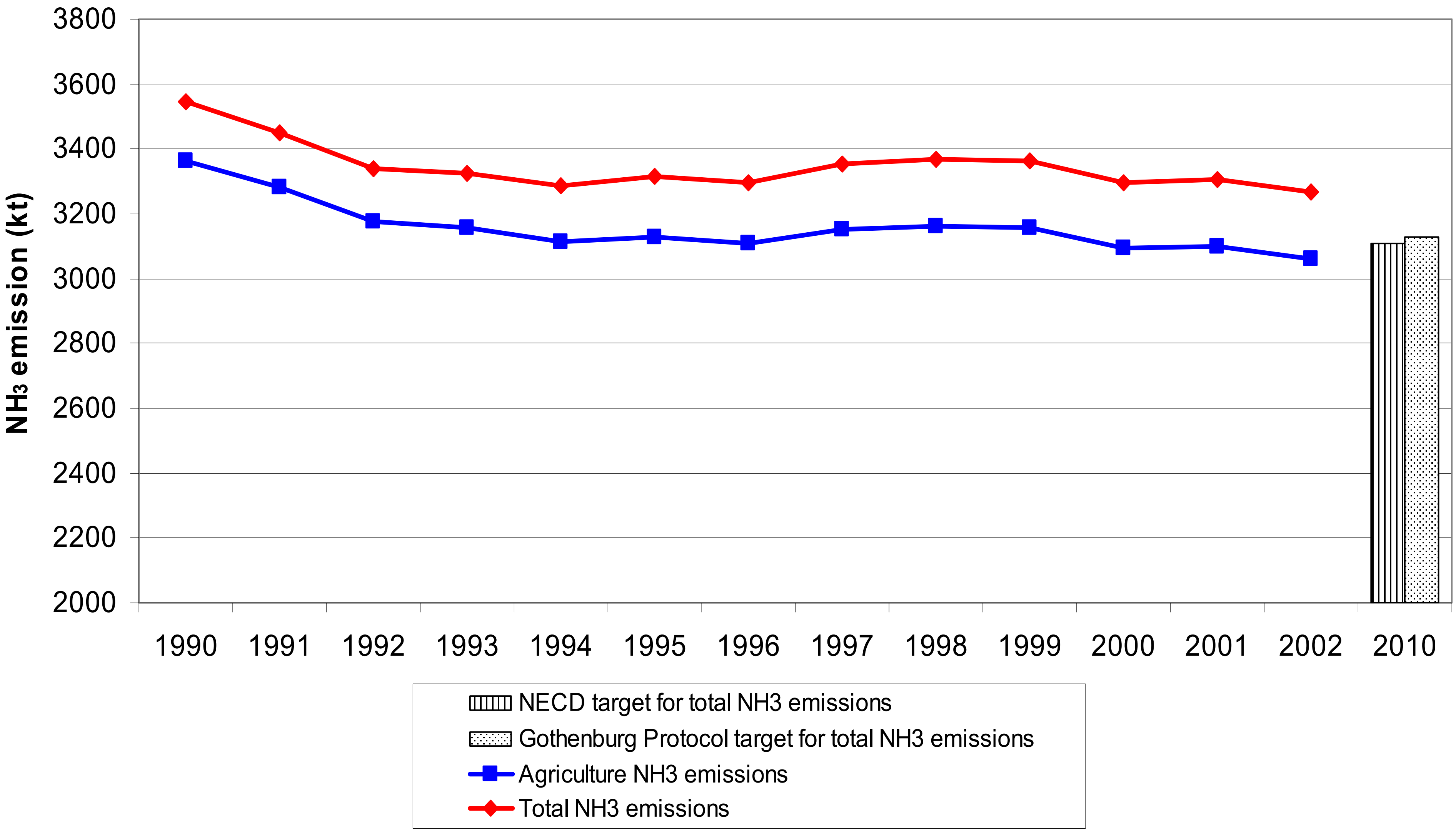
EEA Data Services

Evolution of NO_x emissions in the EU15

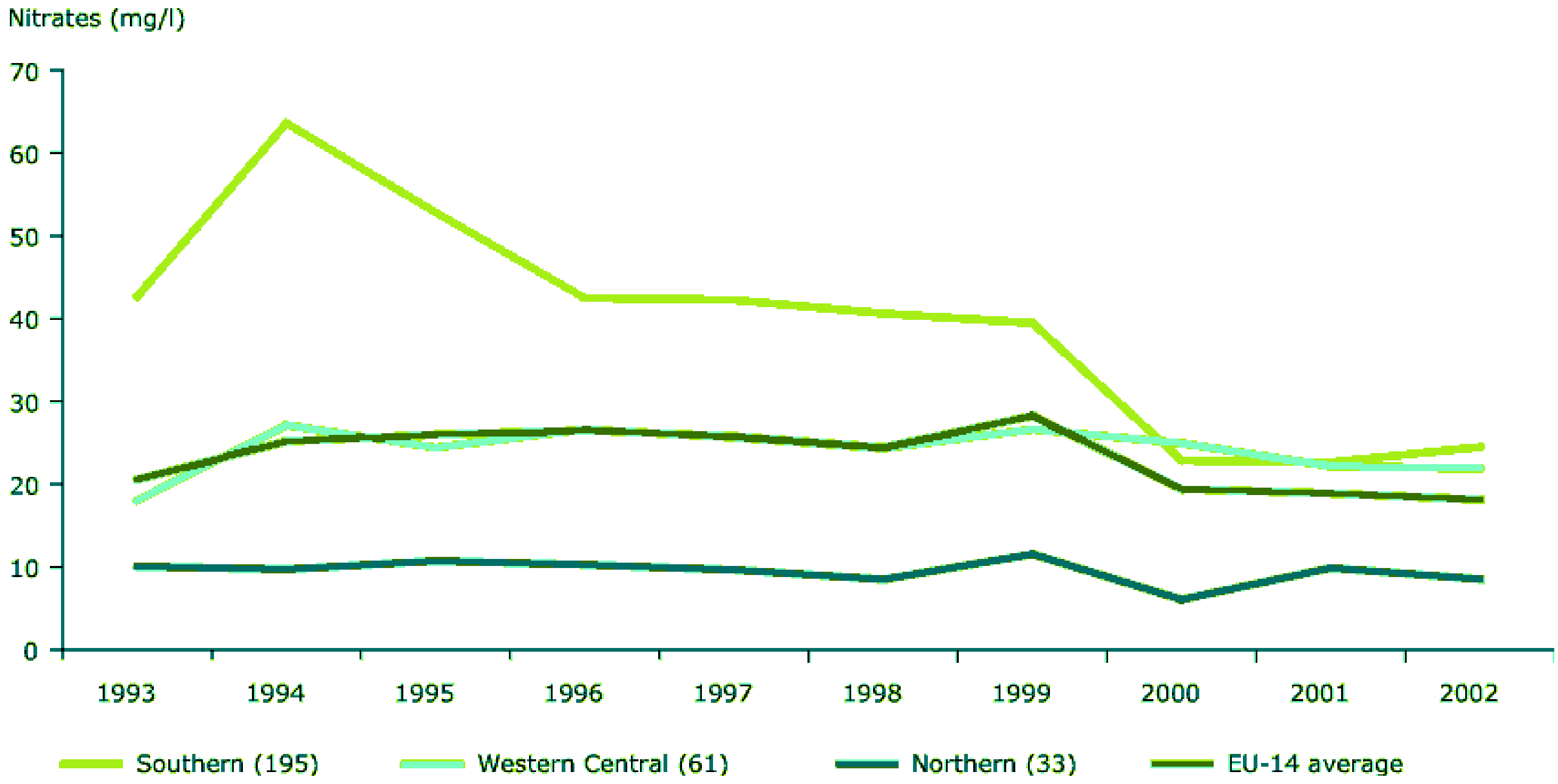


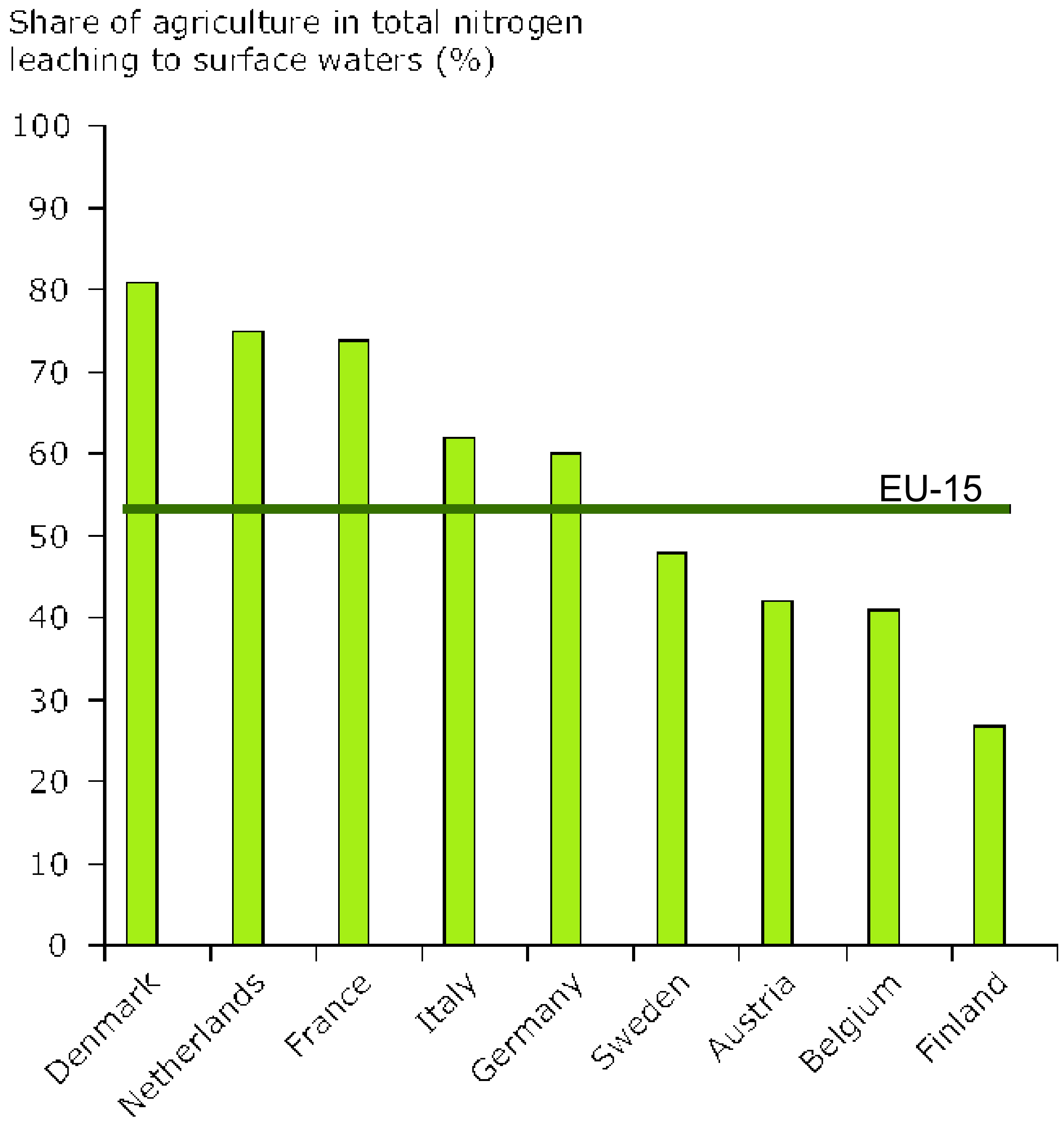
EEA Data Services

EU NH_3 Emissions---EEA Data Service



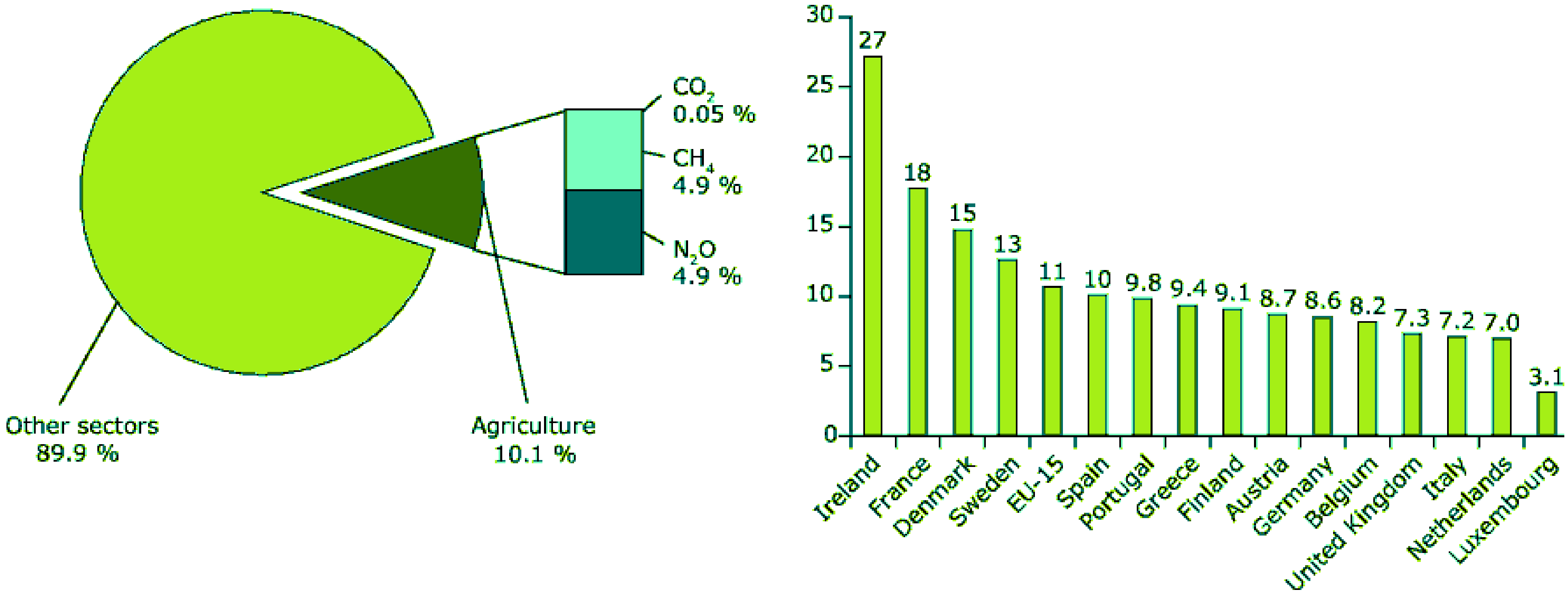
Nitrate in water—European Trends (EEA Data)

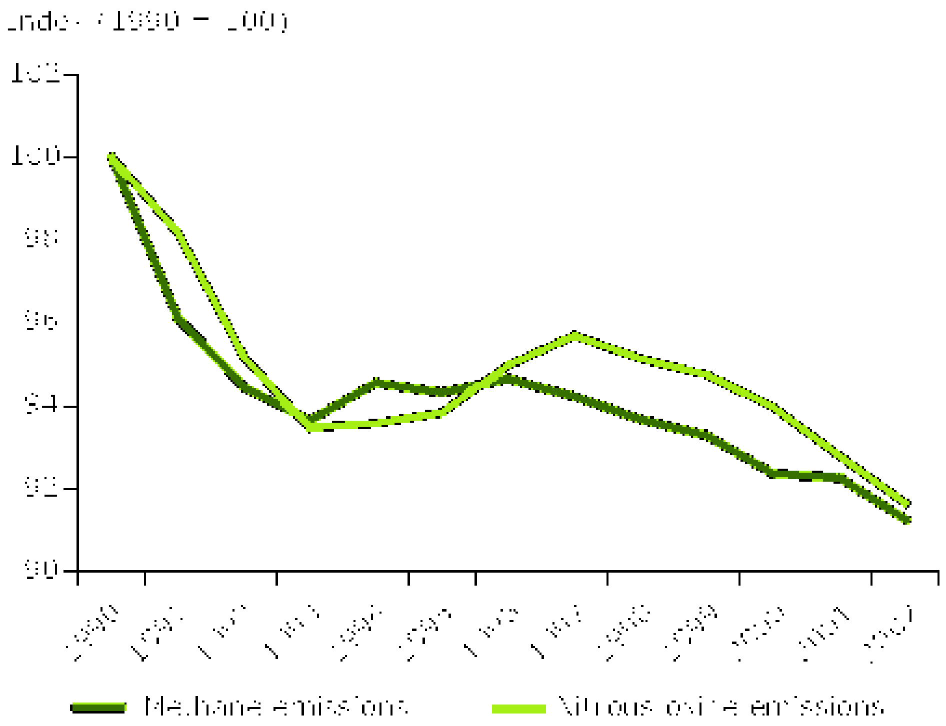


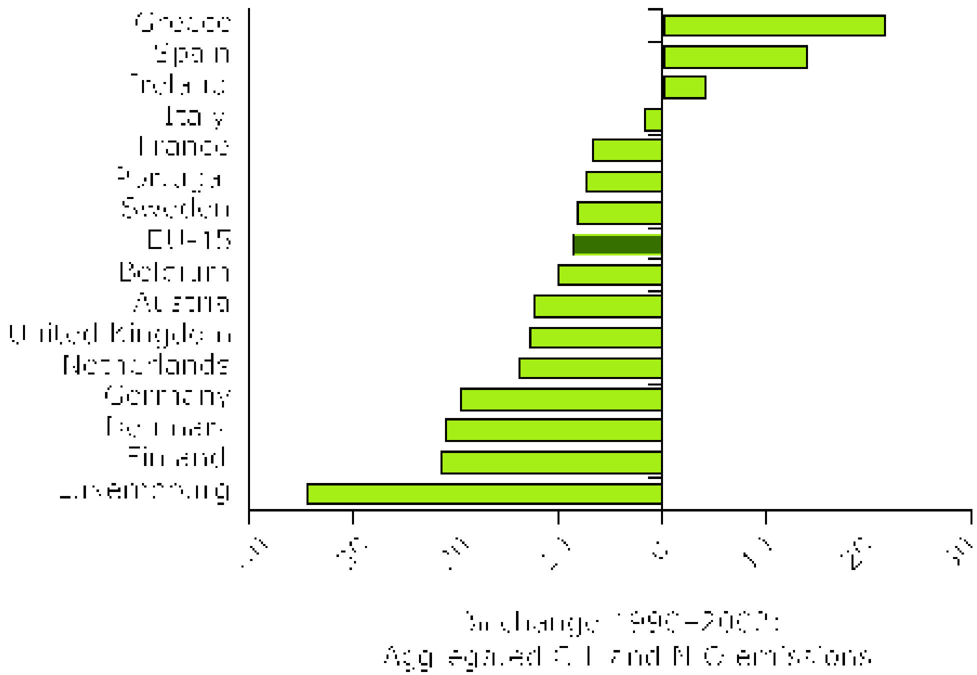

Share of agriculture in total nitrogen
leaching to surface waters (%)
100
90
80
70
60
50
40
30
20
10
0
EU-15
Denmark
Netherlands
France
Italy
Germany
Sweden
Austria
Belgium
Finland

EEA Data

EU GHG Emissions Estimate 2002—EEA, 2006




100
94
Methane emissions
Nitrous oxide emissions

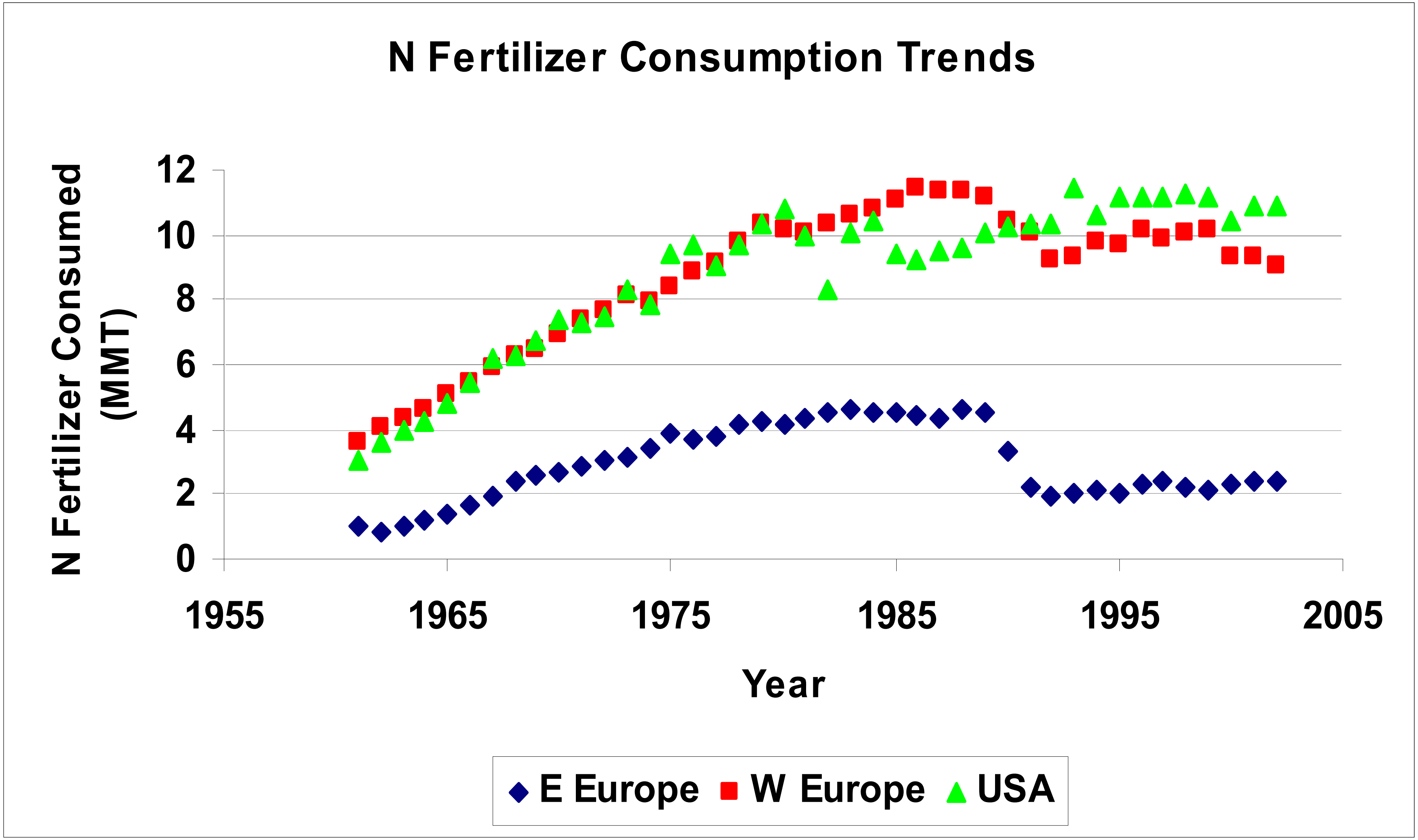

Spain
France
Sweden
EU-15
Belgium
Austria
Netherlands
Germany

EEA Data

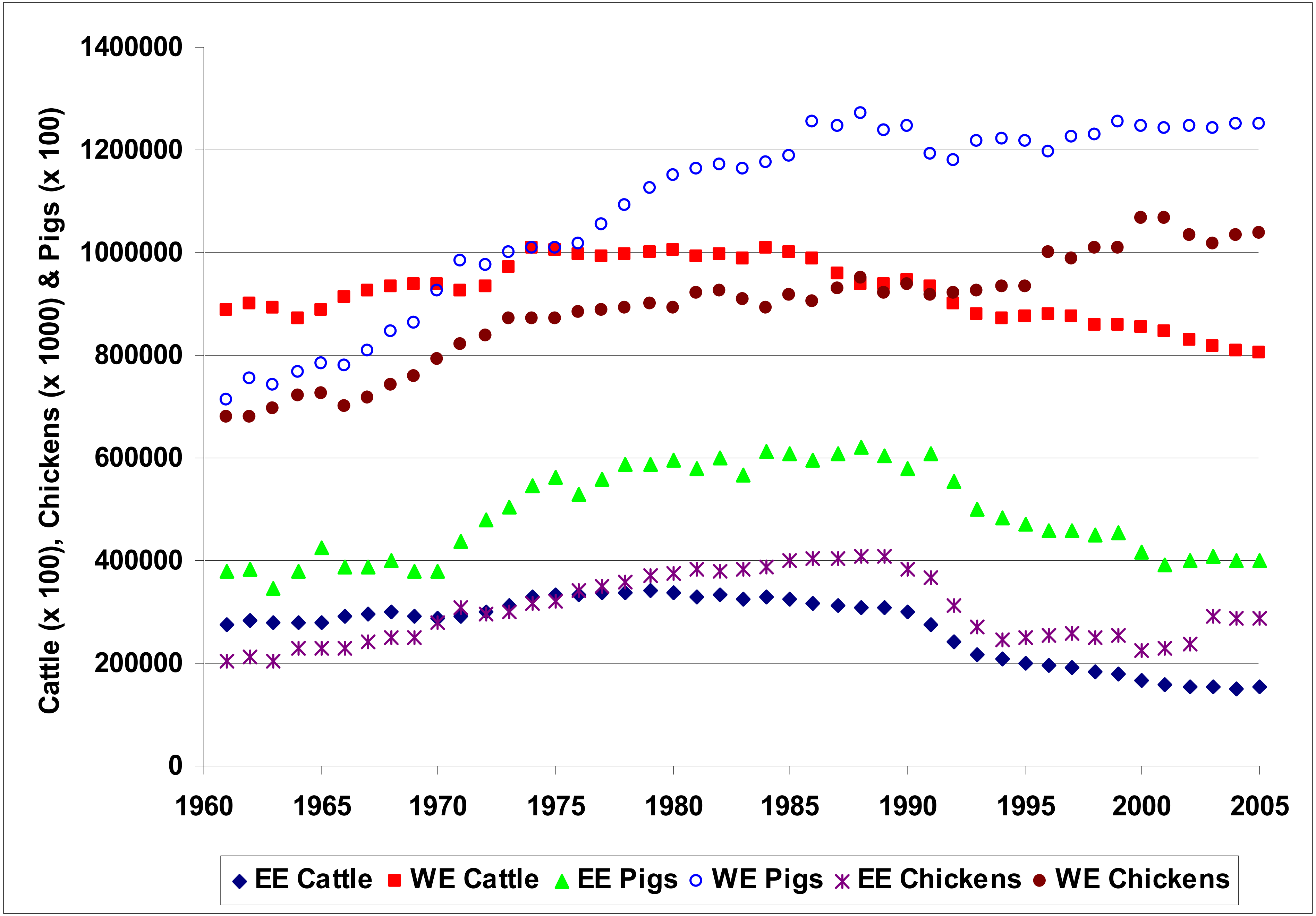
Current trends in NH_3, NO_x & greenhouse gases emissions in Europe

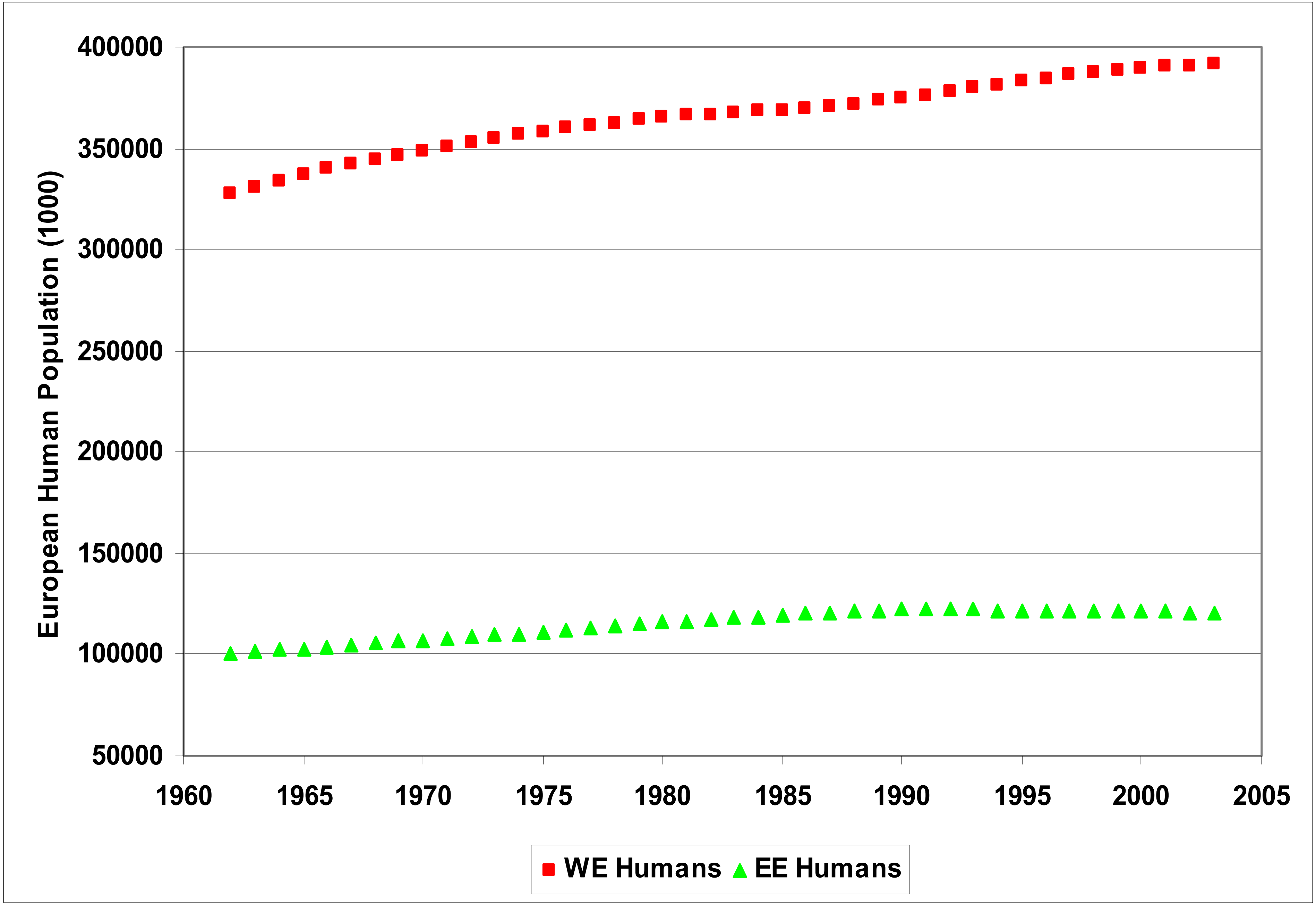
- Ammonia, NO_x, nitrate leaching, CH_4, CO_2 & N_2O

- Trends in European Fertilizer Use, Livestock Production


N Fertilizer Consumption Trends
N Fertilizer Consumed (MMT)
0
2
4
6
8
10
12
1955
1965
1975
1985
1995
2005
Year
E Europe
W Europe
USA

FAO, 2006


Cattle (x 100), Chickens (x 1000) & Pigs (x 100)
1400000
1200000
1000000
800000
600000
400000
200000
0
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
EE Cattle
WE Cattle
EE Pigs
WE Pigs
EE Chickens
WE Chickens
FAO, 2006


European Human Population (1000)
400000
350000
300000
250000
200000
150000
100000
50000
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
WE Humans
EE Humans

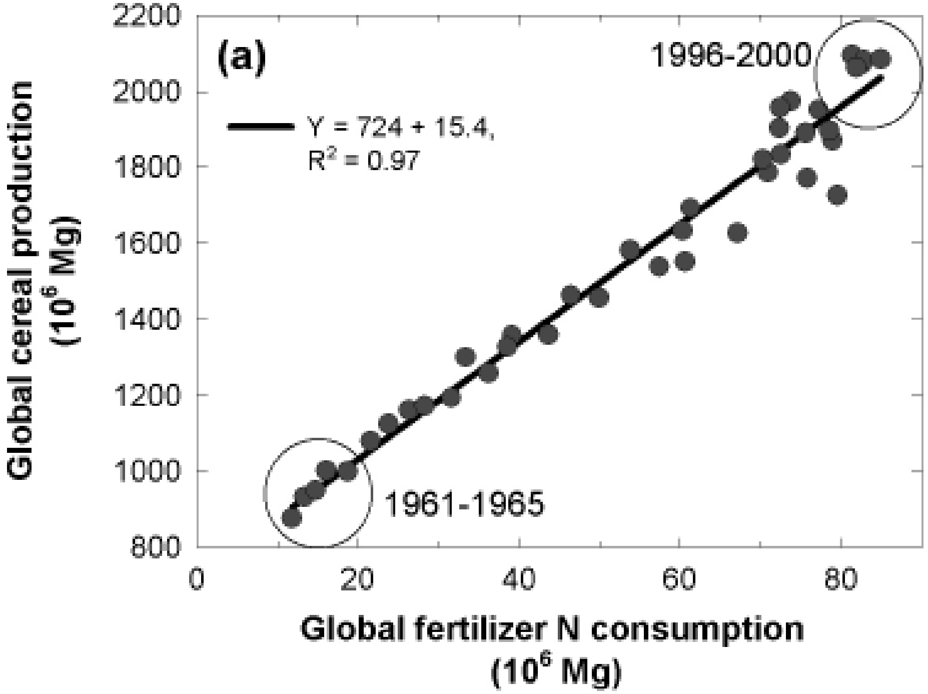
FAO. 2006

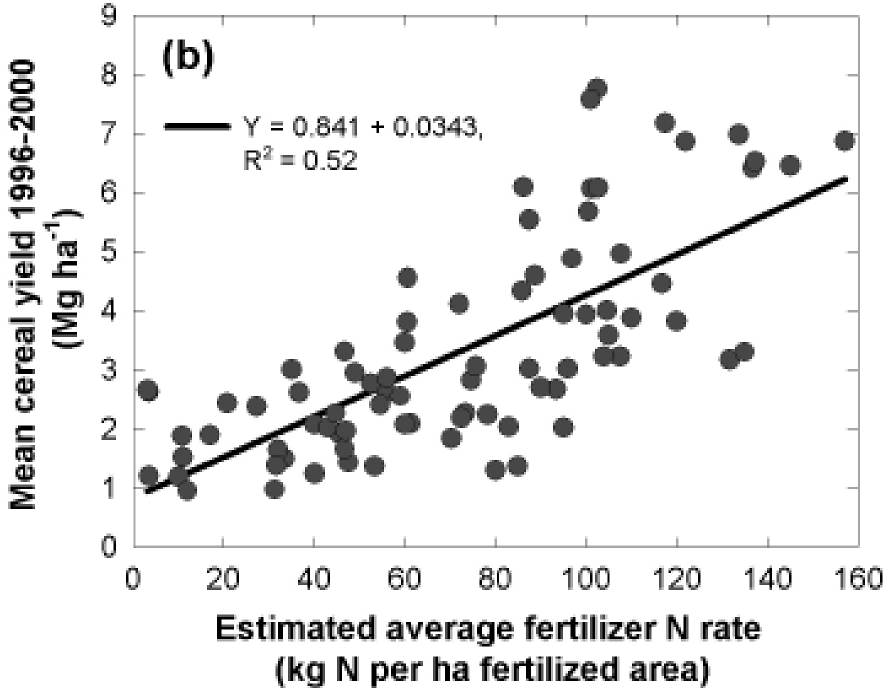
❖ **Societal Responses for Addressing N Fertilizer Needs:**

Balancing Food Production and Environmental Concerns

❖ Nitrogen Fertilizer and Food Production

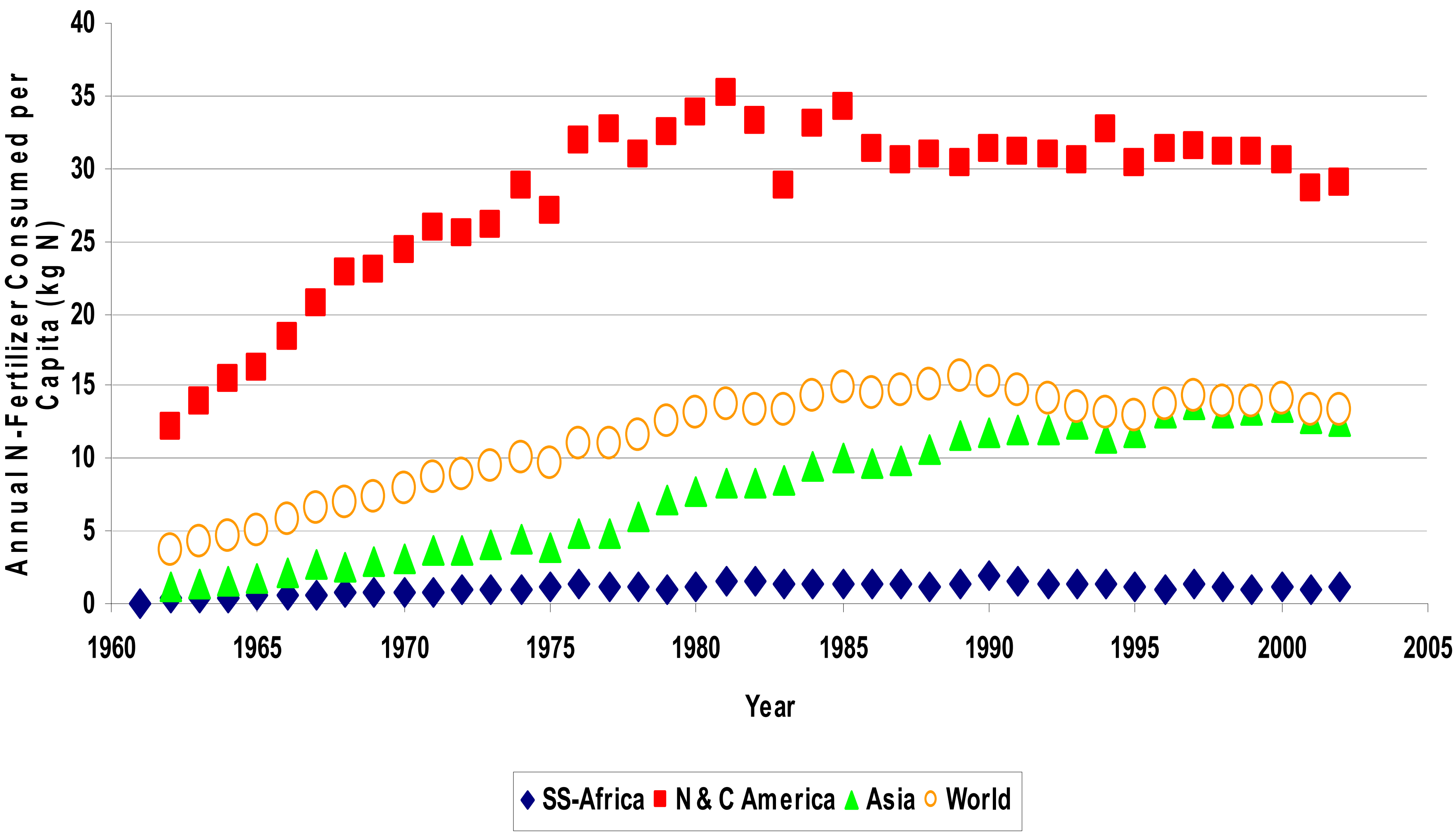
~ 40% of Current Food Production can be Attributed to N Fertilization



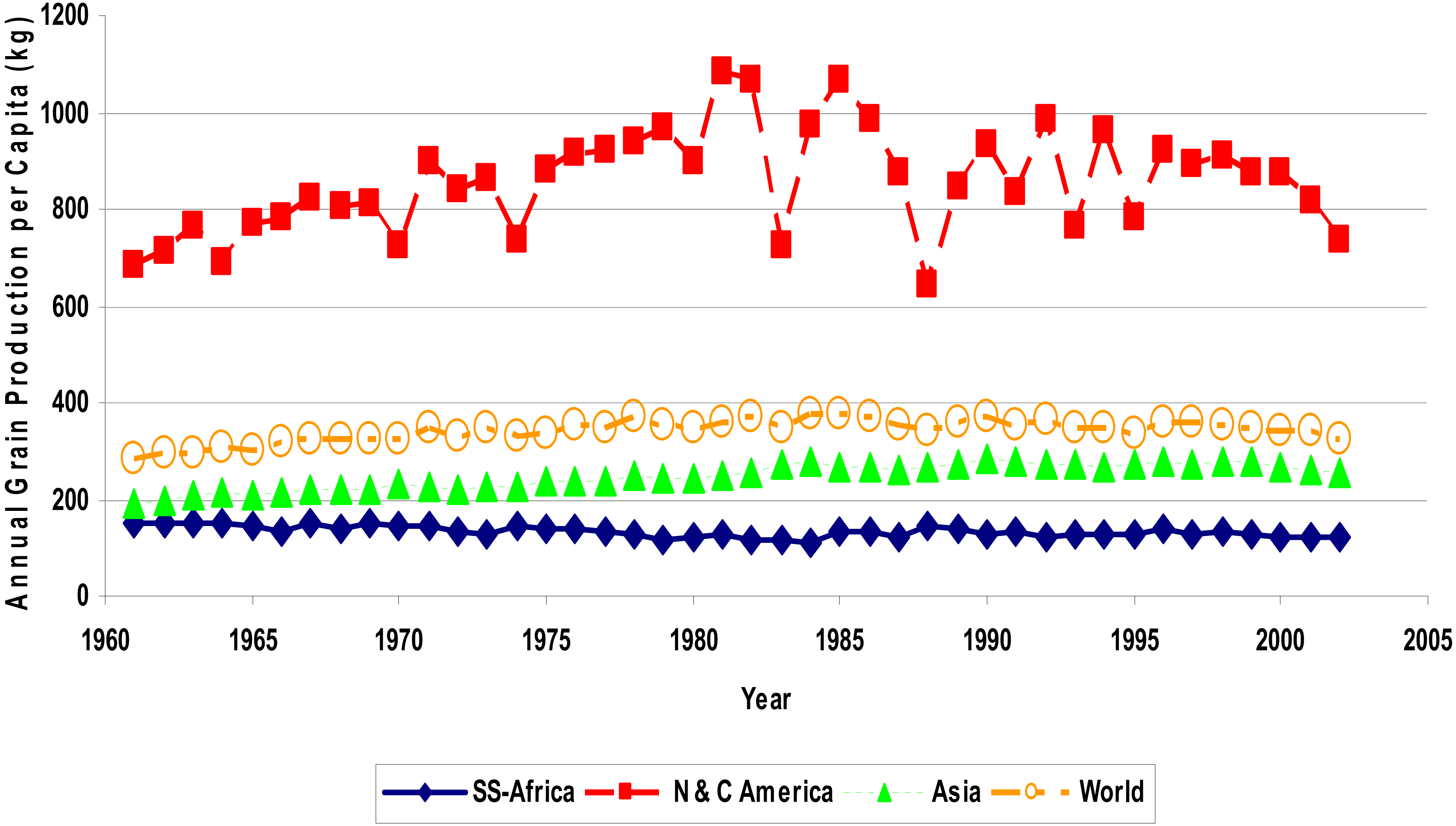


❖ Uneven regional/global distribution of N use

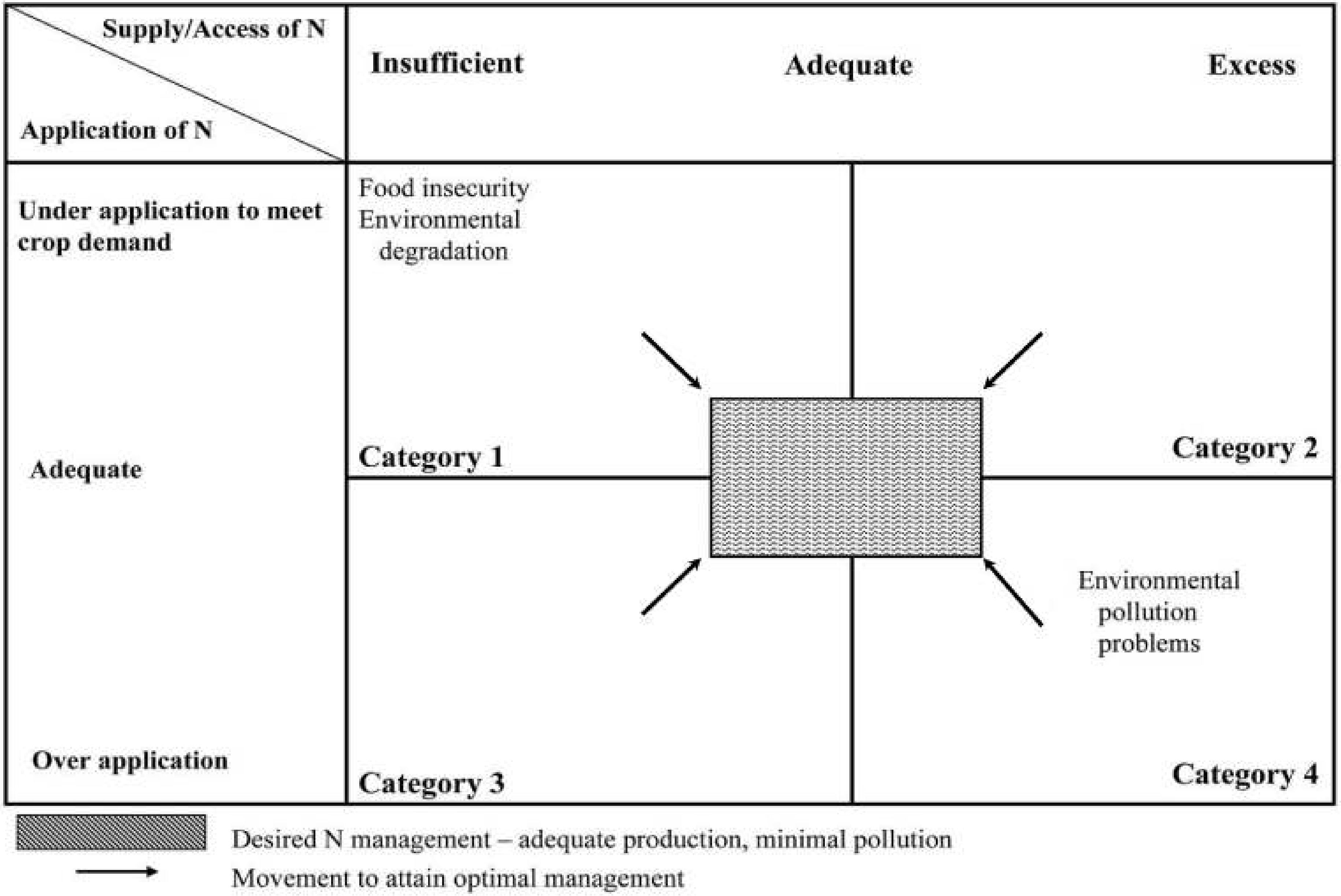
Per Capita N Fertilizer Use (FAO, 2004)



Per Capita Grain Production (FAO, 2004)



N access/supply and effects on food security & environment (SCOPE 65, Fig. 5.1).



GLOBAL IGBP CHANGE

IHDP

WCRP Climate

GECAFS

Global Environmental Change
and Food Systems

FAO

CGIAR

WMO

GECAFS Vision

A food-secure future for those most vulnerable to environmental stress

The International Nitrogen Initiative

ini

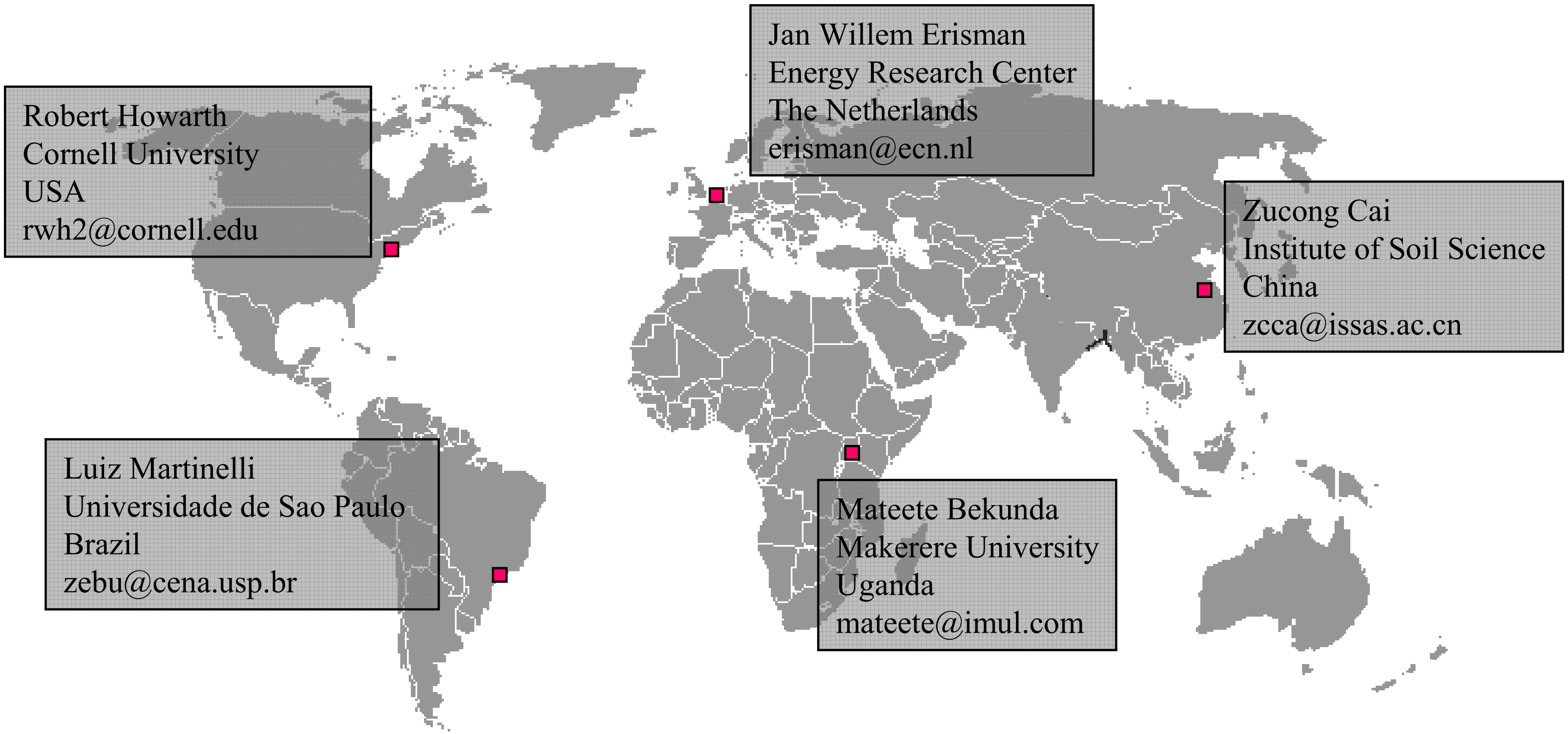
Optimize nitrogen's beneficial role in sustainable food production and minimize nitrogen's negative effects on human health and the environment resulting from food and energy production

Sponsored by: -Scientific Committee on Problems of the Environment
-International Geosphere-Biosphere Programme
-Ministry of the Environment, The Netherlands

http://www.initrogen.org/

International Nitrogen Initiative

Regional Centers and Directors/Coordinators



N Perspectives 1960s-2000s

- 1960s –Nitrate, Denitrification, N_2O Analysis
- 1970s—N_2O---Stratospheric Ozone, Livestock, Analytical Advances N_2O
- 1980s—N_2O, N Use Efficiency, ^{15}N Technology
- 1990s—Kyoto Protocol, GHG Inventories, Greenhouse Gases (C/N Cycles), Analytical Advances, Atmospheric CO_2 impacts on N cycling
- 2000s—GHG Inventories/Process Modeling, Livestock, Enhancing technical & economic efficiency of N

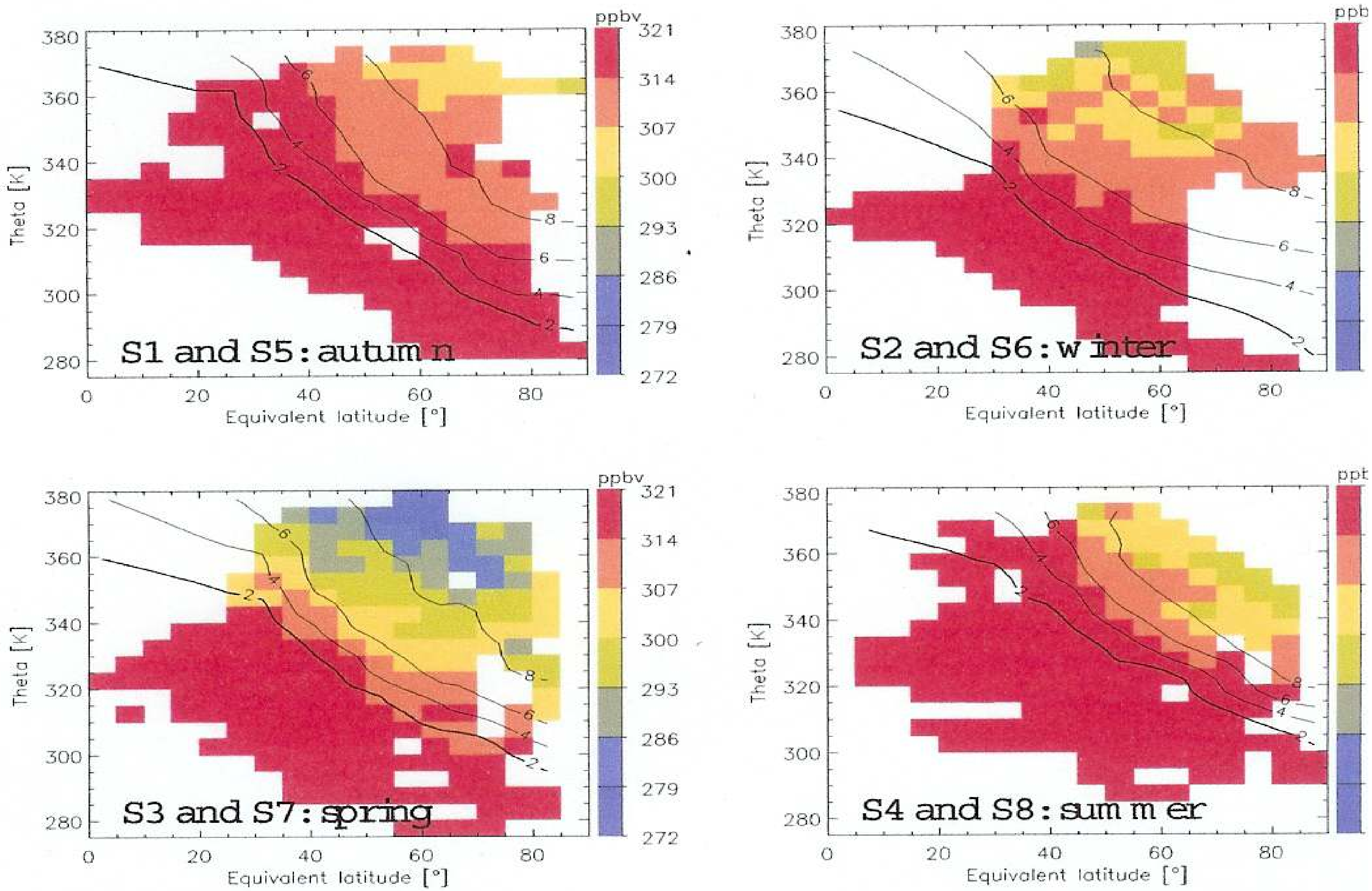


Fig. 6. Observed distribution of N_2O sorted by season as function of equivalent latitude and potential temperature. Data TRISTAR and the GC GhOST II. The black lines represent different PV isopleths (2, 4, 6 and 8 PVU). The 2 PVU isople the dynamical tropopause

Atmos. Chem. Phys. 2006. SPURT (Spurenstofftransport in der Tropopausenregion

Nitro Europe IP
The Nitrogen Cycle and its Influence on the European Greenhouse Gas Balance

- All aspects of the N Cycle at scale (plot to region)
- Linking C and N Cycles
- Integration
- Land Use
- N deposition and CO_2 fertilization
- Spatial & Temporal Variability


THANK YOU