Selected Recommendations

in Support of

Integrated Nitrogen Management

J. N. Galloway
for the
Integrated Nitrogen Committee, SAB

USEPA SAB INC
Workshop and Meeting
October 20 - 22, 2008

Overview of Talk

- **Reactive Nitrogen (Nr) entry into the US.**
- Nr Fate in the US.
- Consequences, Impacts and Metrics.
- Major Findings and Recommendations

Nr Introduction into the US

- Fossil fuel combustion
  - stationary sources
  - transportation sources

- Haber Bosch Nr
  - produced in US
  - imports from other countries

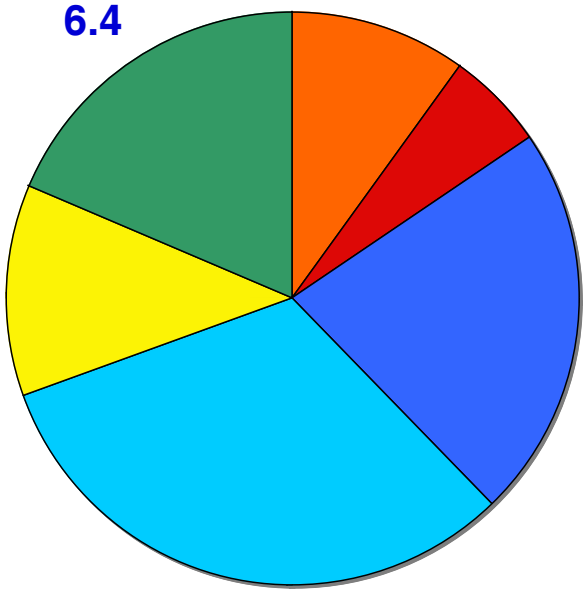
- Import of N-containing commodities
  - grain and meat

- Biological nitrogen fixation (BNF)
  - managed lands
  - unmanaged lands

Nr Introduction into the US

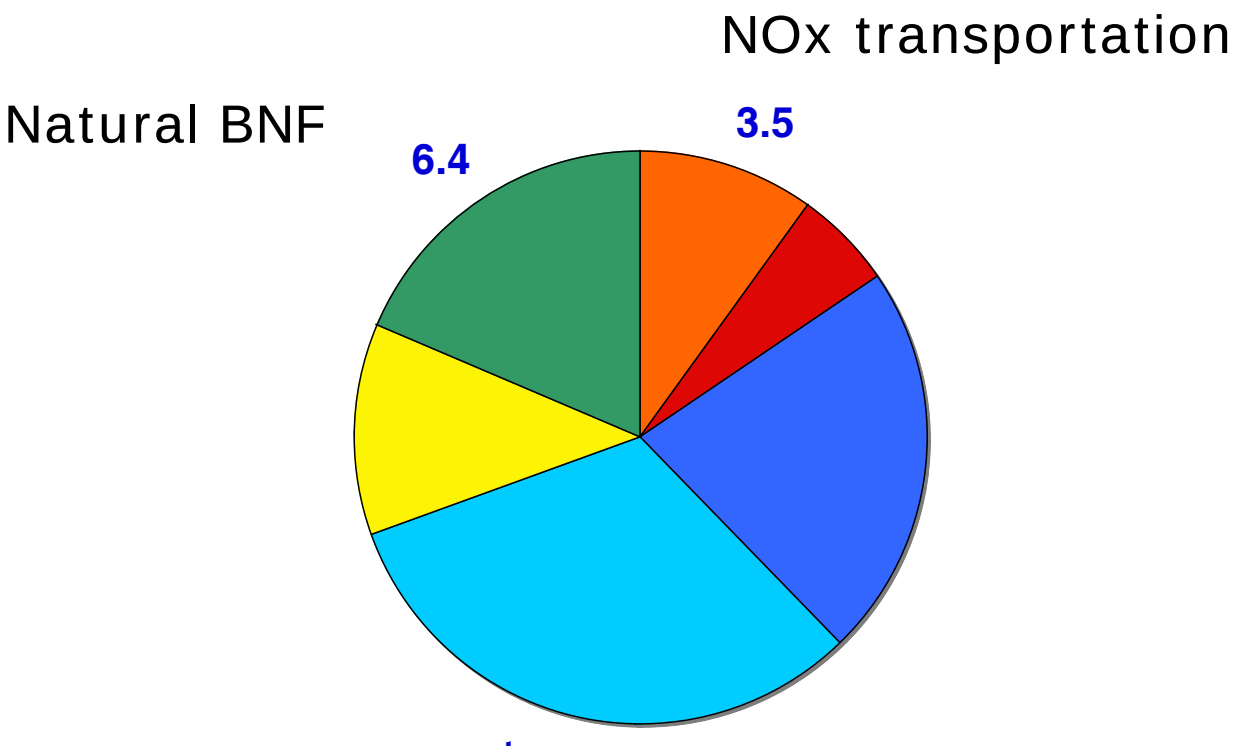
Tg N / yr

Natural BNF



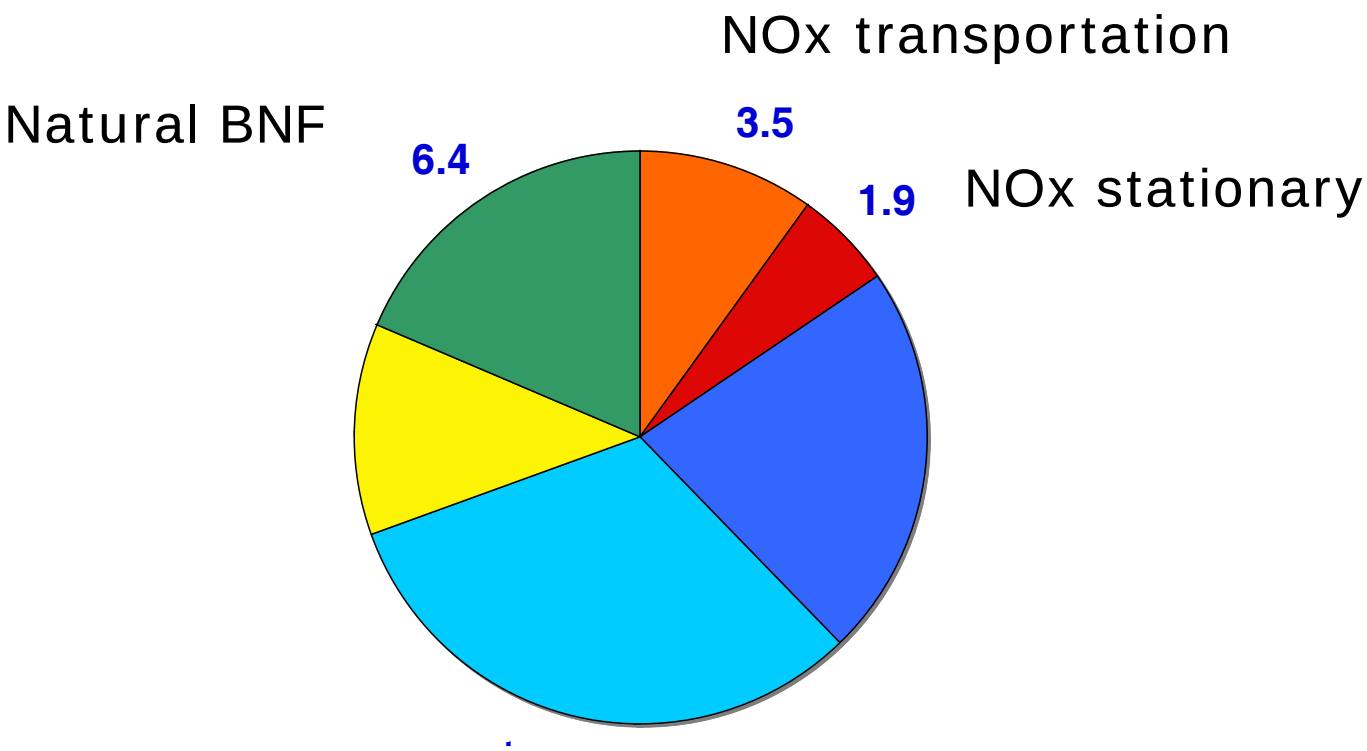
Nr Introduction into the US

Tg N / yr



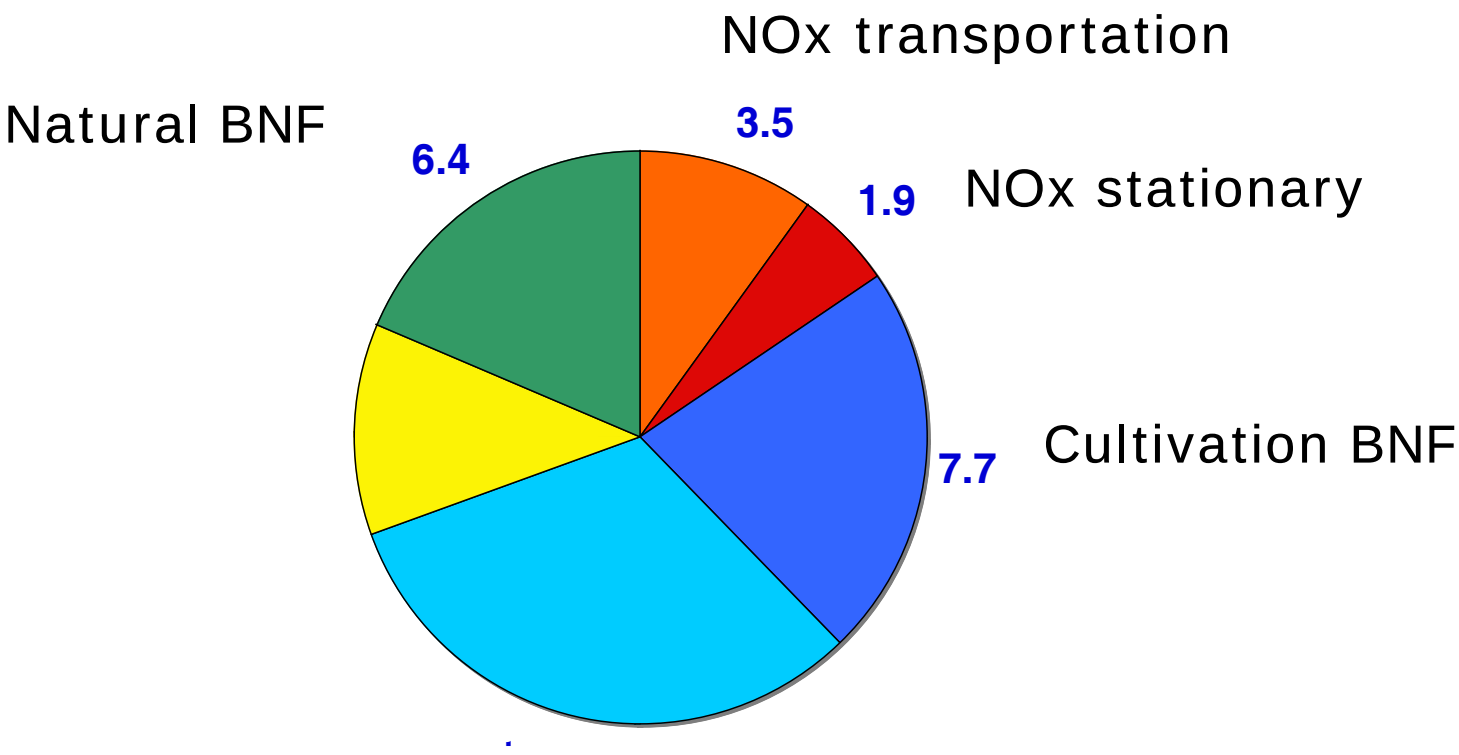
Nr Introduction into the US

Tg N / yr



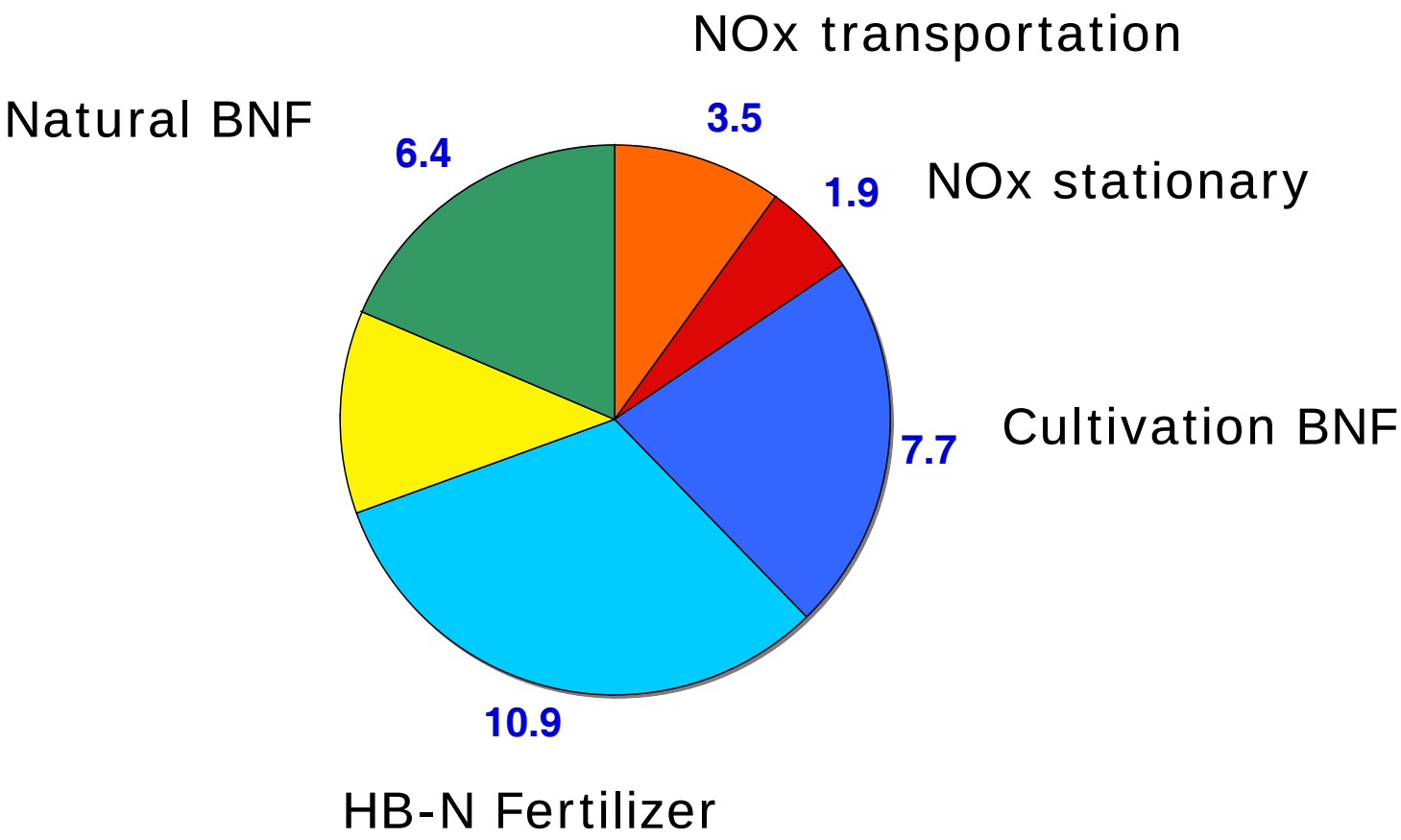
Nr Introduction into the US

Tg N / yr



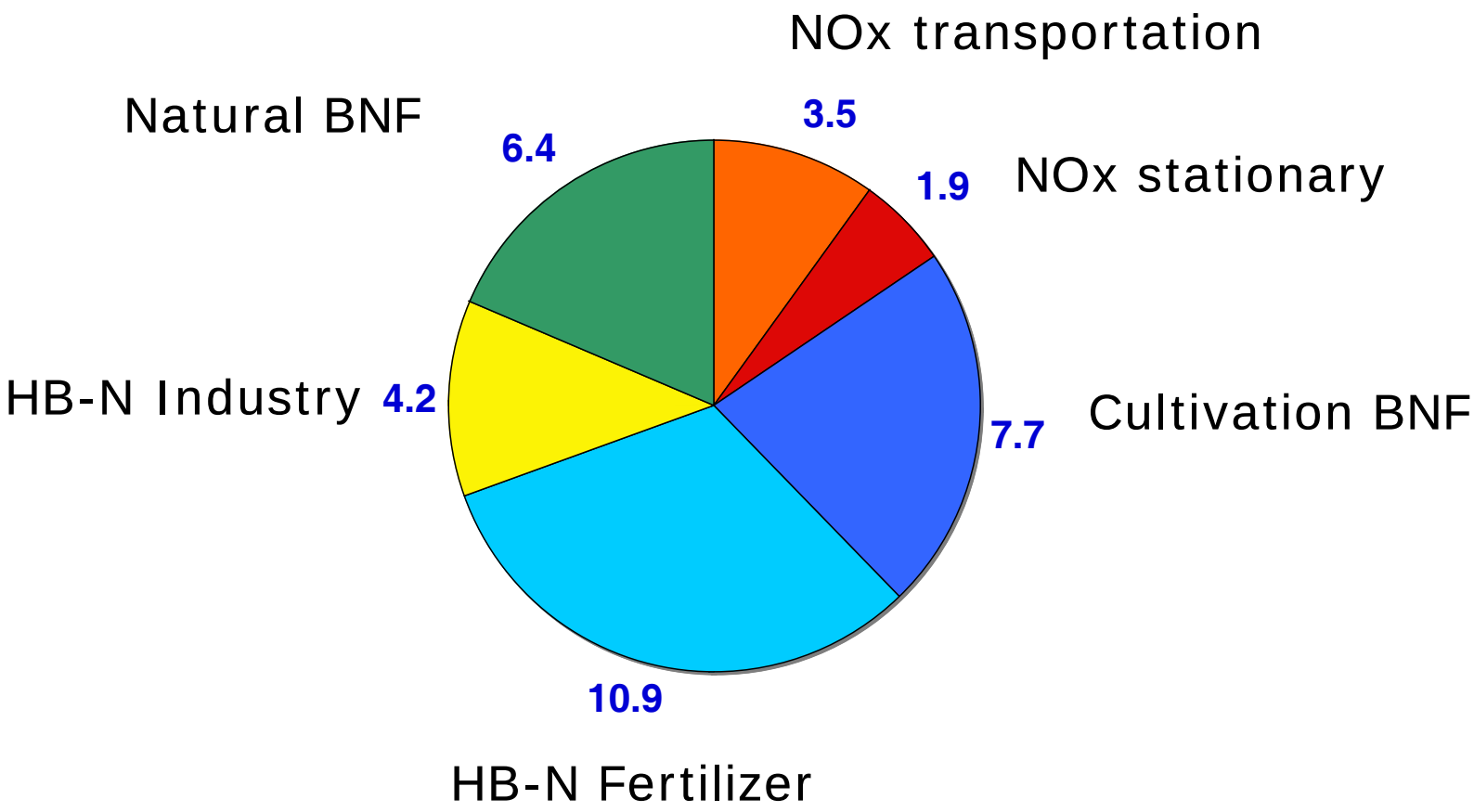
Nr Introduction into the US

Tg N / yr



Nr Introduction into the US

Tg N/yr



Natural, 6.5 Tg N/yr

Anthropogenic, 29 Tg Nr/yr

Overview of Talk

- Reactive Nitrogen (Nr) entry into the US.
- **Nr Fate in the US.**
- Consequences, Impacts and Metrics.
- Major Findings and Recommendations

Fate of Introduced Nr

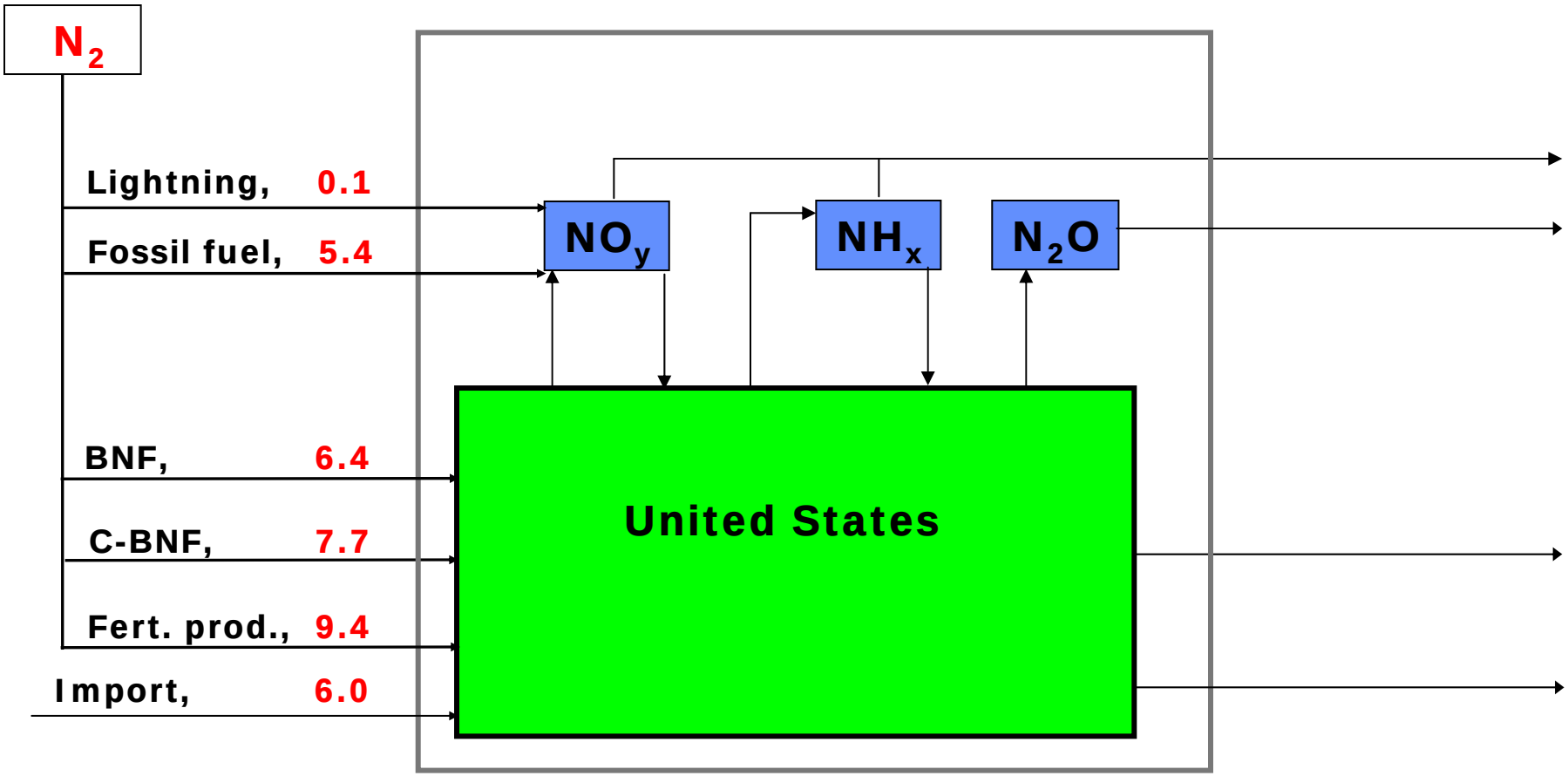
- Lost as Nr from US
  - via rivers
  - via atmospheric advection
  - via exports
- Stored as Nr
  - in soils & vegetation
  - In groundwater
- Denitrified to N_2

There are two aspects to the fate of Nr:

- **how much goes where?**
- **what is the uncertainty**?

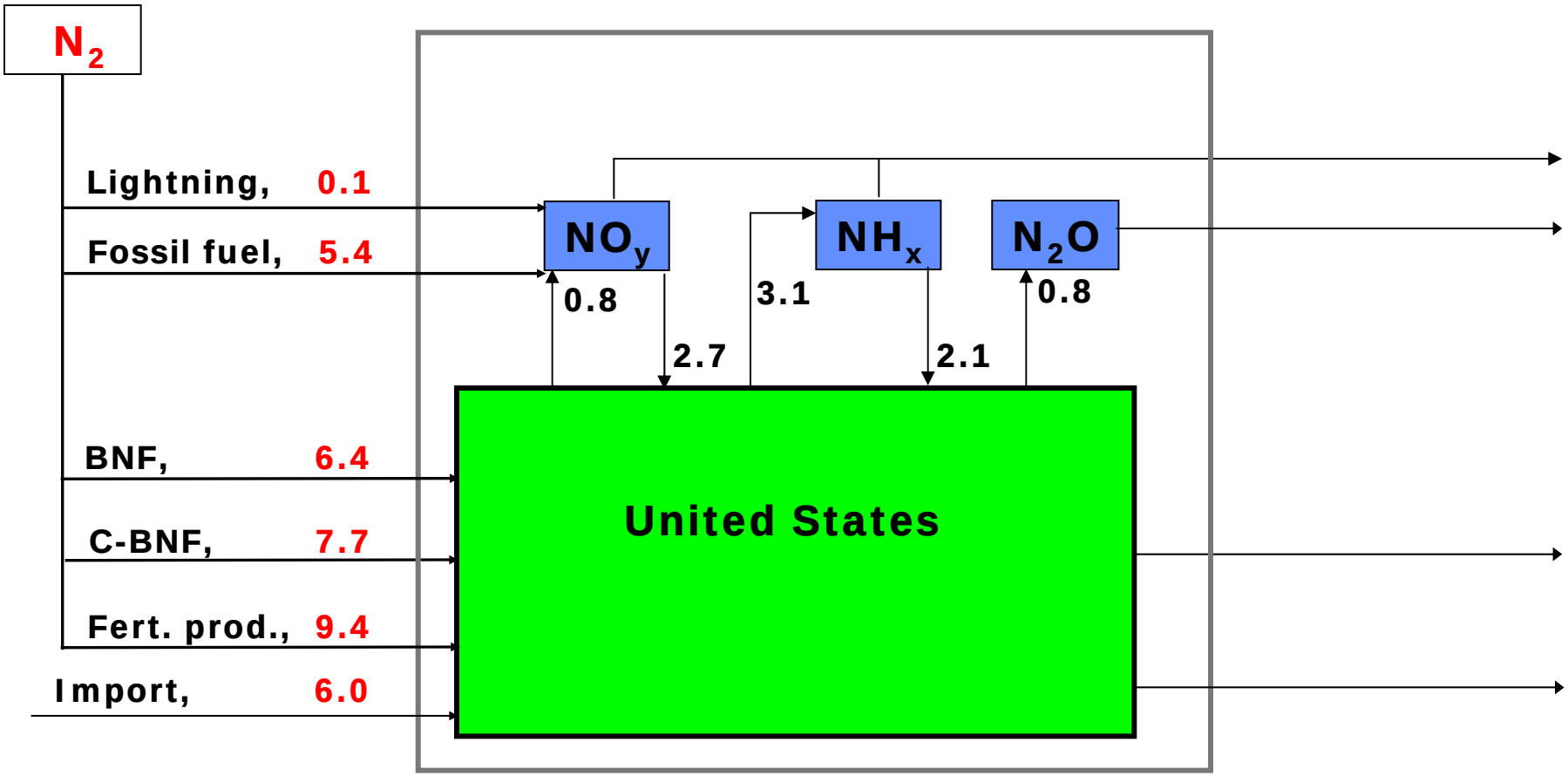
US Nitrogen Budget

Tg N yr^{-1}



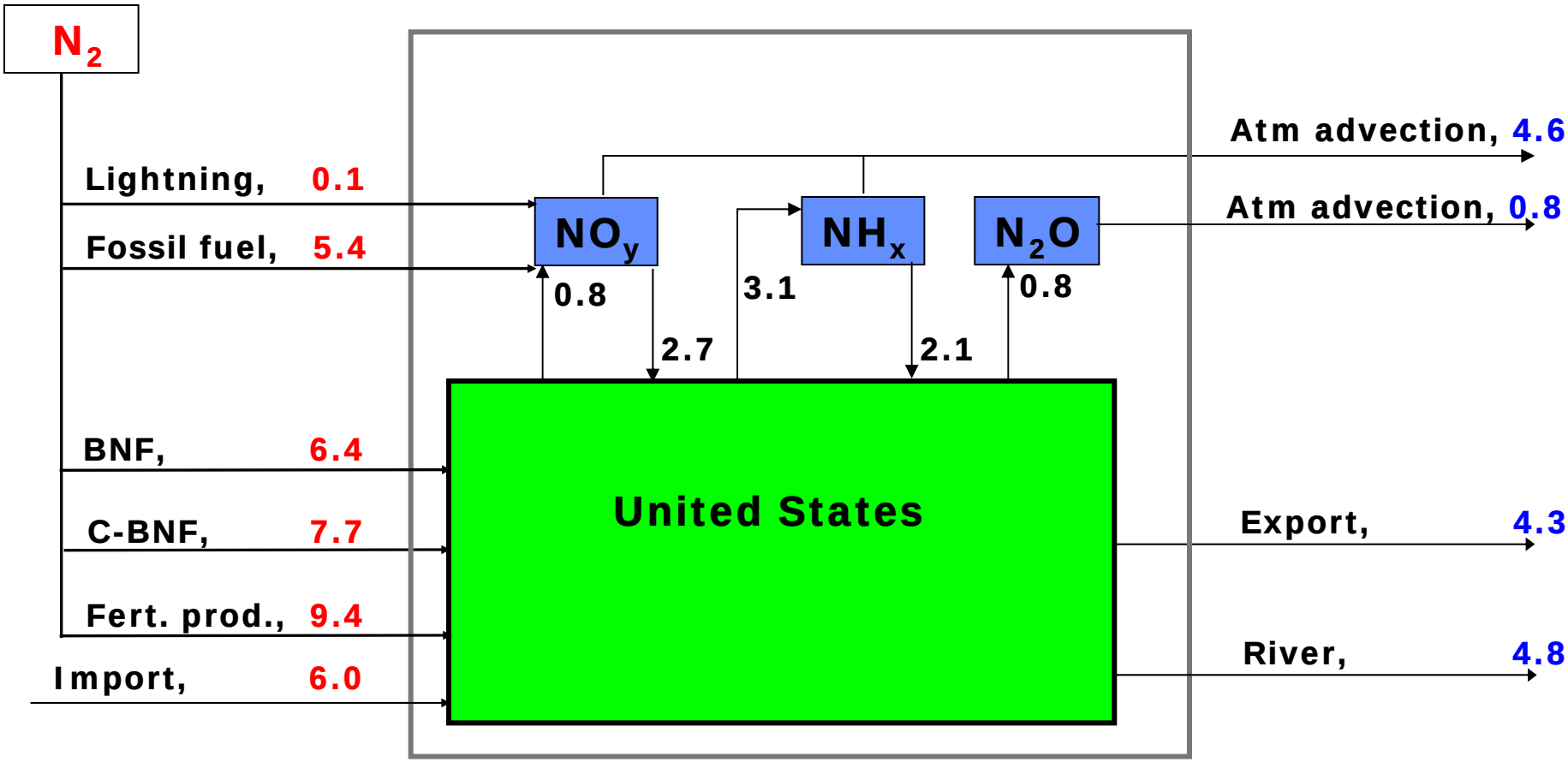
US Nitrogen Budget

Tg N yr^{-1}



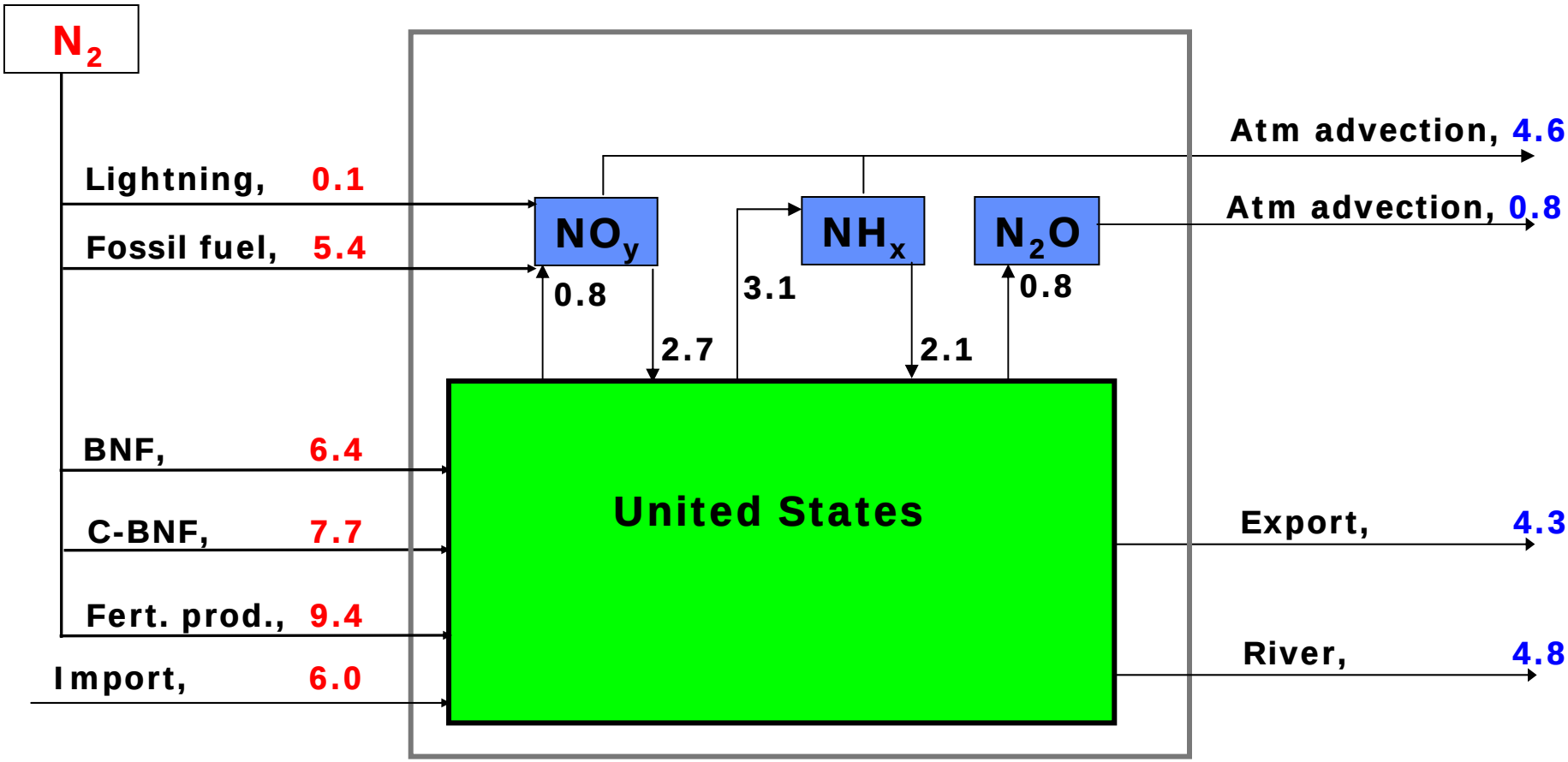
US Nitrogen Budget

Tg N yr^{-1}



US Nitrogen Budget

Tg N yr^{-1}

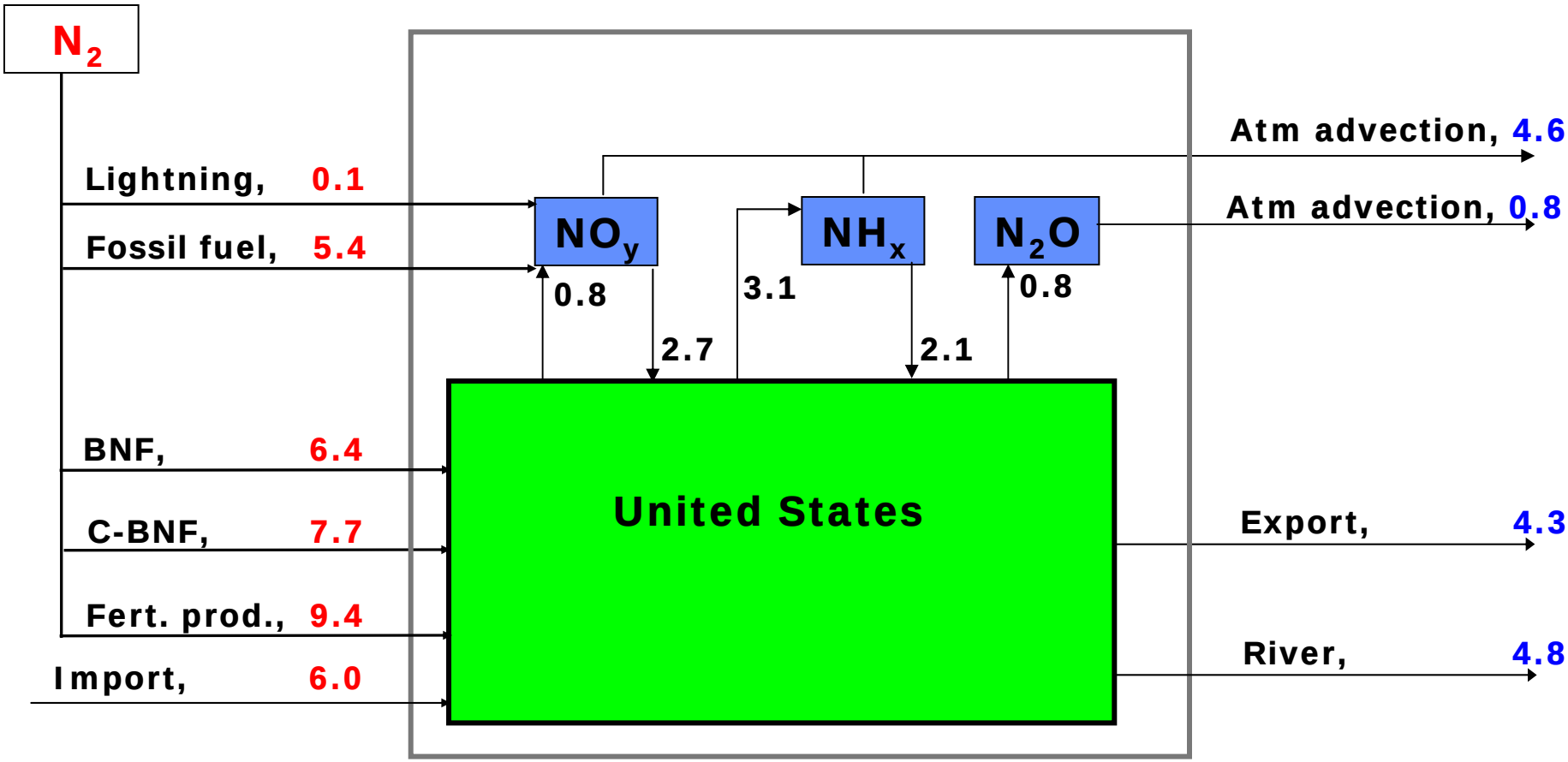


Nr Inputs: 35 Tg N
Nr Outputs: 14 Tg N

Nr Missing: 21 Tg N

US Nitrogen Budget

Tg N yr^{-1}



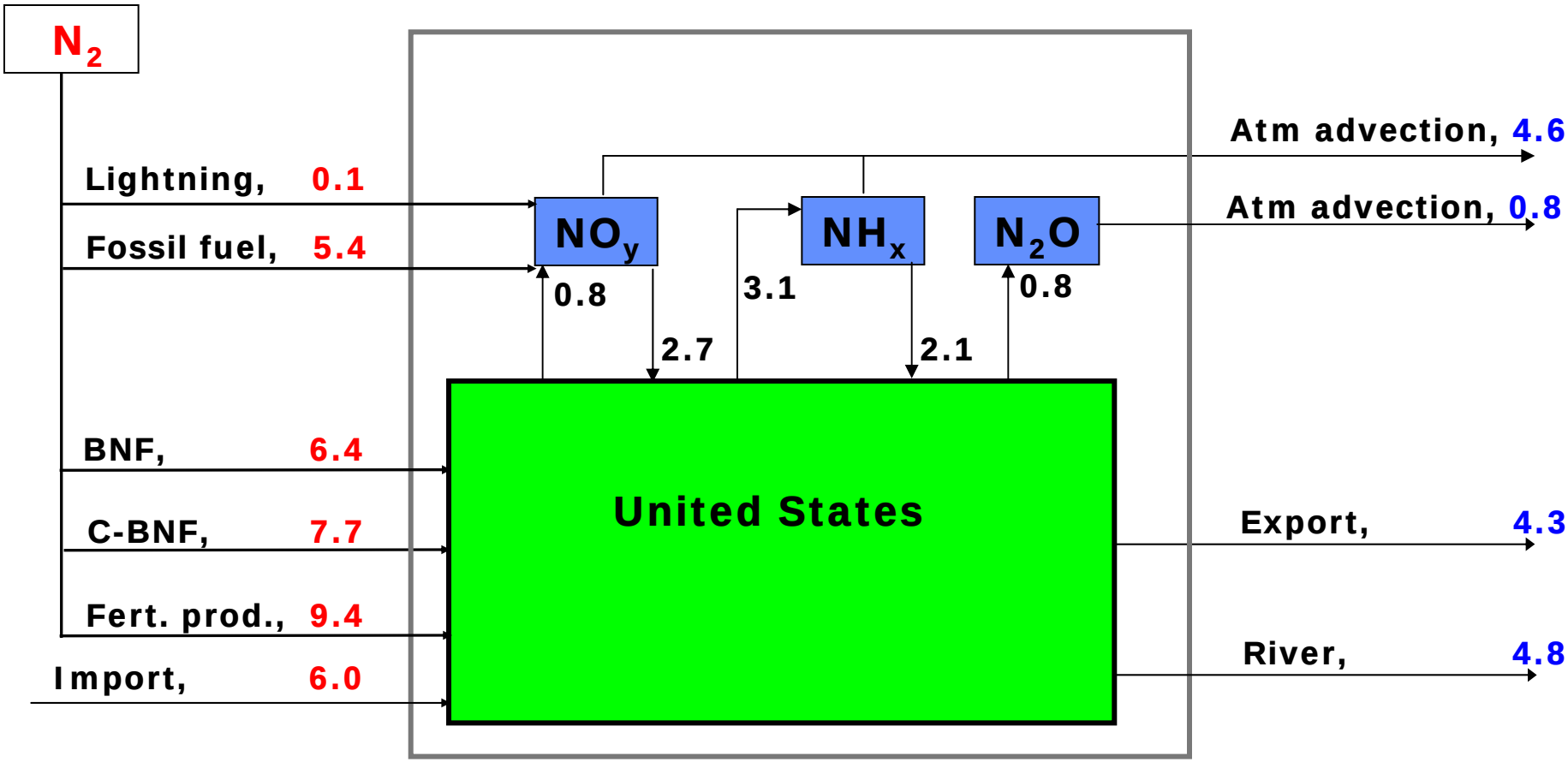
Nr Inputs: 35 Tg N
Nr Outputs: 14 Tg N

Nr Missing: 21 Tg N

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

US Nitrogen Budget

Tg N yr^{-1}



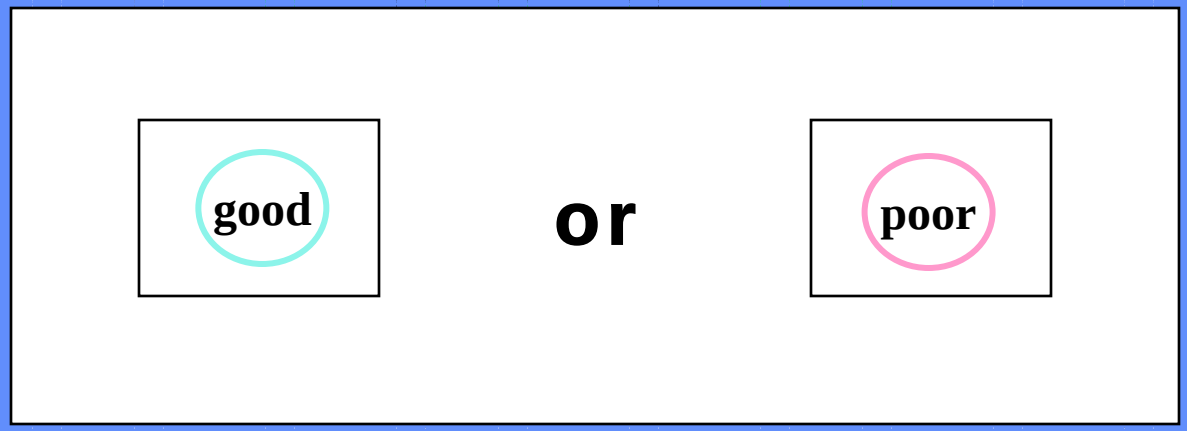
Nr Inputs: 35 Tg N
Nr Outputs: 14 Tg N

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

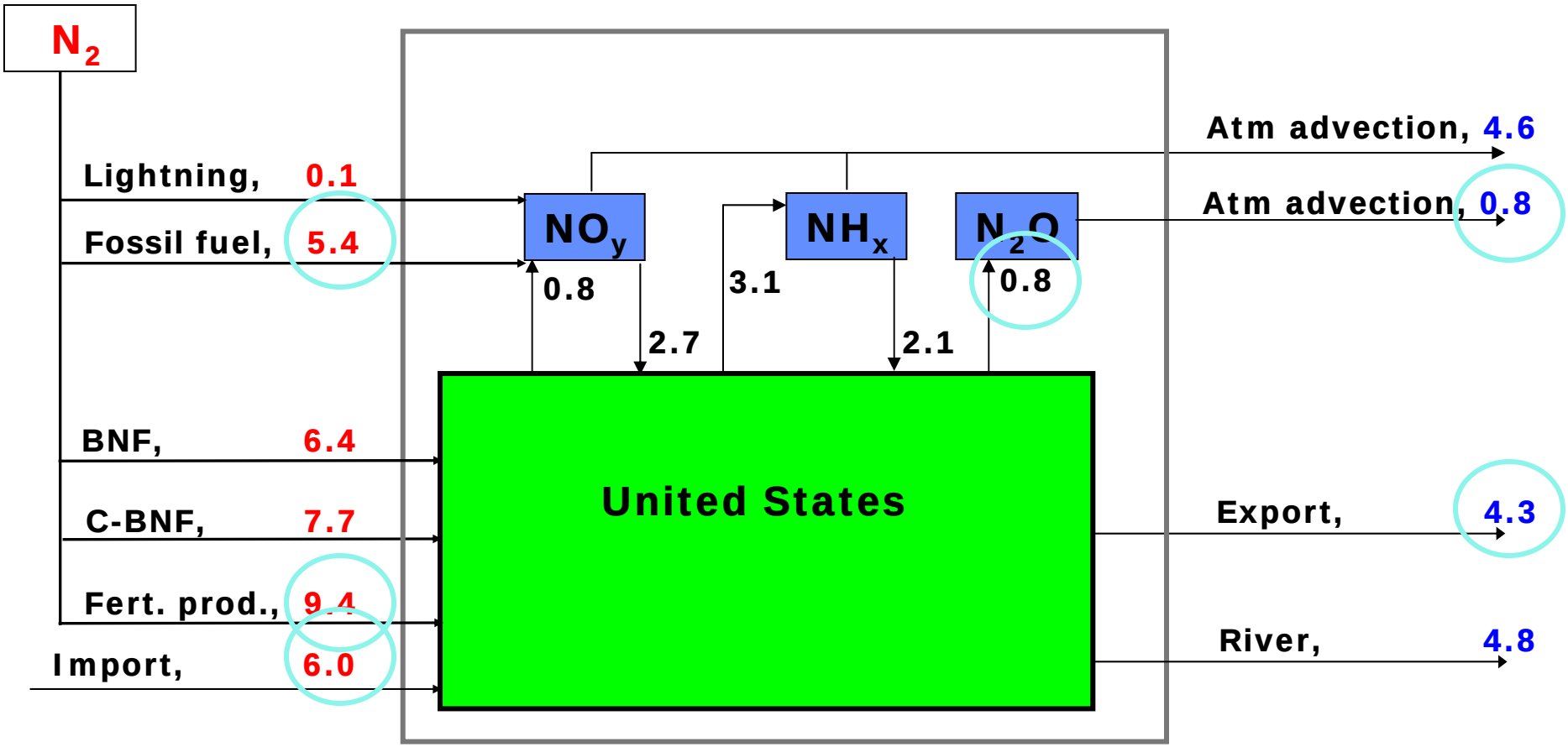
How certain is our knowledge about these fluxes?



good

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

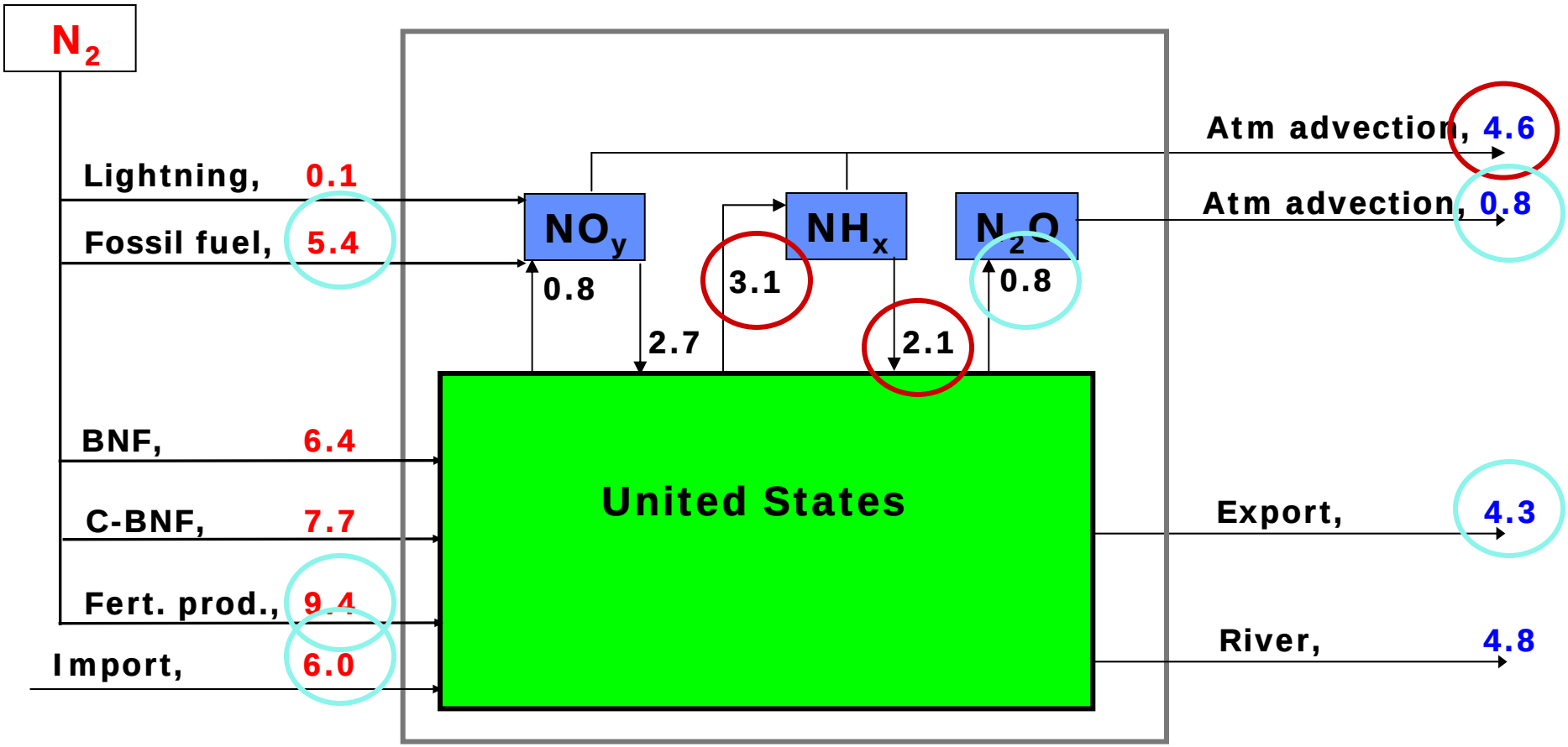
Nr Denitrified to N_2:
21 Tg N - 5 Tg N = 16 Tg N

good

US Nitrogen Budget

Tg N yr^{-1}

poor



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

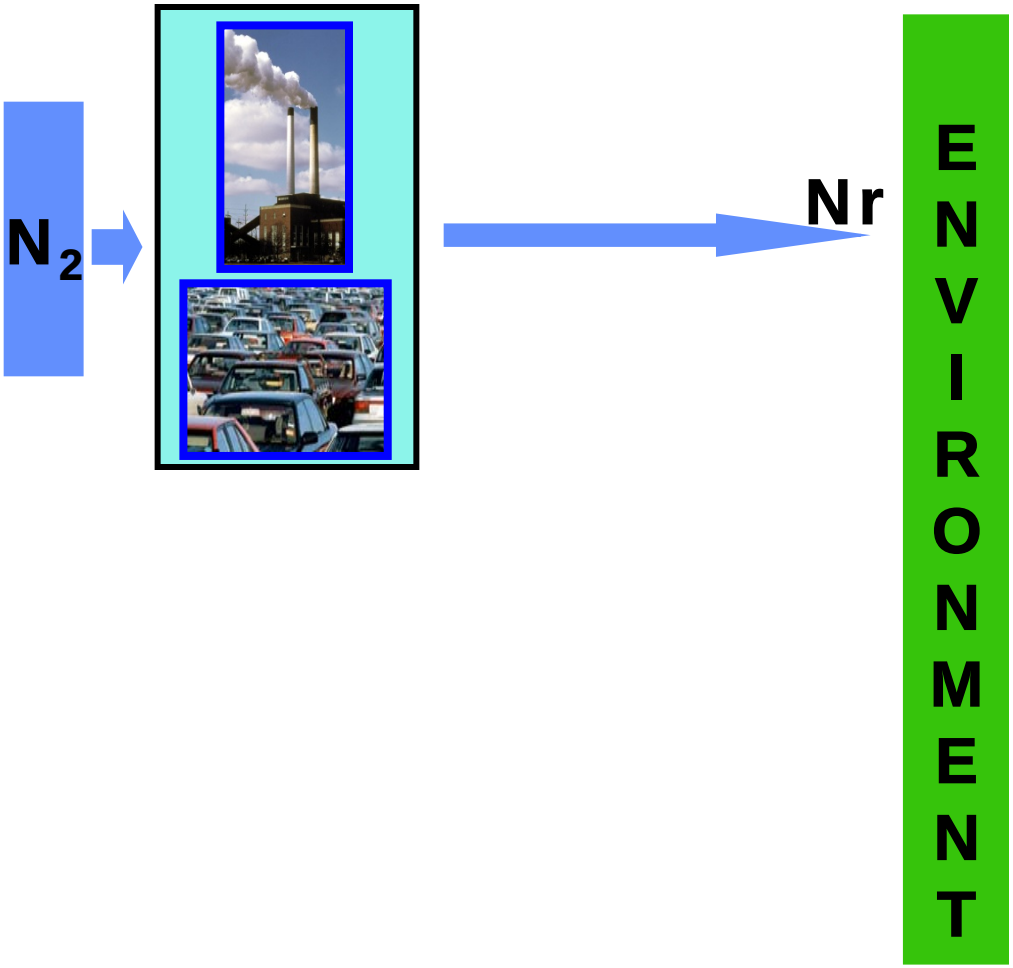
Overview of Talk

- Reactive Nitrogen (Nr) entry into the US.
- Nr Fate in the US.
- **Consequences, Impacts and Metrics.**
- Major Findings and Recommendations

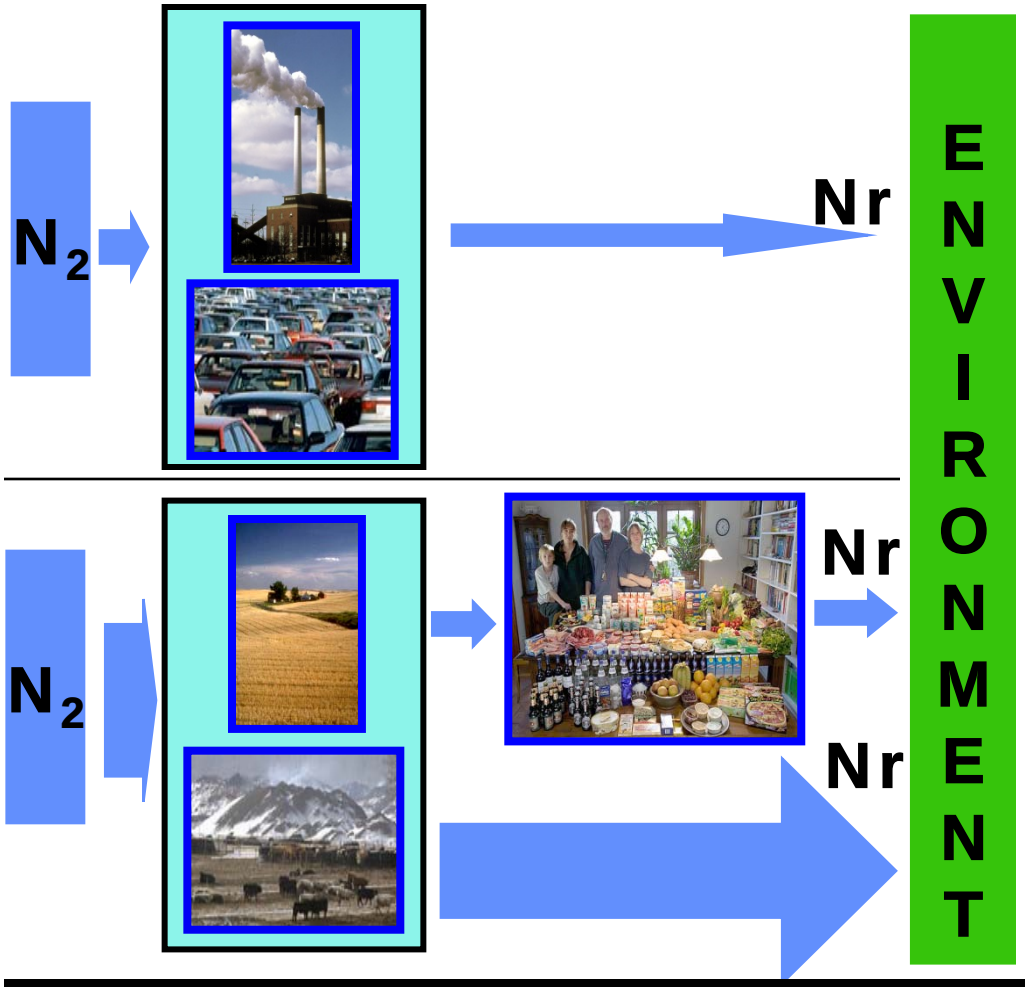
Impact Metrics

- Understanding the environmental impacts of Nr can inform decisions on how best to manage nitrogen risks. There are two main approaches to this problem – traditional impacts and ecosystem services.
  - Traditional impacts include global warming, eutrophication, ecotoxicity, human health, acidification, smog formation, and ozone depletion.
  - The ecosystem services approach complements traditional impact characterizations by assessing causative contaminant emissions. It considers how a specific service provided by one or more ecosystems or the corresponding causative functions (e.g. categories such as climate change, nutrient cycling, and food production) is impaired.
- Both ways of expressing nitrogen impacts have value.
  - Using multiple metrics may provide a clearer picture of priorities for action, identify effective control points for reducing Nr impacts, and provide insights into more effective regulatory strategy.

Most Anthropogenic Nr is lost to the Environment

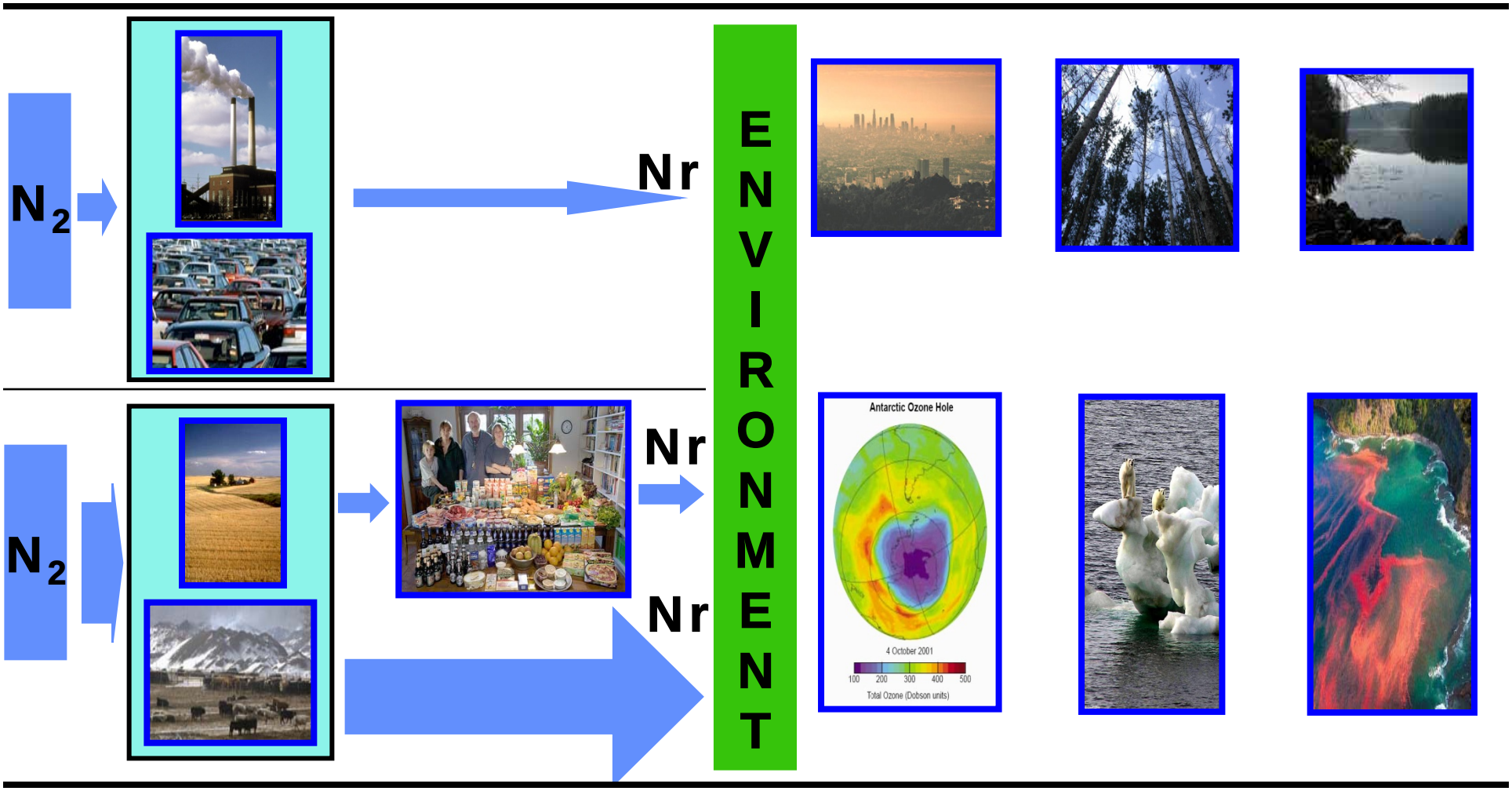


Most Anthropogenic Nr is lost to the Environment

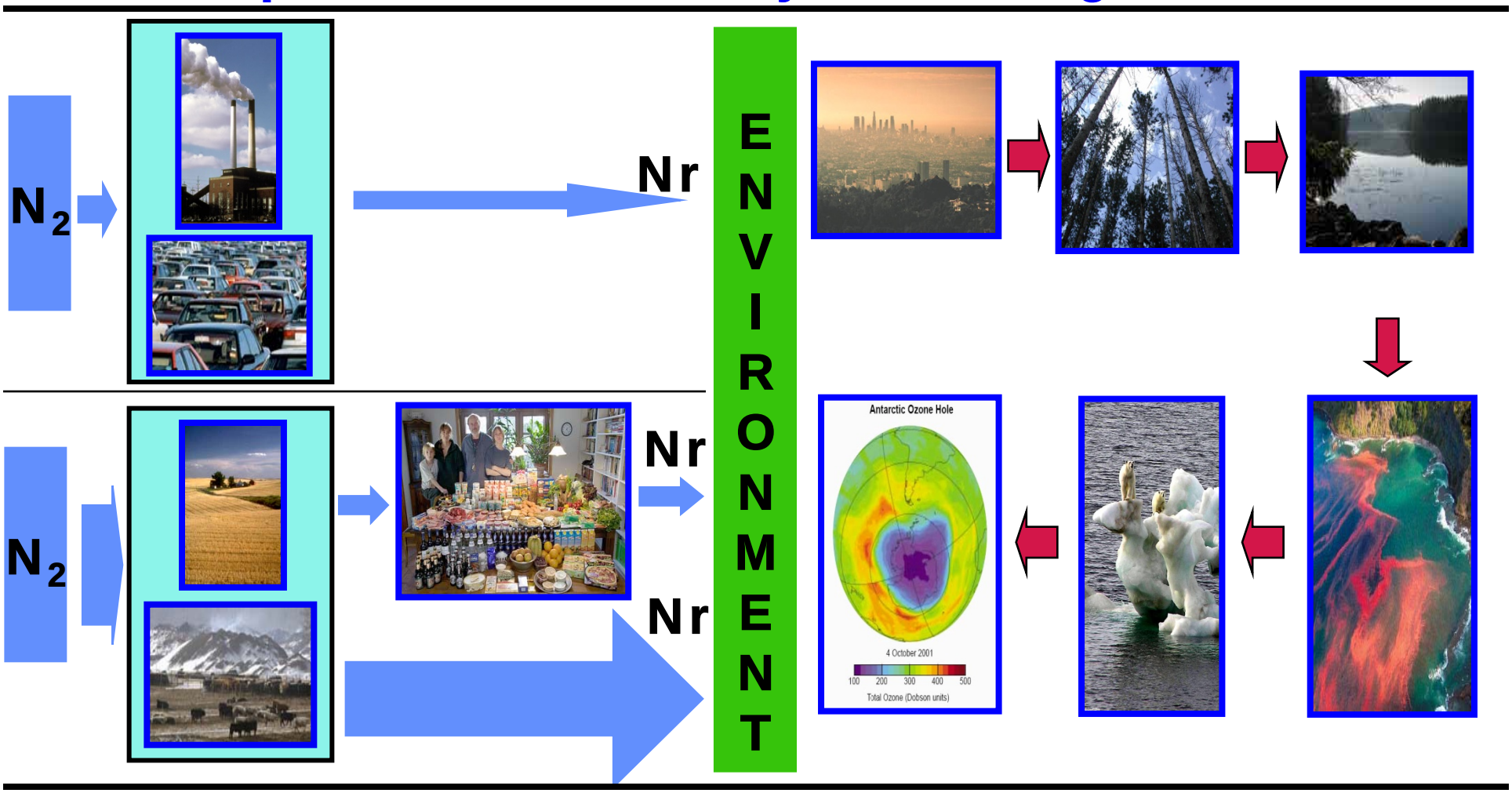


- Globally, ~50% of the world is fed with food grown with Haber-Bosch nitrogen.
  - In the US, the percentage is probably >90%.
- Most of the N atoms in our body are from the Haber Bosch process.

There are Numerous Impacts



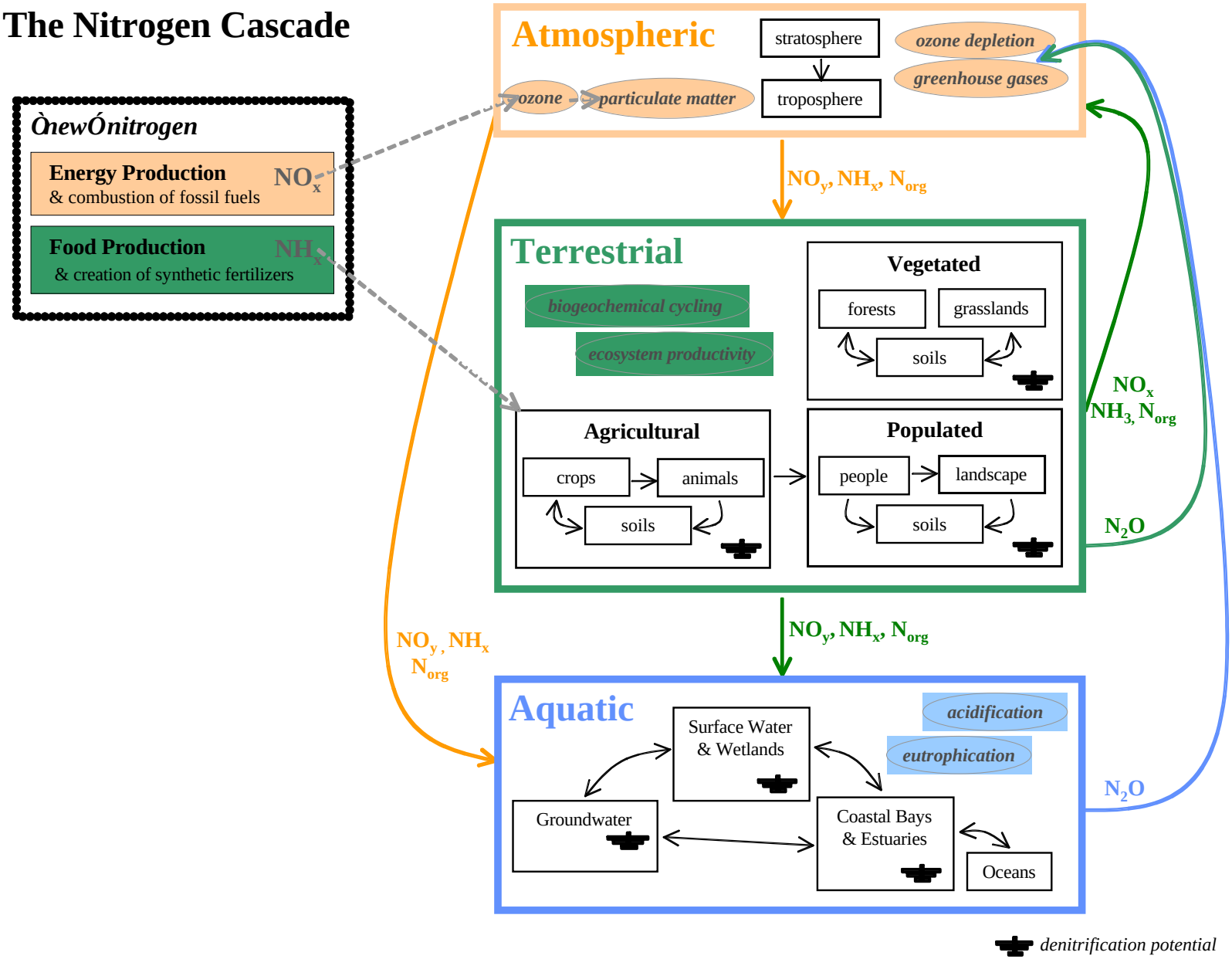
The Impacts are Linked by the Nitrogen Cascade



The Nitrogen Cascade

- The key aspects of the cascade are:
  - How much Nr is introduced to the system?
  - How long does it stay in an environmental reservoir (e.g., atmosphere) before it 'cascades' to the next reservoir (e.g., coastal ecosystem)?
  - What is the rate of Nr accumulation in the reservoir?
  - What are the consequences of Nr accumulation in the reservoir?
  - What is the potential for denitrification in the reservoir?
  - What are the control points where Nr can be managed for risk reduction?

The Nitrogen Cascade



- The concept of the nitrogen cascade highlights that once a new Nr molecule is created, it can, in sequence, travel throughout the environment contributing to major environmental problems.

Overview of Talk

- Reactive Nitrogen (Nr) entry into the US.
- Nr Fate in the US.
- Consequences, Impacts and Metrics.
- **Major Findings and Recommendations**

Integrated Nitrogen Committee
Selected Recommendations

- We recommend that the inorganic reduced nitrogen (ammonia plus ammonium) and total oxidized nitrogen (NOx, HNO_3, etc) be monitored as indicators of total chemically reactive nitrogen, instead of NO_2.

- We recommend the use of multiple metrics to provide a fuller picture of the impacts of reactive nitrogen and improve the setting of priorities.

- We recommend an improvement in the foundational data required to track sources of Nr and Nr loads in the environment, including better geospatial estimates of Nr emission and deposition and Nr crop uptake and loss.

- An overarching recommendation is more effective integration of strategies that work across media, address multiple problems and avoids unintended adverse consequences is necessary to reduce costs and create more enduring solutions.

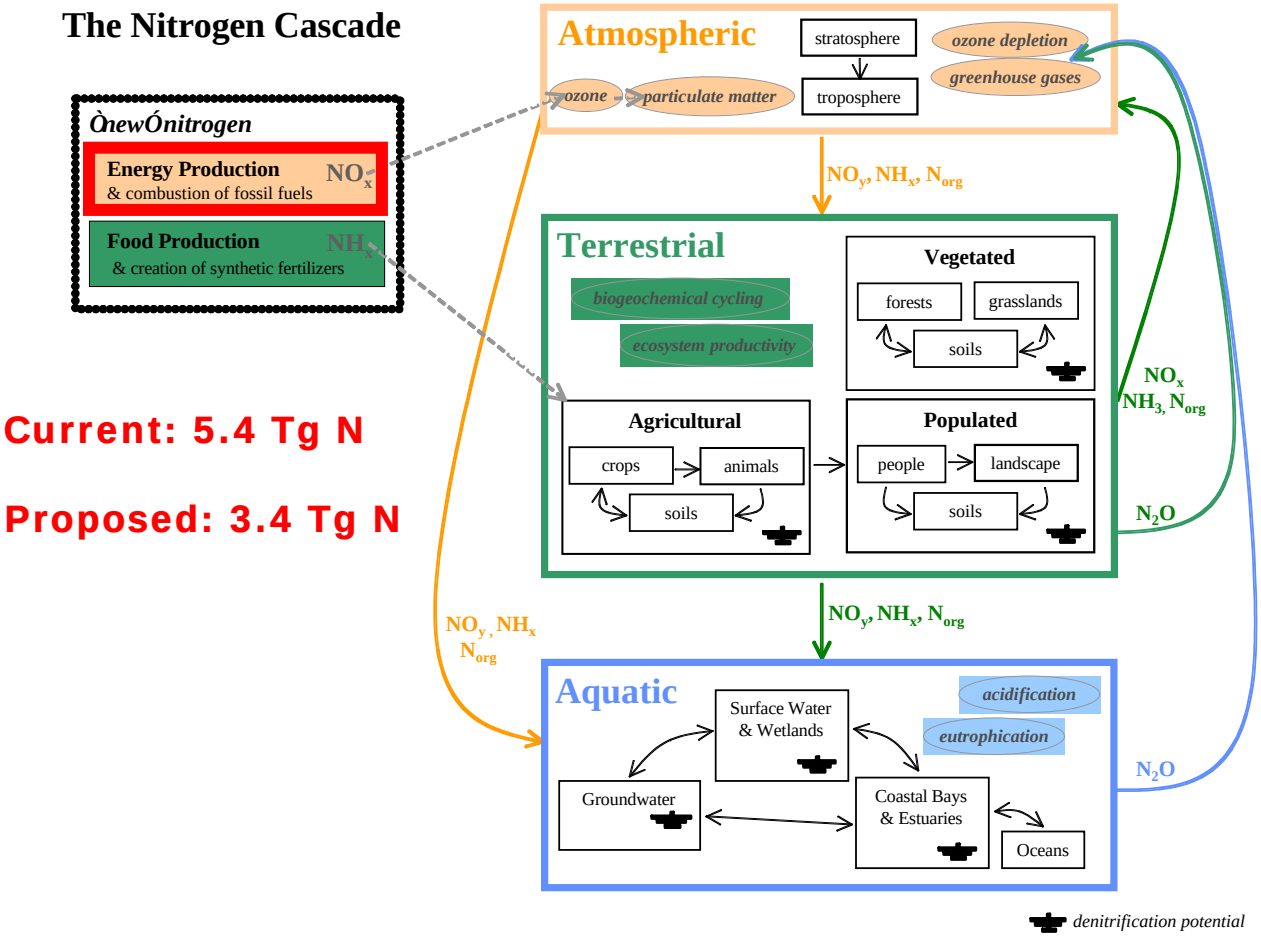
Control Points

- Control points are locations in the N cascade where:
  - N uptake processes can be improved
    - e.g., nitrogen use efficiency
  - N losses to environment are large enough to manage
    - e.g., sewage
- We use the N cascade figure to illustrate where INC is recommending action, and what the impact of that action would be on the Nr flow.

Integrated Nitrogen Committee
Selected Recommendations

- We recommend that control points be identified where the amount of reactive nitrogen
  - needed for food production can be decreased
  - Lost to the environment can be decreased
- The over arching objective is to maximize the benefits of nitrogen while minimizing the losses to the environment.
- INC proposes the following five actions at control points

Control Point: Combustion



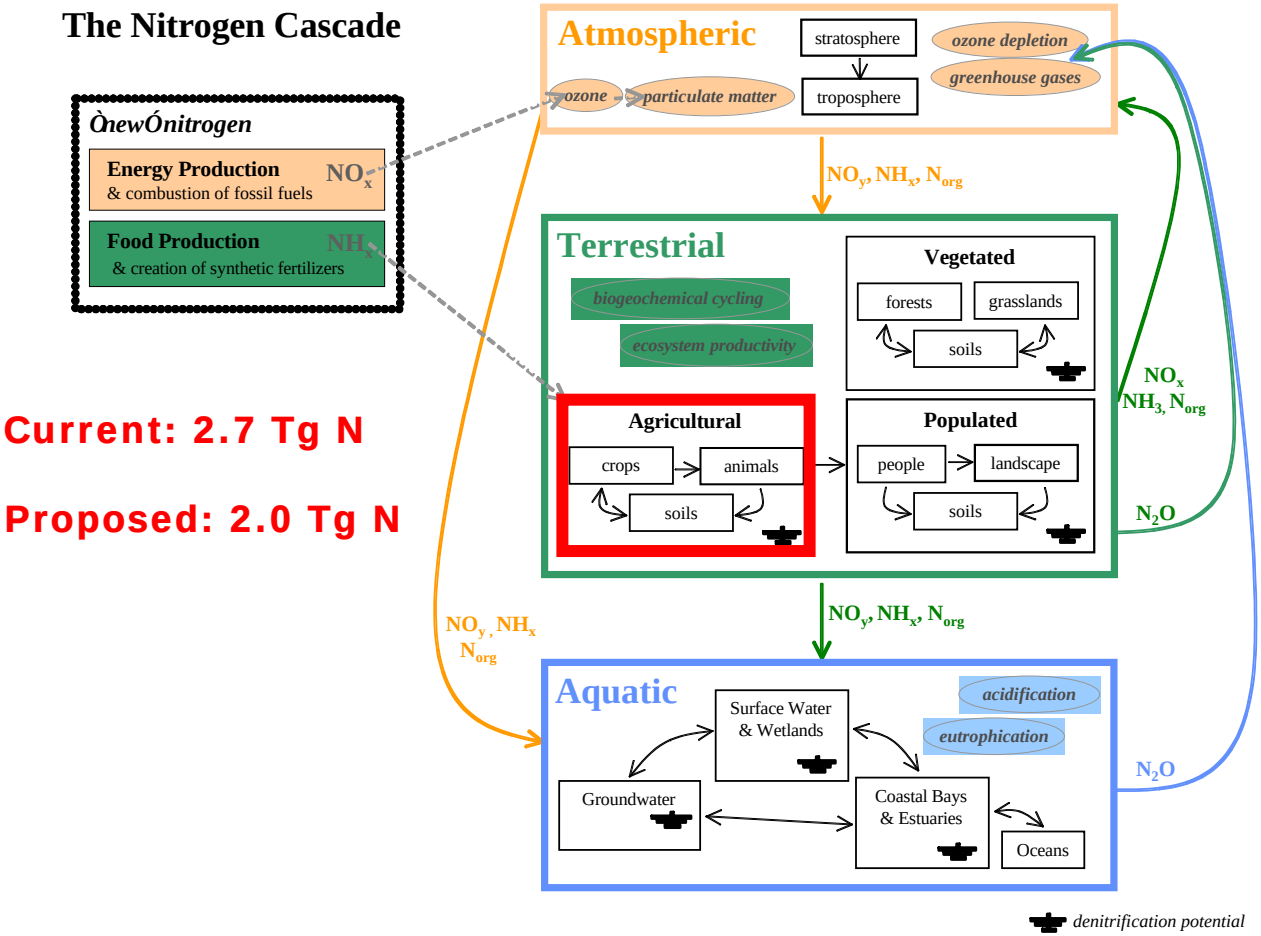
Current: 5.4 Tg N

Proposed: 3.4 Tg N

- We recommend that the EPA expand its NOx control efforts to include 90% decreases of emissions from heavy-duty on-road, all off-road mobile sources and currently uncontrolled electricity generation and industrial processes.

- Instituting this recommendation would decrease annual emissions by about **2 Tg N per year**.

Control Point: NH_3 from Manure and Fertilizer

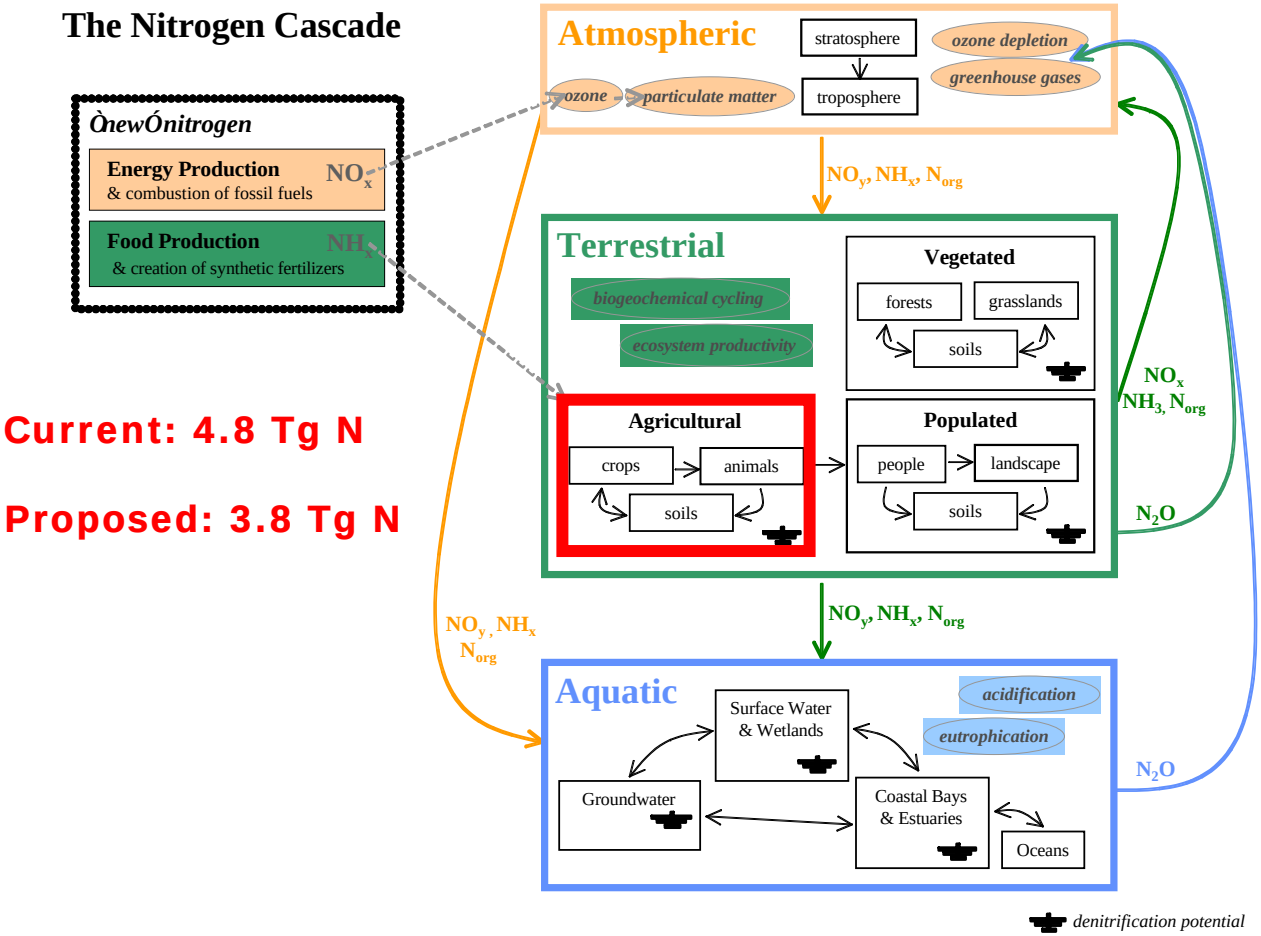


Current: 2.7 Tg N

Proposed: 2.0 Tg N

- We recommend decreasing livestock-derived ammonia emissions to approximately 80% of 1990 emissions, a decrease of **0.5 Tg N per year**.
- We recommend decreasing ammonia emissions derived from fertilizer applications by 20%, a decrease by ~**0.2 Tg N per year**.

Control Point: Nr losses from Croplands

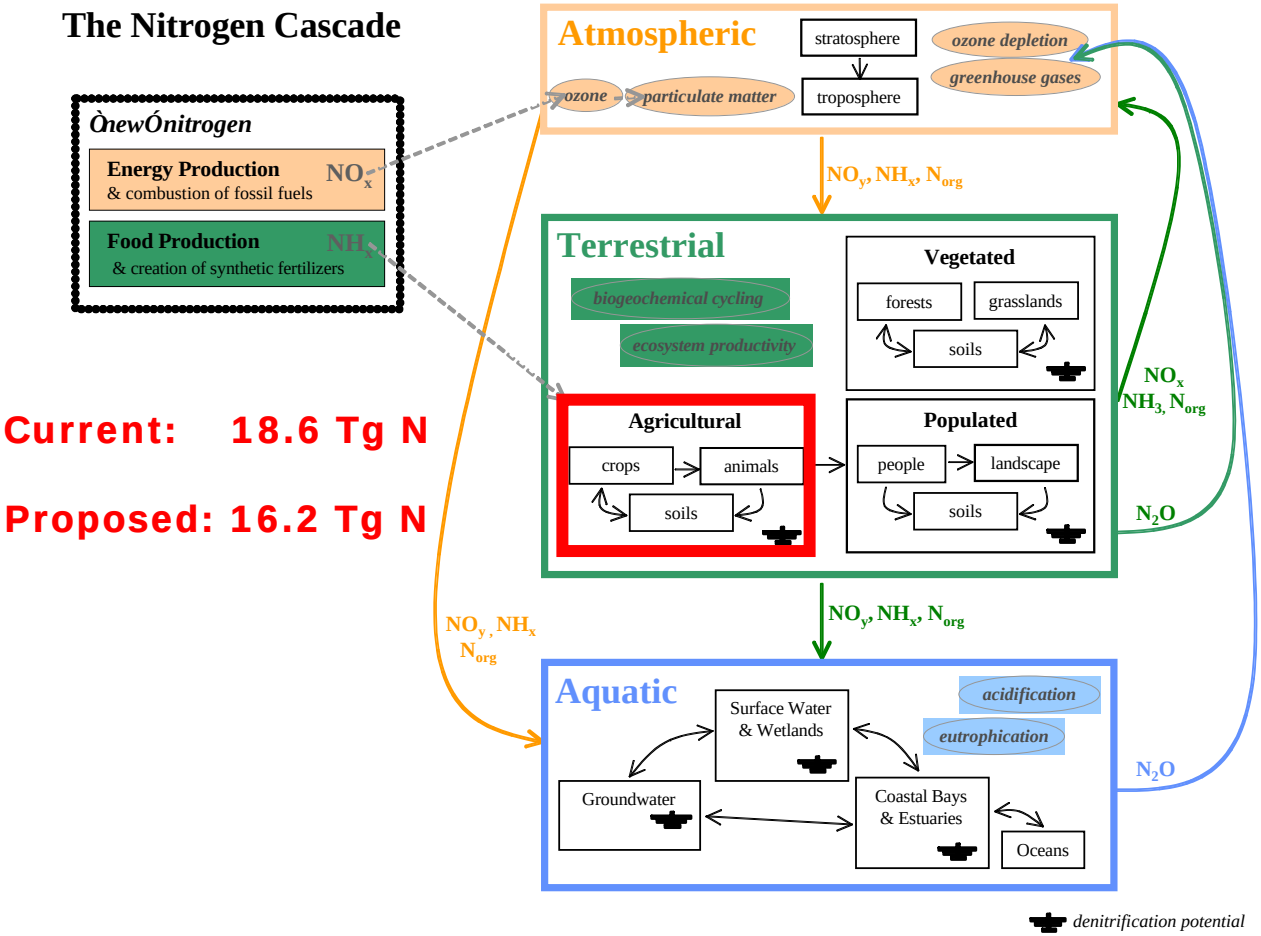


Current: 4.8 Tg N

Proposed: 3.8 Tg N

- We recommend decreasing flows of Nr into streams, rivers, and coastal systems by approximately 20% **(~1 Tg N per year)** through improved landscape management, including wetland management improved tile-drainage systems and riparian buffers on crop land, etc.

Control Point: Nitrogen Use Efficiency

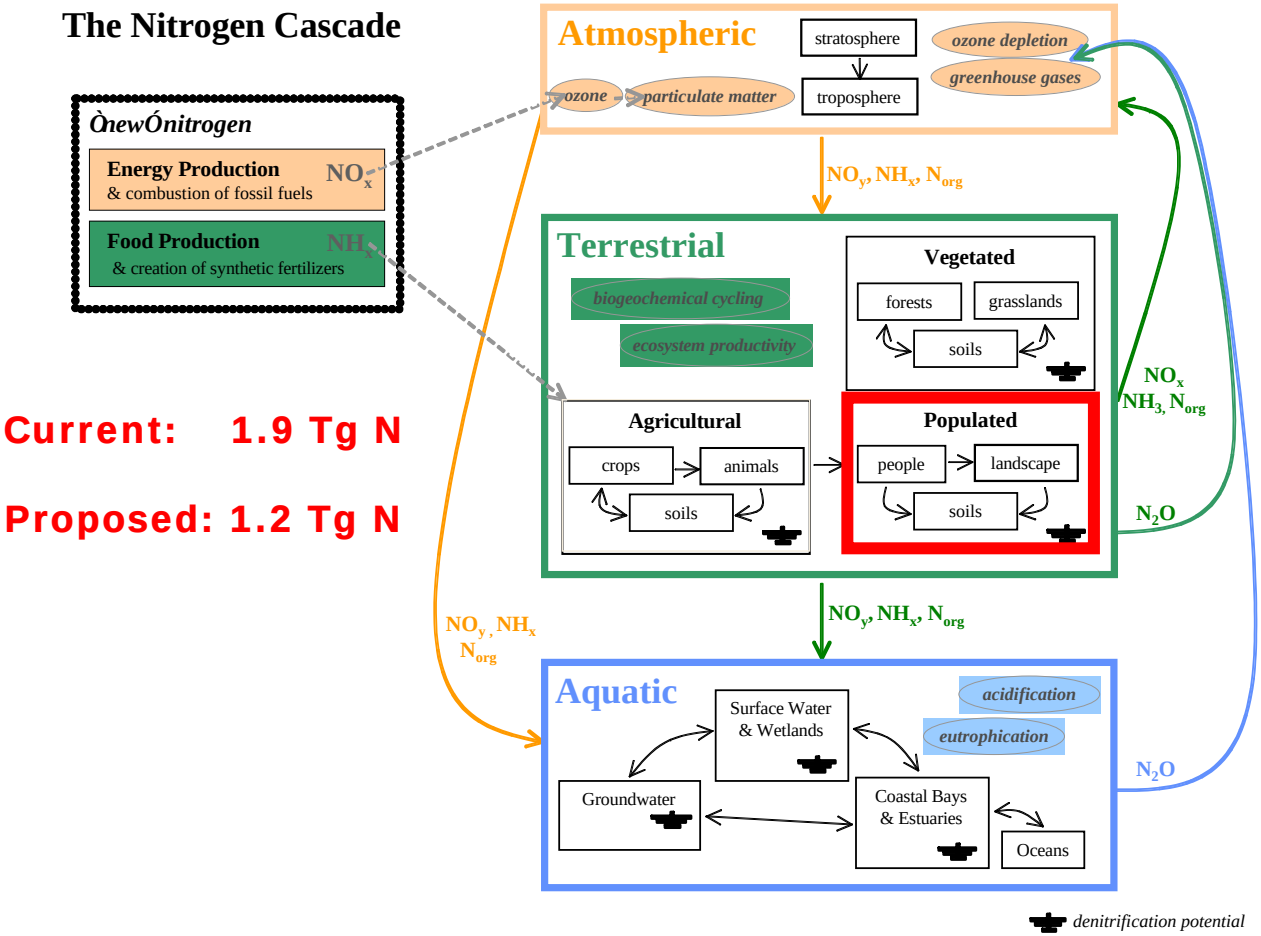


Current: 18.6 Tg N

Proposed: 16.2 Tg N

- We recommend an increase in crop N-uptake efficiencies of 25% over current levels through a combination of knowledge-based practices and advances in fertilizer technology (such as controlled release).
- This would decrease the amount of Nr applications to crop lands by **2.4 Tg N / yr**.

Control Point: Sewage Treatment



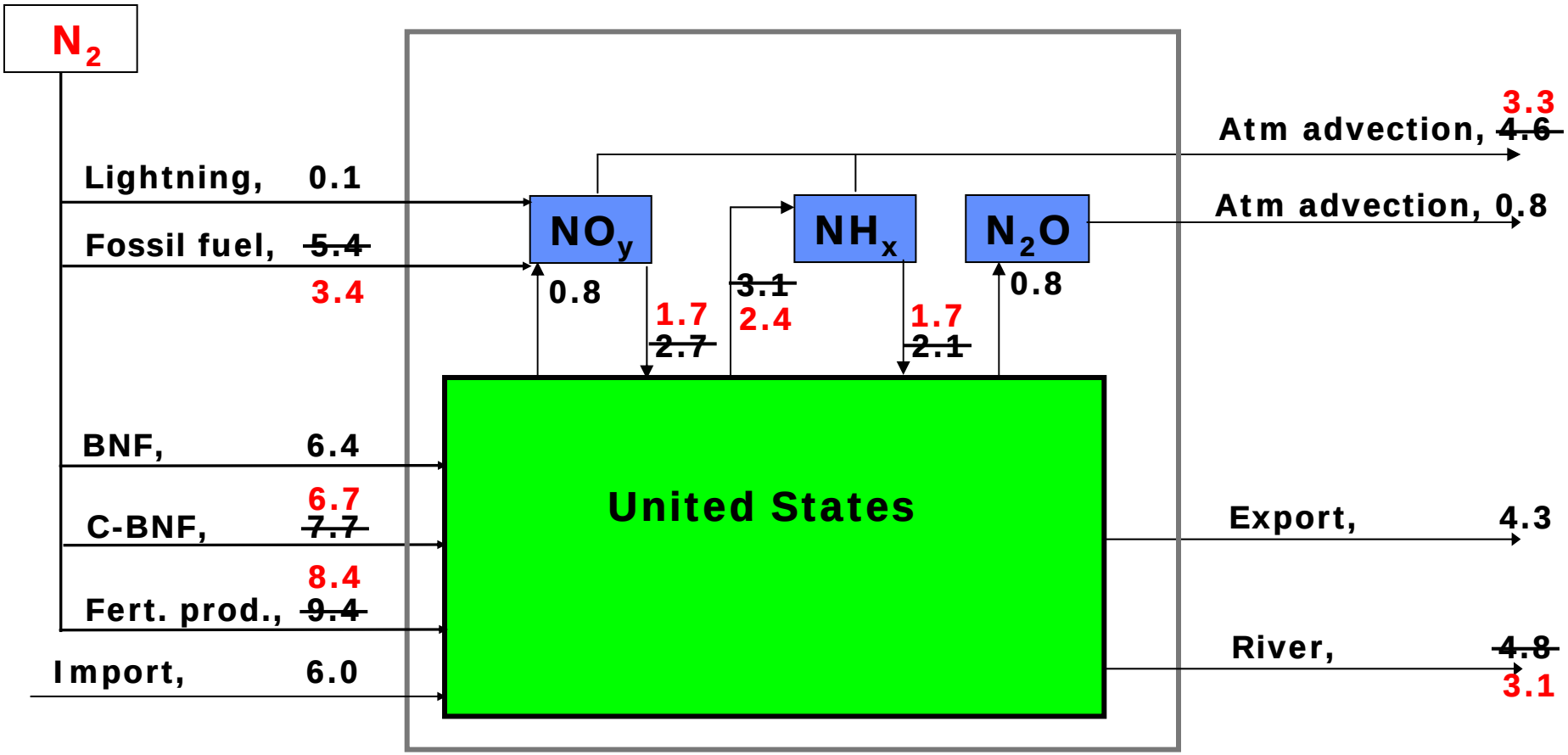
Current: 1.9 Tg N

Proposed: 1.2 Tg N

- We recommends that a high priority be assigned to nutrient management through a targeted construction grants program under the CWA
- Improved sewage treatment practices would decrease Nr losses by **0.5 to 0.8 Tg N/yr**.

US Nitrogen Budget: Revised

Tg N yr^{-1}



Nr Inputs: ~~35~~ 29 Tg N

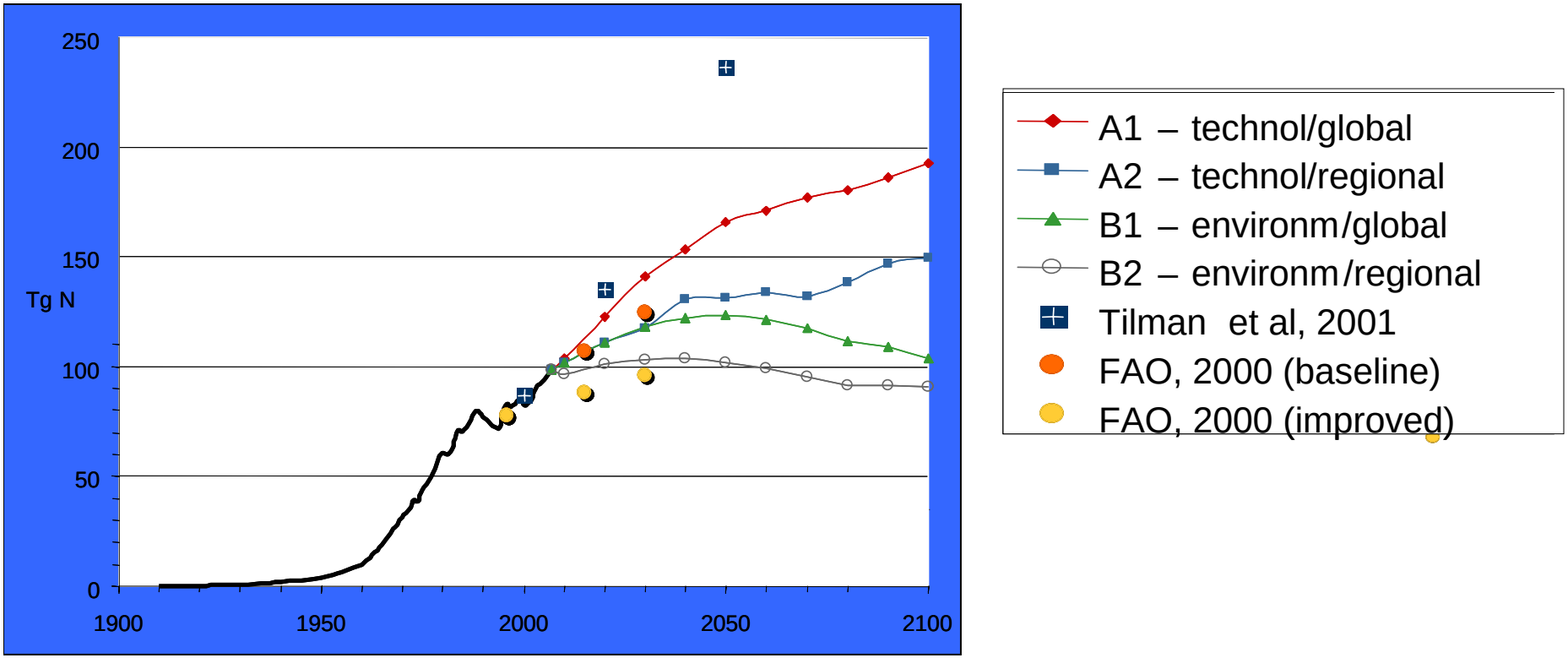
Nr Outputs: ~~14~~ 11 Tg N

The numbers on this slide have been modified, assuming the actions at control points were effective.

Integrated Nitrogen Committee
Summary of Findings

- Human action controls Nr introduction into the US.
- Added Nr has positive impacts for human health--food production.
- Added Nr increases the risk to both human and ecosystem health--N cascade.
- Challenge is how do we maximize the positive yet minimize the risk.
- And how do we do this in an integrated fashion?

Past and future global N fertilizer consumption 1900-2100



Erisman et al.
Nature Geoscience (2008)