

# **More than Just Carbon Dioxide: Nitrous Oxide is the Dominant Greenhouse Gas in Corn Based Biofuels & Bioproducts**

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# “Carbon Neutral” = No Net Greenhouse Gases??

- A typical statement on biobased products reads:  
“Biomass represents an abundant *carbon neutral* renewable resource for the production of bioenergy and bioproducts.”

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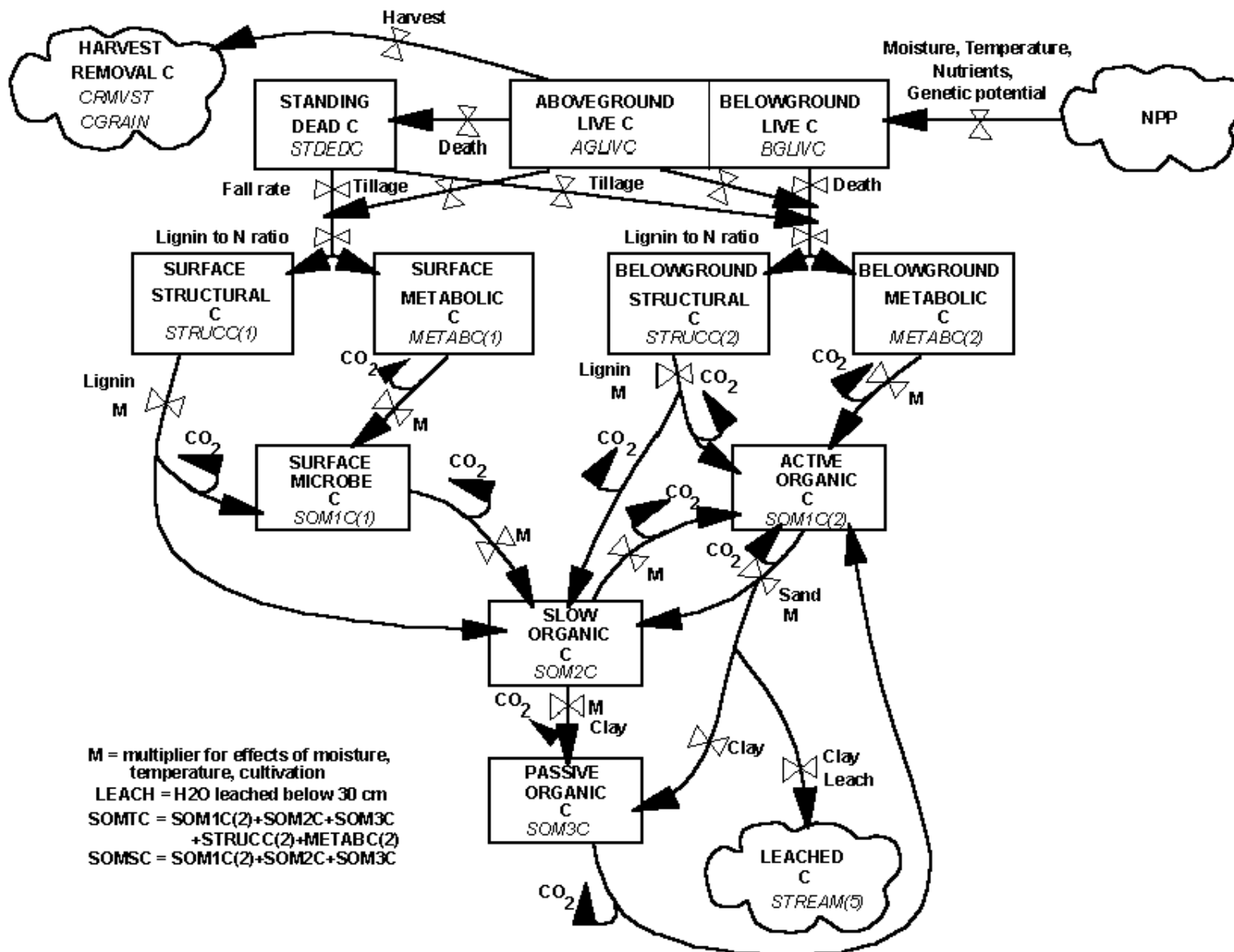
- True if one means that carbon in bioenergy or bioproduct came from atmospheric CO<sub>2</sub>
- **Not true at all** if one implies that all bioproducts are “greenhouse gas neutral”
- We use agricultural ecosystem models to understand relevant GHG dynamics & carbon sequestration

# Global Warming Potentials

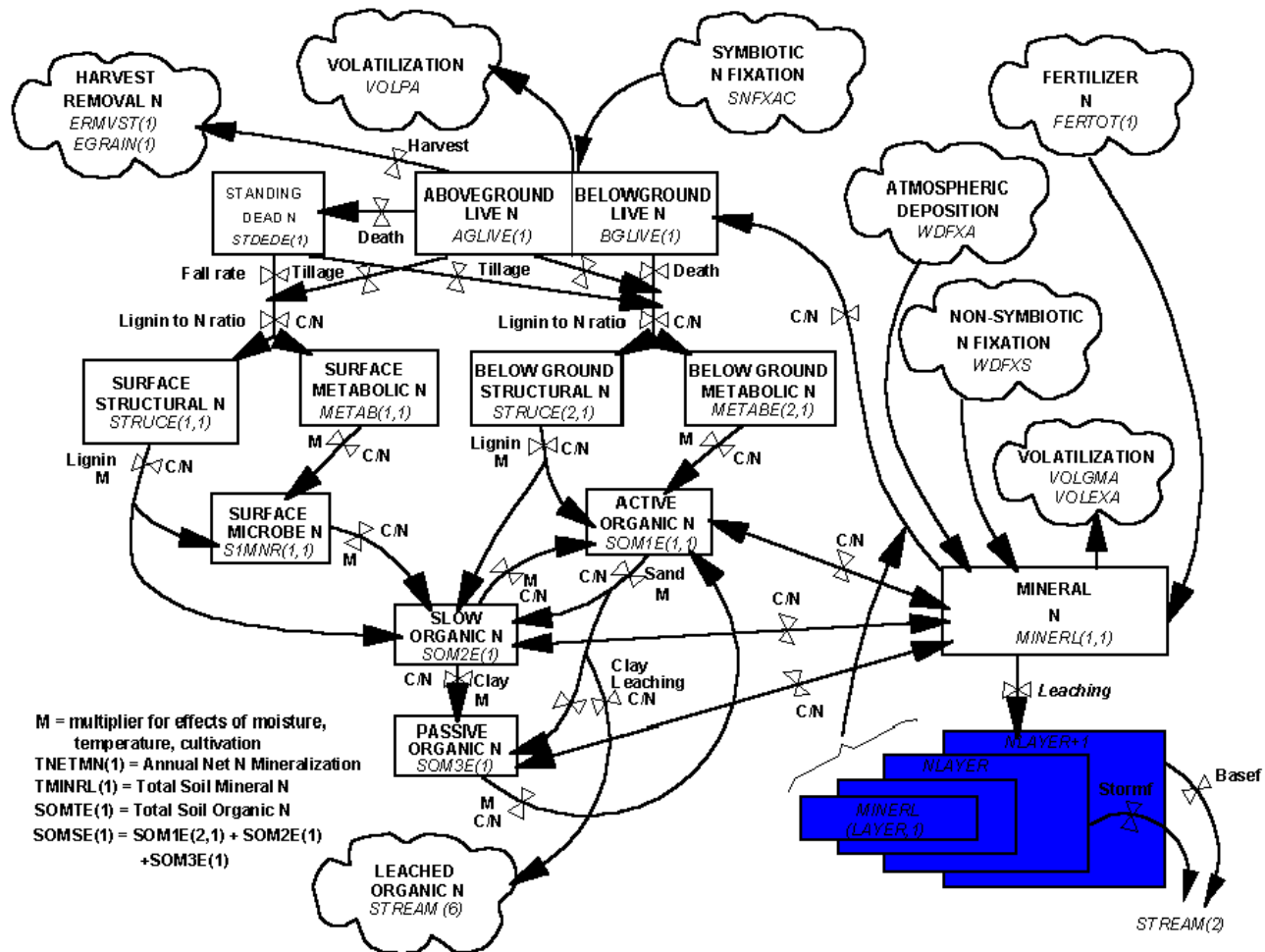
| Greenhouse gas emissions                                      | Unit                  | GWP  |
|---|-----------------------|------|
| Methyl Bromide (CH <sub>3</sub> Br)                           | g eq. CO <sub>2</sub> | 5    |
| Carbon Dioxide (CO <sub>2</sub> )                             | g eq. CO <sub>2</sub> | 1    |
| Carbon Tetrafluoride (CF <sub>4</sub> )                       | g eq. CO <sub>2</sub> | 5700 |
| Chloroform (CHCl <sub>3</sub> , HC-20)                        | g eq. CO <sub>2</sub> | 30   |
| Halon 1301 (CF <sub>3</sub> Br)                               | g eq. CO <sub>2</sub> | 6900 |
| Methane (CH <sub>4</sub> )                                    | g eq. CO <sub>2</sub> | 23   |
| Methyl Chloride (CH <sub>3</sub> Cl)                          | g eq. CO <sub>2</sub> | 16   |
| Methylene Chloride (CH <sub>2</sub> Cl <sub>2</sub> , HC-130) | g eq. CO <sub>2</sub> | 10   |
| Nitrous Oxide (N <sub>2</sub> O)                              | g eq. CO <sub>2</sub> | 296  |

Source: Intergovernmental Panel on Climate Change (IPCC) (2001),  
Climate Change 2001: Working Group I: The Scientific Basis

# Carbon Flow in the CENTURY Model

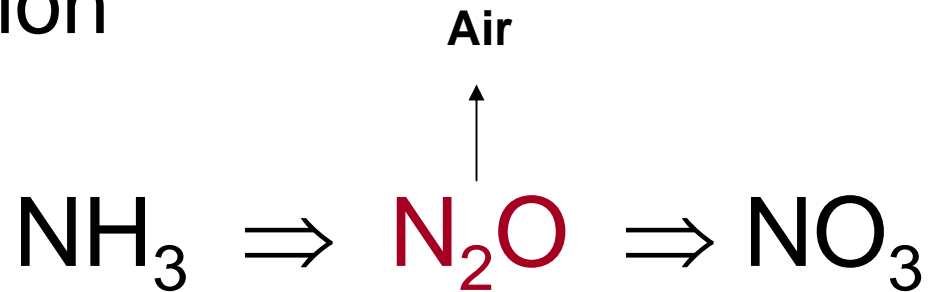


# Soil Nitrogen Dynamics in CENTURY

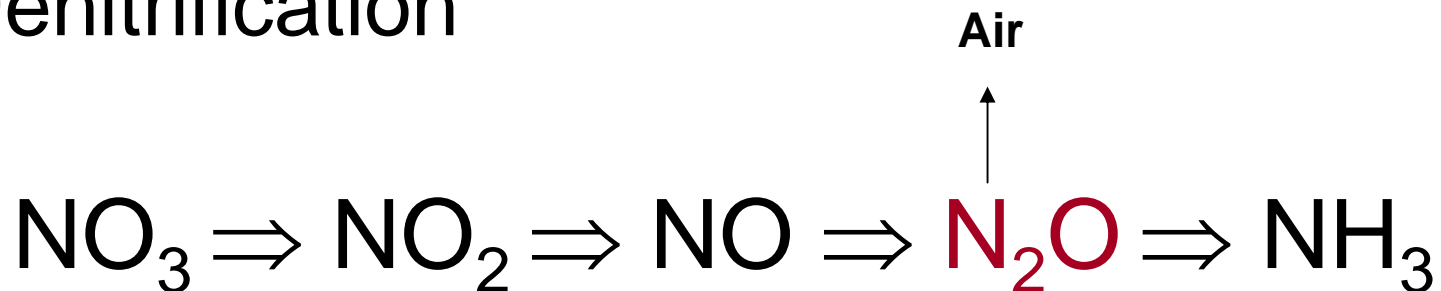


# Nitrification and Denitrification

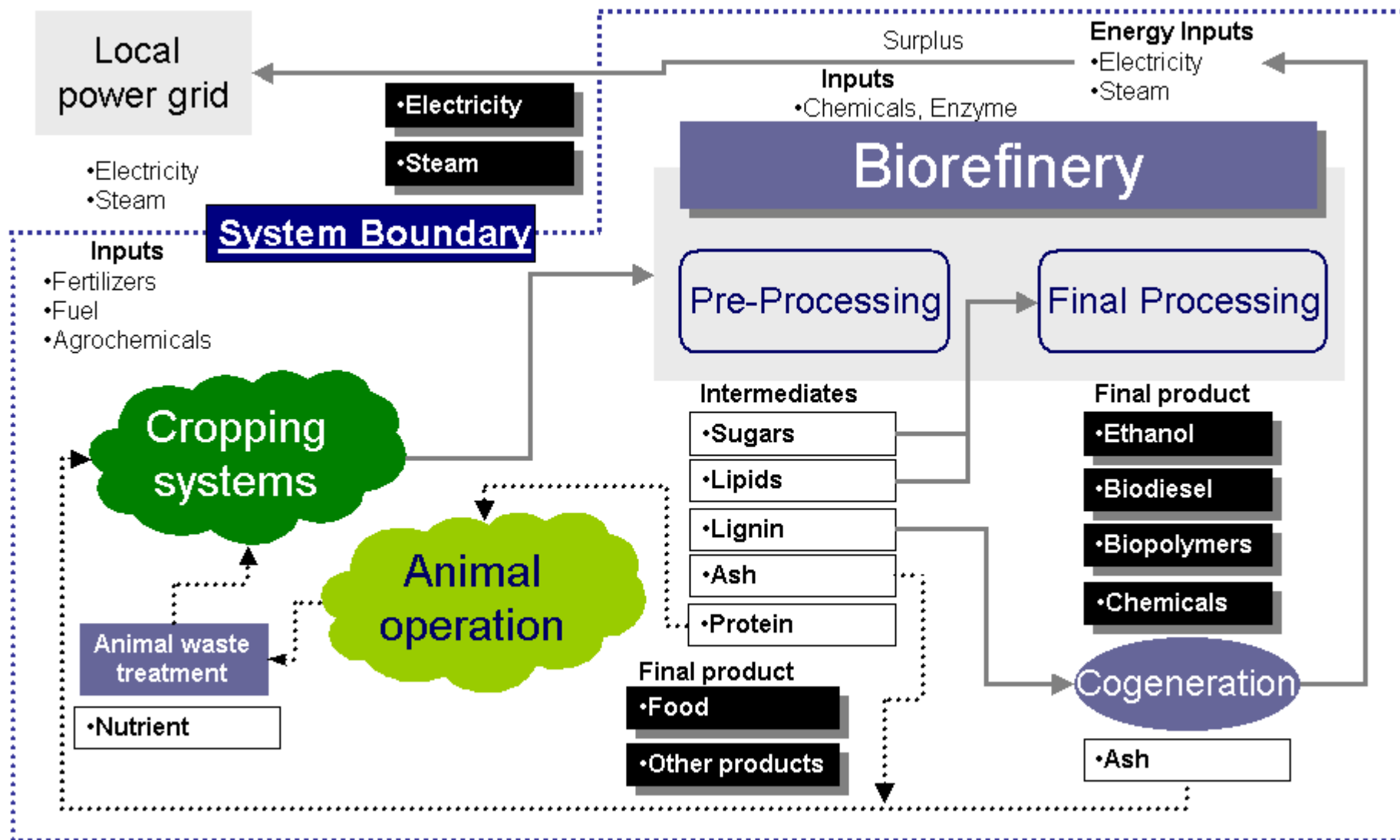
- Nitrification



- Denitrification



# ALL BIOMASS IS LOCAL



# Objective

- Estimate greenhouse gas (GHG) profiles associated with corn based bioproducts
  - Emphasize ethanol fuel system
  - Identify roles of  $N_2O$  and of carbon sequestered by soil in GHG profile
  - Evaluate effects of changing cropping systems on GHG profile of ethanol fuel system
- For agricultural portion of system, ethanol is equivalent to other bioproduct: eg., PLA, PDO....
- Biorefinery & use phases for other bioproducts would require analyses specific to those systems

# Key Findings

- Corn agricultural systems considered release **1.2 ~ 4.8** metric ton CO<sub>2</sub> eq. ha<sup>-1</sup>
- Nitrous oxide dominates these emissions but is highly variable by location
- Collecting corn stover:
  - Decreases carbon sequestered but
  - Reduces N<sub>2</sub>O emissions
  - Increases ethanol production & GHG credits
- Planting cover crops
  - Increases soil organic carbon
  - Reduces N<sub>2</sub>O emissions
  - Increases GHG credits

# Function, Functional Unit, Reference Flow and System Boundary

- Function: moving a compact passenger vehicle by E10 fuel
- Functional unit: quantity of ethanol used in E10 fuel
- Reference flow: one gallon of ethanol
- System boundary
  - Corn production, biorefineries (dry mill, lignocellulosic biorefinery), E10 fueled vehicle operation
  - Including alternative product systems
    - DDGS: corn grain & soybean meal
    - E10 fueled vehicle operation: gasoline fueled vehicle operation
    - Electricity exported: electricity generated in a coal-fired power plant
    - Steam exported: Steam generated from natural gas and petroleum

# System Boundary

## **Agricultural processes**

- Corn culture
- Transportation of biomass



## **Biorefinery systems**

- Dry mill/lignocellulosic biorefinery (if applicable)
- Alternative product systems for DDGS, electricity, steam



## **Vehicle operation**

- Distribution of ethanol
- E10 fueled vehicle operation
- Gasoline fueled vehicle operation as an alternative product system

# Cropping Systems

- Conventional corn cultivation (referred to as **CORN**)
  - Collect no corn stover
- Planting winter cover crops in the CORN system (referred to as **COVER**)
  - Kill winter cover crop with herbicides before corn growing season; do not harvest cover crop
- Conventional corn cultivation with harvesting corn stover (referred to as **STOVER**)
  - Utilize corn stover to produce ethanol in a cellulosic biorefinery

# Farming Sites Chosen: All Biomass is Local

- 38 counties in eight states (Indiana, Illinois, Iowa, Michigan, Minnesota, Missouri, Nebraska and South Dakota)
  - Determine soil organic carbon and soil nitrogen dynamics in the CORN system
  - Each county is adjacent to an ethanol plant (either a dry or wet mill)
- Eight counties of the 38 are selected to:
  - Determine soil organic carbon and soil nitrogen dynamics in other cropping systems
  - Estimate environmental performance of the ethanol application system.

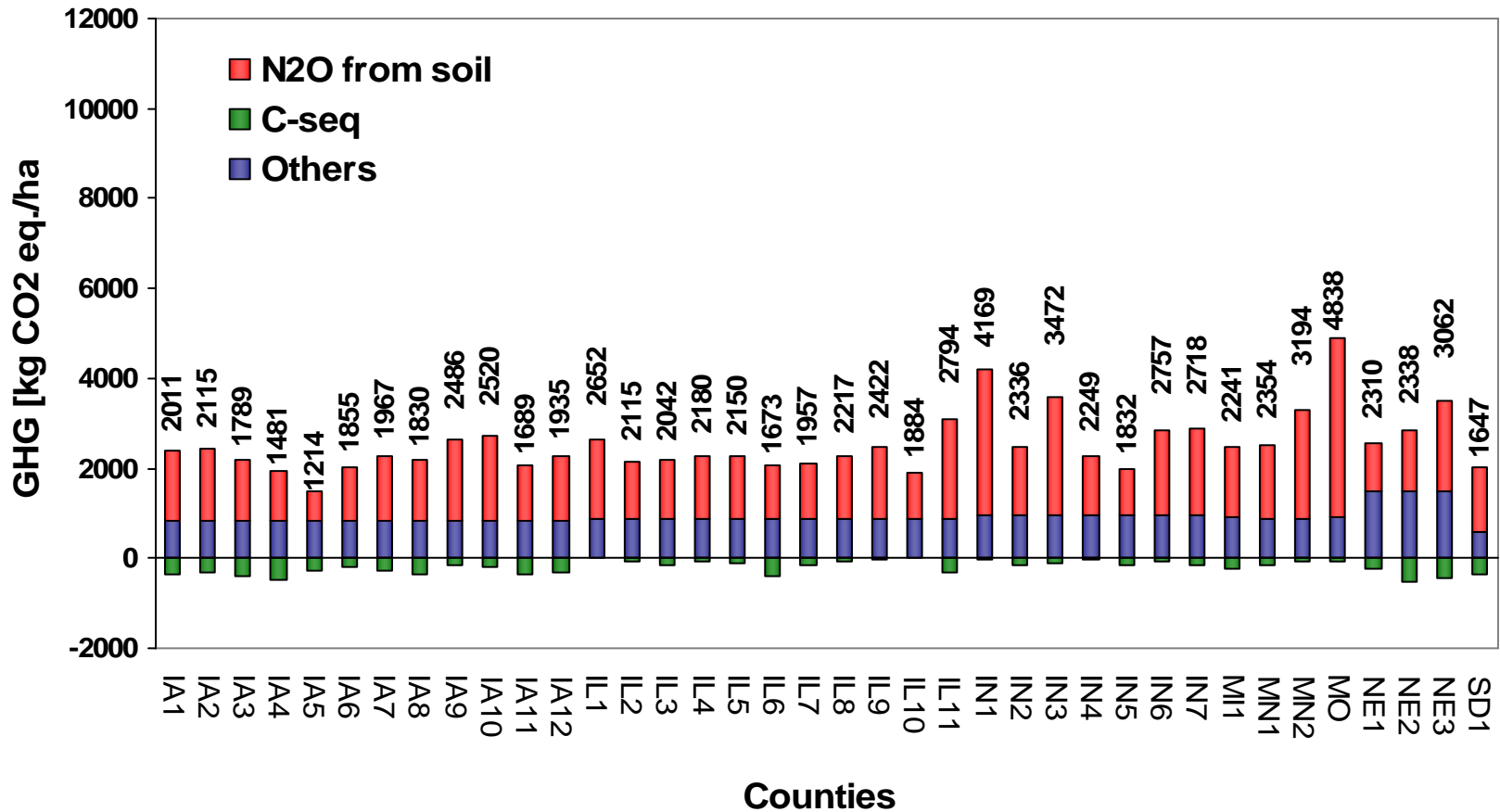
# Biorefinery Parameters

- Dry mill (NREL study, 2000)
  - Yield: 2.7 gallon per bushel
  - DDGS: 11.7 kg (dry) per bushel
  - Energy consumption
    - Electricity: 0.80 kWh per gallon
    - Natural gas: 32,329 Btu per gallon
- Lignocellulosic biorefinery
  - Yield: 103 gallon per dry ton
  - AFEX (ammonia fiber explosion) pretreatment
  - Surplus electricity and steam are exported
    - Electricity: 0.81 kWh per gallon
    - Steam: 10,753 Btu per gallon

# Soil Organic Carbon & Nitrogen Dynamics

- Simulated by the DAYCENT model
  - Predicting
    - Soil organic carbon level
    - $N_2O$  and  $NO_x$  emissions from soil,  $NO_3^-$  leaching
  - Information required
    - County-based soil textures
      - clay, slit, sand
    - County-based data
      - Daily maximum and minimum temperature
      - Daily precipitation
    - Crop management practices
      - Tillage, application rate of nitrogen fertilizer, irrigation, etc

# GHG Profile in the CORN System: Selected Counties

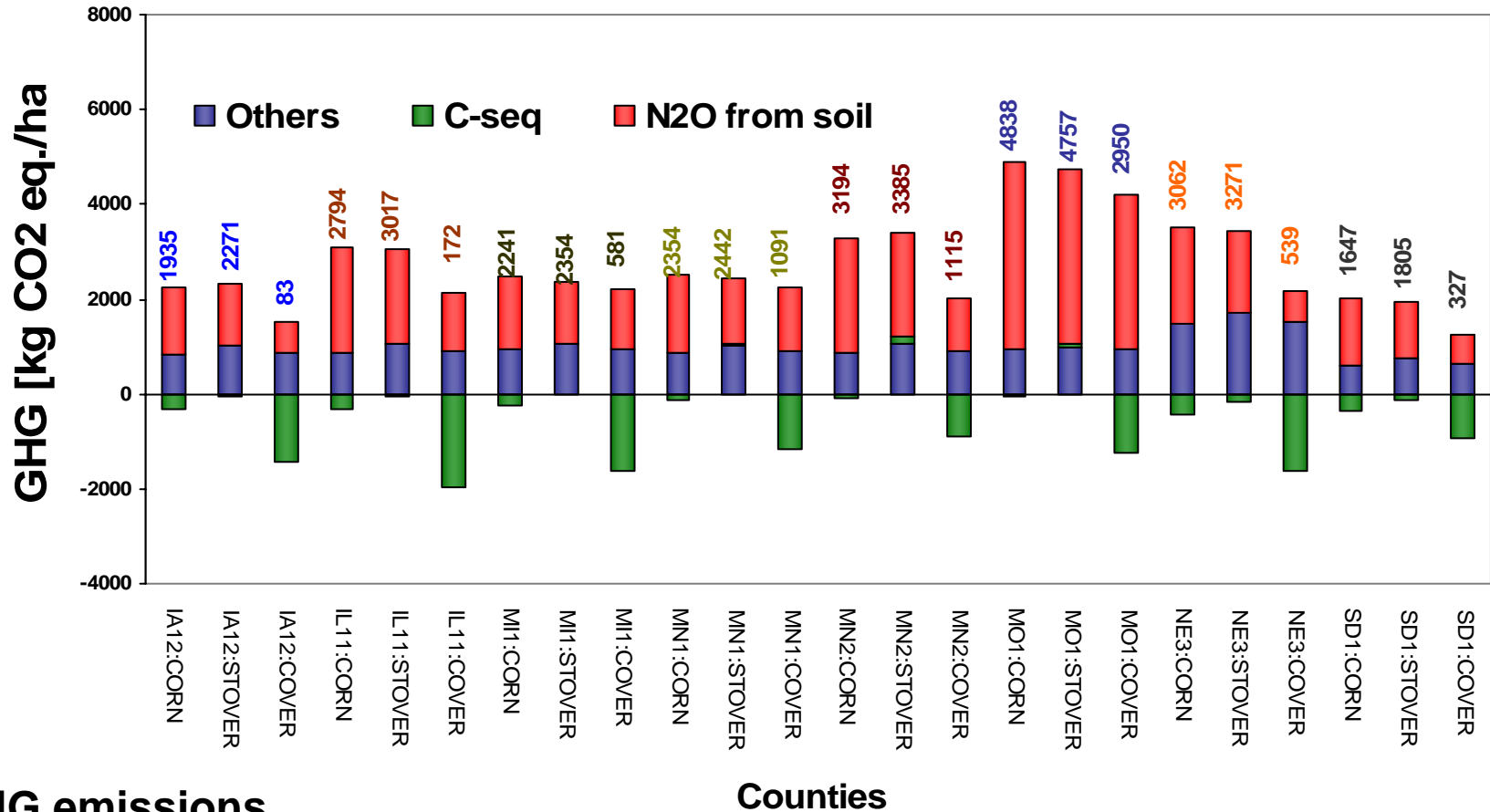


**GHG of corn production: 1.2 ~ 4.8 ton CO<sub>2</sub> per ha**

**C-seq : carbon sequestration by soil**

**Others: GHG emissions associated with agronomic inputs and fuel consumption**

# Effects of Cropping System Management



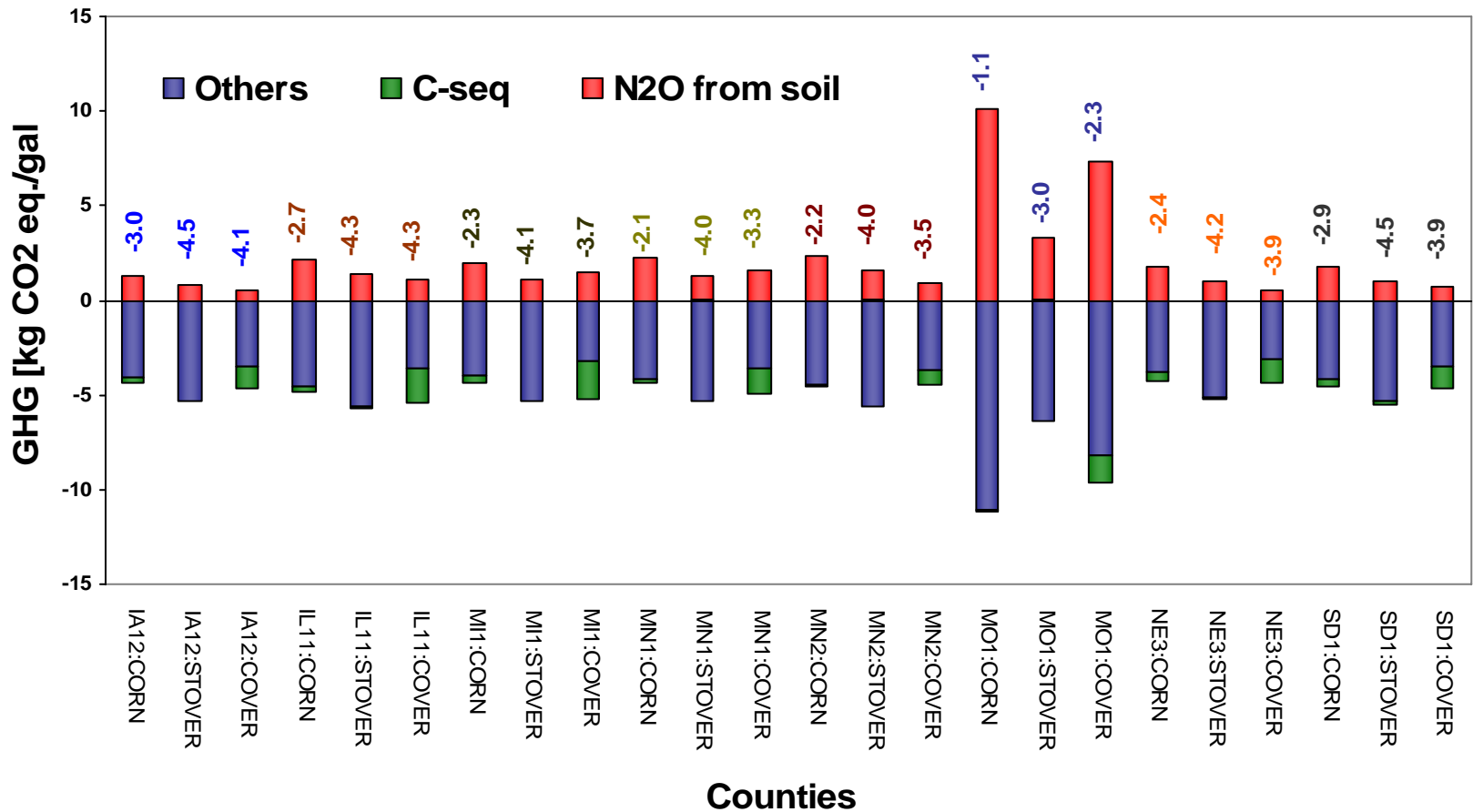
## GHG emissions

CORN: 1.6 ~ 4.8 ton CO<sub>2</sub> per ha

STOVER: 1.8 ~ 4.7 ton CO<sub>2</sub> per ha

COVER: .08 ~ 3.0 ton CO<sub>2</sub> per ha

# GHG Emissions in Ethanol Fuel System



Others: GHG emissions associated with agronomic inputs and fuel consumption in agriculture process, biorefineries, vehicle operation, and alternative product systems

# Conclusions

- Corn agricultural systems considered release **1.2 ~ 4.8** metric ton CO<sub>2</sub> eq. ha<sup>-1</sup>
  - Most GHG emissions come from N<sub>2</sub>O from soil (**0.6 ~ 4.0** metric ton CO<sub>2</sub> eq. ha<sup>-1</sup>)
  - Carbon sequestered by soil ranges from **2.2x10<sup>-3</sup>** to **0.5** metric ton CO<sub>2</sub> eq. ha<sup>-1</sup>
  - GHG emissions of other processes (agronomic inputs and fuel consumption) account for **0.6 ~ 1.5** metric ton CO<sub>2</sub> eq. ha<sup>-1</sup>

- **Collecting corn stover (STOVER system)**
  - Decrease carbon sequestered by soil by **61 % ~ 280%**, compared to CORN
  - Reduce N<sub>2</sub>O emissions from soil by **6 ~ 17 %**
    - eventually increase GHG emissions associated with the corn field in most counties
  - However, more ethanol is derived from one hectare of corn field (grain and stover)
- **Planting winter cover crops (COVER system)**
  - Increase soil organic carbon level by **150% ~ 1800%**
  - Reduce N<sub>2</sub>O emissions from soil by **17~ 69 %**
    - lower GHG emissions associated with the corn field

- **Collecting corn stover (STOVER system)**
  - Increase GHG credits associated with the ethanol application system by **49% ~ 190%**
    - mainly due to more feedstock available per hectare of corn
- **Planting winter cover crops (COVER system)**
  - Increase GHG credits associated with the ethanol application system by **35% ~ 120%**
    - due to higher carbon sequestered by soil and lower soil N<sub>2</sub>O
- N<sub>2</sub>O from soil is the dominant factor influencing GHG associated with the ethanol fuel system.
  - Need research to reduce soil N<sub>2</sub>O emissions
- Planting & harvesting cover crops would (probably):
  - Increase GHG credits
  - Increase soil organic carbon
  - Increase per acre productivity of feedstock
- ***Don't assume that corn based products are greenhouse gas neutral without more effort—they probably are not***

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