A Global View of N_2O Impact on Net GHG Savings from Crop Biofuels: LCA Comparisons

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Purpose of Presentation: Discuss full N_2O accounting in biofuel production

Relate the likely impact of agricultural fertilizer N use on the global N_2O budget as discussed by Crutzen et al. (2008) and examine the impact of full N_2O accounting in biofuel net green house gas emissions using the life cycle analyses from Farrell et al. (2006)(EBAMM), Liska et al. (2008) (BESS), for corn-based ethanol and Smith et al. (2006)(BGGC) for wheat-based ethanol.

Reference

P. J. Crutzen, A. R. Mosier, K. A. Smith and W. Winiwarter, N_2O release from agro-biofuel Production negates global warming reduction by replacing fossil fuels. Atmos. Chem. Phys. 8, 389-395, 2008.

1. Background for the Crutzen et al. N_2O analysis

2. Examine the impact of full N_2O accounting in biofuel net green house gas emissions (Crutzen et al. 2008) using life cycle analyses (Farrell et al. 2006); Liska et al. (2008), and Smith et al. (2006)(BGGC).

1. Background for the Crutzen et al. N_2O analysis:

Indicates that in many cases the specific use of agricultural crops for energy production and climate protection can have the opposite effect on climate due to accompanying N_2O emissions.

NITROUS OXIDE, N_2O

- Chemically inert in troposphere (atmospheric lifetime ~ 120 y)
- Powerful greenhouse gas (GWP ~300 x CO_2)

- Globally, about 70% of all emissions arise from microbial processes in soils: aerobic nitrification and anaerobic denitrification
- Main sink is in the stratosphere:
  - ~ 90% photolysed by solar UV radiation:

    $$N_2O \rightarrow N_2 + O$$

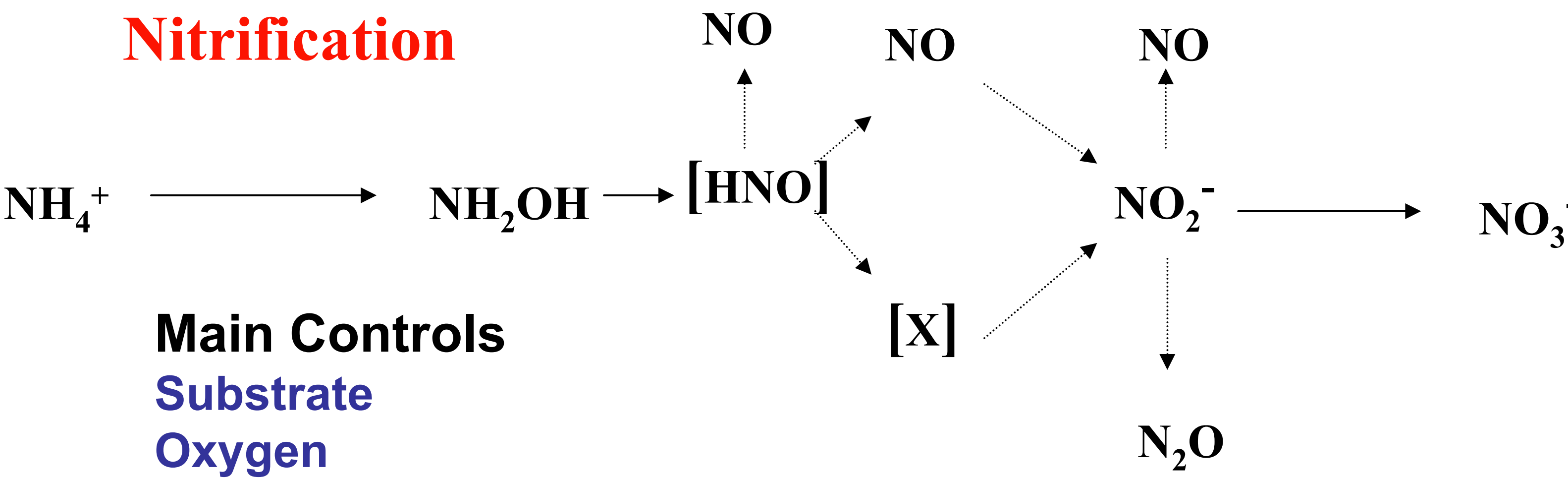
  - Part of the remaining N_2O reacts with energized O atoms to form NO, which together with NO_2 destroys stratospheric ozone:

    $$N_2O + O \rightarrow 2NO$$

    $$NO + O_3 \rightarrow NO_2 + O_2$$

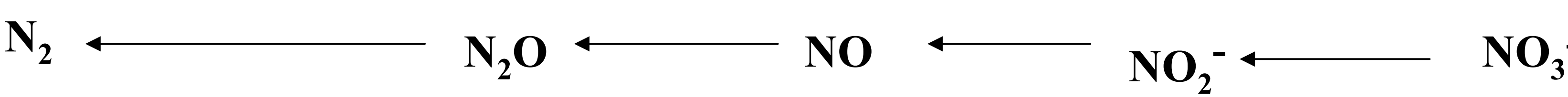
Mechanisms of N_2O Production in the Soil

Nitrification



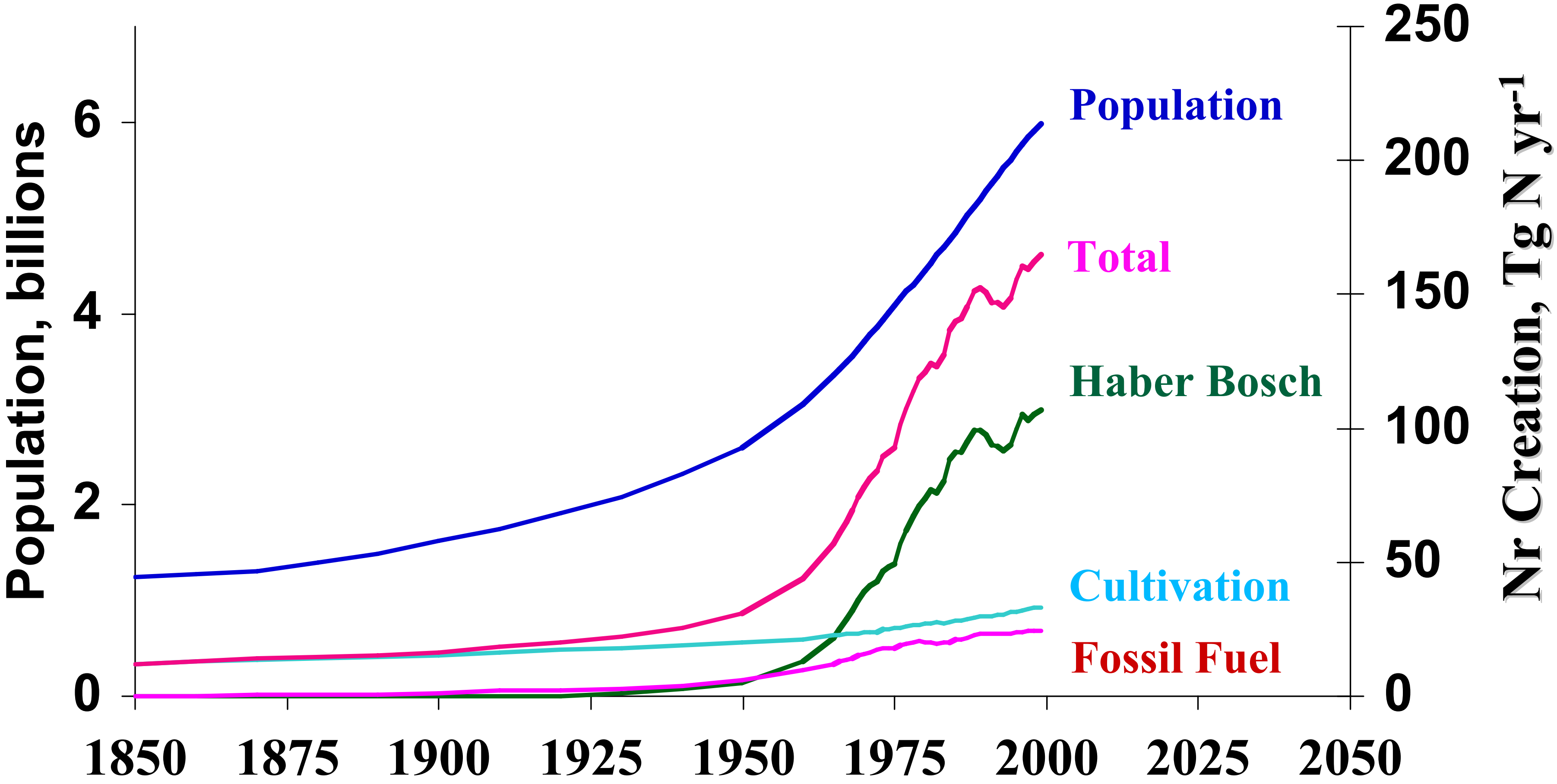
Main Controls
Substrate
Oxygen
Water
Temperature

Denitrification



Main Controls
Substrate, available carbon, O_2 (water & O_2 demand), T

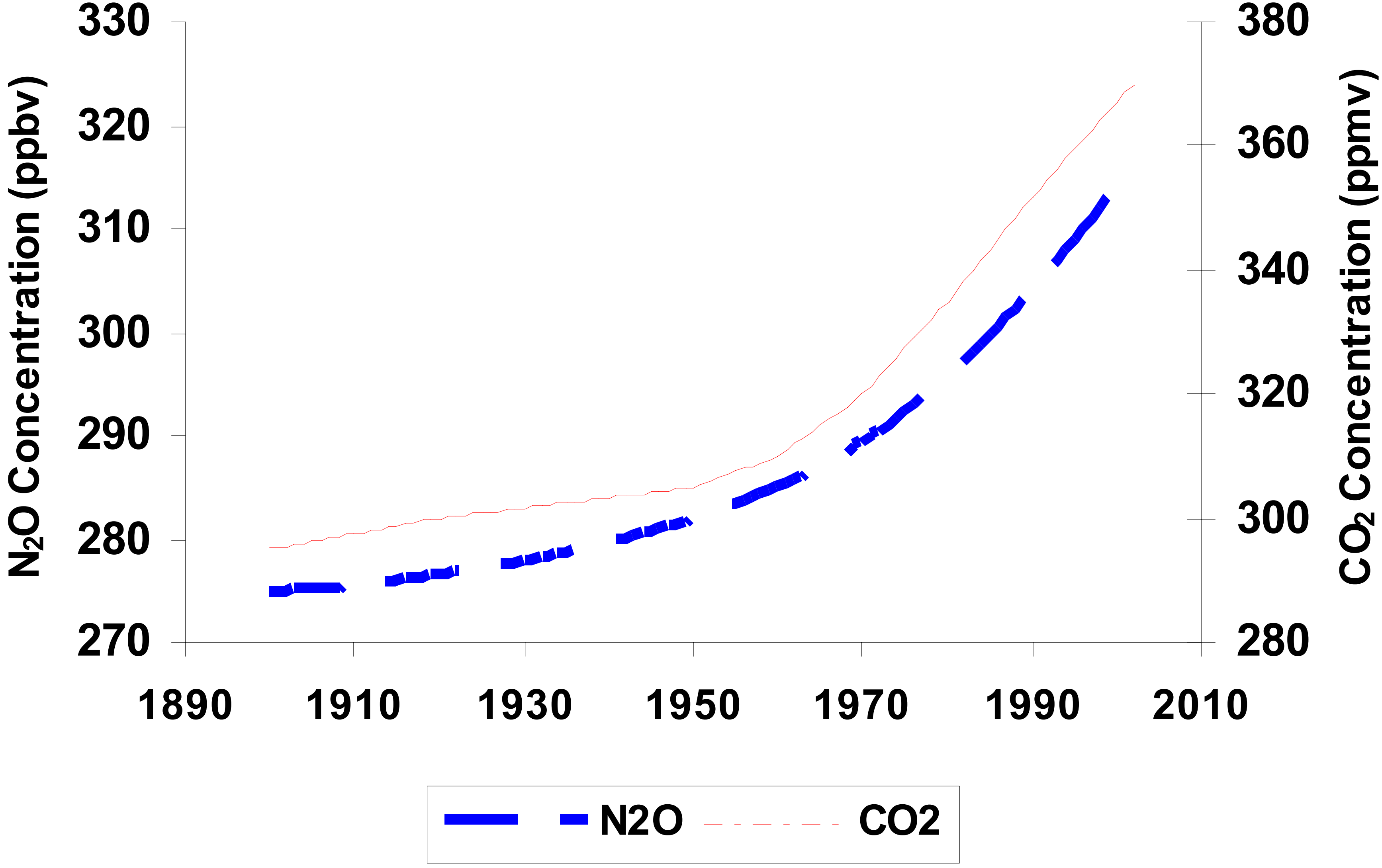
Timeline of Global Reactive N Creation by Human Activity 1850 to 2000



Galloway et al., 2003

Atmospheric N_2O & CO_2 Concentrations From 1900

Recent Data from NOAA CMDL



N_2O and New Reactive N

Prather et al., IPCC 2001

- Pre-industrial (anthropocene) μ_{N_2O} = 270 nmol/mol

  Sink/source of N_2O: 10.3 Tg N_2O-N/year, 2-6 TgN_2O-N /year from oceans
  4.3- 8.3 Tg N_2O-N/year from land.
  N input: 141 Tg N/year (Galloway et al,2004)
  Yield of N_2O-N/ fixed nitrogen = 3.0 - 5.9%

- A.D. 2000: μ_{N_2O} = 315 nmol/mol

  Photochemical loss of N_2O: 12.0 Tg N_2O-N /year
  Atmospheric growth rate: 3.9 Tg N_2O-N/year

→ N_2O source ~ 15.9 Tg N_2O-N /year

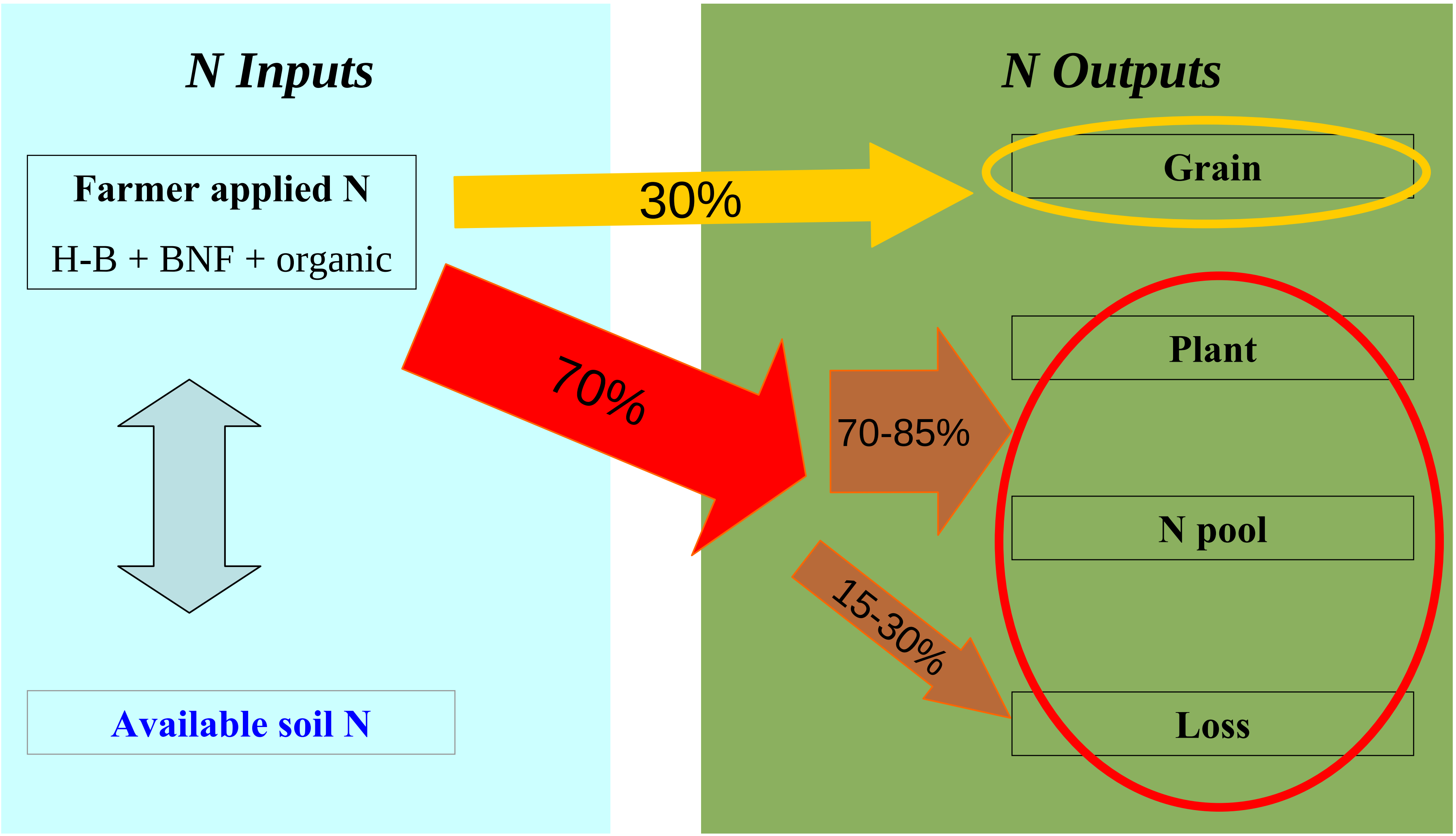
pre-industrial natural source ~ 10.3 Tg N_2O-N/year

→ Anthropogenic N_2O source ~ 5.6 Tg N_2O-N/year
Industrial N_2O source ~ 0.7 Tg N_2O- N/year

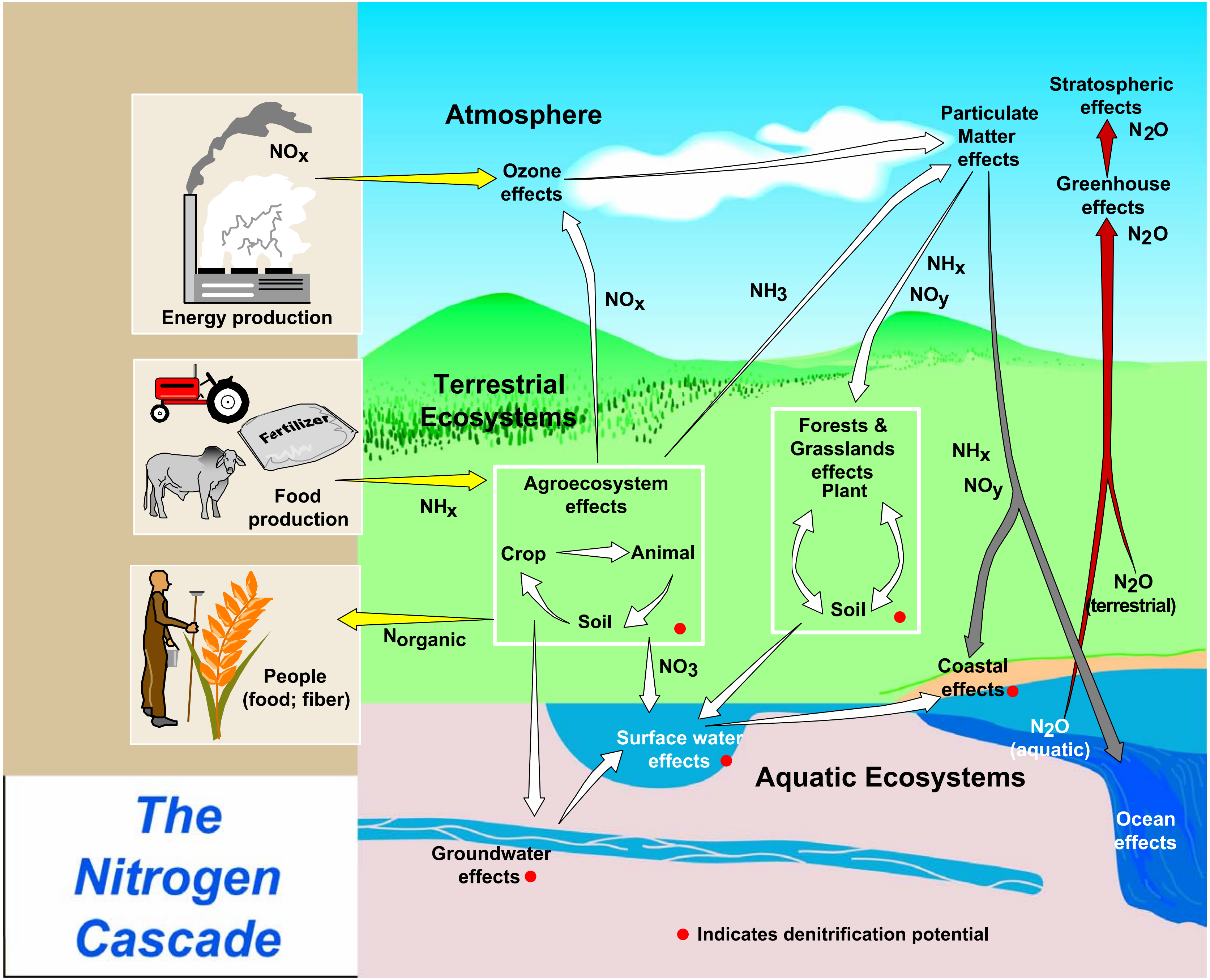
→ Agricultural N_2O source ~ 4.9 Tg N_2O-N /year
New anthropogenic N input ~ 127 Tg N/year (Galloway et al, 2004)
Ratio = 3.9% = y (yield of N_2O-N per unit of fixed N input)

Global average range of yields of N_2O from fixed nitrogen application 3 – 5%
Assumption: This yield will also apply in future for energy plant production.

Crop N cycling



Burke et al. 2005. Consequences of Industrialized Animal Production



Galloway et al., 2003

N_2O release versus CO_2 saved in biofuels by Crutzen et al.

- Only the conversion of biomass to biofuel, and not a full lifecycle, is considered here
  - leaving out, for instance, the input of fossil fuels for biomass production, on the one hand, and energy-saving through the use of co-products, on the other hand.

- It is assumed that the nitrogen which is co-harvested with the biofuels must be replenished over time in the fields with newly fixed nitrogen.

- The carbon processed in the harvested biomass to yield the biofuel gives the fossil fuel C (and thus CO_2) avoided by using the biofuel.

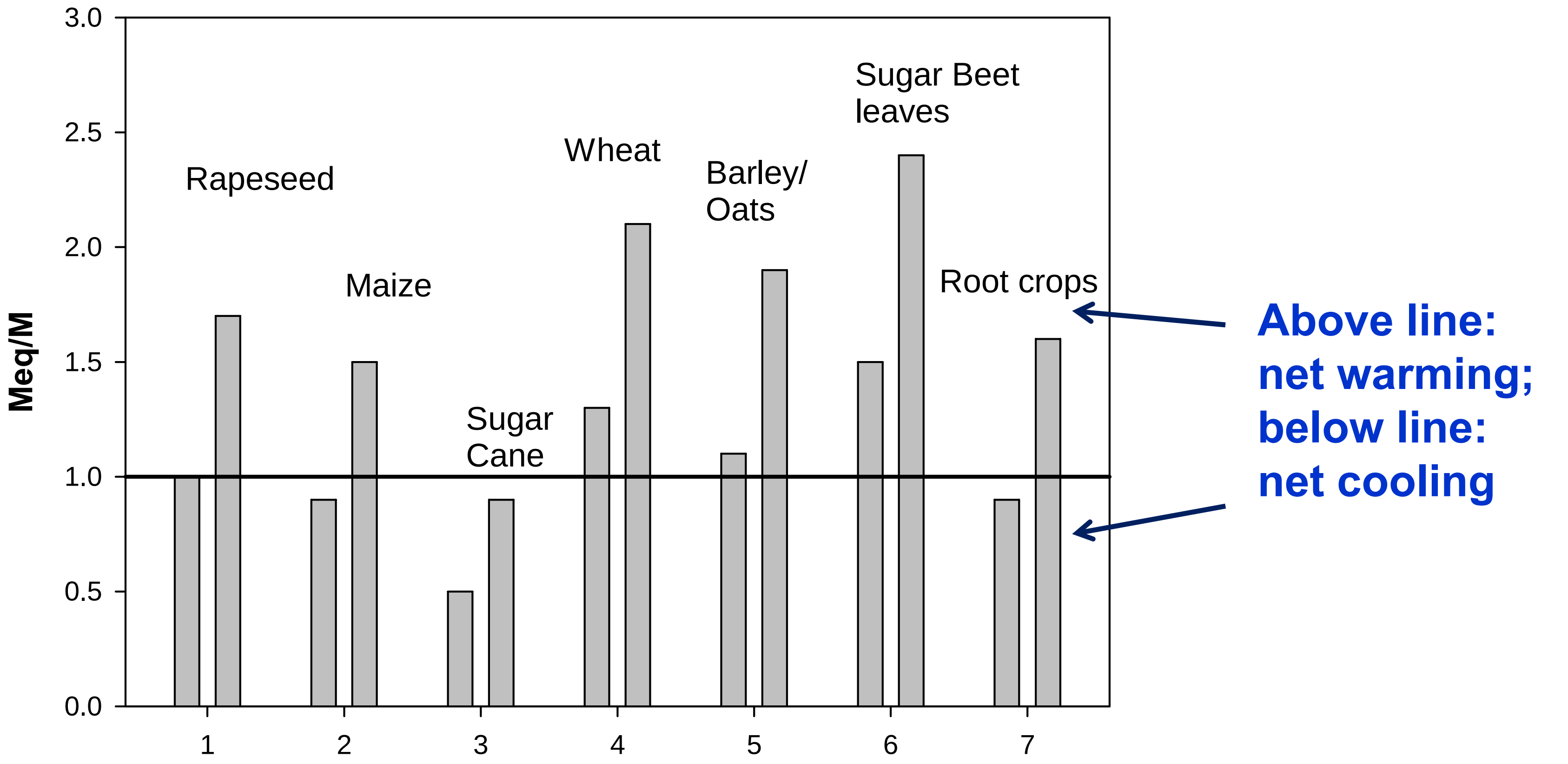
With these assumptions, we compared the climatic gain from fossil fuel-derived CO_2 "savings", or net avoided fossil CO_2 emissions (M), with the counteracting effect of enhanced N_2O release resulting from fixed N input (Meq).

Conclusion from Crutzen et al. 2008:

Net Greenhouse Gas emissions (expressed as CO_2e) from many crop-based biofuels are increased rather than decreased when globally averaged N_2O emissions are used

Warming or cooling?
Crutzen et al. 2008

(pairs of columns show min. and max. of relative warming, Meq/M)



2. Examine the impact of full N_2O accounting in biofuel net green house gas emissions (Crutzen et al. 2008) using the life cycle analyses from Farrell et al. (2006)(EBAMM), Liska et al. (2008) (BESS), for corn-based ethanol and Smith et al. (2006)(BGGC) for wheat-based ethanol.

The Energy Independence and Security Act of 2007 (EISA, 2007) sets the goal of expanding biofuel production in the U.S. to 136 billion liters by 2022. Corn-based ethanol production is to be capped at 57 billion liters by 2015. In 2007 US production of corn-based ethanol was ~ 18 billion liters.

EISA mandates that the USEPA develop a new Renewable Fuel Standard. Perform lifecycle assessments to determine which fuels meet mandated GHG performance thresholds compared to petroleum fuel replaced. The biofuels must achieve GHG reductions of:

- **20% for new facility renewable fuel**
- **50% for biomass-based diesel**
- **60% for cellulosic biofuel**

Lifecycle assessment must include impacts on domestic and foreign land use and corn based ethanol production is to be capped at 57 billion liters by 2015.

Cassman and Liska (2007) note that estimates of GHG reductions from corn-ethanol are typically in the range of 13-35%, based on life cycle analyses conducted by Farrell et al. 2006 and Wang et al. (1999). Recent analysis by Crutzen et al. (2008) suggest that, in general, corn-ethanol production is a net GHG source rather than the projected net sink, when nitrous oxide (N_2O) emissions are fully accounted for. If the Crutzen et al. estimates are correct, then U.S. corn-based ethanol production may not meet the mandated criteria of a 20% reduction in GHG performance.

Life Cycle Analyses with the inclusion of the Crutzen et al. N_2O estimate:

Compare the net GHG estimates using the EBAMM model (Farrell et al., 2006), the BESS model (Liska et al. 2008) for corn based ethanol production, and the bioethanol GHG Calculator (BGHGC) (Smith et al. 2006) using the internal model N_2O estimates (1.5, 1.8 and 1.5% of N input, respectively) with net GHG estimates using the 3-5% N_2O production estimates from Crutzen et al. (2008).

Look into the effect of the release rate of N_2O-N used as a function of applied fertilizer N on net GHG emissions. In these life cycle studies, N_2O release rates typically are based on a interpretation of the default values estimated by IPCC (2006) for "direct" and "indirect"emissions.

Net CO2e emissions from Midwest corn-ethanol production and use, using EBAMM and the impact of larger N_2O emissions on net GHG emissions.

Using EBAMM Farrell et al. (2006) estimated net GHG emissions from corn-based ethanol biofuel production for the U.S. corn belt. In this analysis they calculated N_2O emissions and CO2e based upon the following: N_2O yield = 1.5% of fertilizer N input (7 kg CO2e/kg N = 296 X 44/28 X (0.015 X 149.7)); fertilizer N input 149.7 kg N ha^{-1}; 3.72 kg CO2e needed to produce 1 kg of fertilizer N; corn yield = 8746 kg ha^{-1}; 0.4 l ethanol produced /kg corn (3498 L ethanol/ha).

EBAMM model analysis of net GHG savings (GHG Intensity= g CO2e/MJ) of corn-ethanol production and use compared to conventional gasoline (92 g CO2e/MJ) for Midwest average corn.

N_2O Conversion Factor (% of fertilizer N input)

	1.5	3	5
	-----------------g CO2 e/MJ----------------		
Crop Production	23	23	23
Refinery Production	64	64	64
N_2O	14	29	48
Distribution	1.4	1.4	1.4
Co-Product	-25	-25	-25
Total	78	92	111
% Emission Reduction	15	0	-21

BESS model analysis of net GHG savings (GHG Intensity= g CO2e/MJ) of corn-ethanol production and use compared to conventional gasoline (92 g CO2e/MJ) . Estimate for the U.S. Midwest Average Corn Production*.

	N_2O Conversion Factor (% of fertilizer N input)		
	1.8	3	5
	------------------g CO2 e/MJ----------------		
Crop Production	15	15	15
Refinery Production	30	30	30
N_2O	15	25	41
Distribution	1.4	1.4	1.4
Co-Product	-19	-19	-19
Total	42	52	68
% Emission Reduction	54	43	26

* Corn Production = 9.57 Mg/ha; N Fertilizer = 144 kg N/ha; irrigation = 4.9 cm; chisel tillage

BESS model analysis of net GHG savings (GHG Intensity= g CO_2e/MJ) of corn-ethanol production and use compared to conventional gasoline (92 g CO_2e/MJ) . Estimate for the Nebraska dry mill closed loop facility*.

	N_2O Conversion Factor (% of fertilizer N input)		
	1.8	3	5
	------------------g CO_2 e/MJ----------------		
Production	31	31	31
N_2O	14	28	39
Distribution	1.4	1.4	1.4
Co-Product	-19	-19	-19
Total	27	41	52
% Emission Reduction	70	55	43

*Corn Production = 9.73 Mg/ha; N Fertilizer = 146 kg N/ha; irrigation = 22 cm; plow tillage

UK Bioethanol Greenhouse Gas Calculator (BGGC) analysis of net GHG savings (GHG Intensity= g CO2e/MJ) of wheat-ethanol production and use compared to conventional gasoline (92 g CO2e/MJ)* (Smith et al. 2006).

	N_2O Conversion Factor (% of fertilizer N input)		
	1.5	3	5
	----------------g CO2 e/MJ----------------		
Crop Production	26	26	26
Refinery Production	43	43	43
N_2O	17	33	56
Distribution	0.5	0.5	0.5
Co-Product	-24	-24	-24
Total	62	79	101
% Emission Reduction	32	14	-10

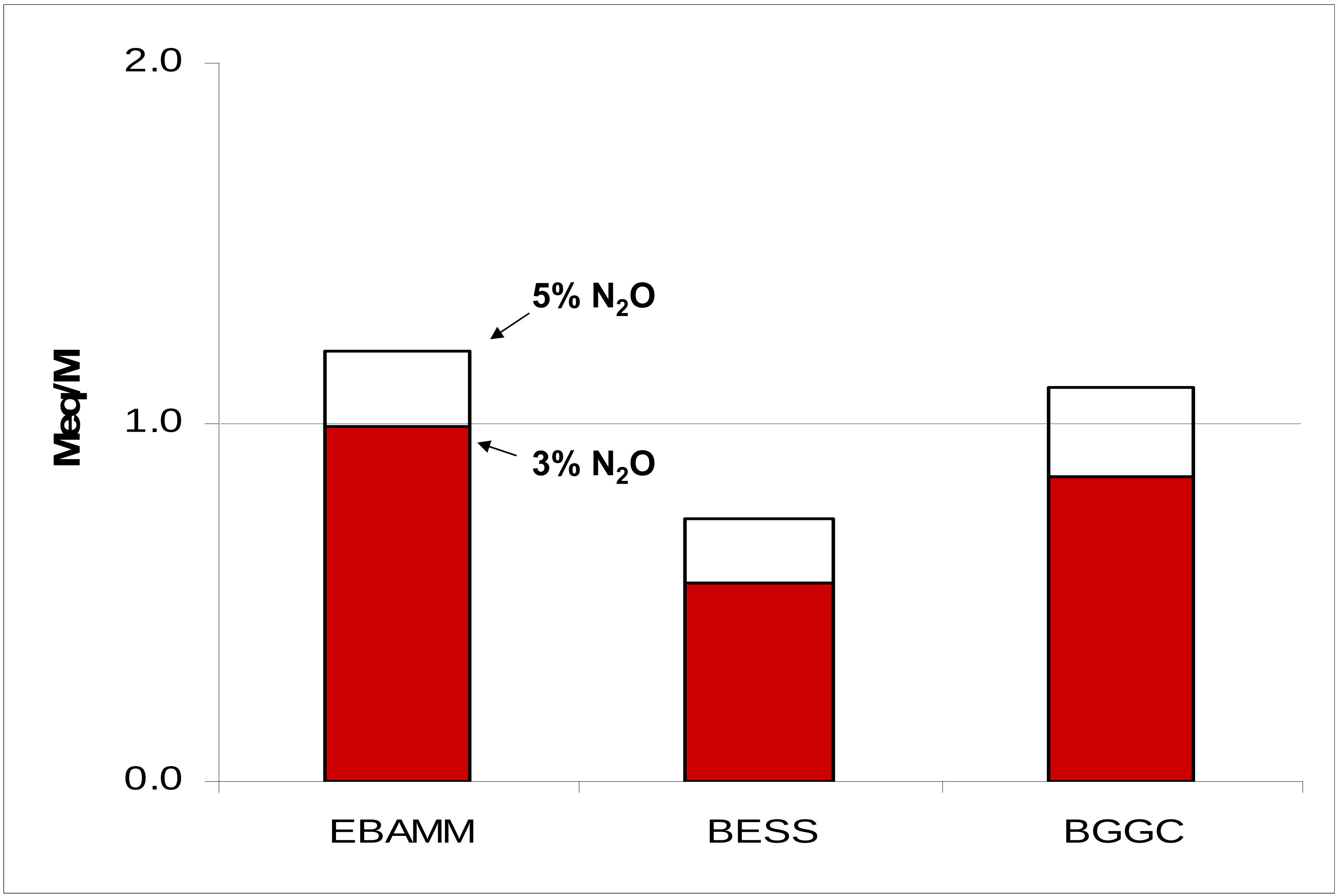
*185 kg fertilizer N/ha

Comparison of EBAMM and BESS net GHG emissions for midwestern corn-ethanol and BGGC for wheat-ethanol values for crop and refinery production.

	----------------g CO_2 e/MJ----------------		
	EBAMM	BESS	BGGC
Crop Production	23	15	26
Refinery Production	64	30	43
Co-Products	-25	-19	-24
N_2O (3% conversion)	29	25	33
N_2O (5% conversion)	48	41	56
% Emission Reduction	0 – (-21)	43 - 26	15 – (-10)

Comparison of LCAs to Crutzen et al. estimates

(Meq), or "equivalent CO_2", to account for the GWP of the N_2O emissions /"saved CO_2",(M), per unit mass of dry matter harvested in biofuel production



U.S. Biofuel Production and the Land Use Change Carbon Debt: What is the effect of including N_2O in the calculations?

During the past year, several studies suggest that additional land use change in the tropics will result from increased corn-based ethanol production in the U.S. (Fargione et al. 2008; Scharlemann and Laurance, 2008; Searchinger et al. 2008). These studies focus on the impact of land use change on decreasing soil carbon and essentially ignore the effect of these changes on the nitrogen cycle and N_2O emissions.

Differences in N_2O emission rates in tropical forest compared to high input corn cropping.

	Primary forest	Corn	Clearing 10 Year Increase	Corn Annual Increase
	N_2O (kg ha^{-1} yr^{-1})		---CO2e (tonnes ha^{-1})---	
Costa Rica*	~6	~9 -16**	~90	1 - 3
Brazil***	~3	~9 - 16**	~20	2 – 4

* Keller et al. (1993)

Estimate made on N fertilizer application of 200 kg N ha^{-1} with N_2O conversion of 3-5% of N input (Crutzen et al. 2008). * Verchot et al. (1999).

Conclusions

- **Based on the EBAMM analyses, net GHG emissions from the average corn-belt corn-ethanol production does not fulfill the requirement for 20% reduction for new facility renewable fuel production from The Energy Independence and Security Act (EISA, 2007).**

- **In all cases tested BESS estimates of net GHG indicate that corn-ethanol decreases GHG emissions that are above EISA requirements. 20 to 70% GHG reductions depending upon N_2O emission estimate.**

- **Including N_2O in corn-ethanol land use change issues makes the net GHG balance even more unfavorable**