

Calculation of Direct and Indirect N₂O emissions and other Procedures in the EPA Draft Regulatory Impact Analysis: A Critical Evaluation

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Note

As used in this evaluation, the term “indirect” referring to N₂O emissions does **not** mean market-driven emissions as the term is used in indirect land use change. Instead, indirect N₂O emissions are those arising from nitrogen-containing chemical species (eg, nitrate, ammonium ion, etc) other than the nitrogen fertilizer applied. In essence, this is N₂O arising outside the biofuel system boundary. It is relatively straightforward to estimate direct N₂O emissions and there is a high degree of confidence in the numerical values. In contrast, it is difficult to estimate indirect N₂O emissions, double counting is likely and numerical values are highly uncertain.

Comments on Crutzen, et al, article

EPA’s interest in nitrogen related emissions for biofuels was stirred at least in part due to the 2008 paper by Crutzen and coworkers. The paper concluded that when the global warming potential from nitrous oxide possibly generated by biofuels was included, that biofuels might not offer any greenhouse gas savings compared to petroleum fuels. We offer the following comments on this paper:

- By its own admission, the Crutzen paper is not a life cycle study and a life cycle study is needed to properly account for relevant factors.
- Because the Crutzen paper is not a true life cycle assessment (LCA), it is very difficult to interpret its findings using accepted life cycle approaches. For example, here are some important LCA deficiencies in the Crutzen paper.
- Because the system boundaries for Crutzen, et al, are not clearly described, one is unable to determine, for example, whether Crutzen has counted nitrogen emissions from animal production (eg, from manure) as part of the biofuel life cycle. If so, this is a serious error. Animal production is responsible for its own greenhouse gas emissions.
- The LCA standard for sensitivity analysis is Monte Carlo simulation around the relevant variables. Crutzen does not do this and therefore we have no way of knowing whether the nitrous oxide generation is truly significant over the range of possible variables. It may well be that the system uncertainty is such that a more extensive uncertainty analysis would show that no statistically relevant conclusions about nitrous oxide production related to biofuels can be drawn at this time.
- Worldwide values are used for key estimated parameters in Crutzen, et al, but biofuel production is concentrated in a relatively few countries where agricultural practices are generally more advanced. It would much more appropriate for Crutzen to use parameters representative of agricultural practice in advanced countries, rather than worldwide values.
- IPCC guidelines provide for three tiers of analysis. Crutzen’s approach is the most simplistic Tier 1 approach, less favored by IPCC. IPCC recommends a Tier 3

approach when possible, based on modeling or experimental results at the field or regional level.

- At least one Tier 3 life cycle study of nitrous oxide generation by biofuels was already available (Kim and Dale, 2005). This study showed that nitrous oxide production potential from biofuels is very location specific and can be significantly reduced if not eliminated by proper management.
- While we agree that nitrous oxide production is potentially very important to the overall GHG performance of biofuels, it can certainly be reduced and dealt with in agricultural practice. The Crutzen approach minimizes the potential for improving biofuel GHG performance by focusing on factors outside the control of any farmer or group of farmers.

Overall Findings: Analysis of DRIA

- The EPA Draft Regulatory Impact Analysis (DRIA) includes direct and indirect N₂O emissions in the biofuel systems analyzed but does not include indirect N₂O emissions in petroleum fuel systems. The 2006 IPCC guidelines show how to estimate indirect N₂O emissions resulting from nitrogen deposition of all anthropogenic sources of NO_x and NH₃, including those related to petroleum products. So the methodologies used in DRIA for the petroleum and biofuel systems are not consistent. EPA's analysis has, intentionally or not, favored petroleum fuels over biofuels by omitting anthropogenic sources of NO_x and NH₃ related to petroleum fuels.
- The EPA should estimate indirect emissions of N₂O from petroleum-derived fuels as it has for biofuels and these should be included in the petroleum baseline against which biofuels are compared. Otherwise, the DRIA is using different system boundaries for the two products, a violation of fundamental life cycle analysis (LCA) principles. EPA claims that they have followed International Standards Organization standards in constructing their analysis (see pg. 300 for example), but this is a clear case in which EPA has not done so.
- EPA has further violated ISO standards by assuming one time frame for some calculations while using another time frame without strong justification for other calculations. For example, on page 281-282 it uses both the 100 year and 30 year analysis of biofuel GHG emissions, while simultaneously employing the IPCC 100 year Global Warming Potential (GWP) values in other calculations (pg 302). It is incorrect to mix these two time frames. EPA needs to choose a consistent time frame of analysis over which it will consider these effects. IPCC obviously believes that decisions taken concerning GHG emissions have a 100 year horizon, so EPA's use of a much shorter time horizon is not consistent with international standards.
- Furthermore, neither IPCC nor any other international body of which we are aware applies a purely arbitrary discount rate to emissions, thereby making future emissions reductions less valuable than current emissions reductions. It is obvious that fossil fuels will be used far into the future. Therefore it is equally

important to reduce carbon emissions in the future as it is to reduce them now. EISA gives no instructions to EPA to differentiate between future emissions and current emissions. And there is no justification for applying an economic concept to life cycle greenhouse gas emissions whereby future emissions are treated differently than current ones. Thus EPA has violated the spirit and letter of EISA as well as LCA principles in applying a discount function to GHG emissions.

- Furthermore, the choice of discount rate is purely arbitrary and has no basis in science, LCA principles or policy. Why does EPA choose 2%? Why not 0.5% or 4%? These numbers are arbitrary, unscientific, and inconsistent with LCA principles.
- Another alternative to be consistent with LCA principles is to only calculate direct emissions for both biofuels and petroleum fuels. This would meet ISO standards and would allow the comparison between petroleum fuels and biofuels that many in Congress apparently assumed would be provided by EPA. Unless EPA actually conducts at least one comparison between petroleum fuels and biofuels with the same system boundaries, both physical and temporal, its claim (top of page 300) that it has compared petroleum fuels and alternative fuels using the same boundaries is untrue. It has not done so. EPA has mixed consequential and attributional analyses in comparing biofuels and petroleum fuels.
- From what we are able to tell from the DRIA, one of EPA's contributors, Winrock, has made a major error in the data they have provided to EPA. This mistake affects both carbon and nitrogen related emissions from indirect land use change. Winrock estimated, based on satellite imaging, the rate of conversion of forest and savannah to cropland in the 1990s and EPA has used these data to estimate forest conversion in the future.
- Setting aside the fact that there is no scientific basis to assume that these earlier data are relevant to the future, Winrock apparently failed to estimate the rate of conversion of cropland back to pasture or forest. We know this occurs as the one billion acres of abandoned cropland in the world attests. Winrock should have provided the net rate of conversion of forest to cropland, if any, rather than assuming that once forest was converted to cropland, it would always stay in cropland and would never revert to forest or pasture, both of which store large amounts of carbon and simultaneously tie up nitrogen so that it is much less likely to emit nitrous oxide or nitrate. Winrock can provide this estimate by using the same data set to determine, for the countries of interest, the rate of conversion of cropland to forest and pasture in the years of interest. The difference between these two rates is the net rate of forest loss, which is the relevant parameter for EPA's use.
- Direct N₂O emissions derived from FASOM are probably overestimated according to our calculations. Our calculations followed the methods described in FASOM report¹ (EPA-HQ-OAR-2005-0161-0866). Since DRIA does not provide

¹ Robert H. Beach, Bruce A. McCarl, Anthony Lentz, Agricultural Impacts of the Energy Independence and Security Act: FASOM Results and Model Description,

details of how direct and indirect N₂O emissions were calculated, the methods given in the FASOM report are reviewed below. We assume that these were the methods used in DRIA.

- FASOM chooses the worst case value (2.5% loss) for an N₂O emission factor for indirect N₂O emissions from leaching in domestic emissions calculations, while an IPCC emission factor is used to calculate international emissions. The methodologies are not consistent—a violation of LCA principles. Also, EPA should use a range of emission factors to estimate the range of N₂O emissions, rather than a point value, to better reflect the uncertainty. This is also consistent with LCA principles while using a high end point value when a range is more representative of the science is not particularly consistent with LCA principles.
- N₂O emissions from nitrogen-fixing crops are included in domestic emissions calculations in FASOM (but not in international emissions), N₂O emissions from nitrogen-fixing crops have been removed in 2006 IPCC guidelines. Therefore, the methodologies apparently used by EPA (in the FASOM report) do not follow IPCC guidelines. If DRIA is going to follow IPCC guidelines in some cases and not in others, it should carefully and thoroughly document its reasons.
- In yet another example of violation of ISO standards, EPA has not conducted the usual Monte Carlo analysis on uncertainty of key input variables. EPA's rationale for omitting the Monte Carlo analysis (pg. 304) is that the probability distribution functions for these variables are not well understood. But this is an inconsistent and unacceptable response. On the previous page (303) EPA states that the indirect, international land use factor has a very high level of uncertainty, and yet it has gone ahead and calculated its results using these highly uncertain numbers. This factor also determines the overall results more than any other single factor. If it is to follow ISO standards, EPA cannot neglect an analysis of variable uncertainty and the usual approach is Monte Carlo simulation. If it is unsure of the probability distribution function, EPA could assume various distribution functions (eg, normal, Poisson, etc) as a sensitivity analysis. EPA's approach of "bounding" the uncertainty with high and low values of what it believes to be key parameters is not scientifically rigorous. Doing so assumes the answer which the Monte Carlo analysis is meant to provide.
- According to DRIA, N leached from agricultural land simultaneously participates in both direct and indirect N₂O emissions. This is simply wrong. It is obvious from fundamental physical and biochemical processes that N leached is not involved in nitrification and denitrification processes that release direct N₂O emissions. N leached is *only* a component of indirect N₂O emissions, but not of direct emissions. Direct N₂O emissions only come from anthropogenic nitrogen applied directly to the soil. Therefore, DRIA is double counting these emissions from leached N.

- According to nitrogen balance calculations (see below), N output per ha using DRIA estimates is significantly larger than anthropogenic N input. N output includes N in above- and below-ground biomass, N volatilized and N leached. N input (anthropogenic) includes fertilizer N only. Anthropogenic N input is the only factor by which biofuel systems impact N₂O emissions. Therefore, the failure to close the nitrogen balance means that DRIA is overestimating the human contribution to N₂O emissions in biofuel systems.

Illustration and Check: Calculation Methods used in DRIA

These point value calculations are given to demonstrate that DRIA calculates the N₂O emissions in the ways we claim they have been calculated above, and therefore that some of the DRIA estimates of N₂O emissions are too high.

1. Direct N₂O emissions

1 % of non-volatilized N is converted into N₂O.

$$[N_S \cdot (1 - V_S) + N_O \cdot (1 - V_O)] \cdot Ef_D$$

where,

N_S: Nitrogen in synthetic N fertilizer (99.86 % of total N fertilizer)[kg/acre]

N_O: Nitrogen in organic N fertilizer (0.14 % of total N fertilizer) [kg/acre]

V_S: fraction of synthetic N volatilized (= 10% from IPCC)

V_O: fraction of organic N volatilized (= 20% from IPCC)

Ef_D: N₂O emission factor (=1% from IPCC)

Example

Nitrogen fertilizer for corn (no residue harvest) in CB region: 130.8 lb/acre (table A-9¹)

$$[[130.8 \cdot 0.9986 \cdot (1 - 0.1) + 130.8 \cdot 0.0014 \cdot (1 - 0.2)] \cdot 0.01] \cdot 0.454 \cdot \frac{44}{28} \cdot 310 = 260$$

This value is compared with the result in Table A-15¹ is 320 kg CO₂/acre or a 23% overestimate. This Table does not provide enough information for us to know why our results are different.

2. N₂O emissions from nitrogen-fixing crops (alfalfa and soybeans)

Data from the EPA GHG inventory for 1990–2003 and the total number of acres in soybeans and alfalfa in 2001 are used. These emissions from leguminous crops are included in the international N₂O emissions as estimated in the DRIA.

However, N₂O emissions from nitrogen-fixing crops have been removed from IPCC guideline². Again, if DRIA wants to use IPCC for some calculations and methodologies, and not for others, it should carefully and completely detail its reasons. IPCC is an authoritative organization, and its recommendations should probably be followed *in toto* or not at all. At the very least, strong reasons are needed to vary from IPCC guidelines, and DRIA does not provide those reasons.

3. Indirect N₂O emissions from volatilization

1 % of volatilized N is converted into N₂O.

$$[N_S \cdot (V_S) + N_O \cdot (V_O)] \cdot Ef_D$$

where,

N_S: Nitrogen in synthetic N fertilizer (99.86 % of total N fertilizer)[kg/acre]

N_O: Nitrogen in organic N fertilizer (0.14 % of total N fertilizer)[kg/acre]

V_S: fraction of synthetic N volatilized (= 10% from IPCC)

V_O: fraction of organic N volatilized (= 20% from IPCC)

Ef_D: N₂O emission factor (=1% from IPCC)

Example

Nitrogen fertilizer for corn (no residue harvest) in CB (Corn Belt) region: 130.8 lb/acre (table A-9¹)

$$[[130.8 \cdot 0.9986 \cdot (0.1) + 130.8 \cdot 0.0014 \cdot (0.2)] \cdot 0.01] \cdot 0.454 \cdot \frac{44}{28} \cdot 310 = 28.9$$

Compare this to the result in Table A-17¹ which is 28.5 kg CO₂/acres.

4. Indirect N₂O emissions from leaching

2.5 % of leached N, which is 30% of non-volatilized N, is converted into N₂O.

The worst case scenario for this emission factor (2.5%) is used in domestic N₂O emissions, while the IPCC factor (0.75%) is used in international N₂O emissions.

$$[N_S \cdot (1 - V_S) + N_O \cdot (1 - V_O)] \cdot Ef_L \cdot L_N$$

where

N_S: Nitrogen in synthetic N fertilizer (99.86 % of total N fertilizer)[kg/acre]

N_O: Nitrogen in organic N fertilizer (0.14 % of total N fertilizer)[kg/acre]

V_S: fraction of synthetic N volatilized (= 10% from IPCC)

V_O: fraction of organic N volatilized (= 20% from IPCC)

² IPCC, 2006 IPCC Guidelines for National Greenhouse Gas Inventories

E_L: N₂O emission factor (=2.5 % (worst case), while 0.75% is recommended by IPCC)

L_N: fraction of N leached (= 30% from IPCC)

Example

Nitrogen fertilizer for corn (no residue harvest) in the Corn Belt region: 130.8 lb/acre (table A-9¹)

$$\left[\left[130.8 \cdot 0.9986 \cdot (1 - 0.1) + 130.8 \cdot 0.0014 \cdot (1 - 0.2) \right] \cdot 0.025 \right] \cdot 0.3 \cdot 0.454 \cdot \frac{44}{28} \cdot 310 = 195$$

while the DIRA result given in Table A-17¹ is 192 kg CO₂/acres.

5. Indirect N₂O emissions from crop residues

1% of the N from unburned crop residues is converted into N₂O.

6. Indirect N₂O emissions from residue burning

0.7% of the N from burned residues (3 % of fields are burned) is converted into N₂O.

7. Nitrogen balance in corn production

Output is larger than input.

	Yield dry [kg/acres]	Nitrogen [kg N/acres]	N loss via volatilization ^F [kg N/acres]	N losses via leaching ^G [kg N/acres]	N consumed [kg N/acres]	N input [kg N/acres]
Grain ^A	3890	16 ^D				
Corn stover ^B	3890	26 ^E				
Below-ground biomass ^C	1712	12 ^E				
Total		54	6	16	76	60

A: 180 bu/acres

B: grain:stover = 1:1

C: below-ground biomass/above-ground biomass = 0.22 (IPCC)

D: 0.41%, E: 0.67%, F: 10 % of N input

G: 27 % of N input (30 % of non-volatilized N)

8. Back calculations from EPA values

N input is estimated from N₂O emissions calculated in the FASOM report.

- Nitrogen participating in direct N₂O emissions

$$\frac{260}{310 \cdot 0.454} \cdot \frac{1}{0.01} \cdot \frac{28}{44} = 117.6 \text{ [lb N/acres]}$$

- Nitrogen participating in indirect N₂O emissions from volatilization

$$\frac{28.9}{310 \cdot 0.454} \cdot \frac{1}{0.01} \cdot \frac{28}{44} = 13.1 \text{ [lb N/acres]}$$

- Nitrogen participating in indirect N₂O emissions from leaching

$$\frac{195}{310 \cdot 0.454} \cdot \frac{1}{0.025} \cdot \frac{28}{44} \cdot \frac{1}{0.3} = 35.3 \text{ [lb N/acres]}$$

Total nitrogen is 166 lb N/acres, which is larger than N input (130.8 lb N/acres) because N leached (according to FASOM) participates in both direct and indirect N₂O emissions. But as pointed out above, N leached can only participate in indirect emissions. Therefore FASOM and, as a consequence, DIRA have double-counted N₂O emissions from leached nitrogen.

9. Recalculations for direct N₂O emissions

Direct N₂O emissions

Leached N (~30% of non-volatilized N) is not involved in denitrification or nitrification processes to release direct N₂O emissions. Thus, 1 % of 70% of non-volatilized N is converted into N₂O.

$$[N_S \cdot (1 - V_S) + N_O \cdot (1 - V_O)] \cdot E_{f_D} \cdot (1 - L_N)$$

where

N_S: Nitrogen in synthetic N fertilizer (99.86 % of total N fertilizer)[kg/acre]

N_O: Nitrogen in organic N fertilizer (0.14 % of total N fertilizer)[kg/acre]

V_S: fraction of synthetic N volatilized (= 10% from IPCC)

V_O: fraction of organic N volatilized (= 20% from IPCC)

E_{f_D}: N₂O emission factor (=1% from IPCC)

L_N: fraction of N leached (= 30% from IPCC)

Example

Nitrogen fertilizer for corn (no residue harvest) in the Corn Belt region: 130.8 lb/acre (table A-9¹)

$$[[130.8 \cdot 0.9986 \cdot (1 - 0.1) + 130.8 \cdot 0.0014 \cdot (1 - 0.2)] \cdot 0.01] \cdot 0.454 \cdot \frac{44}{28} \cdot 310 \cdot 0.7 = 182$$

This value is compared with the result in Table A-15¹ is 320 kg CO₂/acre (direct N₂O emissions) or a 43% overestimate in DIRA for direct N₂O emissions.