Laboratório Nacional de Ciência e Tecnologia do Bioetanol

Sustainability of biofuels: GHG emissions

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Scientific Issues on Biofuels – Fapesp
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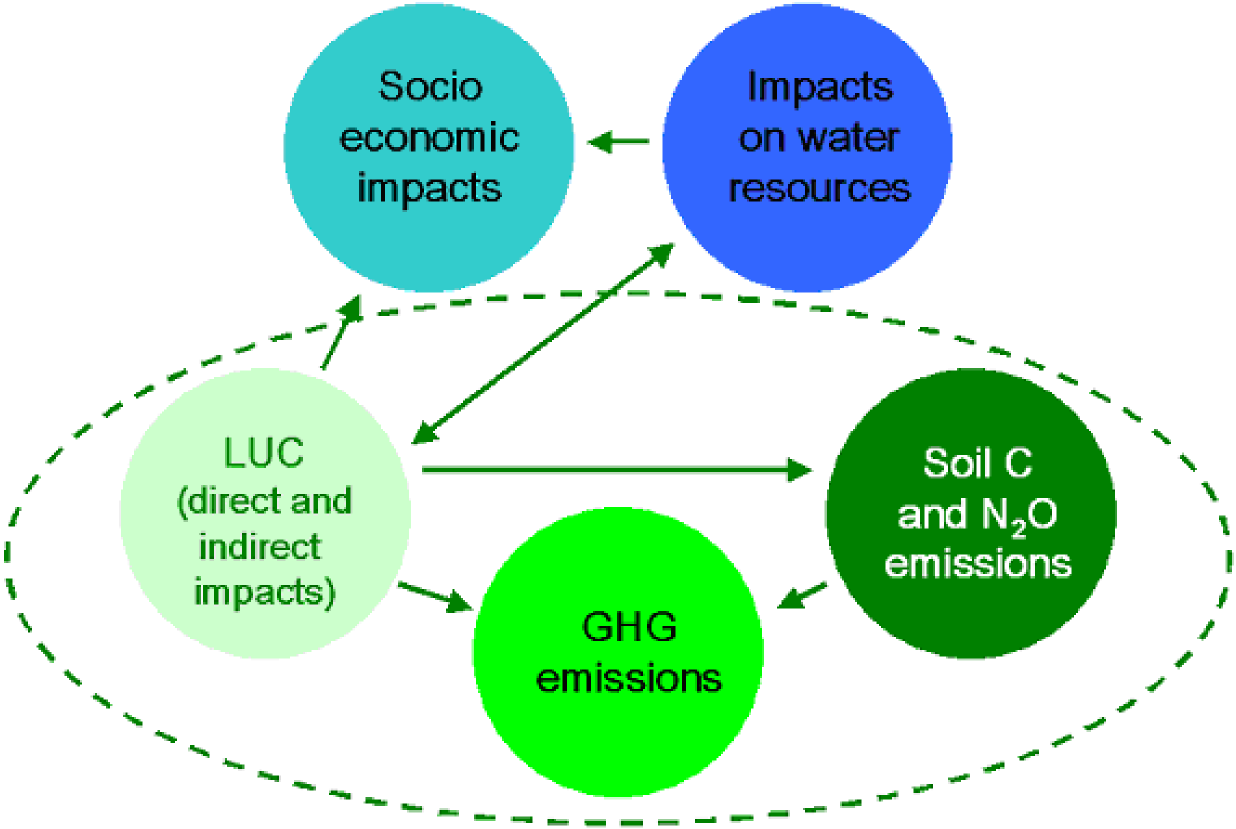
Sustainability of biofuels

- ✓ Worldwide, the main driving-forces for biofuels are:
  - Improving energy security, that includes diversification of the energy matrix, use of other energy sources than oil, development of indigenous energy sources;
  - Mitigation of GHG emissions and climate change impacts;
  - Improvement of life conditions of farmers and agricultors;
  - Supply of energy services;
  - Mitigation of other environmental (potential) impacts.

Sustainability of biofuels

- ✓ Sustainability of biofuels has been one of the focus points of the debate concerned to biofuels.
- ✓ Scientific arguments (sometimes not based on scientific evidences) have impacted both the society's behavior and policy makers.
- ✓ It is absolutely necessary to have science-based arguments; without them it is not possible to answer the "critics".
- ✓ In the mid- to long-term, the future of the biofuels will depend on their effective sustainability (both in the external and in the domestic markets).

CTBE: Sustainability RP



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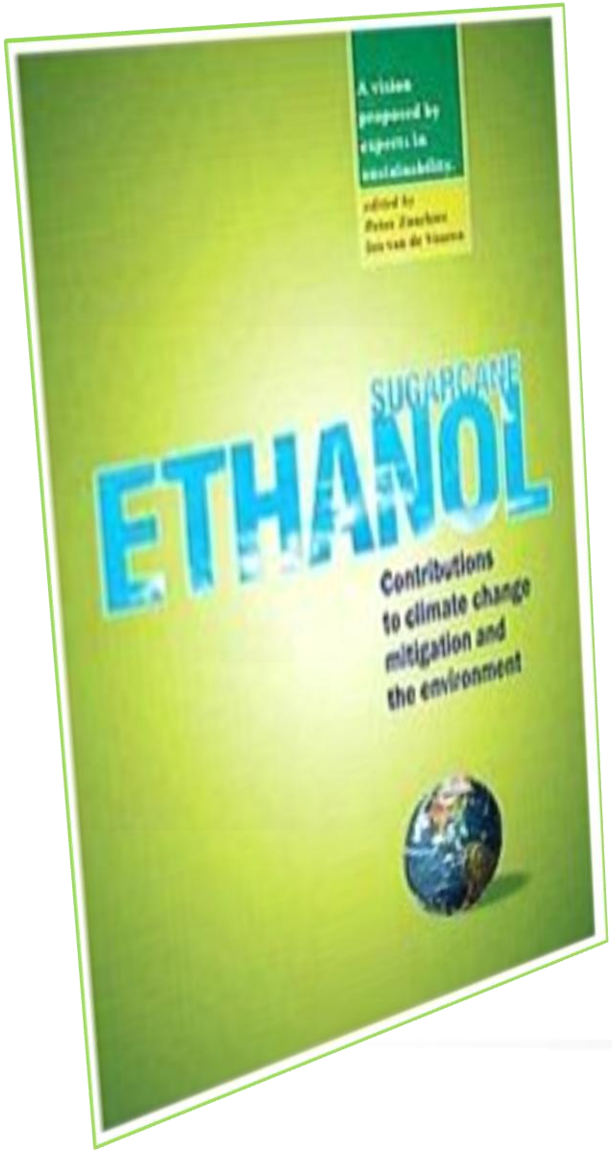
Sugarcane ethanol: Energy balance and GHG emissions



- ✓ **Macedo and Seabra (2008)**:
  - **<u>2006</u>**: 44 mills (~100 Mtc/year) of Brazilian C-S Region – data from CTC Mutual Control.
  - **<u>2020 Electricity Scenario</u>**: trash recovery (40%) and surplus power production with integrated commercial, steam based cycle (CEST system).
  - **<u>2020 Ethanol Scenario</u>**: trash recovery and ethanol production from biochemical conversion of surplus biomass in a hypothetical system integrated to the mill.

Scope

- ✓ Sugarcane production and processing, and ethanol distribution:
  - Carbon fluxes due to:
    - Fossil fuel utilization in agriculture, industry and ethanol distribution;
    - All process inputs;
    - Equipment and buildings production and maintenance.
  - GHG fluxes not related with the use of fossil fuels:
    - N_2O and methane: trash burning, N_2O soil emissions from N-fertilizer and residues (including stillage, filter cake, trash). CO2 from limestone.
  - GHG emissions due to land use change.
- ✓ GHG emissions mitigation: ethanol and surplus electricity substitution for gasoline or conventional electricity.

Energy flows in ethanol production (MJ/t cane)

	2006	2020 electricity	2020 ethanol
Energy input	235	262	268
Agriculture	211	238	238
Cane production	109	142	143
Fertilizers	65	51	50
Transportation	37	45	45
Industry	24	24	31
Inputs	19	20	25
Equip./buildings	5	4	6
Energy output	2,198	3,171	3,248
Ethanol [a]	1,926	2,060	2,880
Electricity surplus [b]	96	1,111	368
Bagasse surplus [a]	176	0.0	0.0
Energy ratio	9.4	12.1	12.1

[a] Based on LHV (Low Heating Value).

[b] Considering the substitution of biomass-electricity for natural gas-electricity, generated with 40% (2006) and 50% (2020) efficiencies (LHV).

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Life cycle GHG emissions ($kg\ CO_2eq/m^3$ anhydrous)

	2006	2020 Electricity	2020 Ethanol
Cane production	417	326	232
Farming	97	117	91
Agr. inputs	57	43	23
Transportation	32	37	26
Trash burning	84	0	0
Soil emissions	146	129	92
Ethanol production	25	24	22
Chemicals	21	20	19
Equip. and buildings	4	4	3
Ethanol distribution	51	43	43
Credits			
Electricity surplus[b]	-74	-803	-190
Bagasse surplus[c]	-150	0	0
Total	269	-409	107

a. Emissions for hydrous ethanol/m3 are about 5% less than values verified for anhydrous ethanol.
b. Considering the substitution of biomass-electricity for natural gas-electricity, generated with 40% (2006) and 50% (2020) efficiencies (LHV).
c. Considering the substitution of biomass fuelled boilers (efficiency = 79%; LHV) for oil fuelled boilers (efficiency = 92%; LHV).

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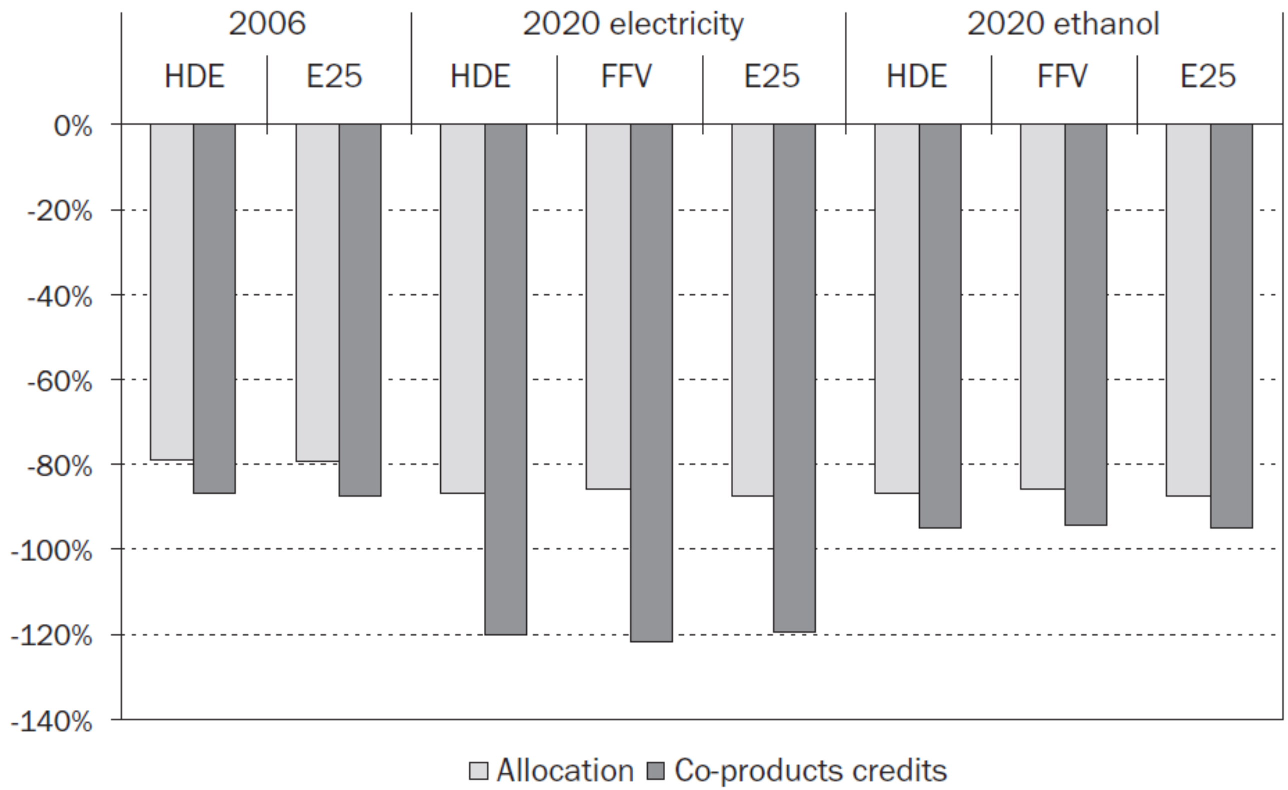
BRASIL UM PAÍS DE TODOS GOVERNO FEDERAL

GHG emissions mitigation with respect to gasoline



Net avoided emissions by sugarcane products

Scenario	Ethanol use	Net emissions		
		t CO_2eq/ha.y ↔	kg CO_2eq/tc ↔	t CO_2eq/m^3
2005/2006	HDE	-11,3	-155	-1,7
	E25	-11,5	-159	-1,8
2020 – Electricity	HDE	-18,1	-229	-2,4
	FFV	-16,8	-212	-2,2
	E25	-18,4	-233	-2,5
2020 – Ethanol	HDE	-20,0	-253	-1,9
	FFV	-18,2	-229	-1,7
	E25	-20,5	-258	-2,0

Source: Seabra (2008)

Direct effects of land use change

Reference crop	Carbon stock change[a] (t C/ha)	Emissions (kg CO_2 eq./m^3)		
		2006	2020 electricity	2020 ethanol
Degraded pasturelands	10	-302	-259	-185
Natural pasturelands	-5	157	134	96
Cultivated pasturelands	-1	29	25	18
Soybean cropland	-2	61	52	37
Maize cropland	11	-317	-272	-195
Cotton cropland	13	-384	-329	-236
Cerrado	-21	601	515	369
Campo Limpo	-29	859	737	527
Cerradão	-36	1,040	891	638
LUC emissions[b]		-118	-109	-78

[a] Based on measured values for below and above ground (only for perennials) carbon stocks.
[b] Considering the following LUC distribution – 2006: 50% pasturelands (70% degraded pasturelands; 30% natural pasturelands), 50% croplands (65% soybean croplands; 35% other croplands); 2020: 60% pasturelands (70% degraded pasturelands; 30% natural pasturelands); 40% croplands (65% soybean croplands; 35% other croplands). Cerrados were always less than 1%.

Expansion includes only a very small fraction of lands with high soil carbon stocks, and some degraded pasturelands, leading to increased carbon stocks.

INDIRECT effects of land use change

In the Brazilian context, most scenarios (based on Internal Demand plus some hypotheses for exports) indicate a total of ~ 60 M m^3 ethanol in 2020, or 36 M m^3 more than in 2008. Such expansion corresponds to a relatively small requirement for new cane areas (~5 M ha), which must be considered combined with probable release of areas due to the progressive increase of pasture productivities. Within Brazilian soil and climate limitations, the strict application of the environmental legislation for the new units, and the relatively small areas needed, the expansion of sugarcane until 2020 is not expected to contribute to ILUC GHG emissions.

International analyses

EU Directive

Sugar cane ethanol	Default GHG emissions (g CO2eq/MJ)
Cultivation (e_{ec})	14
Processing (e_p – e_{ee})	1
Transport and distribution (e_{td})	9
Total	24
Default GHG emission saving	71%

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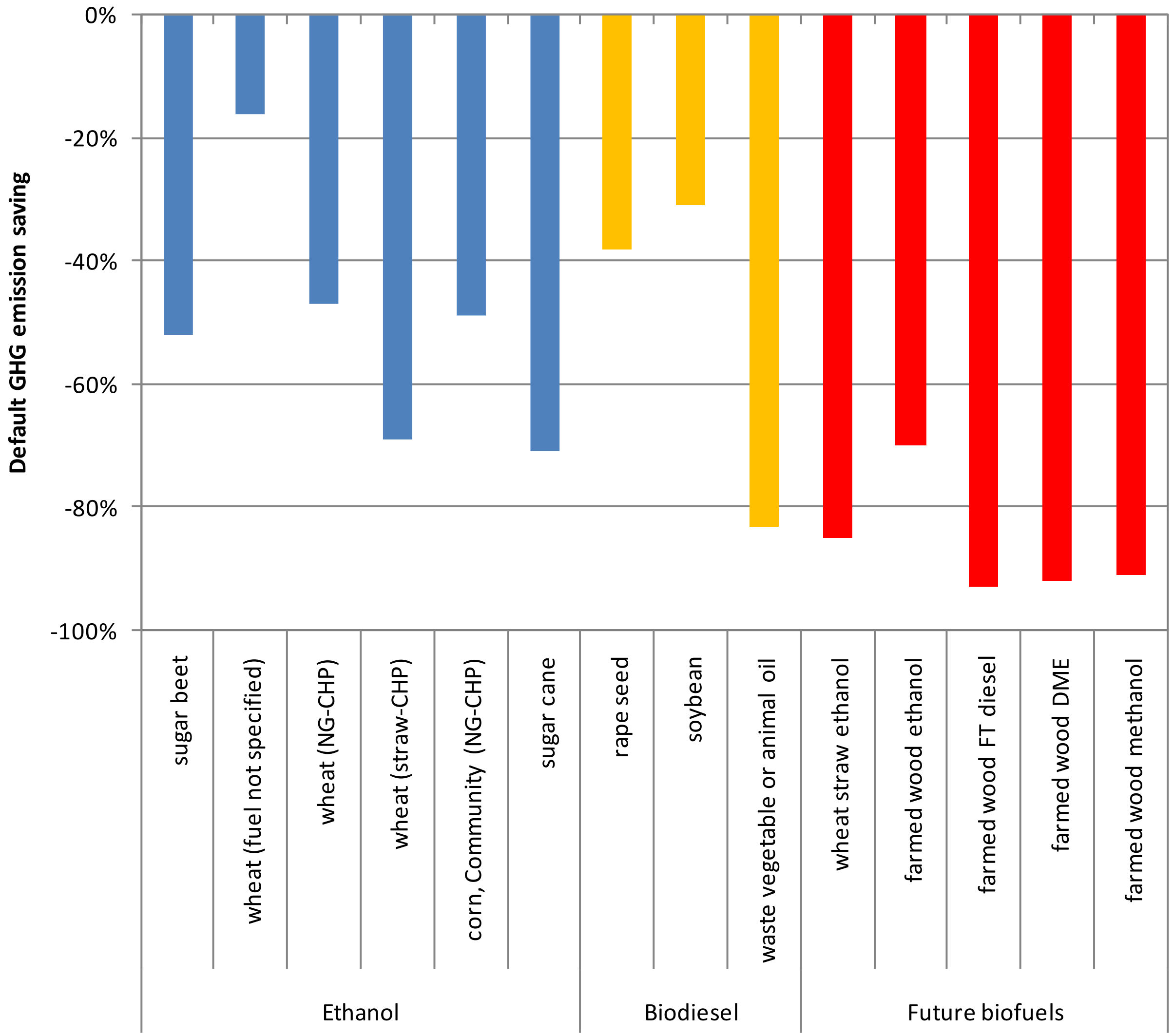
EU Directive



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EU Directive

- ✓ "Biofuels should be promoted in a manner that encourages greater agricultural productivity and the use of degraded land."
- ✓ "The Commission should develop a concrete methodology to minimise greenhouse gas emissions caused by indirect land-use changes."
- ✓ $e_l = (CS_R - CS_A) \times 3{,}664 \times 1/20 \times 1/P - e_B$
  - The bonus of **29 gCO2eq/MJ** shall be attributed if evidence is provided that the land:
    - (a) was not in use for agriculture or any other activity in January 2008; and
    - (b) falls into one of the following categories:
      - (i) severely degraded land, including such land that was formerly in agricultural use;
      - (ii) heavily contaminated land.

RTFO

Carbon intensity (kg CO_2/t ethanol)

Module	Sugar cane Brazil	Sugar beet UK	Corn USA	Corn France
Crop production	348	530	913	999
Drying and storage	-	-	55	19
Feedstock transport	49	176	33	30
Conversion	0	645	1752	263
Liquid fuel transport and storage	93	0	27	8
Liquid fuel transport and storage	175	0	122	-
TOTAL	665	1351	2902	1319

CARB

Table B. GHG Emissions Summary for Sugar Cane Ethanol

Sugar Cane Ethanol Components	GHGs (g CO_2e/MJ)	% Emission Contribution
Sugar Cane Farming *(incl. straw burning)*	9.9	37.2%
Ag Chemicals Production and Use Impacts	8.7	32.7%
Sugar Cane Transportation	2.0	7.5%
Ethanol Production	1.9	7.1%
Ethanol T&D	4.1	15.4%
Total Well-to-Tank	26.6	100%
Total Tank-to-wheel	0	0%
Total Well-to-Wheel	**26.60**	**100%**
Inclusive of Tailpipe Emissions and Land Use Change	**73.40***	

LUC: **46 g CO2e/MJ**

CARB

Pathway Description	WTW GHG* Emissions (gCO_2e/MJ)
Baseline Pathway Brazilian sugarcane using average production processes	27.40
Scenario 1 Brazilian sugarcane with average production process, mechanized harvesting and electricity co-product credit	12.20
Scenario 2 Brazilian sugarcane with average production process and electricity co-product credit	20.40

*These values do not include contributions from Land Use Change. This analysis is available in report titled "Proposed Regulation to Implement the Low Carbon Fuel Standard - Initial Statemer Reasons (ISOR)" from the website: www.arb.ca.gov/fuels/lcfs/lcfs.htm.

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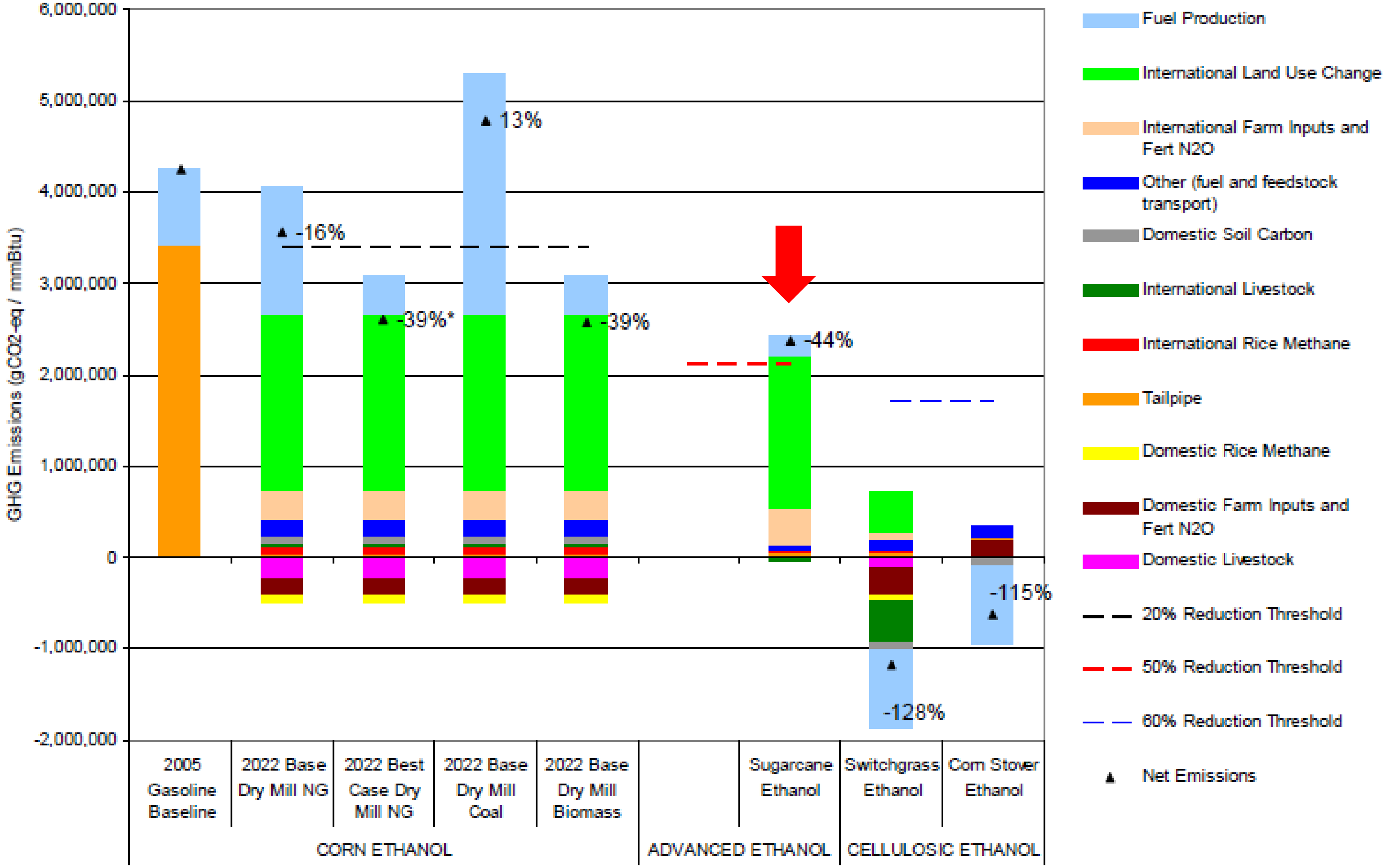
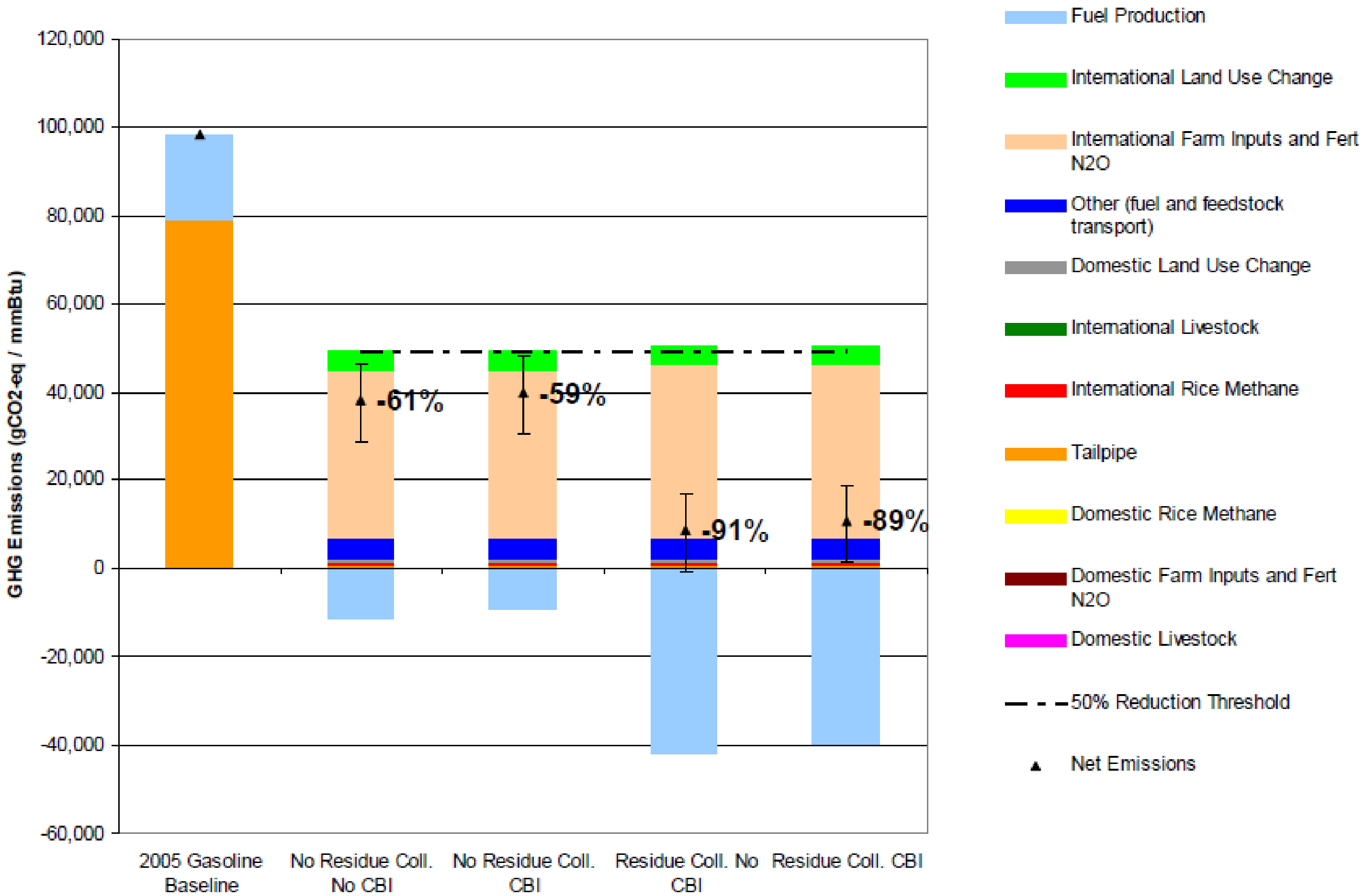
US EPA

(NPV, r=2%, T=100 years)

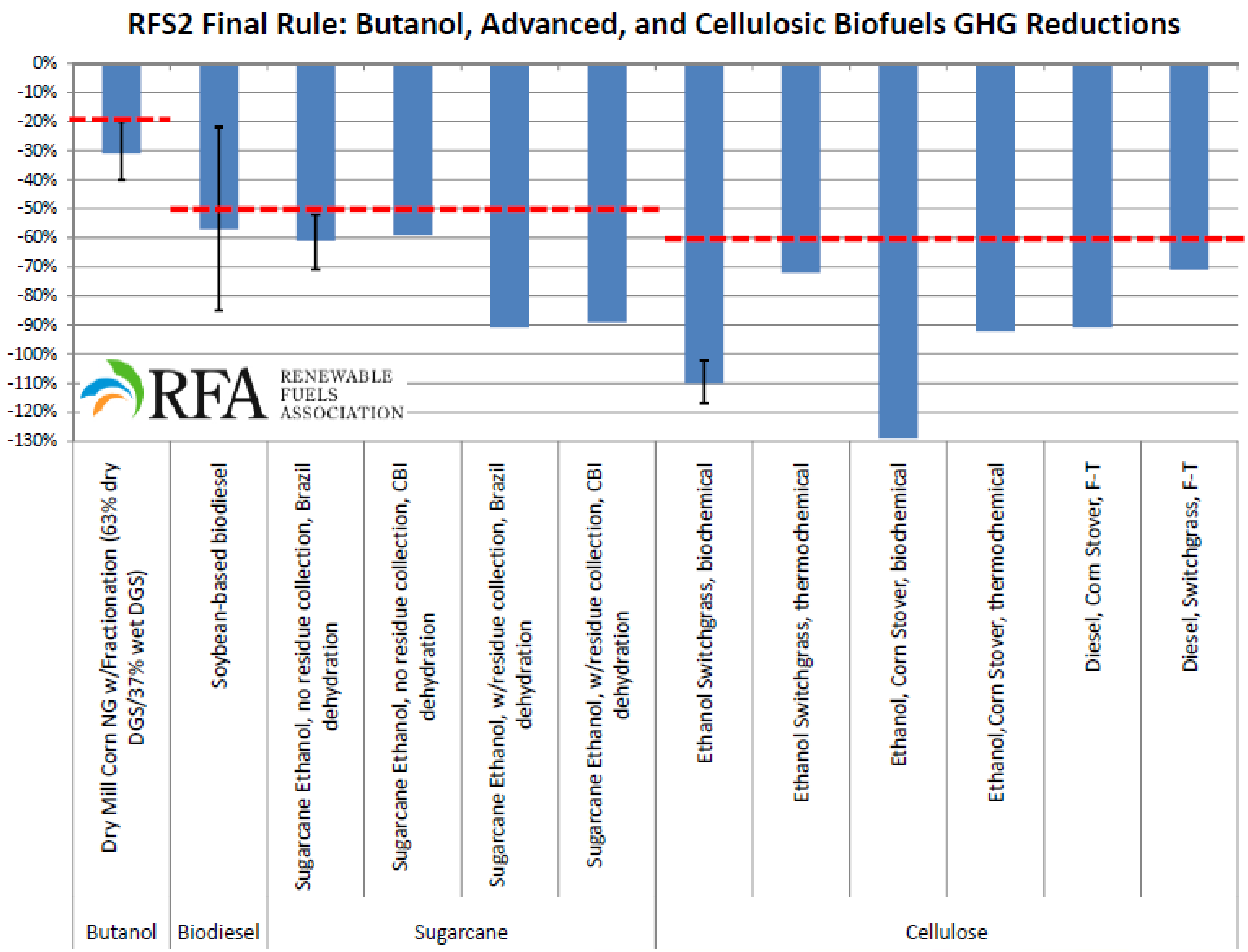


US EPA

Figure 2.6-10. Results for Sugarcane Ethanol by Lifecycle Stage With and without residue collection and CBI



US EPA



RFS2 Final Rule: Butanol, Advanced, and Cellulosic Biofuels GHG Reductions
0%
-10%
-20%
-30%
-40%
-50%
-60%
-70%
-80%
-90%
-100%
-110%
-120%
-130%
RFA RENEWABLE FUELS ASSOCIATION
Dry Mill Corn NG w/Fractionation (63% dry DGS/37% wet DGS)
Soybean-based biodiesel
Sugarcane Ethanol, no residue collection, Brazil dehydration
Sugarcane Ethanol, no residue collection, CBI dehydration
Sugarcane Ethanol, w/residue collection, Brazil dehydration
Sugarcane Ethanol, w/residue collection, CBI dehydration
Ethanol Switchgrass, biochemical
Ethanol Switchgrass, thermochemical
Ethanol, Corn Stover, biochemical
Ethanol,Corn Stover, thermochemical
Diesel, Corn Stover, F-T
Diesel, Switchgrass, F-T
Butanol
Biodiesel
Sugarcane
Cellulose

Critical aspects

- ✓ Database quality;
- ✓ Scope of the analysis;
- ✓ Co-products:
  - Allocation (mass, energy, market value, other);
  - Substitution.
- ✓ LUC and ILUC;
- ✓ Biorefineries.

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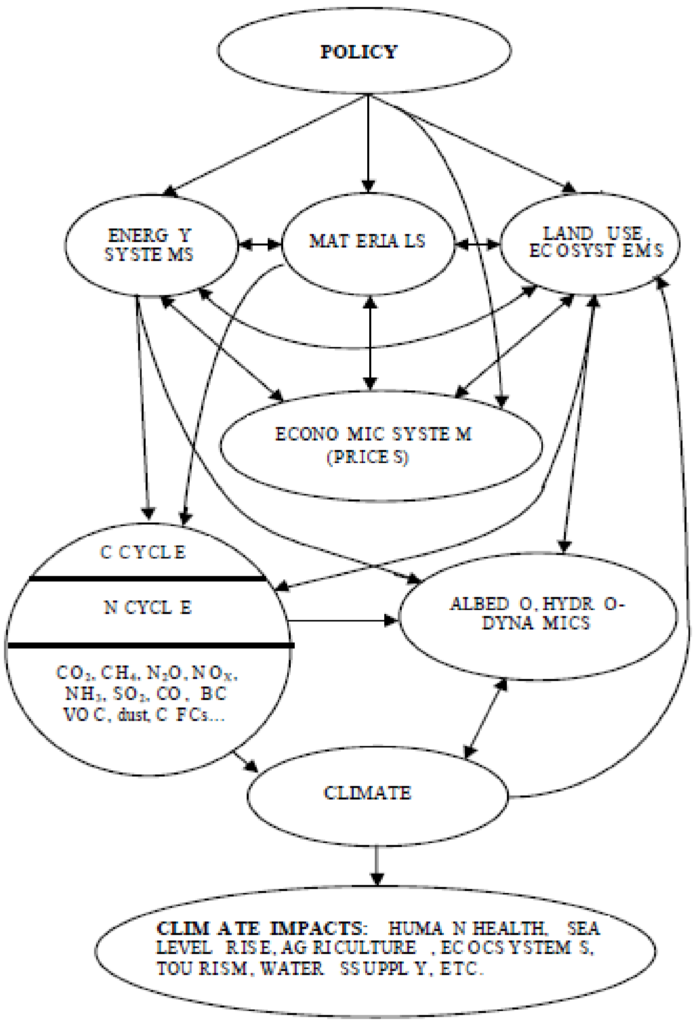
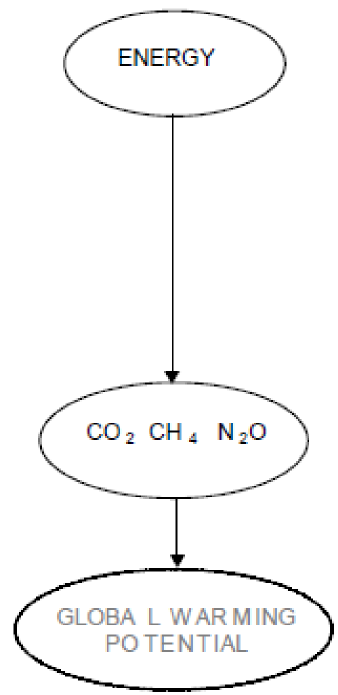
LCA models / approach

REALITY (IDEAL)



CONVENTIONAL LCA



CONVENTIONAL LCA VS. REALITY

No policy analysis: conventional LCA assumes that one set of activities replaces another.

Energy systems are well represented (~90%), but materials life cycle, infrastructure, and land-use usually are not.

Conventional LCAs do not model price changes and their effects.

Some CH_4, N_2O omitted. CO, NO_X, SO_X, PM, O_3, etc., omitted. C cycle and N cycle are incomplete. Albedo, water cycle not modeled.

GWPs are simplistic and do not capture several important aspects of climate change

Conventional LCA does not model impacts of climate change.

Source: Delucchi (2009)

Defaults suitability

Atmos. Chem. Phys., 8, 389–395, 2008
www.atmos-chem-phys.net/8/389/2008/

Atmospheric
Chemistry
and Physics

N_2O release from agro-biofuel production negates global warming reduction by replacing fossil fuels

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Abstract. The relationship, on a global basis, between the amount of N fixed by chemical, biological or atmospheric processes entering the terrestrial biosphere, and the total emission of nitrous oxide (N_2O), has been re-examined, us- into account the use of fossil fuel on the farms and for fertilizer and pesticide production, but it also neglects the production of useful co-products. Both factors partially compensate each other. This needs to be analyzed in a full life cycle as-

Defaults suitability

Allen et al. (2010)

Table 4
Cumulative annual N_2O-N emission and emission factor (mean ± S.E.) estimated for November 2003–2004 period in 3rd and 4th ratoon sugarcane crop, subtropical Queensland, Australia.

	0N	50 + 50N	100N	100 + 100N	200N
Cumulative annual N_2O-N emission (kg N_2O-N ha^{-1} $year^{-1}$)	2.86 ± 0.34	3.86 ± 0.65	3.93 ± 0.23	5.81 ± 1.88	9.56 ± 1.33
Emission factor		1.00 ± 0.64	1.07 ± 0.25	2.95 ± 0.17	6.70 ± 0.63

Denmead et al. (2009)

Table 1
Emission factors for N_2O for various Australian cropping systems.

Crop	Emission factor (%)	Reference
Non-irrigated crops	0.3	Galbally et al. (2005)
Pasture	0.4	Galbally et al. (2005)
Cotton	0.5	Galbally et al. (2005)
Sugarcane	1.25	NGGI (2007)
Sugarcane	2.8	This paper
Sugarcane on ASS	21	This paper
Horticulture and vegetables	2.1	Galbally et al. (2005)
Irrigated crops	2.1	Galbally et al. (2005)

Fator de emissão de N_2O obtido de estudos feitos pela equipe da Embrapa Agrobiologia em solos agrícolas

Uso do solo	Ciclo de avaliação[1] (dias)	N-Fertilizante (fonte kg N ha^{-1})	Tipo de solo	FE baseado em área de referência (%)
Londrina, PR			Latossolo Vermelho distroférrico	
Milho SP rotação (ano 1 e 2)	136/141	Uréia – 80		0,05/0,04
Milho PD rotação (ano 1 e 2)	136/141	Uréia – 80		0,09/0,03
Passo Fundo, RS			Latossolo Vermelho escuro	
Trigo PD rotação	137	Uréia – 40		0,13
Soja/trigo PD (ano 1 e 2)	1 ano	Fert+Res – 120/116		0,56/0,81
Soja/trigo PC (ano 1 e 2)	1 ano	Fert+Res – 126/133		0,47/0,52
Milho/trigo PD	1 ano	Fert+Res – 162		0,41
Milho/trigo PC	1 ano	Fert+Res – 141		0,70
Sorgo/trigo PD	1 ano	Fert+Res – 193		0,24
Sorgo/trigo PC	1 ano	Fert+Res – 193		0,29
Santo Antônio de Goiás, GO			Latossolo Vermelho Escuro	
Milho PD sucessão	140	Uréia – 80		0,22
Arroz sequeiro PD (ano 1 e 2)	133/132	Uréia – 90		0,13/0,14
Feijão irrigado PD	149	Uréia – 80		0,12
Seropédica, RJ			Argissolo Vermelho Amarelo	
Milho SP	120	Uréia – 50		0,16
Milho SP	120	Uréia – 100		0,35
Milho SP	120	Uréia – 150		0,33
Capim elefante	180	Uréia – 40		0,18
Capim elefante	180	Uréia – 80		0,22
Capim elefante	180	Uréia – 120		0,22
Capim elefante	180	Uréia – 160		0,37

Fator de emissão direta
Dados medidos no Brasil
Média geral
0,30 % (0,20 – 0,47%)

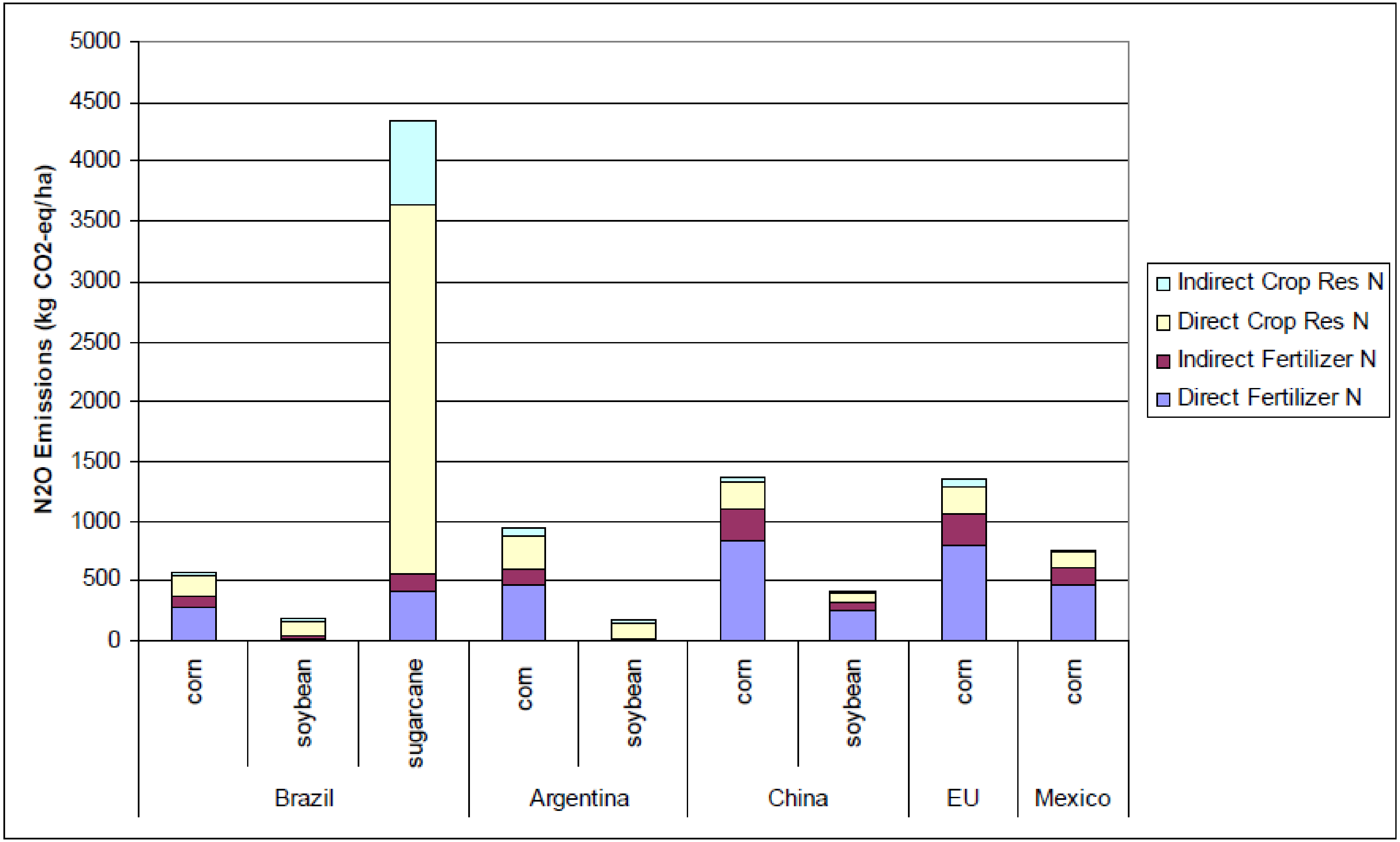
↓

Fator de emissão direta
IPCC
1% (0,3 – 3%)

Source: Boddey (2009) – EMBRAPA Agrobiologia, Seropédica,RJ

Residues

Figure 2.4-12. Sources of N2O Emissions by Crop for Select Regions



Source: EPA (2010)

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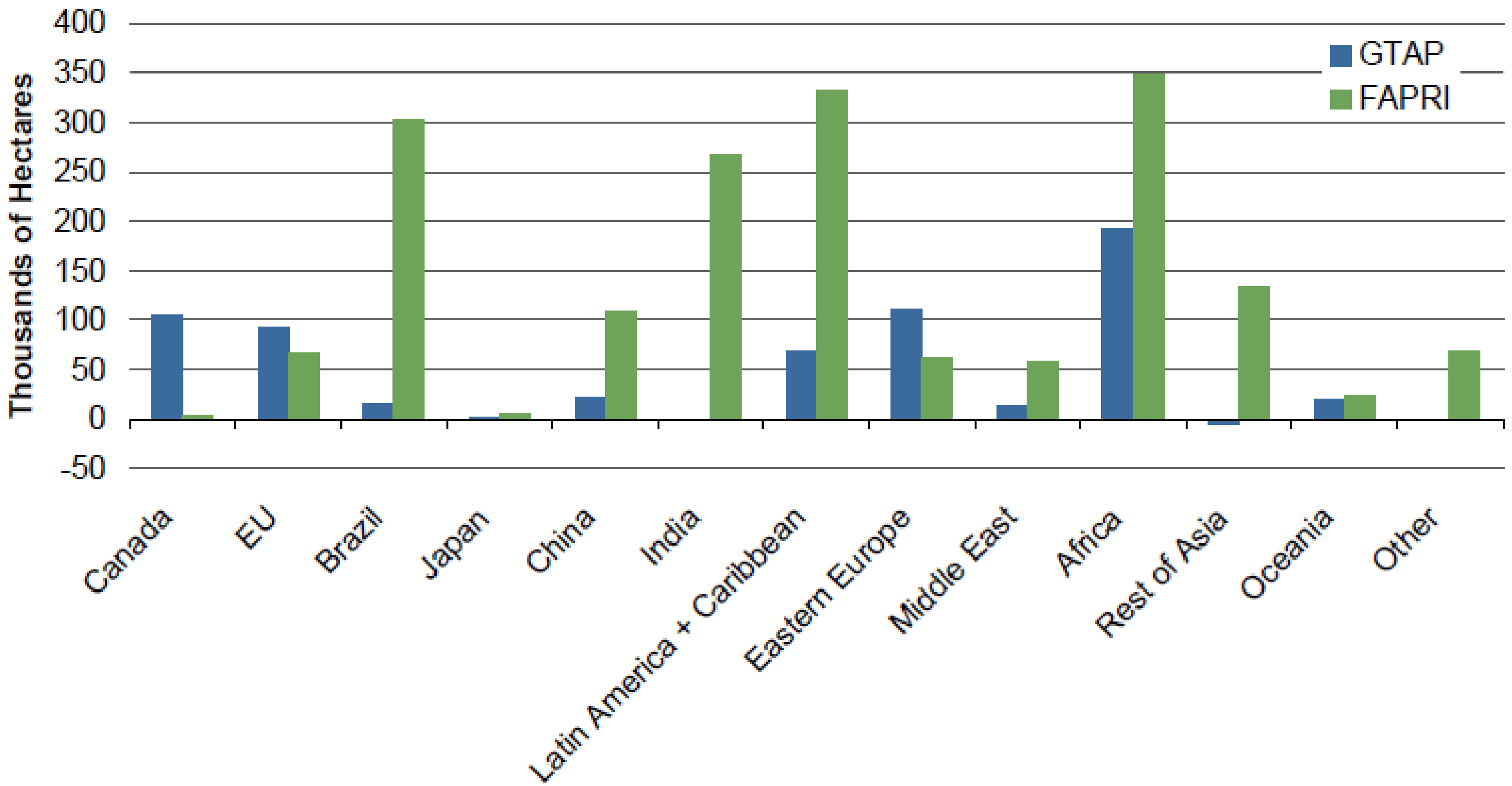
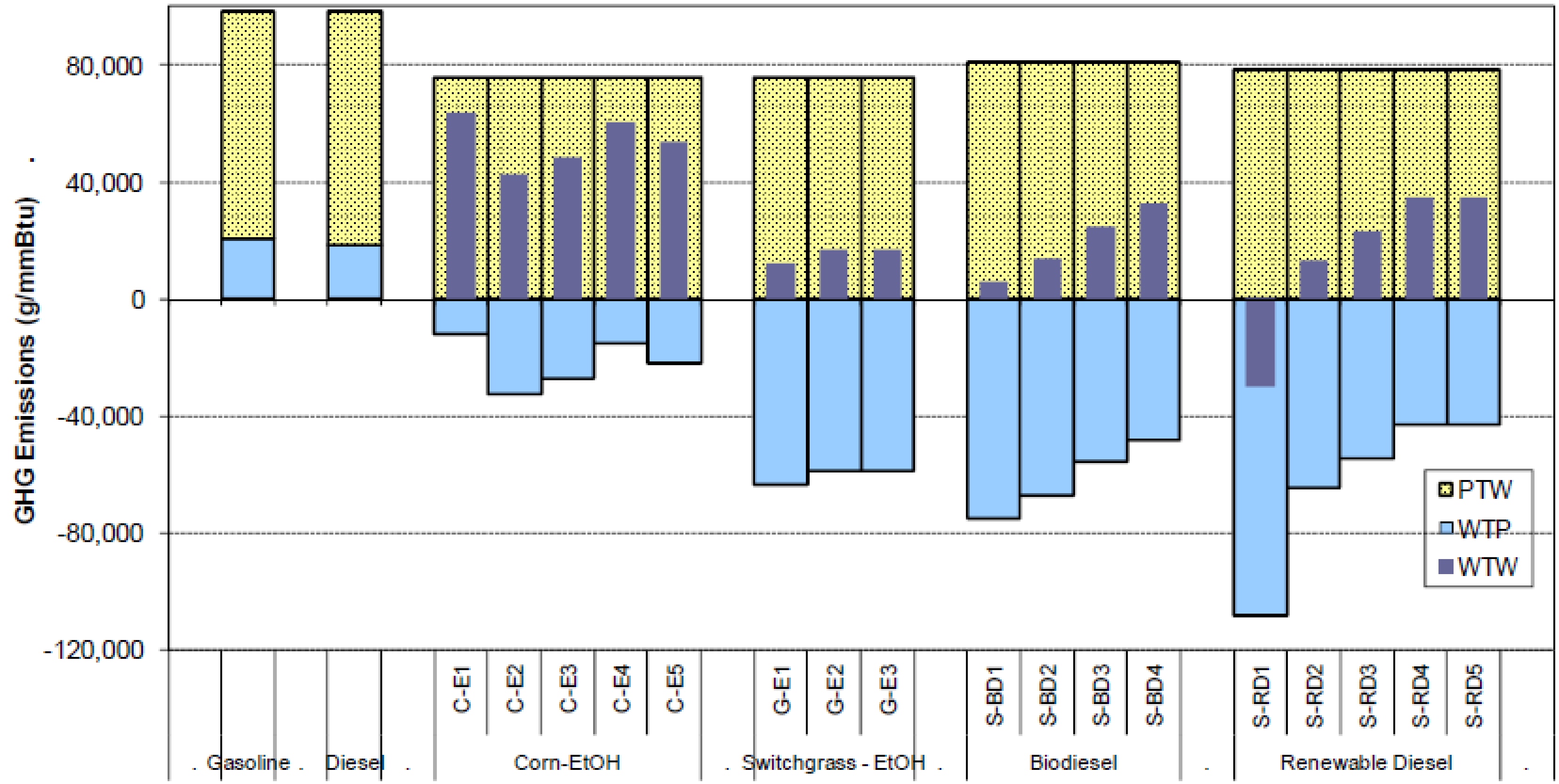
Tools for ILUC analysis (?)

Change in International Crop Acres from 2.6 Billion More Gallons of Corn Ethanol



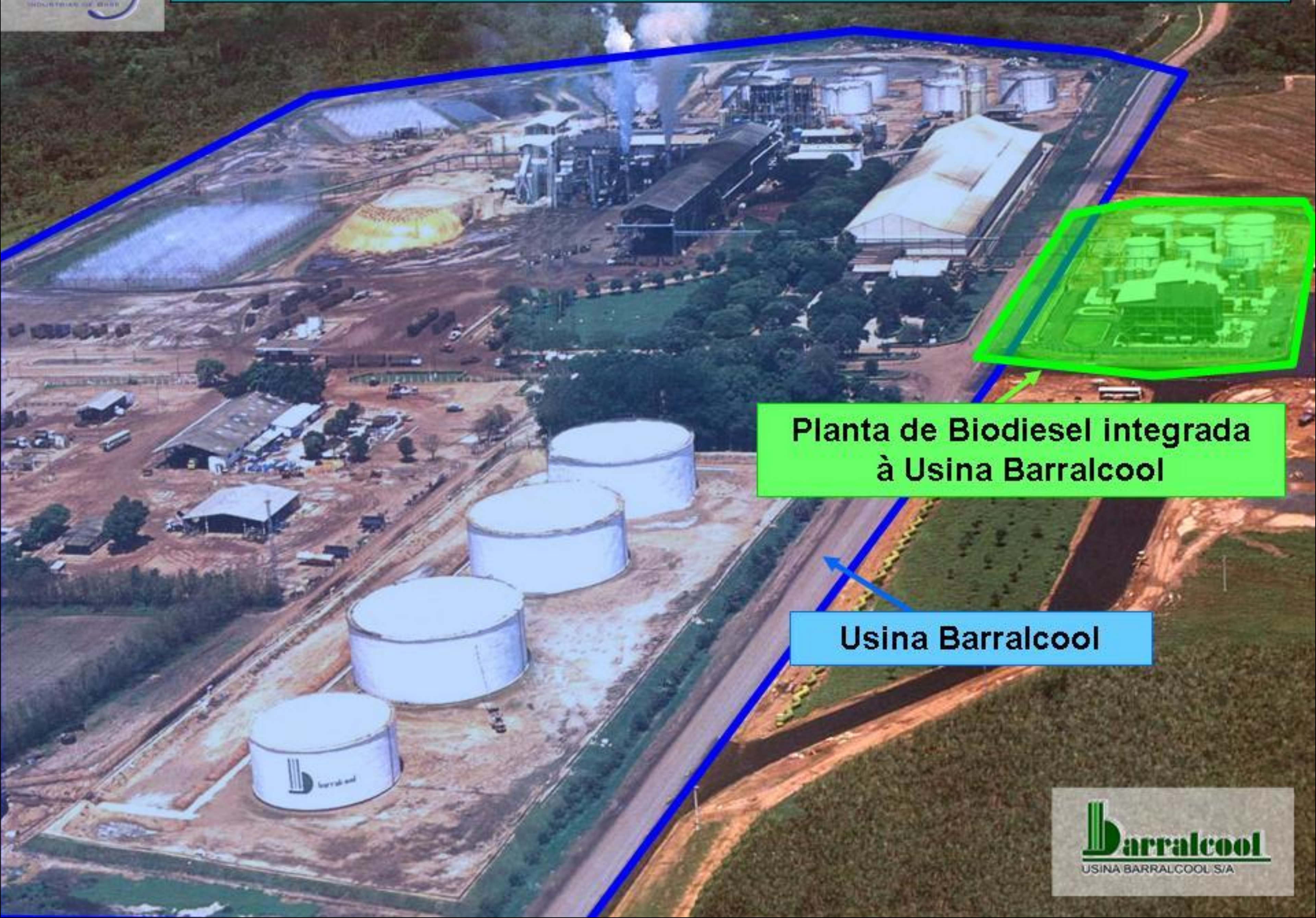
Source: Babcock (2009)

Influence of co-products



Source: Wang et al. (2009)

INTEGRAÇÃO BIOETANOL ↔ BIODIESEL



Thank you

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