1st Brazil-U.S. Biofuels Short Course:
Providing Interdisciplinary Education in Biofuels Technology
July 27 - August 7, 2009
University of Sao Paulo, São Paulo, Brazil

Methodologies: Emission and Mitigation of GHG in the production and Use of Ethanol from Sugarcane

I C Macedo, NIPE / UNICAMP

The implementation of the Brazilian sugar cane ethanol program always included a continuous assessment of its sustainability. The possibilities for advancing in the next years the expansion started in 2002 consider the promises of new technologies (that may lead to 50% more commercial energy / ha, from sugar cane) as well as environmental restrictions. The main issues in greenhouse gases emissions / mitigation associated with this expansion are analyzed.

Cane bioethanol and GHG emissions: methodologies

- Methodology "harmonization" has been sought (system boundaries, mitigation accounting, by-products allocation, the land use change impacts, N_2O emissions, baselines for electricity production emissions, etc):

  Renewable Transport Fuel Obligation, UK (bio-fuels)

  NREL/DoE and NIPE/UNICAMP: introducing the ethanol from cane in the GREET model

  GHG Working Group (RSB), EPFL - Switzerland

  Global Bioenergy Partnership (GBEP, FAO, G8+5)

→*Transparency; adequate simplifications; suitable database*

GHG emissions and mitigation in the life cycle

Carbon fluxes associated with C absorption with cane growth and its release as CO_2 : trash and bagasse burning, residues, sugar fermentation and ethanol end use

Carbon fluxes due to fossil fuel utilization in agriculture, industry and ethanol distribution; in all the process inputs; also in equipment and buildings production and maintenance.

GHG fluxes not related with the use of fossil fuels; mainly N_2O and methane: trash burning, N_2O soil emissions from N-fertilizer and residues (including stillage, filter cake, trash)

GHG emissions due to land use change

GHG emissions mitigation: ethanol and surplus electricity substitution for gasoline or conventional electricity.

Macedo, I.C., Seabra, J.E.A., Silva, J.E.A.R., 2008. Green house gases emissions in the production and use of ethanol from sugarcane in Brazil: The 2005/2006 averages and a prediction for 2020. Biomass and Bioenergy, Vol. 32, Issue 7, July 2008, pp. 582-595.

Note 1: the data base quality

Even for a homogeneous set of producers (Brazil Center South region) differences in processes (agricultural and industrial) impact energy flows and GHG emissions.

- 2005/2006: sample of 44 mills (100 M t cane / season), all in the Center South; data from CTC "mutual benchmarking": last 15 years, agriculture and industry.
- Additional information from larger data collection systems for some selected parameters

Parameter	Units	Average	SD[a]	Min.	Max.	Mills	Cane[b]
N-fertilizer use	kg N $(ha.year)^{-1}$	60	16	35	97	31	72.52
Trucks' energy efficiency	t.km L^{-1}	52.4	9.7	38.9	74.3	36	80.83
Transportation distance [c]	Km	23.1	6.1	9.3	39.0	39	84.50
Mechanical harvesting	%	49.5	27.1	0	87.7	44	98.59
"Other" agr. (diesel)	L ha^{-1}	67	38	2.7	136	27	67.23
Unburned cane	%	30.8	21.7	0	87.7	44	98.59
Cane productivity	tc ha^{-1}	87.1	13.7	51.3	119.8	44	98.59
Ethanol yield	L tc^{-1}	86.3	3.5	78.9	94.5	41	43.71[d]
Bagasse surplus	%	9.6	6.4	0	30.0	30	29.48[d]
Electricity surplus [e]	kWh tc^{-1}	9.2		0	50.0	22	28.61[d]

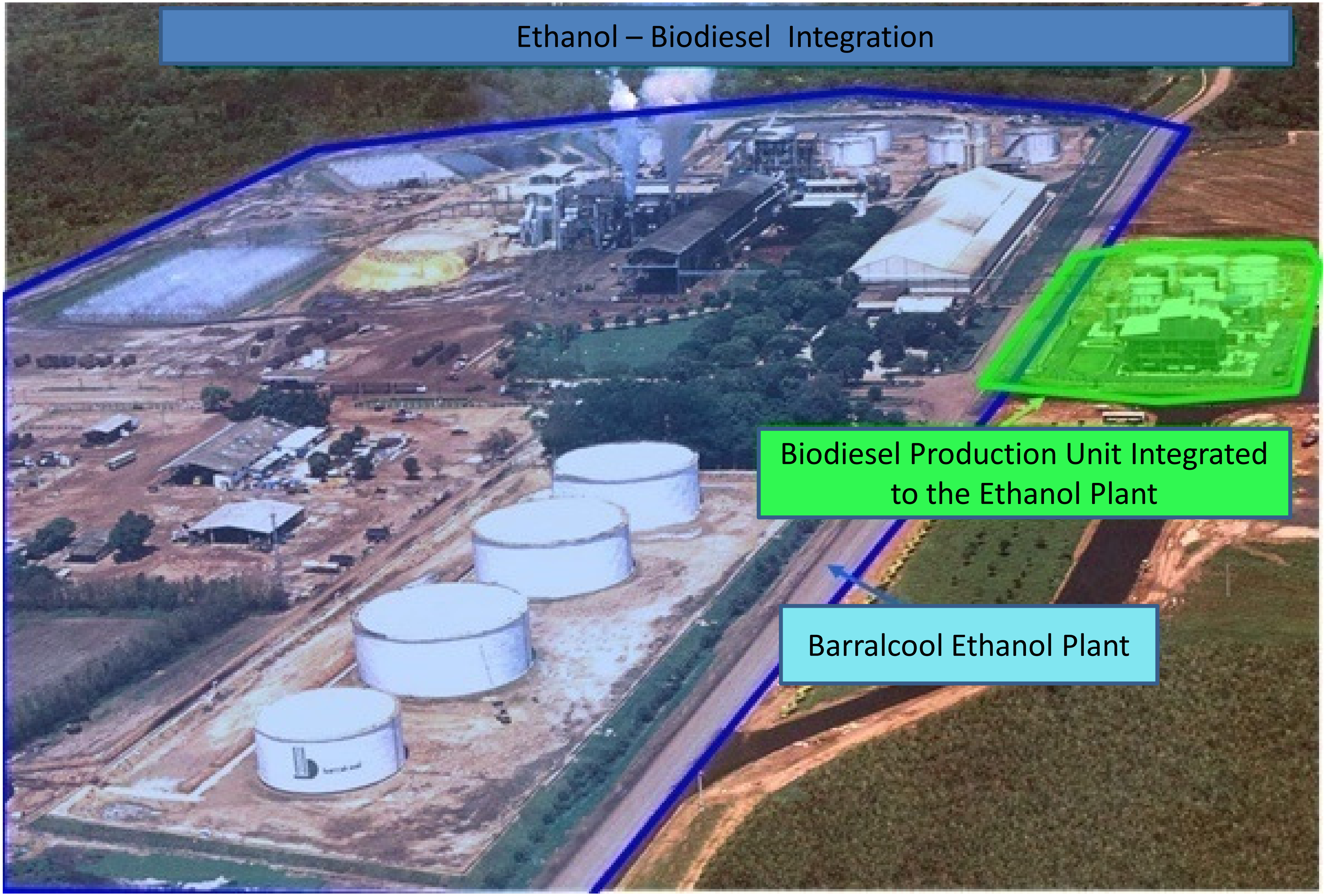
a. Standard deviation.
b. Mt $year^{-1}$.
c. Cane transportation
d. For industrial parameters, weighted averages considered the cane used exclusively for ethanol production.
e. Average from (Cogen's estimation [16]); no standard deviation available.

Selected parameters for sensitivity analysis (2005/2006)

Note 2: diversification → higher complexity

- Almost all (>90%) of the mills produce sugar (~50% of the cane); and surplus yeast
- Other sucrose co-products are commercially produced in many mills (citric acid, lysine, MSG, special yeast and derivatives, etc)
- Bagasse is becoming rapidly a source of electricity; cane trash recovery and use for power is already being done.
- Ethanol derived products using the mill's surplus energy are being considered in new plants (ethylene → plastics, other)
- More complex systems (production of soy and its bio-diesel in crop rotation with cane) are being implemented

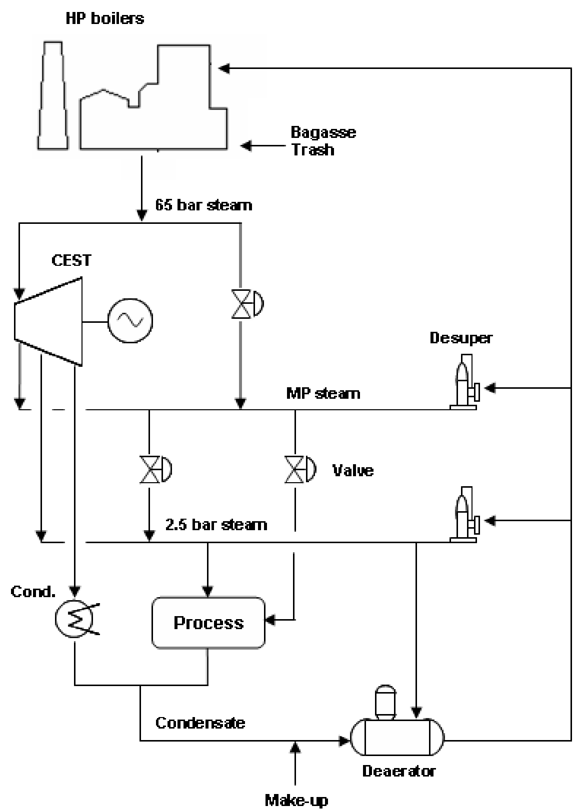
→ *Need for more comprehensive analyses*

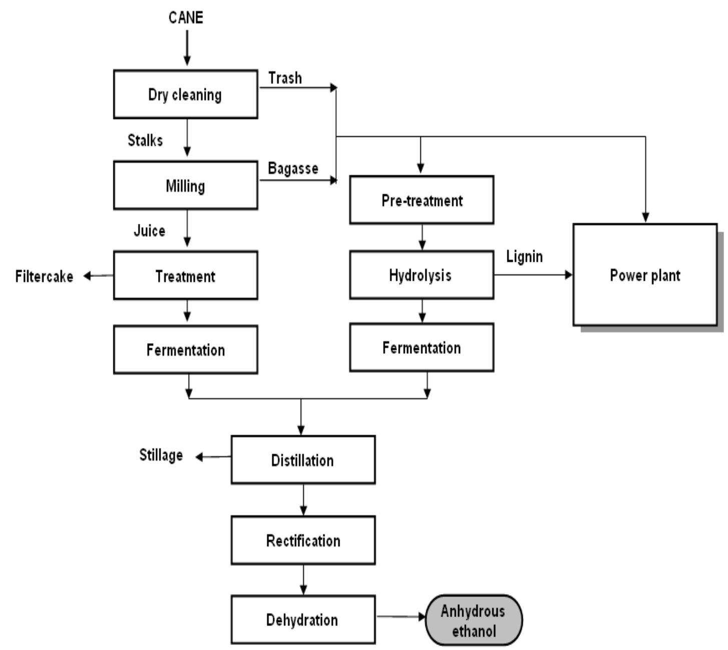

Ethanol – Biodiesel Integration
Biodiesel Production Unit Integrated to the Ethanol Plant
Barralcool Ethanol Plant

GHG emissions: Brazilian Ethanol Scenarios for 2020

- *2006*
- *2020 “Electricity” Scenario*: trash recovery (40%) and surplus power production with *integrated* (*commercial)* steam based cycle (CEST system)
- *2020 “Ethanol” Scenario*: trash recovery, use of surplus biomass to produce ethanol from hydrolysis in a (*hypothetical*) SSCF system, *integrated* with the ethanol plant

Scenario	2020 Electricity	2020 Ethanol





Biomass use	Advanced cogeneration [a]	Biochemical conversion [b]
Ethanol yield (L/t cane)	92.3	129
Electricity (kWh/t cane)	135	44
Bagasse surplus (%)	0	0

a) 65 bar/480 ℃ CEST system; b) SSCF process (adapted from Aden et al. (2002)).

Energy flows in ethanol production (MJ/t cane) (Seabra, 2007)

	2006	**2020 Electricity Scenario**	**2020 Ethanol Scenario**
Cane production / transportation	211.	238.	238.
Ethanol production	24.	24.	31.
Fossil Input (total)	***235.***	***262.***	***268.***
Ethanol [a]	1926.	2060.	2880.
Surplus bagasse [a]	176.	0.	0.
Surplus electricity [b]	96.	1111.	368.
Renewable Output (total)	***2198.***	***3171.***	***3248.***
Energy Ratio (Renewable/Fossil)	**9.4**	**12.1**	**12.1**

a. Based on LHV.

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

Total emissions in ethanol life cycle (kg CO_2*eq*/m^3 anhydrous)[a]

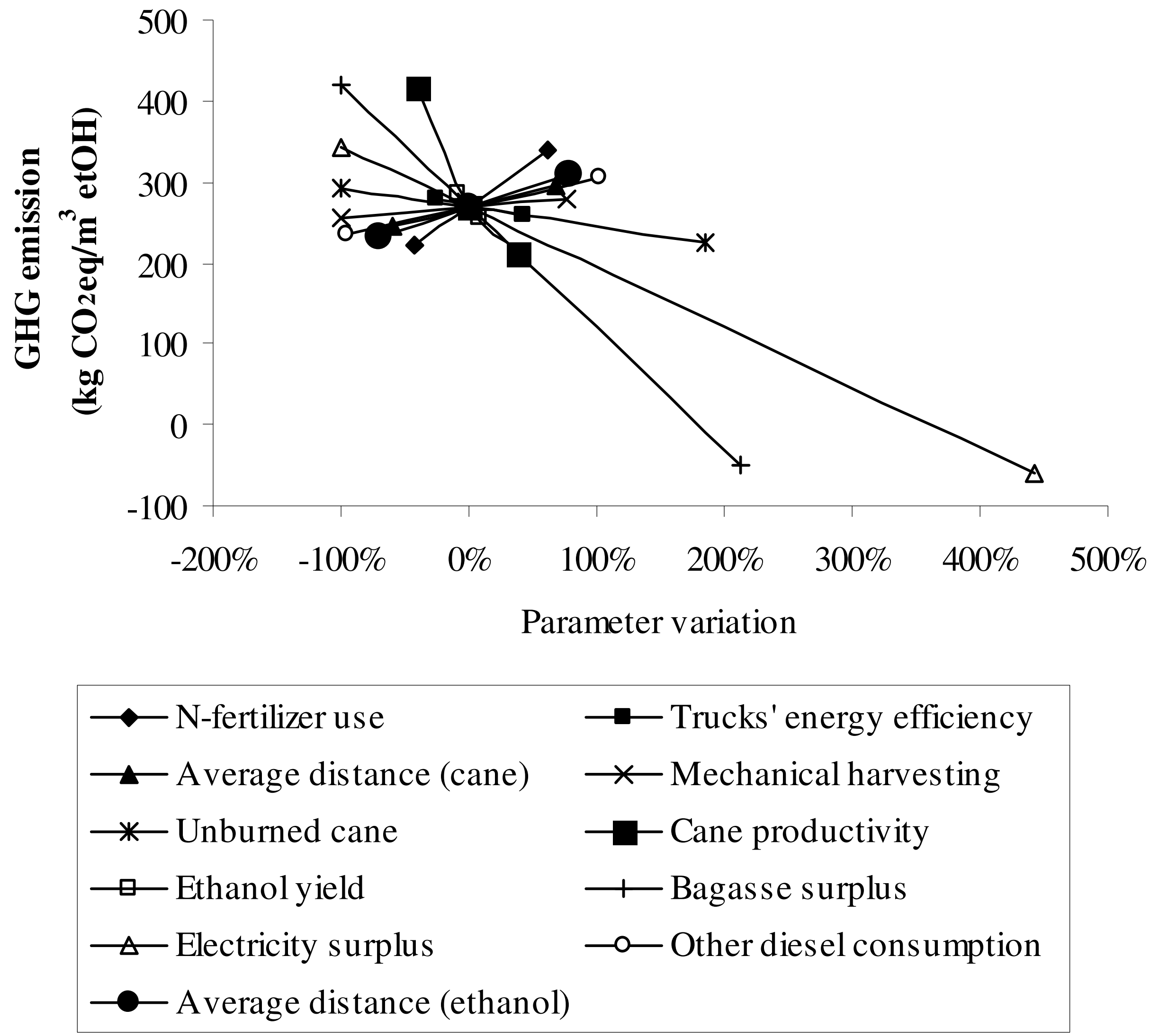
	2006	2020 Electricity Scenario	2020 Ethanol Scenario
Cane production (total)	***416.8***	***326.3***	***232.4***
Farming	107.0	117.2	90.6
Fertilizers	47.3	42.7	23.4
Cane transportation	32.4	37.0	26.4
Trash burning	83.7	0.0	0.0
Soil emissions (*without LUC*)	146.3	129.4	92.0
Ethanol production (total)	***24.9***	***23.7***	***21.6***
Chemicals	21.2	20.2	18.5
Industrial facilities	3.7	3.5	3.2
Ethanol distribution	***51.4***	***43.3***	***43.3***
Credits			
Electricity surplus[b]	-74.2	-802.7	-190.0
Bagasse surplus[c]	-150.0	0.0	0.0
Total	**268.8**	**-409.3**	**107.3**

a. Emissions for m^3 hydrous ethanol 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).

GHG total emissions variation in response to single parameter variation; including co-product credits (2006 only)



Net emissions (t CO_2eq/m^3 hydrous or anhydrous): substitution criterion for the co-products; no LUC effects

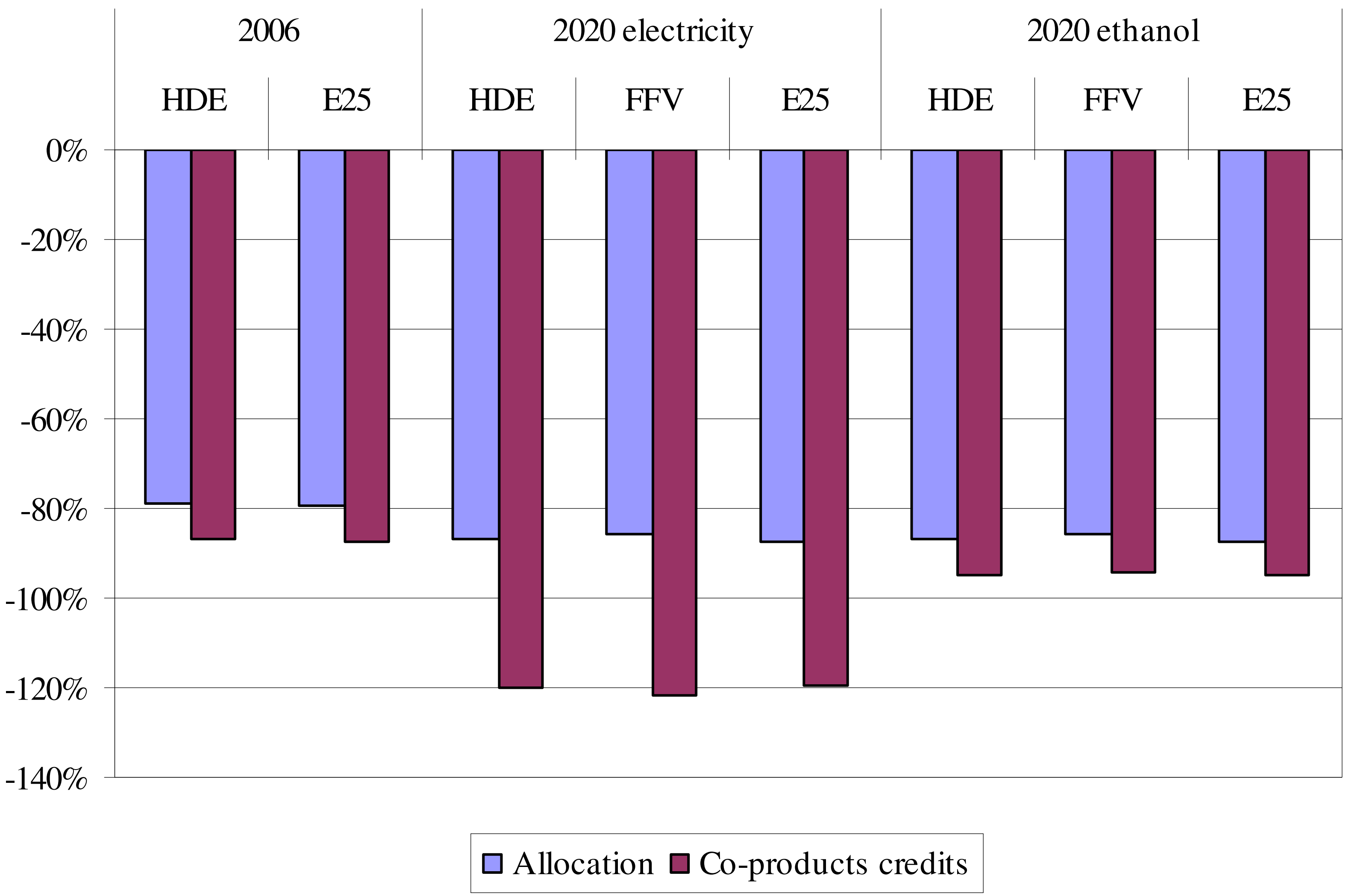
	Ethanol use [a]	Avoided Emission [b]	Net Emission [c]
2006	E100	-2.0	-1.7
	E25	-2.1	-1.8
2020 Electricity	E100	-2.0	-2.4
	FFV	-1.8	-2.2
	E25	-2.1	-2.5
2020 Ethanol	E100	-2.0	-1.9
	FFV	-1.8	-1.7
	E25	-2.1	-2.0

a. E100: hydrous ethanol in dedicated engines; FFV: hydrous ethanol in flex-fuel engines; E25: anhydrous ethanol (25% volume) and gasoline blend.

b. Avoided emission (negative values) due to the substitution of ethanol for gasoline; fuel equivalencies verified for each application in Brazil (Macedo et al., 2008).

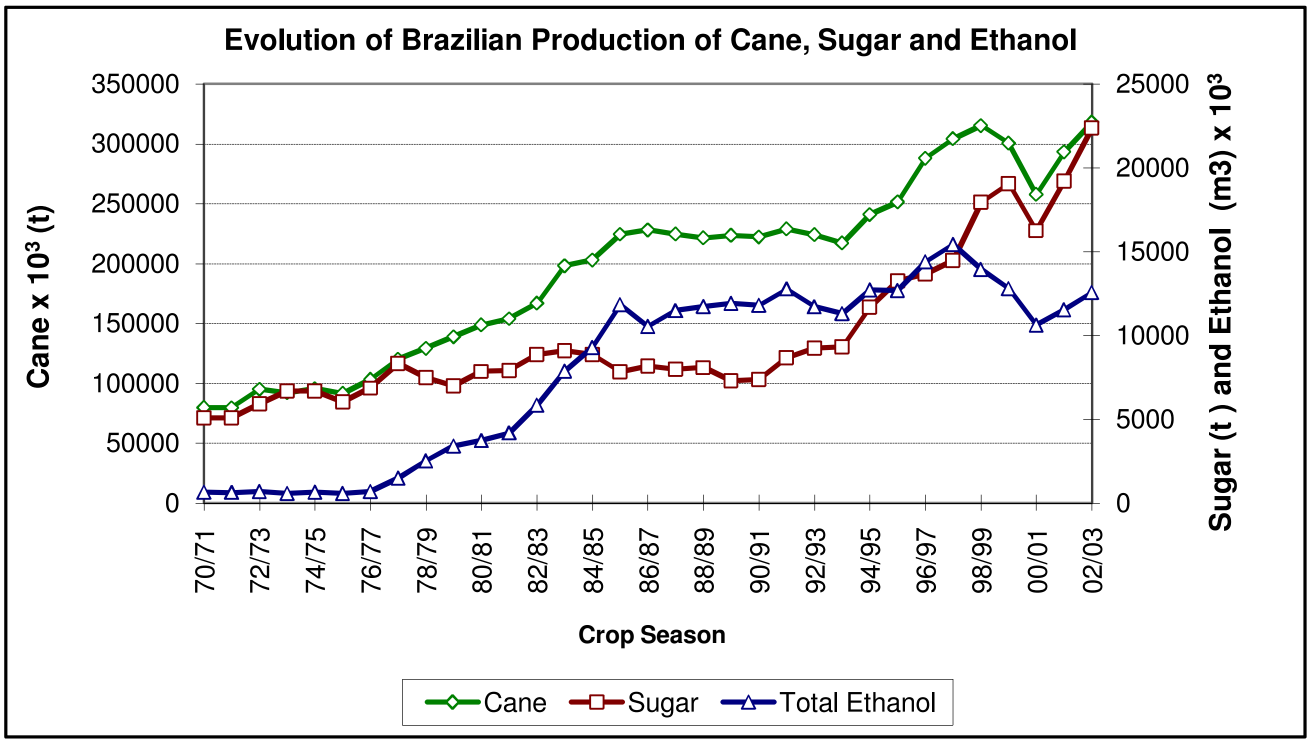
c. Net emission = (avoided emission due to ethanol use) + (ethanol life cycle emission). Co-products credits are included.

GHG mitigation with respect to gasoline: allocation or co-products credits



Direct effects of land use change

- Change in Carbon storage in soil and above ground, when the land use is changed
  From 1984 to 2002: 11.8 to 12.5 M m^3/year → *no land use change for ethanol*



Ethanol: direct effects of land use change

The growth in sugar cane areas since 2002 was over pasture lands (mostly extensive grazing areas) and annual crops:

1. Satellite images (Landsat and CBERS, *since 2003*) (1)
2. Detailed survey from the CONAB (MAPA/DCAA) for the changes in land use *(2007 to 2008);* all sugar cane producing units (349, in 19 states) (2)
3. Data from IBGE, *2002 – 2006*: evaluation at micro-regional level (295 groups), with a Shift Share model (3).
4. Preliminary data from the EIA – RIMA (approved Environmental Impact Analyses) for the units being built in Brazil, *2002 - 2008* (ICONE) (1)

(1) Nassar et al, 2008

(2) CONAB, 2008

(3) ICONE, with IBGE data: Sustainability Considerations for Ethanol, A M Nassar, May 12, 2008

Ethanol: direct effects of land use change

- Satellite Data: 2007 and 2008: 98% from Pasture and Crops; 1.3% from Citrus; *less than 1% from arboreal vegetation.*
- CONAB: 2007/08; 89.5 % from Pasture and Annual crops; 5.4% from Permanent crops; Other, 3.7%; *"new areas" (not all native vegetation): less than 1.5%.*
- Preliminary Data from the EIA – RIMA confirms the *very small use of native vegetation areas.*

This, and the nature of the new sugar cane developments (mechanized harvesting of semi-perennial crop, no cane burning, high residue levels remaining in soil) indicates that the LUC is occurring without increasing GHG emissions. In many cases it will help increase the carbon stock in soil.

Soil carbon content for different crops (t C/ha)

Crop	IPCC defaults[a]		Experimental[b]		Selected Values
	LAC	HAC	HAC	Other	
Degraded pasturelands	33	46	41	16[c]	41
Natural pasturelands	46	63	56		56
Cultivated pasturelands	55	76	52	24[c]	52
Soybean cropland	31	42	53		53
Corn cropland	31	42	40		40
Cotton cropland	23	31	38		38
Cerrado	47	65	46		46
Campo limpo	47	65	72		72
Cerradão	47	65	53		53
Burned cane	23	31	35-37	35[d]	36
Unburned cane	60	83	44-59		51

a. Based on IPCC parameters indicated , IPCC 2006
b. Amaral et al, 2008 (all 0-20 cm).
c. Sandy soils.
d. LAC soils.

Above ground carbon stocks (t C/ha)[a]

Degraded pasturelands	1.3
Cultivated pasturelands (LAC soils)	6.5
Soybean croplands (HAC soils)	1.8
Corn croplands	3.9
Cotton croplands	2.2
Cerrado *sensu strictu* (>20 year without burning)	25.5
Campo limpo (3 year without burning)	8.4
Cerradão (21 year without burning)	33.5
Unburned cane	17.8

a. (Amaral et al, 2008)
Values corresponding for the fully grown plant, annual crops

Emissions associated with LUC to unburned cane

Reference crop	Carbon stock change[a] (t C/ha)	Emissions ($kg\ CO_2eq/m^3$) 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
Corn cropland	11	-317	-272	-195
Cotton cropland	13	-384	-329	-236
Cerrado	-21	601	515	369
Campo limpo	-29	859	737	527
Cerradão	-36	1040	891	638
LUC emissions[b]		**-118**	**-109**	**-78**

a. Based on measured values for below and above ground (only for perennials) Carbon stocks

b. LUC distribution:

2006: 50% pasturelands (70% degraded; 30% natural pasturelands)
50% croplands (65% soybean; 35% other croplands);

2020: 60% pasturelands (70% degraded; 30% natural pasturelands)
40% croplands (65% soybean; 35% other croplands).

Cerrados were always less than 1%.

Comments: Direct LUC effects on GHG emissions

- Expansion areas include a very small fraction of lands with high C stocks, and some degraded land, leading to increased C stocks. Land availability, environmental restrictions and economic conditions (crop values and implementation costs) indicate that direct LUC emissions will not impact ethanol production growth in Brazil in the time frame considered (2020).
- The above ground C stock in sugar cane is relatively high; the change from other crop, or even a *campo limpo*, to sugar cane will produce an additional Carbon capture (corresponding to differences in the "average" above ground Carbon in the plants). This was not included here, since it has not been considered in the IPCC methodology.

General considerations: ILUC effects

Exceptions have been considered for ILUC effects: the use of residues, marginal or degraded lands; or improving yields. *Some* indirect impacts may happen in all other cases, but *we do not have suitable tools (or sufficient information) to quantify them:*

Many agricultural products are interchangeable; and the drivers of LUC vary in time and regionally. "Equilibrium" conditions are not reached. Drivers are established by *local* culture, economics, environmental conditions, land policies and development programs.

→ *Need for the development of a range of methodologies and acquisition / selection of suitable data to reach acceptable, quantified conclusions on ILUC effects.*

General considerations: ILUC effects

- Simplified methodologies consider “distributing” the total ILUC emissions equally among all biofuels. Results would need a large number of significant corrections to accommodate the actual specificities o f many different situations.
- Land used for agriculture today is ~1300. M ha (*excluding pasture lands, ~3000. M ha)*; biofuels use less than 1.5% of that; and possibly less than 4% in 2030 (1). Today’s distribution of production among regions / countries has never considered GHG emissions; it was determined by the local / time dependent drivers. *The better knowledge of those “drivers” and their effects could be much more effective if used to re-direct land use over the 1300. M ha (plus pasture lands) worldwide than just to work on the “marginal” biofuels growth areas.*

(1) Alternative Policy Scenario, IEA – 2006

Ethanol expansion and ILUC effects in Brazil

To produce 60 M m^3 ethanol in 2020, the additional area needed would be 4.9 M ha (Electricity Scenario). This is only 2.5% of the pasture area today (or 1.4% of the arable land).

Land use in Brazil,selected uses (2006)

(UNICA, 2008; Scolari, 2006; FAO,2005;IBGE, 2005).

Land use	Area, M ha	% of arable land	% cultivated land
Total land	850		
Forests	410		
Arable land	340 (40%)	100.0	
Pasture land	200	58.8	
Cultivated land (all crops)	63	18.5	100.0
Soybean	22	6.5	34.9
Corn	13	3.8	20.6
Sugarcane (total)	7	2.1	11.1
Sugarcane for ethanol	3.5	1.0	5.6
Available land	77	22.6	122.2

Ethanol expansion and ILUC effects in Brazil

- The conversion of low quality to higher efficiency productive pasture is liberating area to other crops:
  Heads/ha, Brazil: 0.86 (1996); 0.99 (2006)
  São Paulo State: 1.2 - 1.4 (last years)

  Conversion could release ~ 30 M ha.
- Sugar cane expansion has been independent of (and much smaller than) the growth of other agricultural crops, in the same areas. In all sugar cane expansion areas the eventual competition products (crops and beef production) also expanded.

Sugarcane Expansion: Displacement of Pasture, Crops and Original Vegetation in Selected States, 2002 – 2008 (1)

• Crop area displacement by sugarcane:	0.5%
Crop area *increase*	10.0%
Cereal + Oilseeds production growth	40.0 %
• Pasture area displacement by sugar cane:	0.7%
Pasture area *decrease*	1.7%
Beef production growth	15.0%

(1) Nassar et al, 2008

Ethanol expansion and ILUC effects in Brazil

Within its soil and climate limitations, the environmental legislation in use, and the relatively small areas needed compared to the large land availability, the expansion of sugar cane until 2020 is expected to present (at most) a very small contribution to ILUC GHG emissions.

Cane ethanol and GHG mitigation - Brazil

The aggregated GHG emissions from all sectors in Brazil (excluding forestry – LUC) is ~ 430 M t CO_2 *e* (2008) (1)

The largest fraction is due to the transportation sector (~160 M t CO_2 *e*) (1)

Ethanol production and use in Brazil (2008) reduced emissions in ~36 M t CO_2 *e* (22% of the transportation sector emissions)

Ethanol supplies 50% of all fuel for light duty vehicles.

Sugar cane for ethanol uses 0.5% of Brazil's area.

(1) EPE, 2007. Plano Nacional de Energia 2030; MME, 2007