Interactions between Climate & Bioenergy

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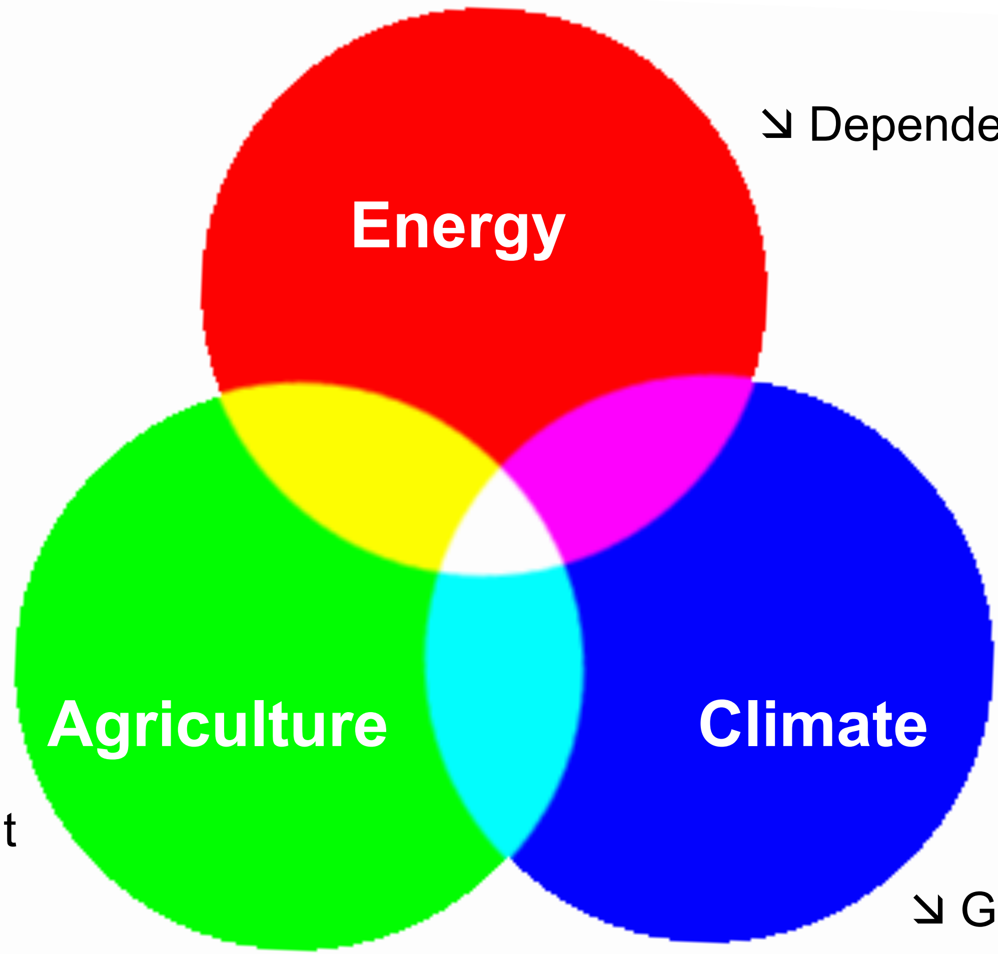
What means ‘Biornergy’ ?

- Energy from biomass
- Biomass: organic matter resulting of the photosynthetic process
    - Crops
    - Wood
    - Residues (straw, sawdust,...)
    - Organic wastes (urban wastes, déchets urbains, sludge, manure, ...)

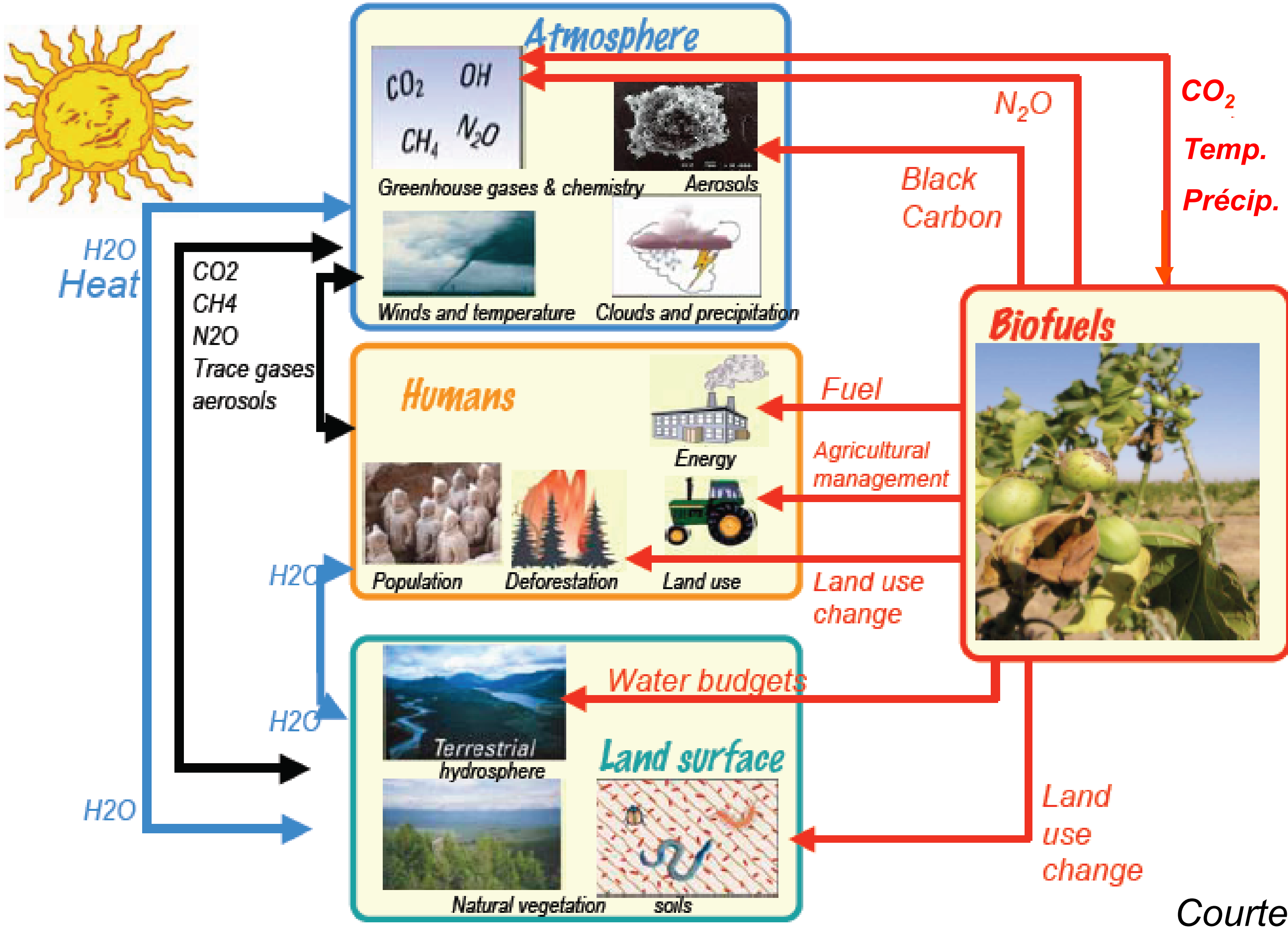
Reasons for enthusiasm

↘ Dependence on fossil fuels



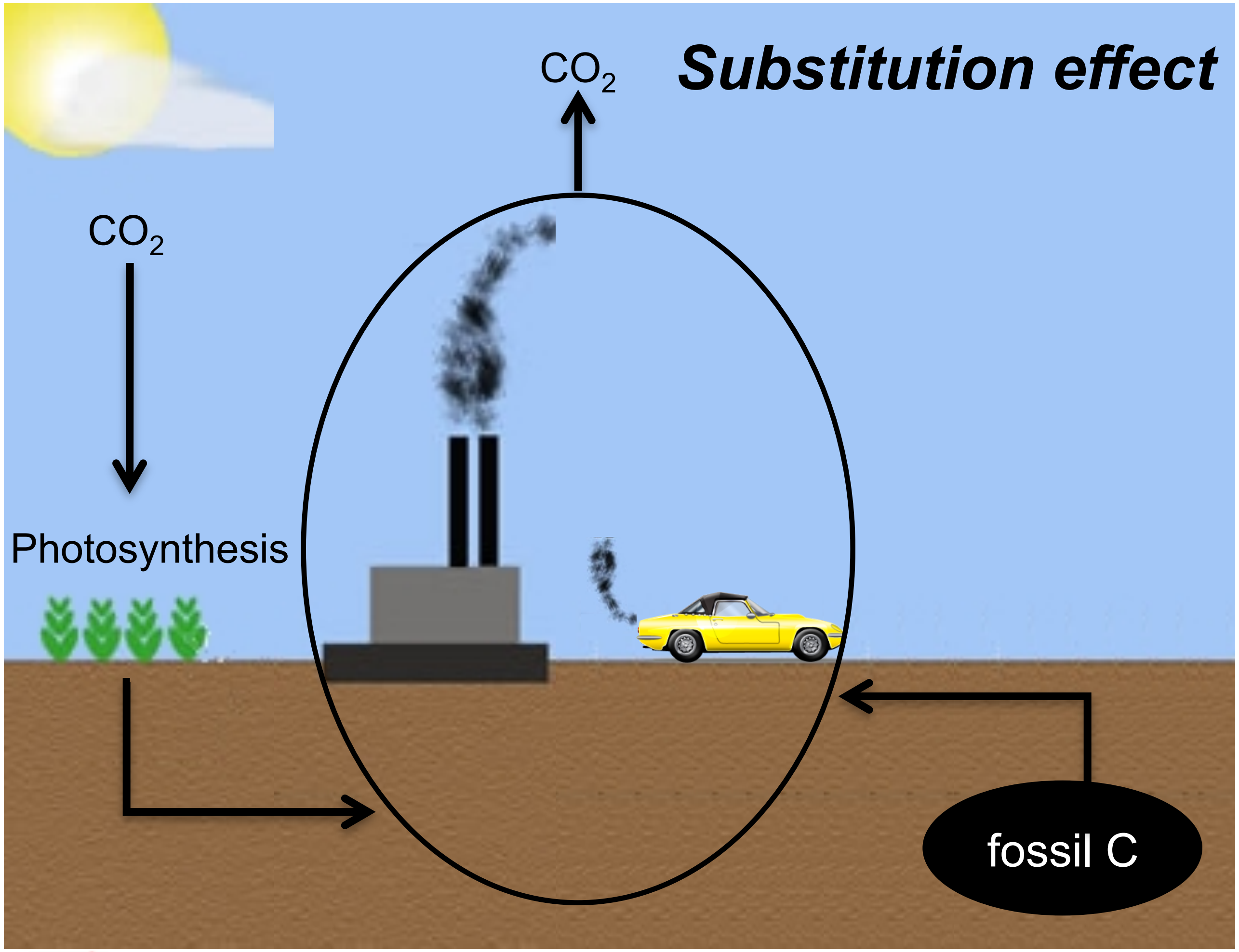
↗ Income
↗ Employment

↘ GHG emissions



Courtesy P. Ciais

Principle of 'Bioenergy'

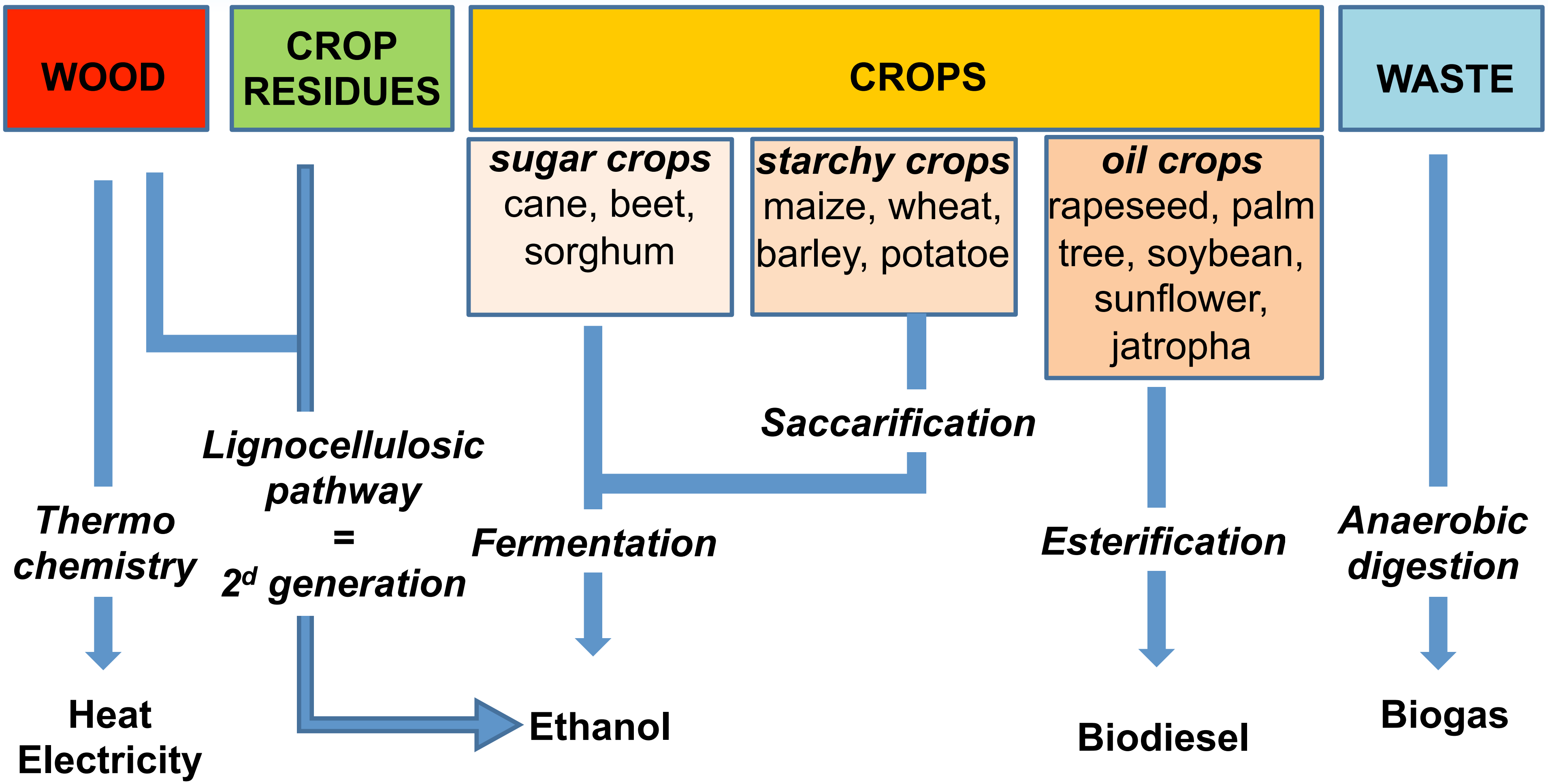


Plan of the presentation

- Overview of the current production
- Quantifying the environmental benefit of biofuel pathways
- Uncertainties and risks associated to the development of biofuel pathways
- Overview of some alternatives

Overview of the current production and potential for near future

The different pathways

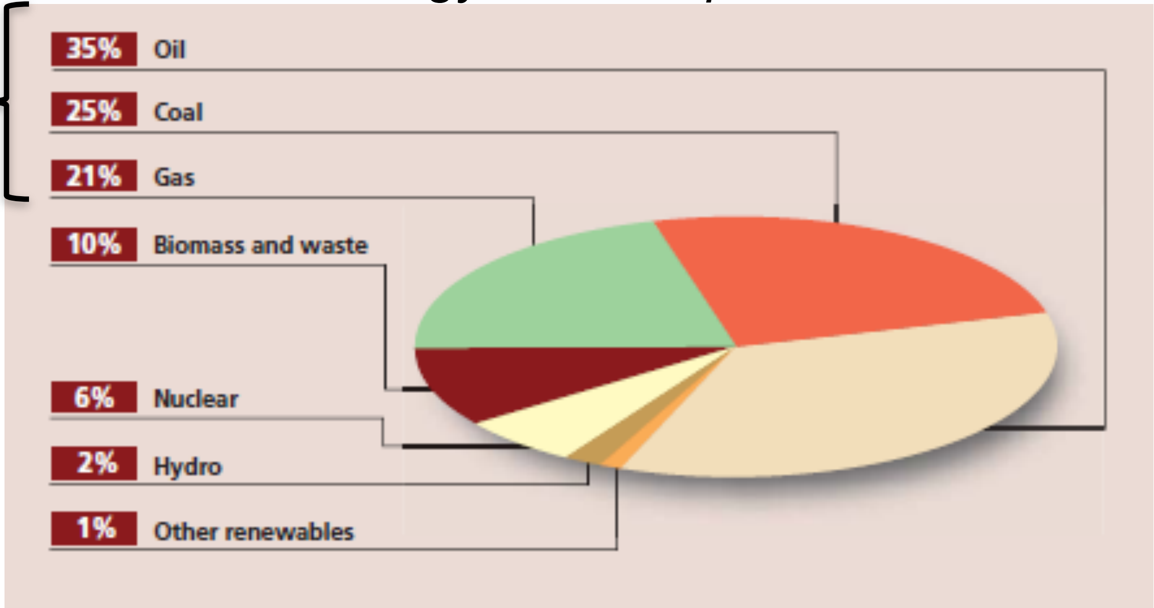


Bioenergy today

Global energy demand per source in 2005

81% fossil

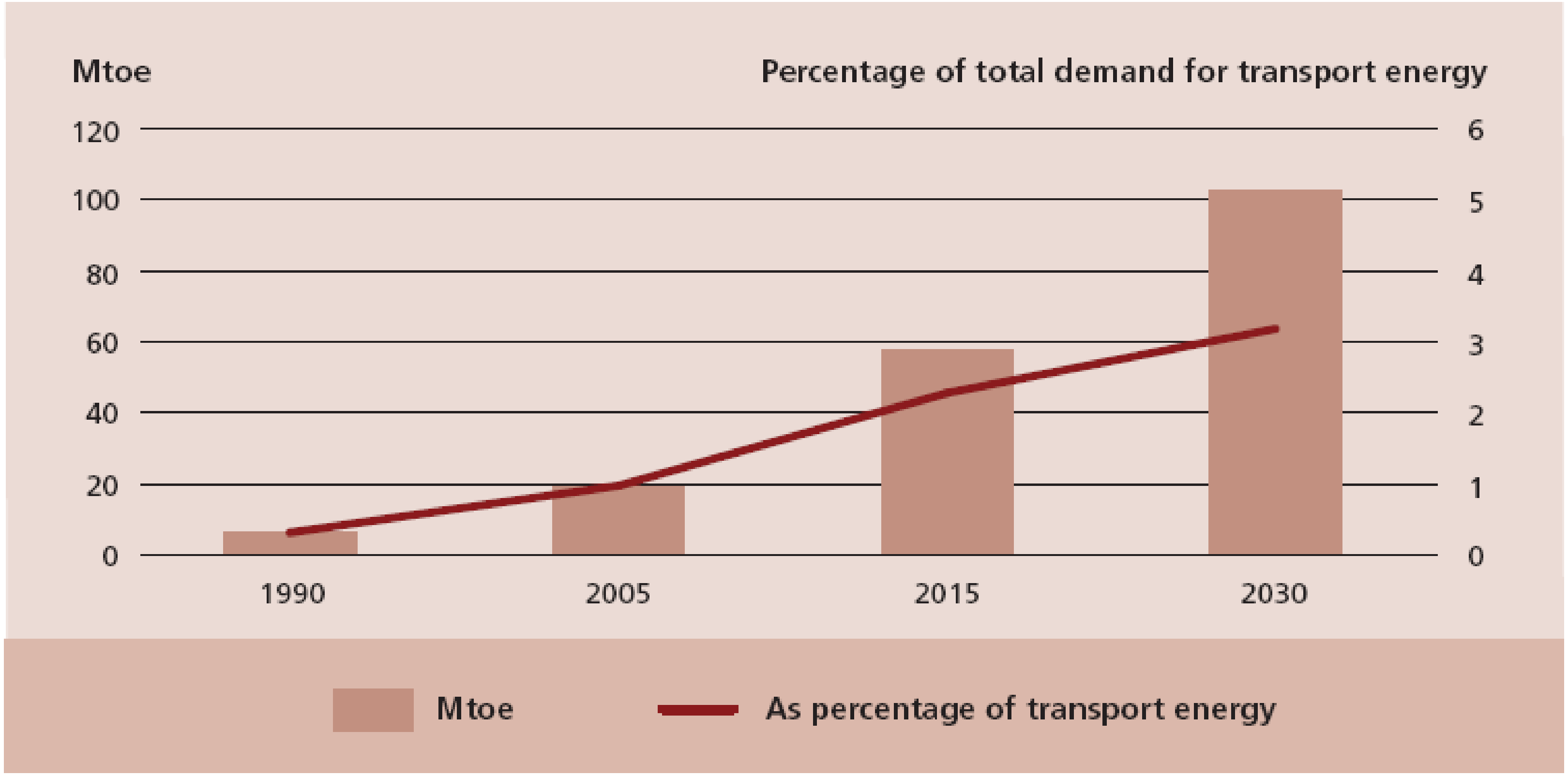
Solid fuels 9,8%
Liquid fuels 0,2%



Source: IEA, 2007 from FAO, 2008

- Solid bioenergy
  - Majority but with only a potential substituting effect
- Liquid bioenergy (biofuels)
  - Minority but with a realized substituting effect

Production evolution



IEA, 2007 from FAO, 2008

Biofuel production per country

COUNTRY/COUNTRY GROUPING	ETHANOL		BIODIESEL		TOTAL	
	(Million litres)	*(Mtoe)*	*(Million litres)*	*(Mtoe)*	*(Million litres)*	*(Mtoe)*
Brazil	19 000	10.44	227	0.17	19 227	10.60
Canada	1 000	0.55	97	0.07	1 097	0.62
China	1 840	1.01	114	0.08	1 954	1.09
India	400	0.22	45	0.03	445	0.25
Indonesia	0	0.00	409	0.30	409	0.30
Malaysia	0	0.00	330	0.24	330	0.24
United States of America	26 500	14.55	1 688	1.25	28 188	15.80
European Union	2 253	1.24	6 109	4.52	8 361	5.76
Others	1 017	0.56	1 186	0.88	2 203	1.44
World	**52 009**	**28.57**	**10 204**	**7.56**	**62 213**	**36.12**

FAO, 2008

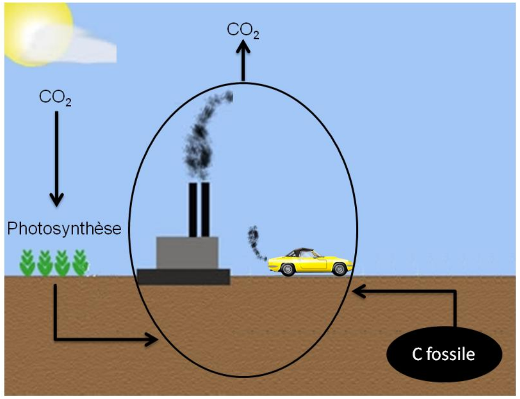
Yields

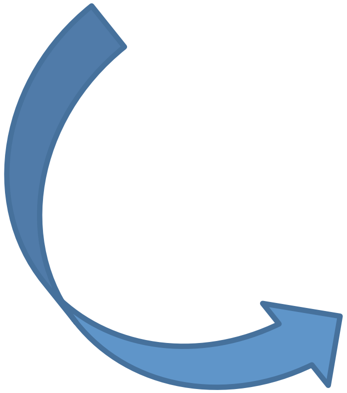
CROP	GLOBAL/NATIONAL ESTIMATES	BIOFUEL	CROP YIELD	CONVERSION EFFICIENCY	BIOFUEL YIELD
			(Tonnes/ha)	*(Litres/tonne)*	*(Litres/ha)*
Sugar cane	Brazil	Ethanol	73.5	74.5	5 476
Sugar cane	India	Ethanol	60.7	74.5	4 522
Oil palm	Malaysia	Biodiesel	20.6	230	4 736
Oil palm	Indonesia	Biodiesel	17.8	230	4 092
Maize	United States of America	Ethanol	9.4	399	3 751
Maize	China	Ethanol	5.0	399	1 995
Cassava	Brazil	Ethanol	13.6	137	1 863
Cassava	Nigeria	Ethanol	10.8	137	1 480
Soybean	United States of America	Biodiesel	2.7	205	552
Soybean	Brazil	Biodiesel	2.4	205	491

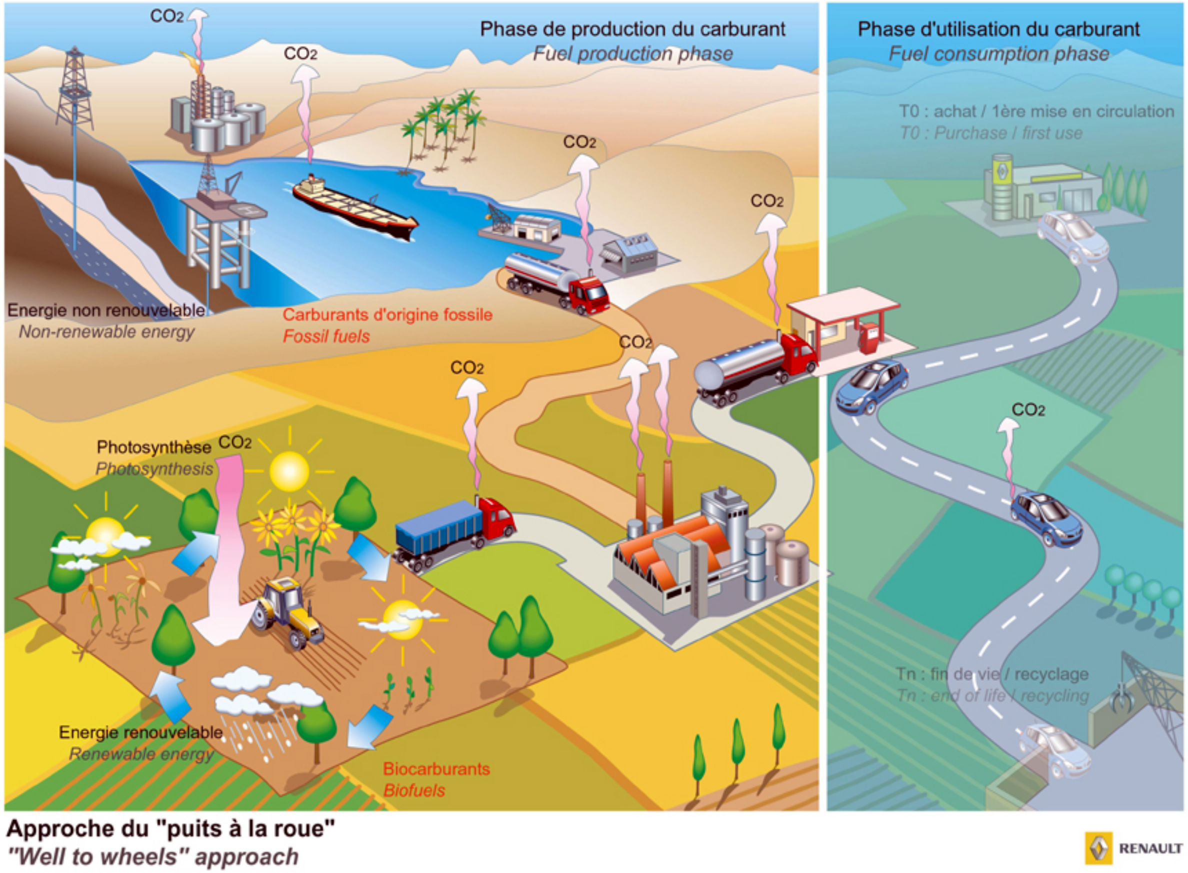
Sources: Rajagopal *et al.*, 2007, for global data; Naylor *et al.*, 2007, for national data.

Quantifying the environmental benefit of biofuel pathways

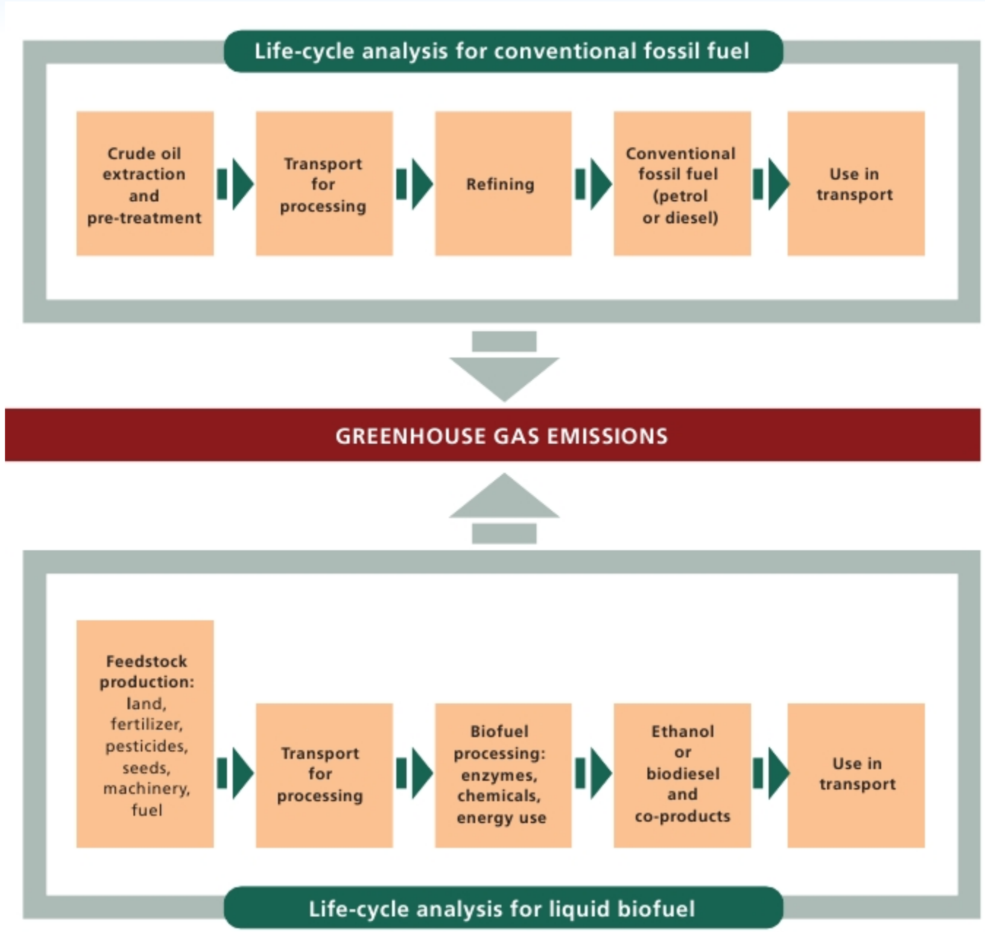
Towards a more realistic approach





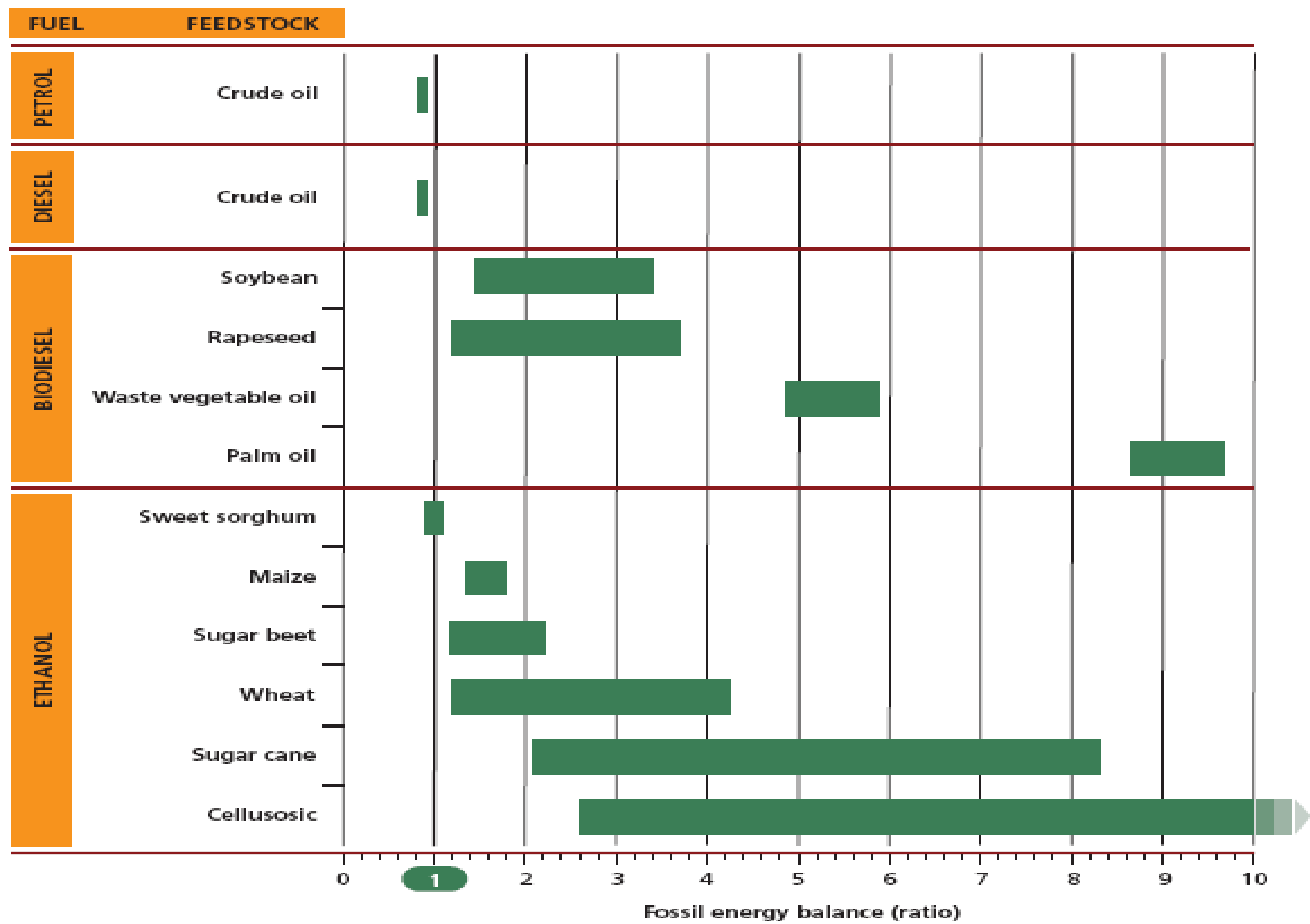


Life cycle analysis

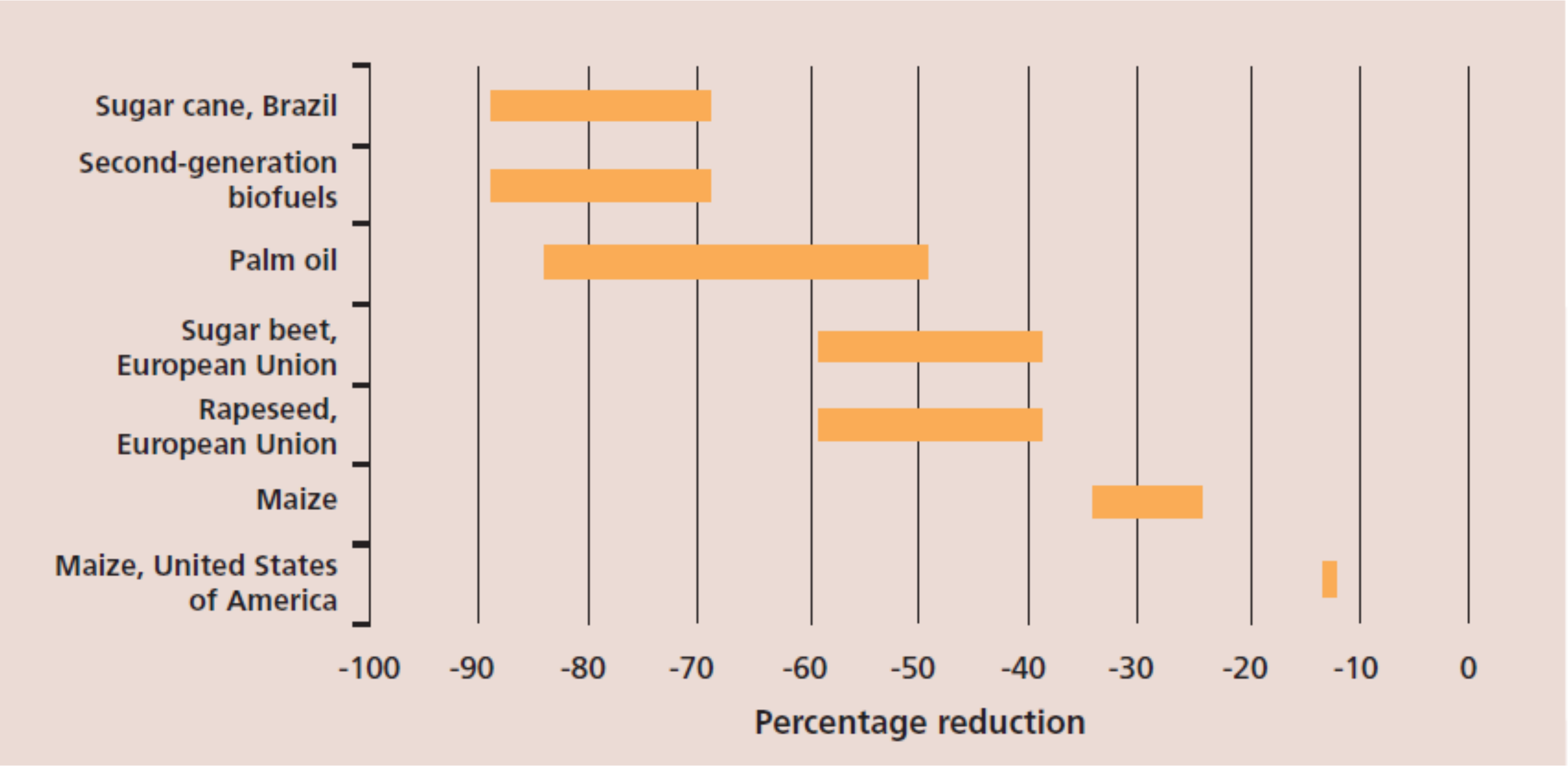


FAO, 2008

Evaluating the energy efficiency



GHG mitigation of different pathwaysfilières



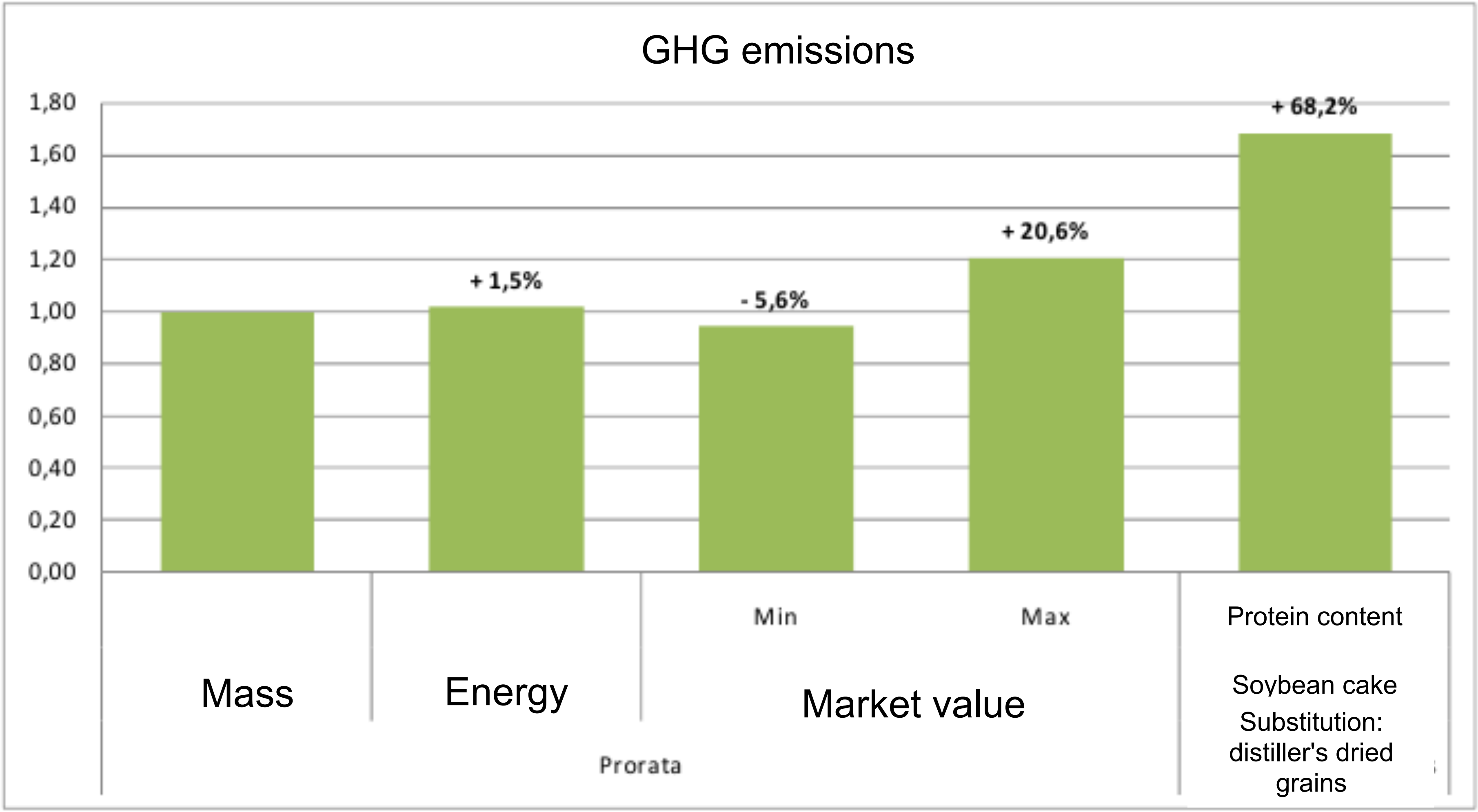
Source: IEA, 2007 from FAO, 2008

Why so much uncertainty ?

- Partial accounting of equipment
- Non-standardized emission factors
- Accounting for Co-products
  – By allocation
    - Mass basis
    - Energy basis
    - Market value basis
  – By system extension (substitution)

Treatment of the co-products

Relative GHG emissions for ethanol from wheat in France

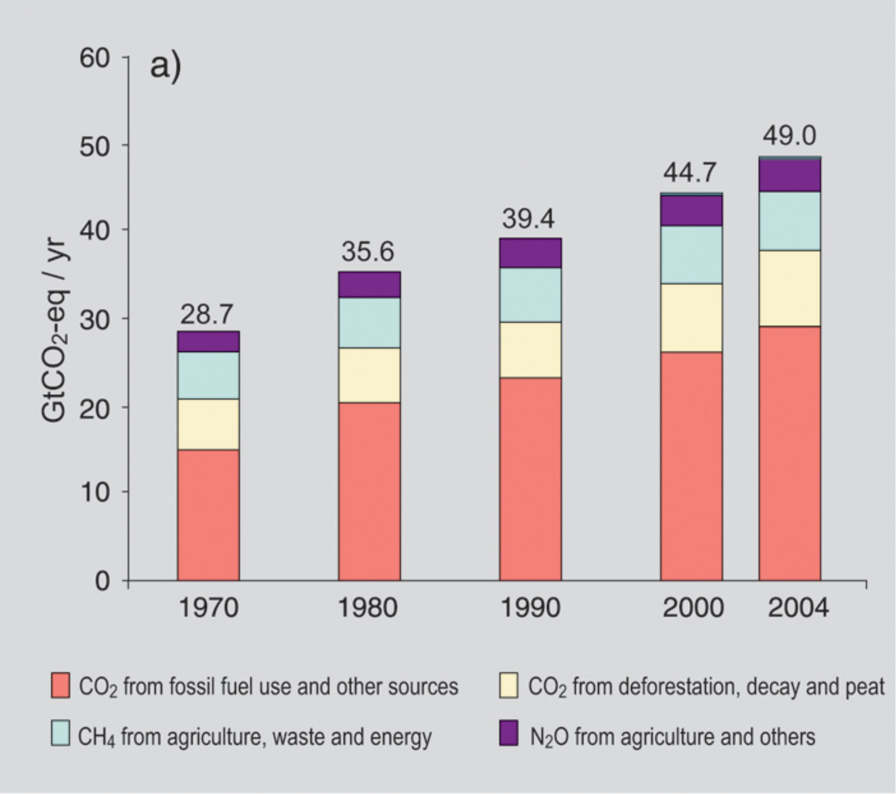


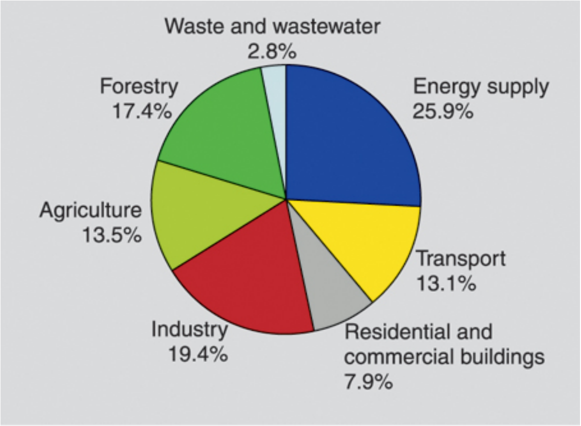
Source: Référentiel pour les ACV des biocarburants de première génération en France, BioIS/ADEME, 2008.

Present-day Substituting effect at global scale

- Biofuel production estimated at ~ 1.5 EJ per year (over 14 Mha)
- With a 'gasoline' reference at 86 gCO_2/MJ and 90% reduction
- The emission of 0.12 $GtCO_2$ per year is avoided by substitution effect

Global GHG Emissions





- 0.2% of the global GHG emissions
- 1.8% of the emissions of the Transport sector

The potential for up-scaling

- 400 EJ en 2050 ⬄ 1500 Mha (IEA Bioenergy, 2008)

Region	Population in 2050	Total land with crop production potential	Cultivated Land in 1990	Additional cultivated land required in 2050	Available area for biomass production in 2050	Max. Additional amount of energy from biomass[a]
	Billion	Gha	Gha	Gha	Gha	EJ/yr
Developed[b]	-	0.820	0.670	0.050	0.100	30
Latin America						
Central & Caribbean	0.286	0.087	0.037	0.015	0.035	11
South America	0.524	0.865	0.153	0.082	0.630	189
Africa						
Eastern	0.698	0.251	0.063	0.068	0.120	36
Middle	0.284	0.383	0.043	0.052	0.288	86
Northern	0.317	0.104	0.04	0.014	0.050	15
Southern	0.106	0.044	0.016	0.012	0.016	5
Western	0.639	0.196	0.090	0.096	0.010	3
China[c]	-	-	-	-	-	2
Rest of Asia						
Western	0.387	0.042	0.037	0.010	-0.005	0
South –Central	2.521	0.200	0.205	0.021	-0.026	0
Eastern	1.722	0.175	0.131	0.008	0.036	11
South –East	0.812	0.148	0.082	0.038	0.028	8
Total for regions above	8.296	2.495	0.897	0.416	1.28	396
Total biomass energy potential, EJ/yr						**441**[d]

Uncertainties and risks associated to the development of biofuel pathways

Reducing the uncertainty of LCA

- Treatment of the co-products
- N_2O emissions
- Accounting for Land-Use change (LUC) impact

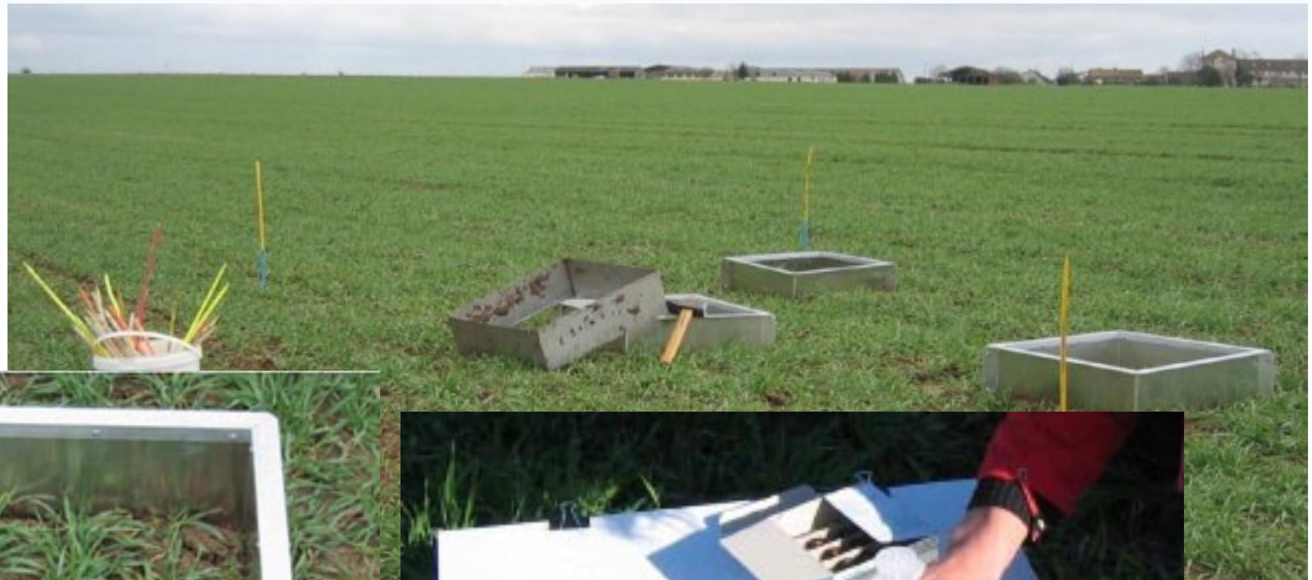
N_2O emissions by soils

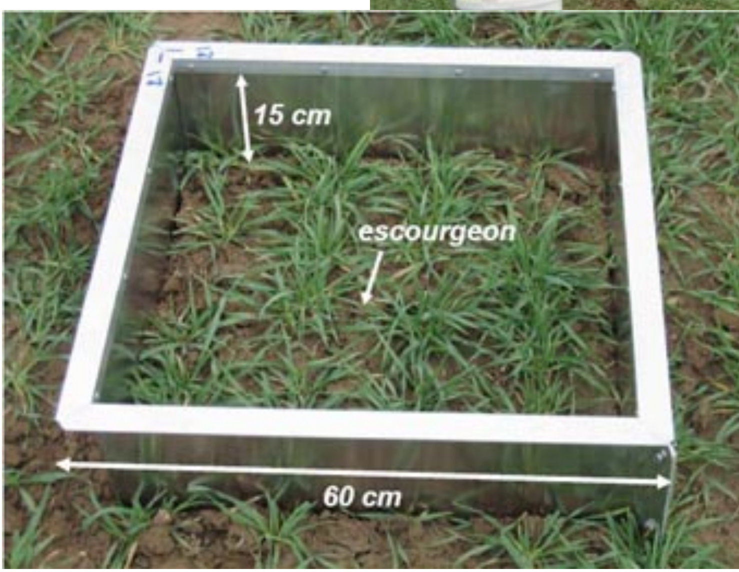
- GHG ~300 times warmer than CO_2
- Nitrification
  - Oxydation from ammonium (NH_4^+) to nitrite (NO_2^-) and nitrate (NO_3^-). N_2O = by product
- Denitrification
  - Microbial process processus microbien transforming des soluble nitrogen oxydes (NO_3^-, NO_2^-) into gaseous compounds (NO, N_2O, N_2)
- Intensity is function of
  - Soil type
  - Humidity / Temperature

Measurement methods

- Static chambers
  - With the measurements of the concentration by mean of different methods:
    - Gas chromotography
    - Tunable Diode Laser (TDL)
- Flux tower
  - By mean of TDL technique

N_2O Measurement methods





High spatial and temporal variability

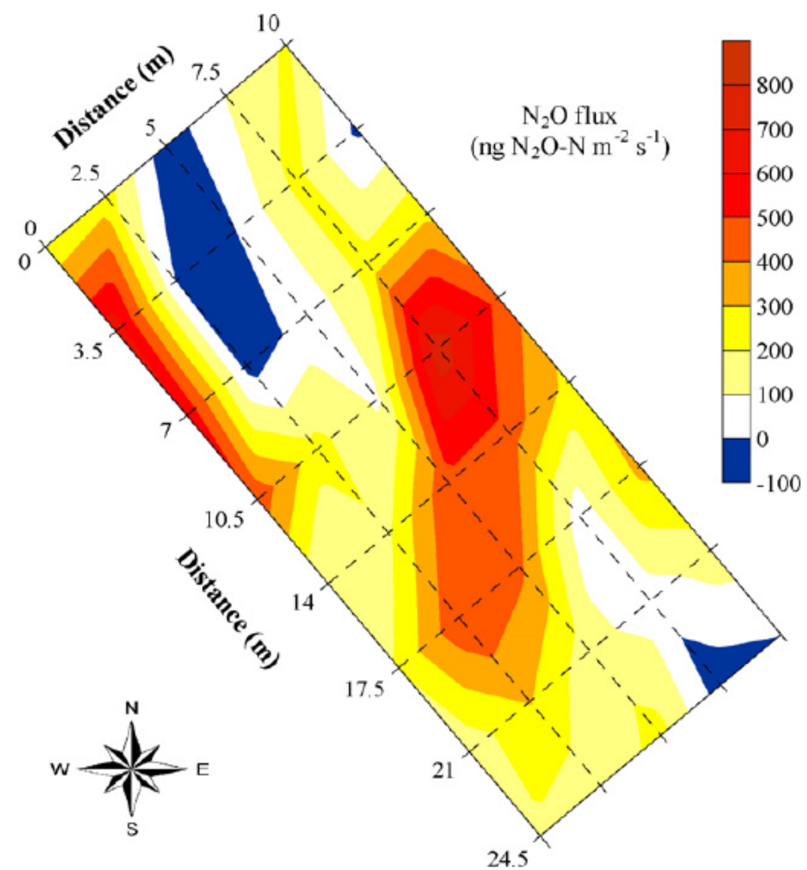
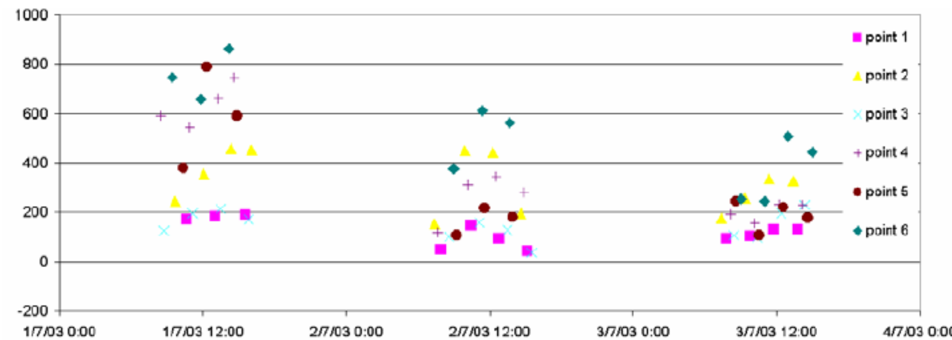


Fig. 2. Spatial variability of N_2O fluxes measured with the Fast-Box technique at Nl-LE. The contour plot is based on flux measurements at 40 points on the 25 m × 10 m grid, each sampling point being at the corner of a 2.5 m × 3.5 m rectangle.

Flechard et al., 2007

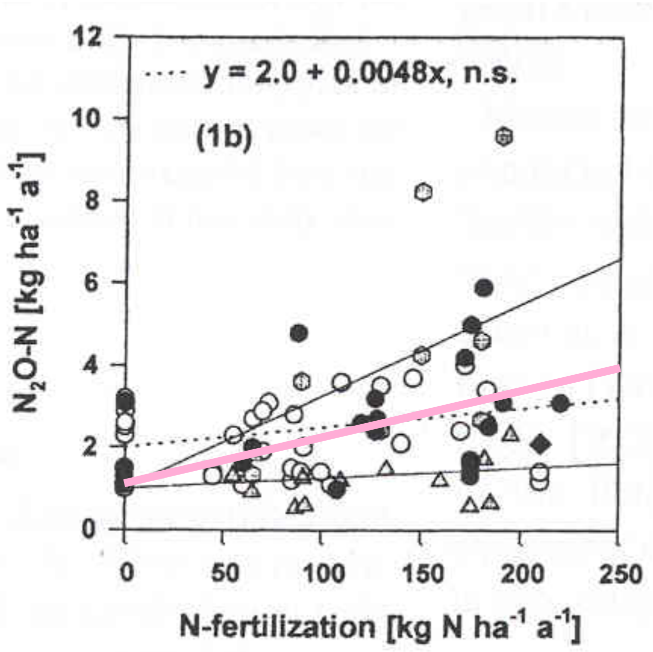
N_2O emissions (en ng m-2 s-1, FAL, Zürich) at Oensingen site (Switzerland)



- Crutzen et al, N2O : ***Release from agro-biofuel production negates global warming reduction by replacing fossil fuels***, ACP, 2008.
  - Q1: How are the N2O emissions by soil estimated in the IPCC methodology ?
  - Q2: Which approach is used in this paper leading the authors to revisit the IPCC estimates ?

Emission factor

- Review of N_2O emission data (≠ crops, regions, years) vs N-input



Envelope of the 'IPCC (1996)' relationship
~1% of the mineral N inputs

Kaiser et al., 2000

A 'top-down' approach

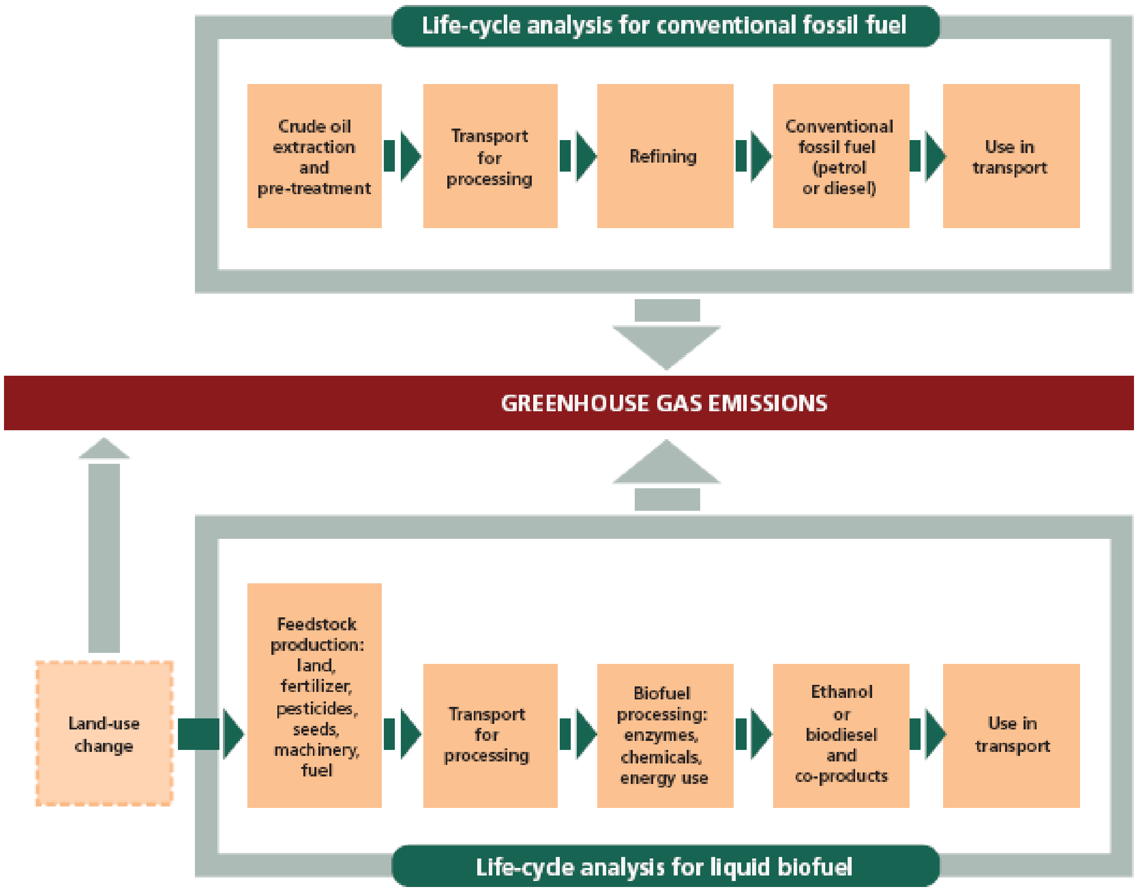
- Crutzen et al. (2007) paper
- Calculation based on the today and pre-industrial N_2O atm. sources and sinks

  => Present-day emissions : ~6 TgN_2O-N yr^{-1}
- Deduction of Industrial Emissions

  => Agricultural emissions : ~5 TgN_2O-N yr^{-1}

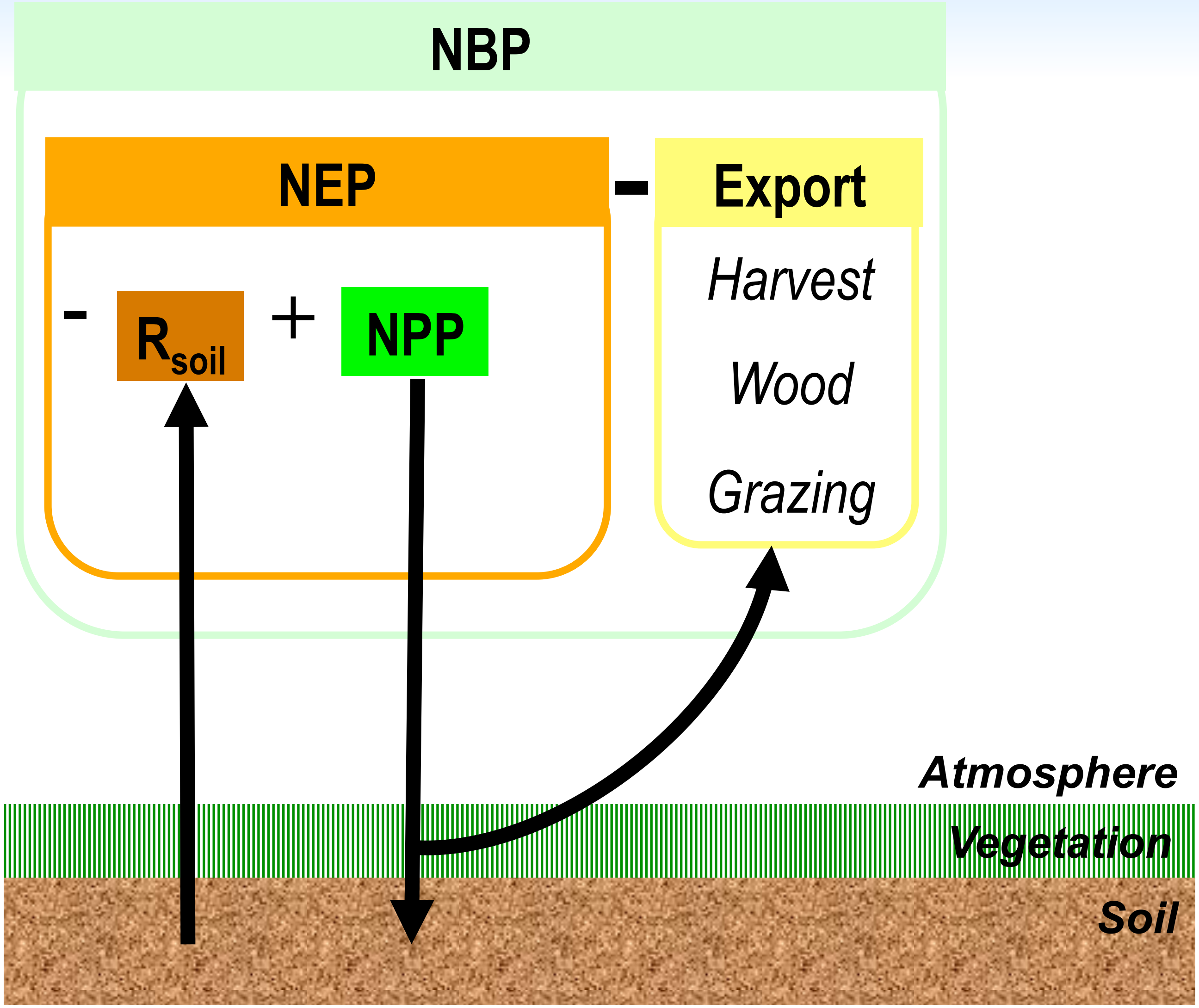
  ~5% of the global mineral fertilisation

Accounting for LUC



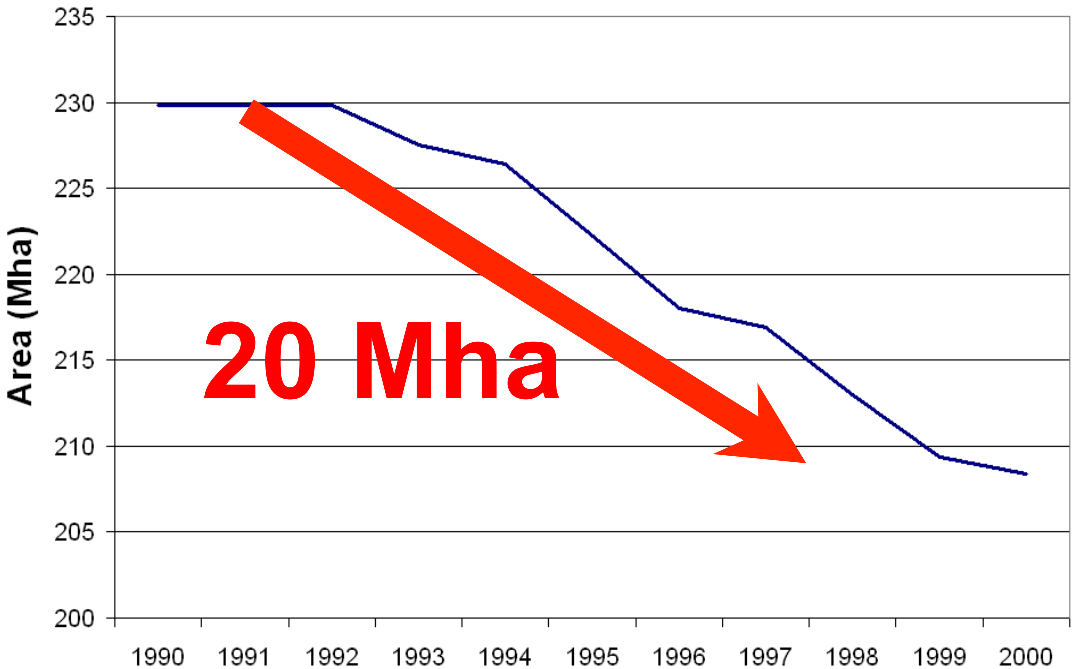
- Fargione et al., ***Land Clearing and the Biofuel Carbon Debt***, Science, 2008
  - Q1: What is the process highlighted in this paper that increases the CO2 emissions of biofuel production ?
  - Q2: What is the definition of the 'carbon debt' ?
  - Q3: Based on this study, on which type of lands, the carbon debt of biofuel produciton is the higest ? the lowest ?

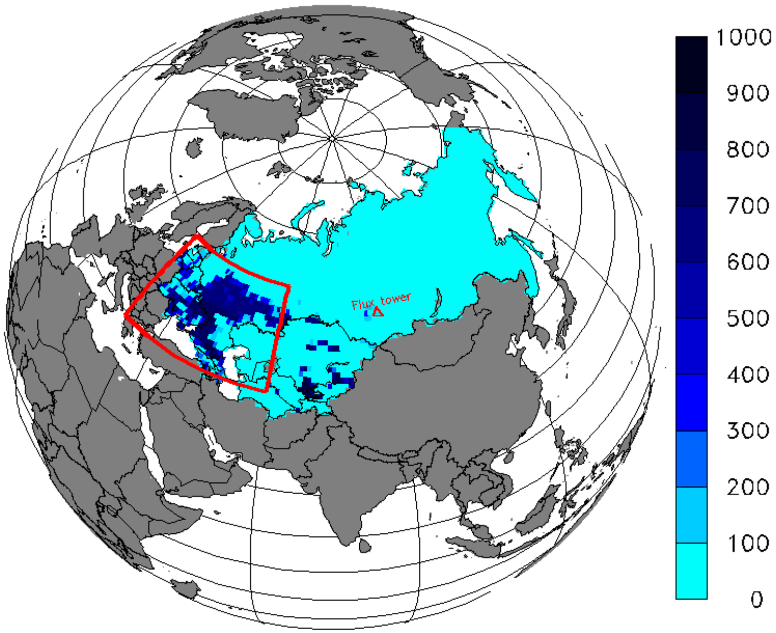
The associated process



An example

- Massive abandonment of cultivated lands in former USSR since 1990

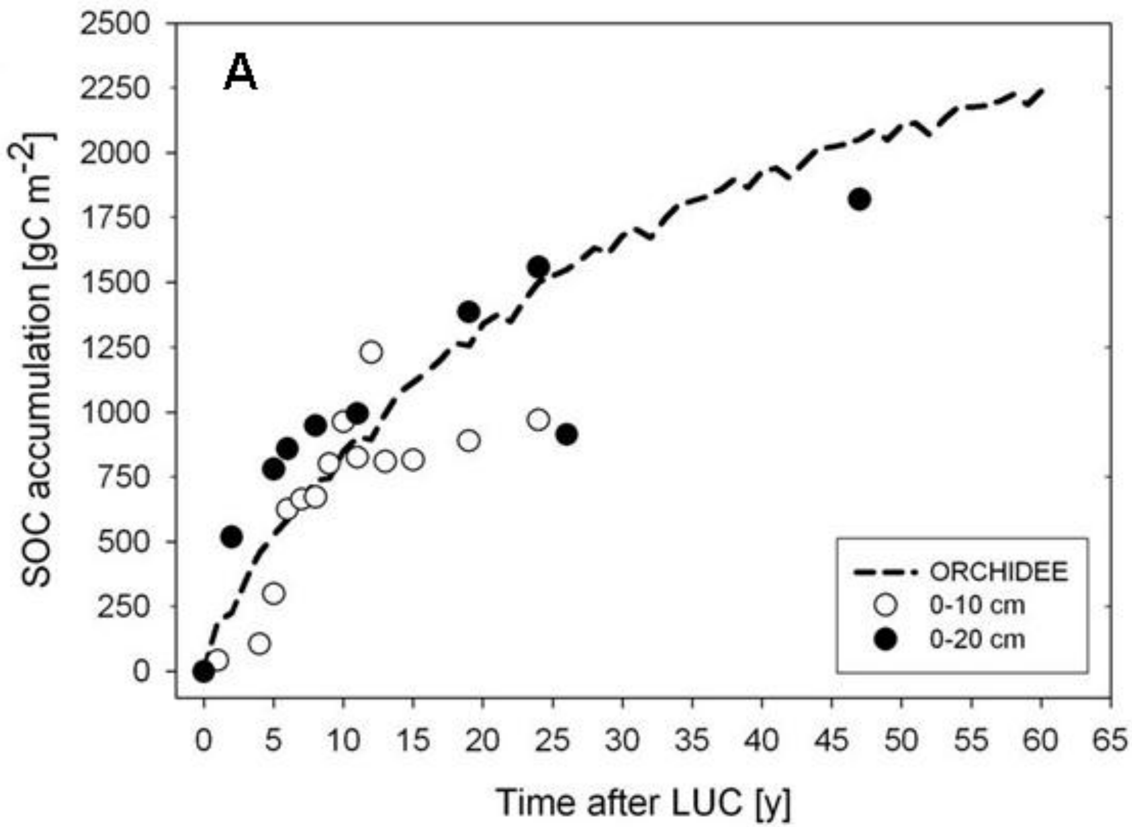




Hurtt *et al.*, Global Change Biology, 2006

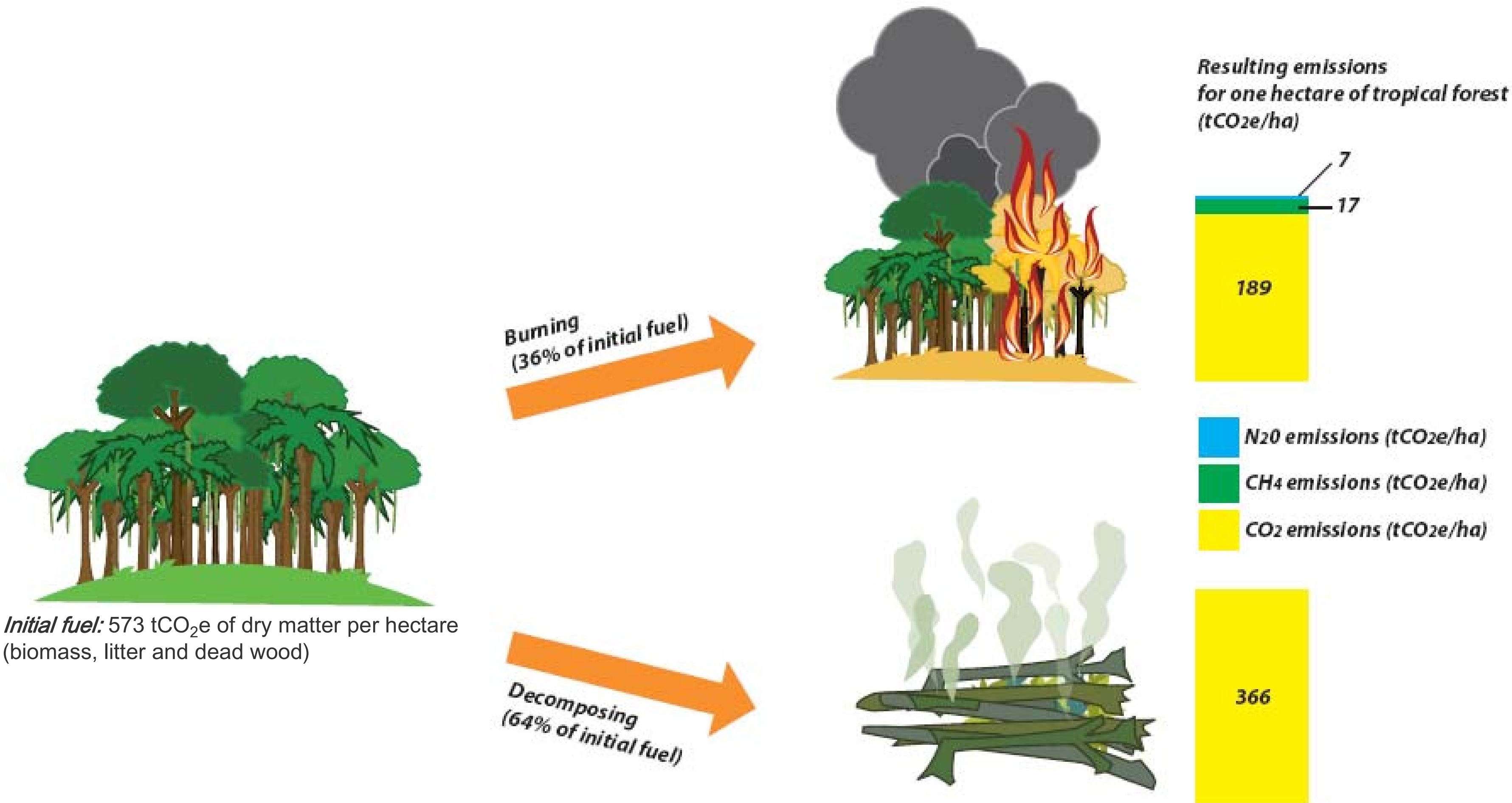
An example

- Carbon stock in abandoned agricultural soils



From Belelli (pers. comm.)

Deforestation process

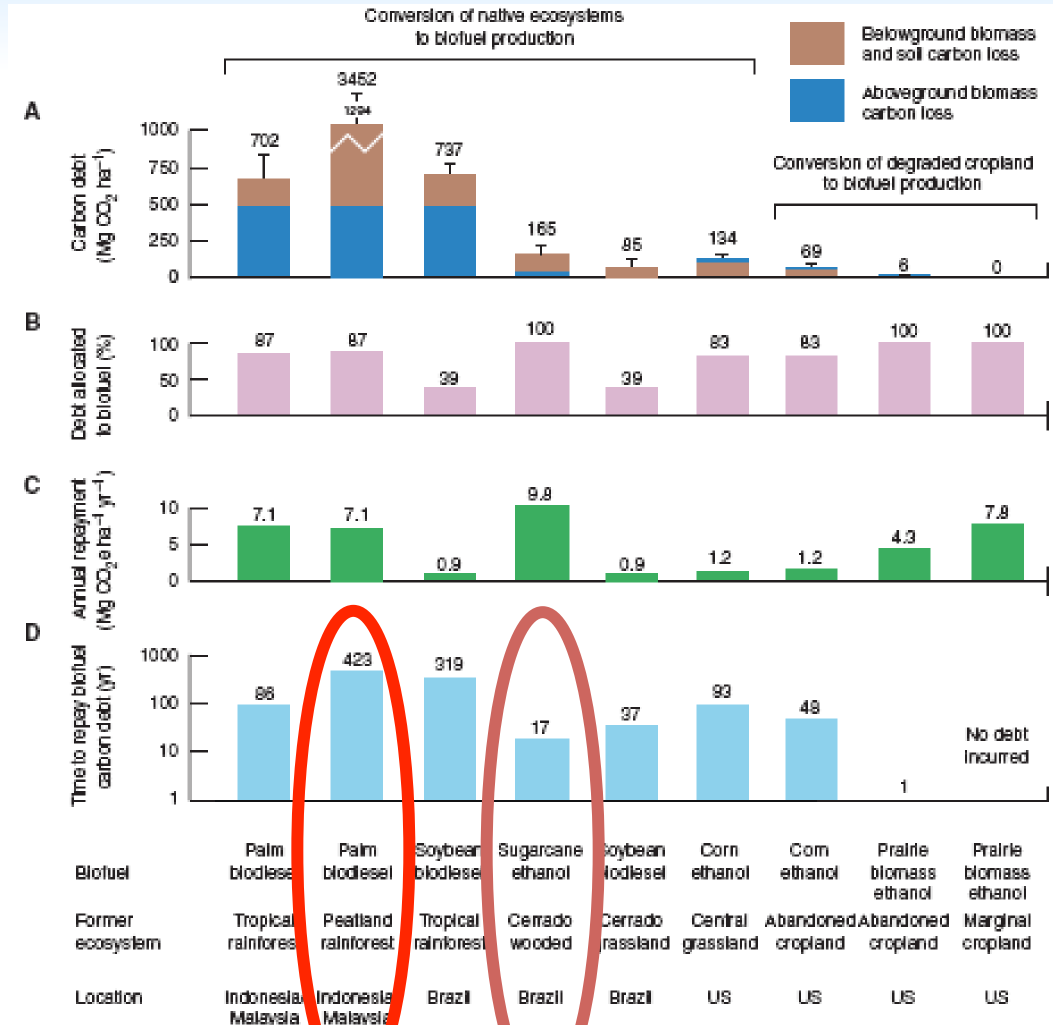


Bellassen, 2008

The concept of "carbon debt"

Science, 2008

- LUC may induce a carbon loss
- Some Bioenergy crops will need several years for compensating this C loss



Land Clearing and the Biofuel Carbon Debt

Joseph Fargione,[1] Jason Hill,[2,3] David Tilman,[2*] Stephen Polasky,[2,3] Peter Hawthorne[*]

- Lapola et al., ***Indirect land-use changes can overcome carbon savings from biofuels in Brazil***, PNAS, 2010
  - Q1: What are the two types of Land-use changes that are considered in this sutdy? Could you provide a definition for both terms ?
  - Q2: What are the different models used in this study and what do they simulate ?

Up-scaling: from local to globe

- Impact of Indirect Land Use Change (iLUC)
  - US Corn-base ethanol production

20% GHG reduction

↓ *iLUC*

100% GHG increase

Searchinger, 2008, Science

Story of a scientific controversy

- April 2009 – Implementation of a regulation process on Oil in California state (Low Carbon Fuel Standard, LCFS)

- Precedeed of a public consultation process
  - Controversy about iLUC impacts

California carbon intensity values for gasoline, diesel and fuels that substitute them[22][41][47] (grams of CO_2 equivalent released per MJ of energy produced)			
Fuel type	**Carbon intensity**	**Carbon intensity + land-use changes**	**Intensity change respect to 2011 LCFS**
Midwest corn ethanol	75.10	105.10	+10%
California gasoline	95.86	95.86	+0.2%
CARB LCFS 2011 for gasoline[41]	**-**	**95.61**	**-**
California diesel (ULSD)	94.71	94.71	+0.2%
CARB LCFS 2011 for diesel[41]	**-**	**94.47**	**-**
California ethanol	50.70	80.70	-16%
Brazilian sugarcane ethanol	27.40	73.40	-23%
Biodiesel (B100) Midwest soybeans(1)	26.93	68.93	-27%
Renewable diesel Midwest soybeans(1)	28.80	68.93	-27%
Cellulosic ethanol (farmed trees)(1)	2.40	20.40	-79%
Compressed natural gas (bio-methane)	11.26	11.26	-88%

Mary D. Nichols, Chairman
California Air Resources Board
1001 "I" Street
P.O. Box 2815
Sacramento, CA 95812

June 24, 2008

Dear Chairwoman Nichols,

We are writing regarding the California Air Resources Board's (ARB) ongoing development of the Low Carbon Fuel Standard (LCFS). As you are well aware, the Governor issued Executive Order S-1-07 on January 18, 2007, which calls for a reduction of at least 10 percent in the carbon intensity of California's transportation fuels by 2020.

As researchers and scientists in the field of biomass to biofuel conversion, we are convinced that there simply is not enough hard empirical data to base any sound policy regulation in regards to the indirect impacts of renewable biofuels production. The field is relatively new, especially when compared to the vast knowledgebase present in fossil fuel production, and the limited analyses are driven by assumptions that sometimes lack robust empirical validation.

As an example of the confusion that this lack of reliable data produces, there has been significant attention to a recent article by Searchinger and

As researchers and scientists in the field of biomass to biofuel conversion, we are convinced that there simply is not enough hard empirical data to base any sound policy regulation in regards to the indirect impacts of renewable biofuels production. The field is relatively new, especially when compared to the vast knowledgebase present in fossil fuel production, and the limited analyses are driven by assumptions that sometimes lack robust empirical validation.

Searchinger, 2008). Searchinger also ignored the fact that the protein in corn still goes on for use as cattle feed as it cannot be converted to ethanol, with the result that there is no reduction in protein available for feeding animals, the major (about 60%) market for corn.

The traditional tools used by researchers, including Searchinger et al., to determine the direct and indirect impacts of renewable biofuel production are life cycle analysis (LCA) coupled with land-use change (LUC) projections. The results produced by the majority of the LCA models are highly sensitive to LUC assumptions, as well as baseline projections and test cases that have very limited scope. These sensitivities highlight how common LCA models can be applied to the same problem but produce significantly different, and often contradictory, results. There remain great uncertainties and challenges in combining LUC and LCA models that make their use highly problematic, particularly if the outputs of these models are used as a basis for policy decisions, or for comparing indirect impacts between fuel types. Some of the problems include the lack of large-scale, reliable data sets from field and process trials of growing, harvesting, and converting dedicated energy crops into biofuels. These data are needed as "training sets" for the LCA models.

NEW FUELS ALLIANCE

October 23, 2008

Mary D. Nichols, Chairman
California Air Resources Board
Headquarters Building
1001 "I" Street
Sacramento, CA 95812

Dear Chairman Nichols,

We, the undersigned 30 companies and individuals, are writing to provide comment on the

> We are aware that proponents of including ILUC in the regulation argue that a preliminary quantification of ILUC is better than ignoring the impact all together; that "zero" is not the right number for ILUC for biofuels. While it is likely true that zero is not the right number for the indirect effects of any product in the real world, enforcing indirect effects in a piecemeal way could have very serious consequences for the LCFS. For example, zero is also not the right

the LCFS be careful in its regulatory approach if it is to foster sustainable fuel production.

The argument in favor of including ILUC in the LCFS is based on the belief that biofuels have significant indirect land use impacts, and ignoring them is the wrong public policy decision. The argument against including ILUC in the LCFS is based on the belief that the field of ILUC – and perhaps indirect impact modeling in general – is too uncertain to regulate at this time.

> effects, they must be enforced against all fuel pathways. The argument that zero is not the right number does not justify enforcing a different wrong number, or penalizing one fuel for one category of indirect effects while giving another fuel pathway a free pass.

ripple effects of any given market decision in the global economy. Indirect impacts have not been enforced by any regulatory agency against any product in the world. Indirect impacts, whether applied to biofuels or any other fuel, occur as a consequence of a myriad of nested, policy and socio-economic variables. An article published in *BioScience* magazine captures the complexity of indirect effects, as they relate to deforestation: "[a]t the underlying level, tropical deforestation is … best explained by multiple factors and drivers acting synergistically rather than by single-factor causation, with more than one-third of the cases being driven by the full interplay of

April 21, 2009

Mary D. Nichols, Chairman
California Air Resources Board
Headquarters Building
1001 "I" Street
Sacramento, CA 95812

Dear Chairman Nichols,

As scientists and economists with relevant expertise, we are writing to recommend that you include indirect land use change in the lifecycle analyses of heat-trapping emissions from biofuels and other transportation fuels. This policy will encourage development of sustainable, low-carbon fuels that

As scientists and economists with relevant expertise, we are writing to recommend that you include indirect land use change in the lifecycle analyses of heat-trapping emissions from biofuels and other transportation fuels. This policy will encourage development of sustainable, low-carbon fuels that avoid conflict with food and minimize harmful environmental impacts.

science. However, you should not delay inclusion of known sources of emissions, including indirect emissions from biofuels, pending discovery of potential effects from other fuels.

Recent peer-reviewed research indicates that conventional biofuels can directly or indirectly result in substantial heat-trapping emissions through the conversion of forests and grasslands to croplands to

There are uncertainties inherent in estimating the magnitude of indirect land use emissions from biofuels, but assigning a value of zero is clearly not supported by the science. The data on land use change indicate that the emissions related to biofuels are significant and can be quite large.

change indicate that the emissions related to biofuels are significant and can be quite large.
Grappling with the technical uncertainty and developing a regulation based on the best available science is preferable to ignoring a major source of emissions. Over time, greater accuracy and detail in a more refined analysis can be reflected in future LCFS rulemakings.

The need to address uncertainties applies to other areas the analysis as well, and we urge you to evaluate the increasing use of nitrogen fertilizers and herbicides associated with greater biofuel production. In particular, nitrogen fertilizers enhance the emission of nitrous oxide—a powerful greenhouse gas in Earth's atmosphere.

State of California
AIR RESOURCES BOARD

Resolution 09-31

April 23, 2009

Agenda Item No.: 09-4-4

WHEREAS, sections 39600 and 39601 of the Health and Safety Code authorize the Air Resources Board (ARB or the Board) to adopt standards, rules and regulations and to do such acts as may be necessary for the proper execution of the powers and duties granted to and imposed upon the Board by law;

WHEREAS, the California Global Warming Solutions Act of 2006 (AB 32; Stats 2006, ch. 488, Health and Safety Code sections 38500-38599) declares that global warming poses a serious threat to the economic well-being, public health, natural resources, and the environment of California, and creates a comprehensive multi-year program to reduce California's greenhouse gas (GHG) emissions to 1990 levels by 2020;

WHEREAS, section 38510 of the Health and Safety Code designates ARB as the State

For some crop-based biofuel pathways, the certified carbon intensity values would also account for additional GHG emissions that can result from changes in land use arising from use of the biofuels; the Global Trade Analysis Project (GTAP) model is to be used to evaluate the worldwide land use conversion associated with the production of crops for fuel production;

Board to adopt regulations on or before January 1, 2010 to implement the Discrete Early Action Measures; these regulations are to be enforceable no later than January 1, 2010;

WHEREAS, section 38560.5(c) of the Health and Safety Code provides that the regulations adopted to implement Discrete Early Action Measures must achieve the maximum technologically feasible and cost-effective reductions in GHG emissions;

WHEREAS, in January 2007, Governor Schwarzenegger issued Executive Order S-01-07, which established the goal of developing a low carbon fuel standard (LCFS) to reduce the carbon intensity of transportation fuels by at least 10 percent by 2020; the Executive Order provides that the LCFS shall apply to all providers of transportation

California's Low Carbon Fuel Standard

(An Update on the California Air Resources Board's
Low Carbon Fuel Standard Program)

To help address indirect land use issues, the Board, at the April public hearing, directed staff to convene an expert workgroup to assist staff in refining and improving the land use and indirect effect analysis of transportation fuels and to return to the Board no later than January 1, 2011, with regulatory amendments or recommendations, if appropriate, on approaches to address issues identified. Staff is to coordinate this effort with similar efforts by the U.S. EPA, European Union, and other agencies pursuing a low carbon fuel standard.

October 2009

California Environmental Protection Agency
Air Resources Board

Overview of some alternatives

Cultivating on Abandoned Agricultural Lands

- Two studies

The Global Potential of Bioenergy on Abandoned Agriculture Lands

J. ELLIOTT CAMPBELL,*,†,‡
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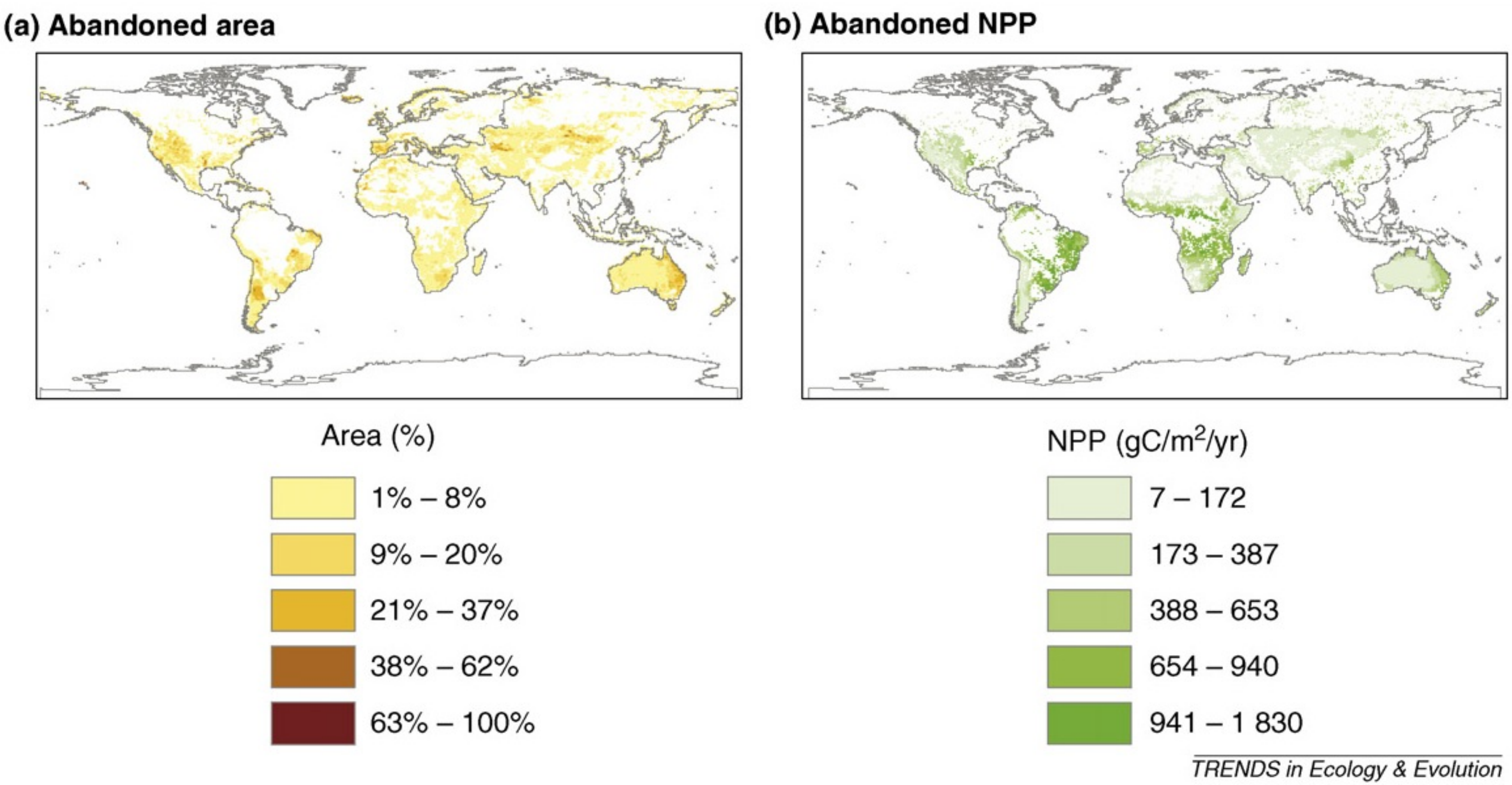
Envir. Sci. Technol., 2008

Biomass energy: the scale of the potential resource

Christopher B. Field[1], J. Elliott Campbell[1] and David B. Lobell[2]

Trends in Ecology and Evolution, 2007

Potential area and associated NPP



At global scale

- Quelques ordres de grandeur:
  - Global area : ~400 Mha
  - Mean NPP : ~3 tC ha^{-1} an^{-1}
  - 50% of shoot biomass, 45% C, energy content: 20 kJ g^{-1}

  => 5% of global energy demand
- Conclusion
  - Maximum to not exceed
    - On a larger area -> food vs fuel competition
    - With more inputs -> ↘ climate benefit

2d generation biofuels

- For instance, Tilman (2006)

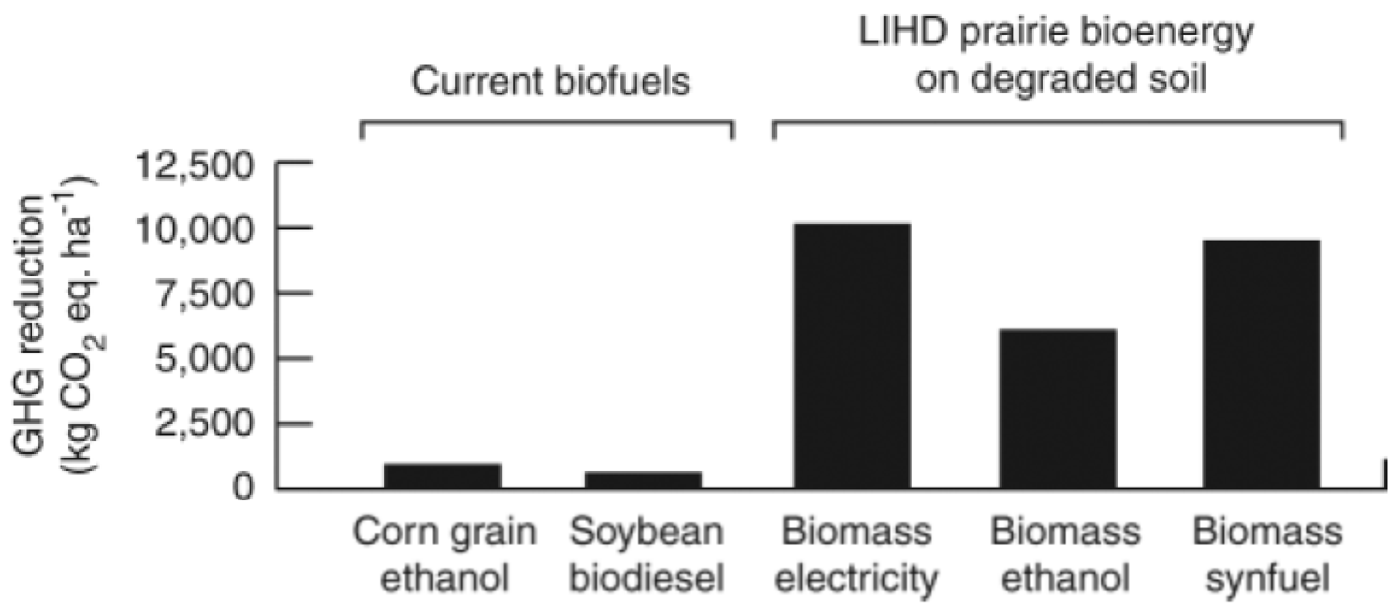
Carbon-Negative Biofuels from Low-Input High-Diversity Grassland Biomass

Science, 2006

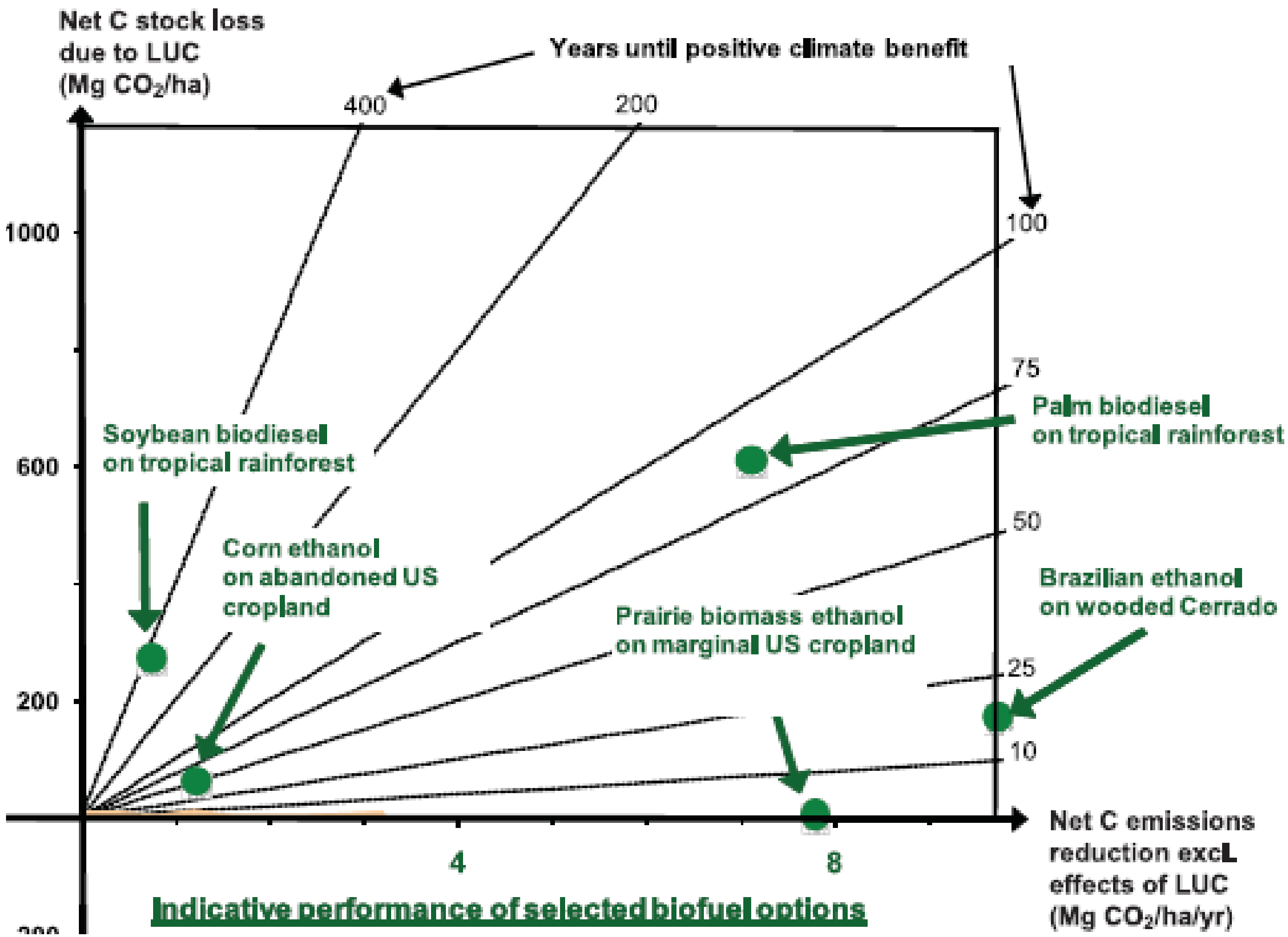
David Tilman,[1*] Jason Hill,[1,2] Clarence Lehman[1]

  - Bioenergy production from perennial herbaceous species (Low Input High Diversity (LIHD) grasslands)
    - Good energy yield
    - High GHG mitigation potential

Comparison to first generation biofuels



Contracting a carbon debt



Source: IEA Bioenergy, 2008 d'après Fargione, 2008

Rather than growing biofuels…plant forests

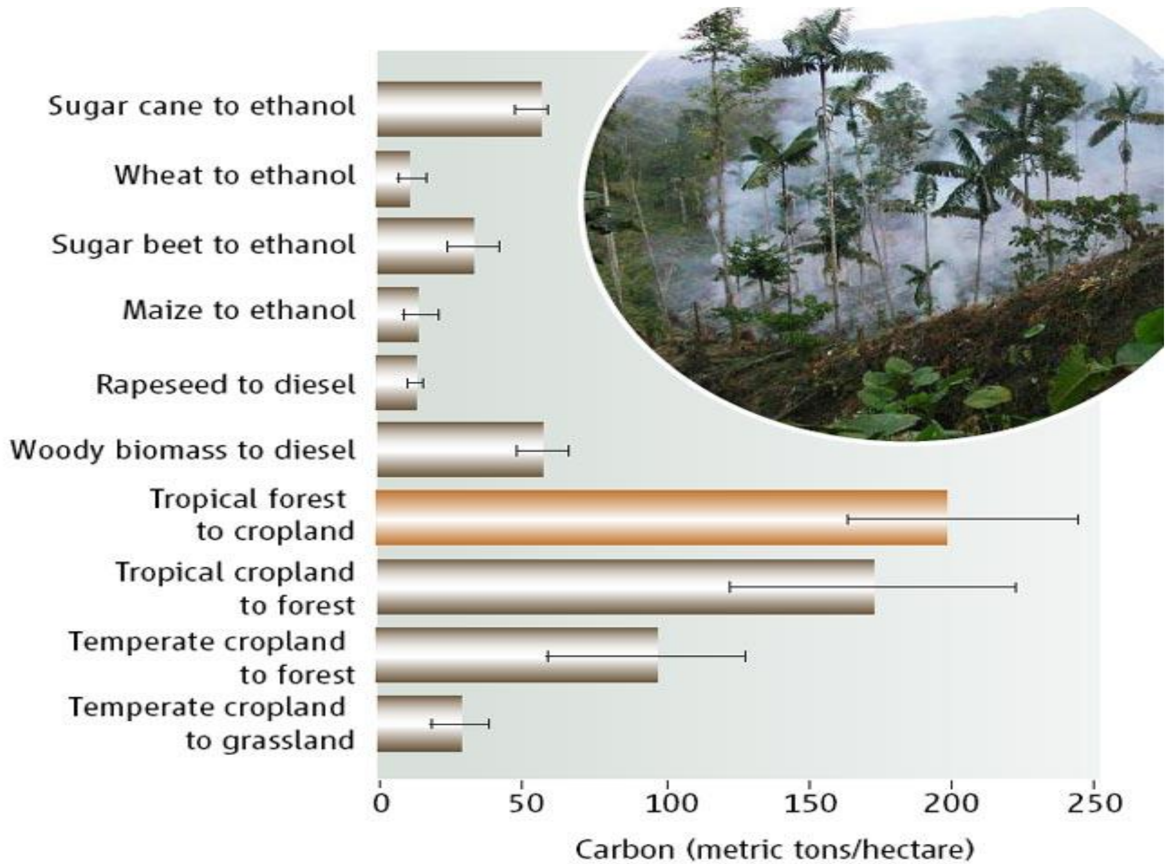
- A study of Righelato et al. (2007) based on estimations of LUC impact on C budget

- The environmental benefit of the sequestration can be larger than the one by substitution effect

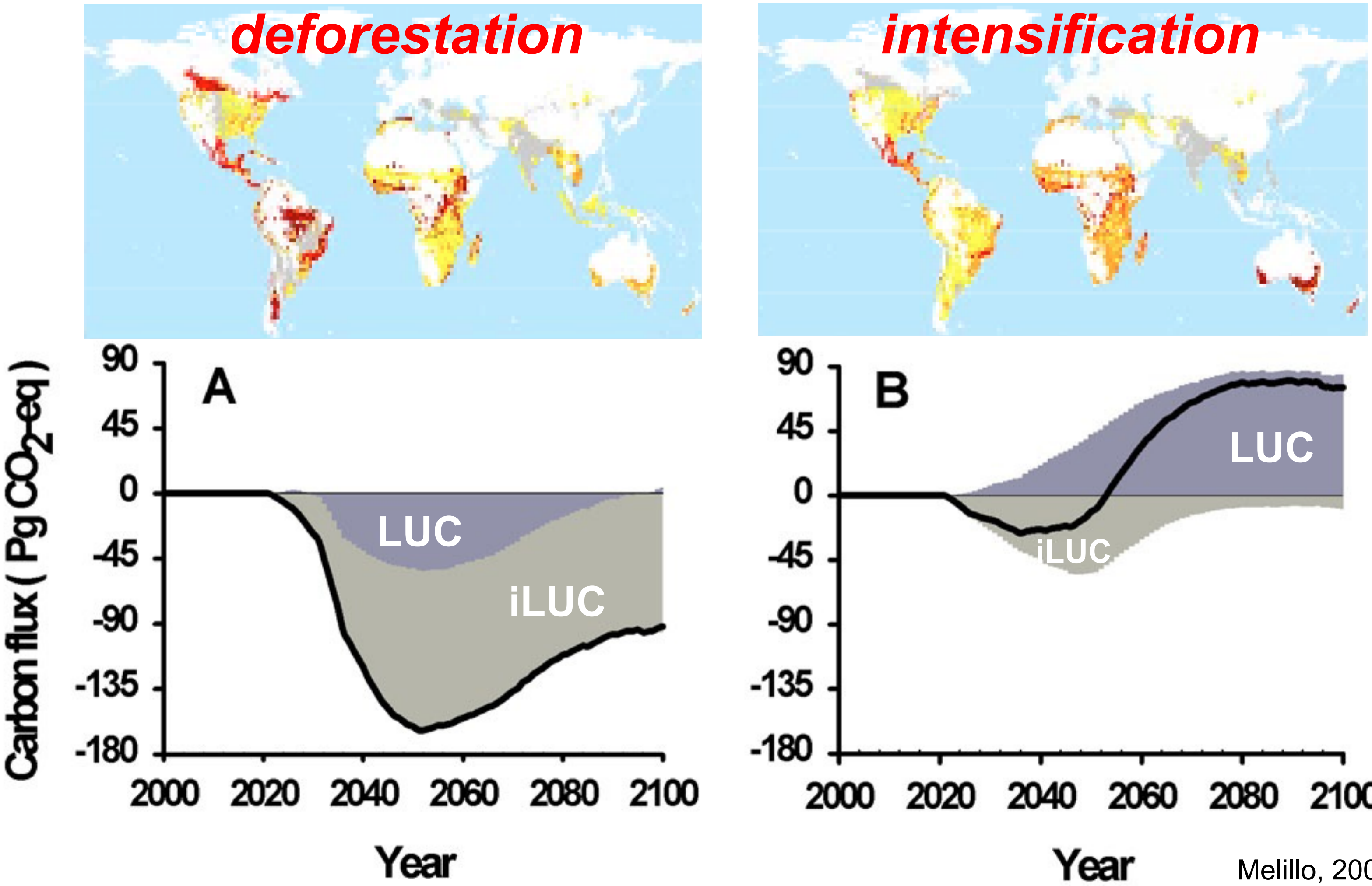
Carbon Mitigation by Biofuels or by Saving and Restoring Forests?

Science, 2007

Renton Righelato* and Dominick V. Spracklen

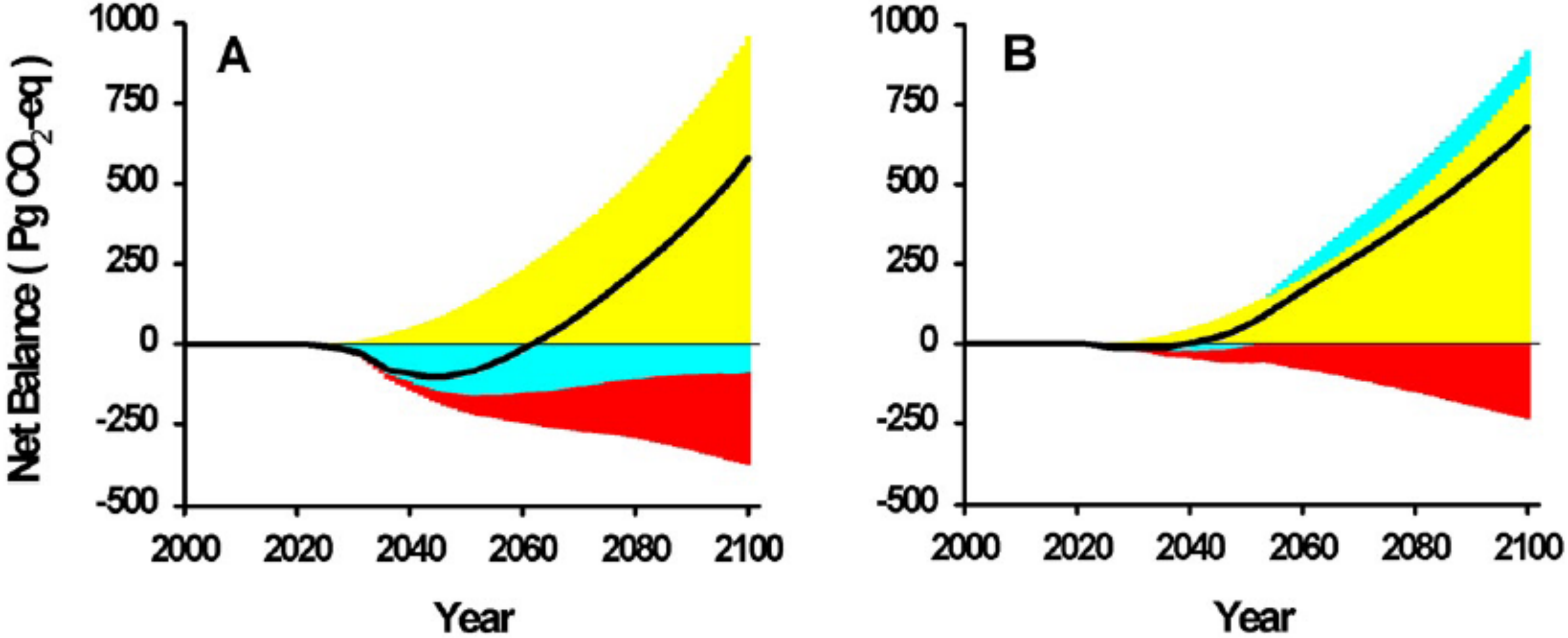


At least, save forests



Melillo, 2009, Science

Net GHG budget



Substitution effect

Net terrestrial C budget

N_2O emission

A market-based mechanism

- Reduce emissions from deforestation and degradation = REDD
- Based on a Carbon market, to give a market value to the avoided emissions due to deforestation
- Mitigation potential: ~0.75 GtC yr^{-1}

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