Les interactions entre Bioénergies et Climat

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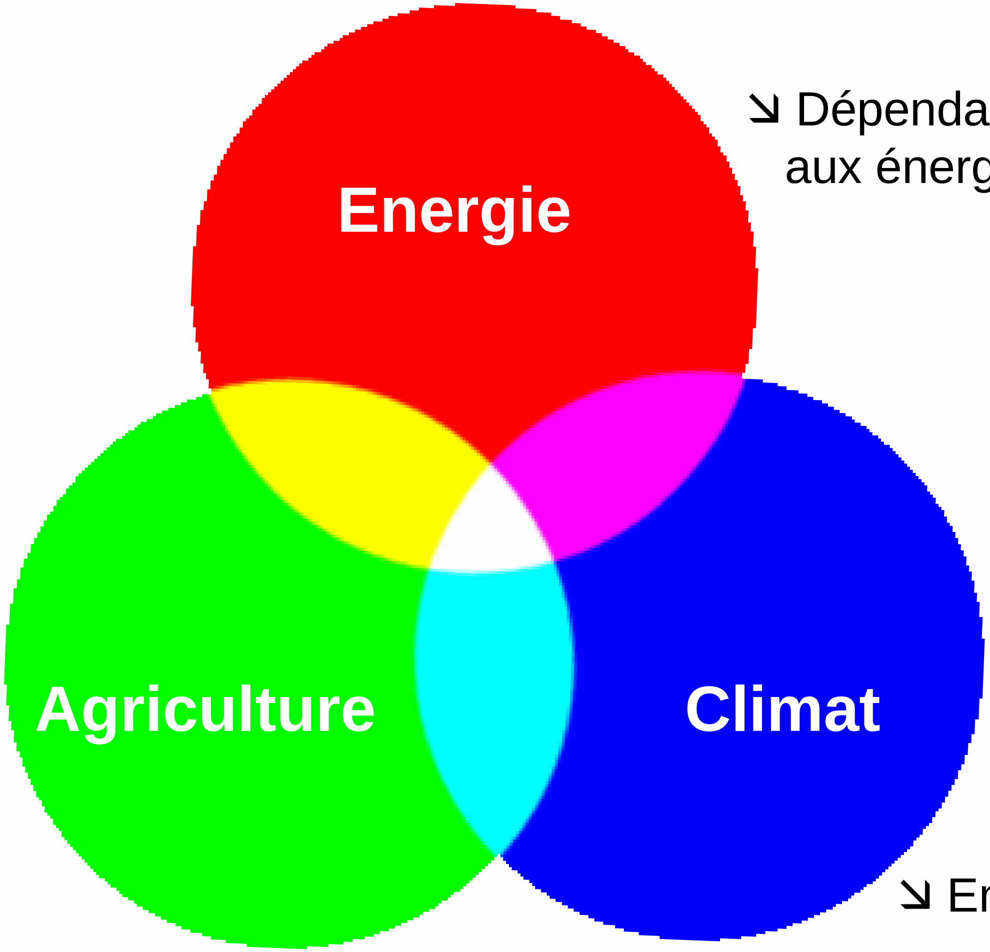
Master ICE – 14 Octobre 2010 -
‘L’évaluation environnementale des filières de bioénergies’

Qu’entend-on par ‘Bioénergies’ ?

- Energie provenant de la biomasse
- Biomasse: matière organique résultant du processus de photosynthèse
    - Les cultures agricoles
    - Le bois
    - Les résidus (pailles, sciure,...)
    - Les déchets organiques (déchets urbains, boues d'épuration, lisiers, fumiers,...)

Les raisons d’un engouement



Energie

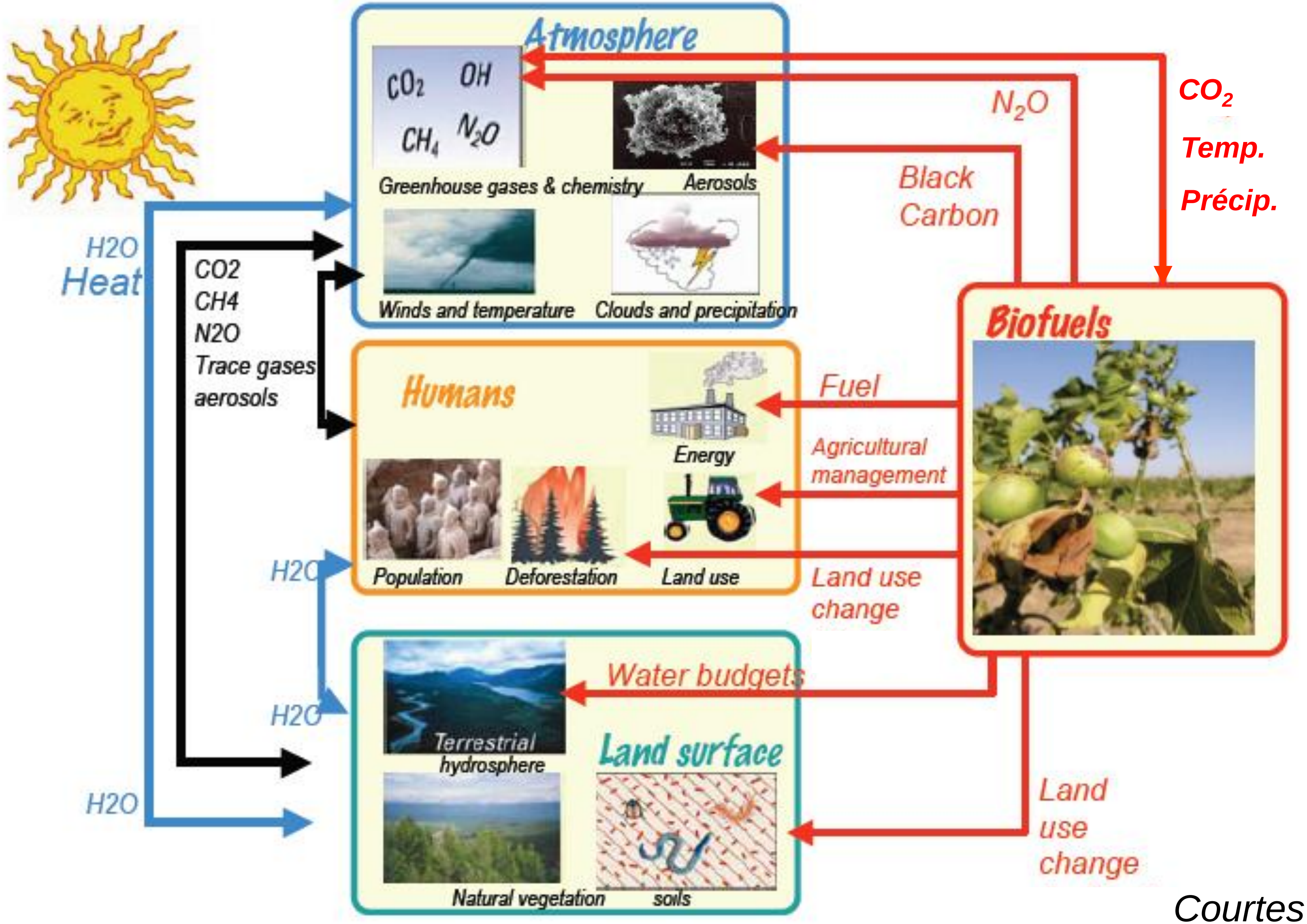
Agriculture

Climat

↘ Dépendance
aux énergies fossiles

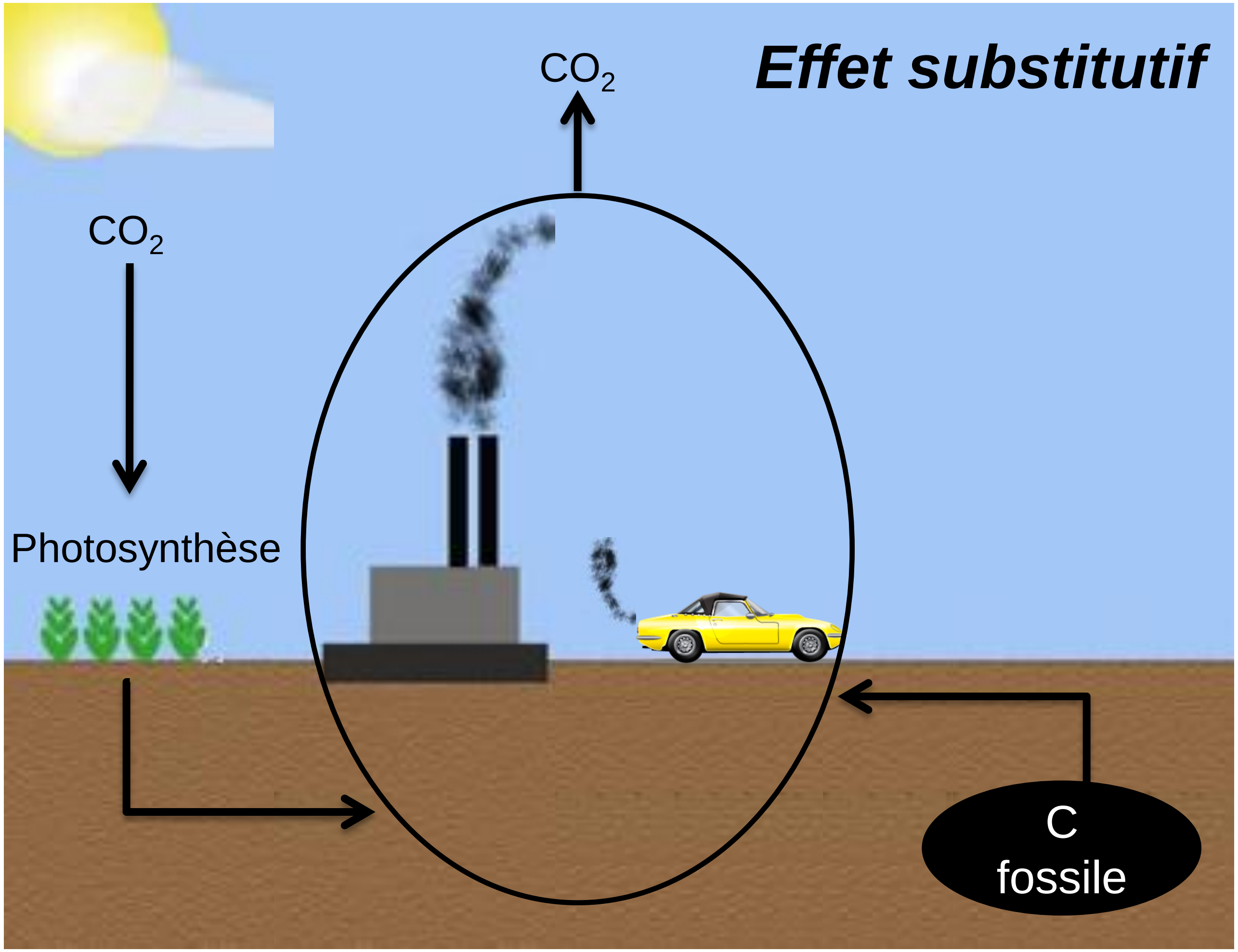
↗ Revenus
↗ Emplois

↘ Emissions de GES



Courtesy P. Ciais

Le ‘principe’ des Bioénergies

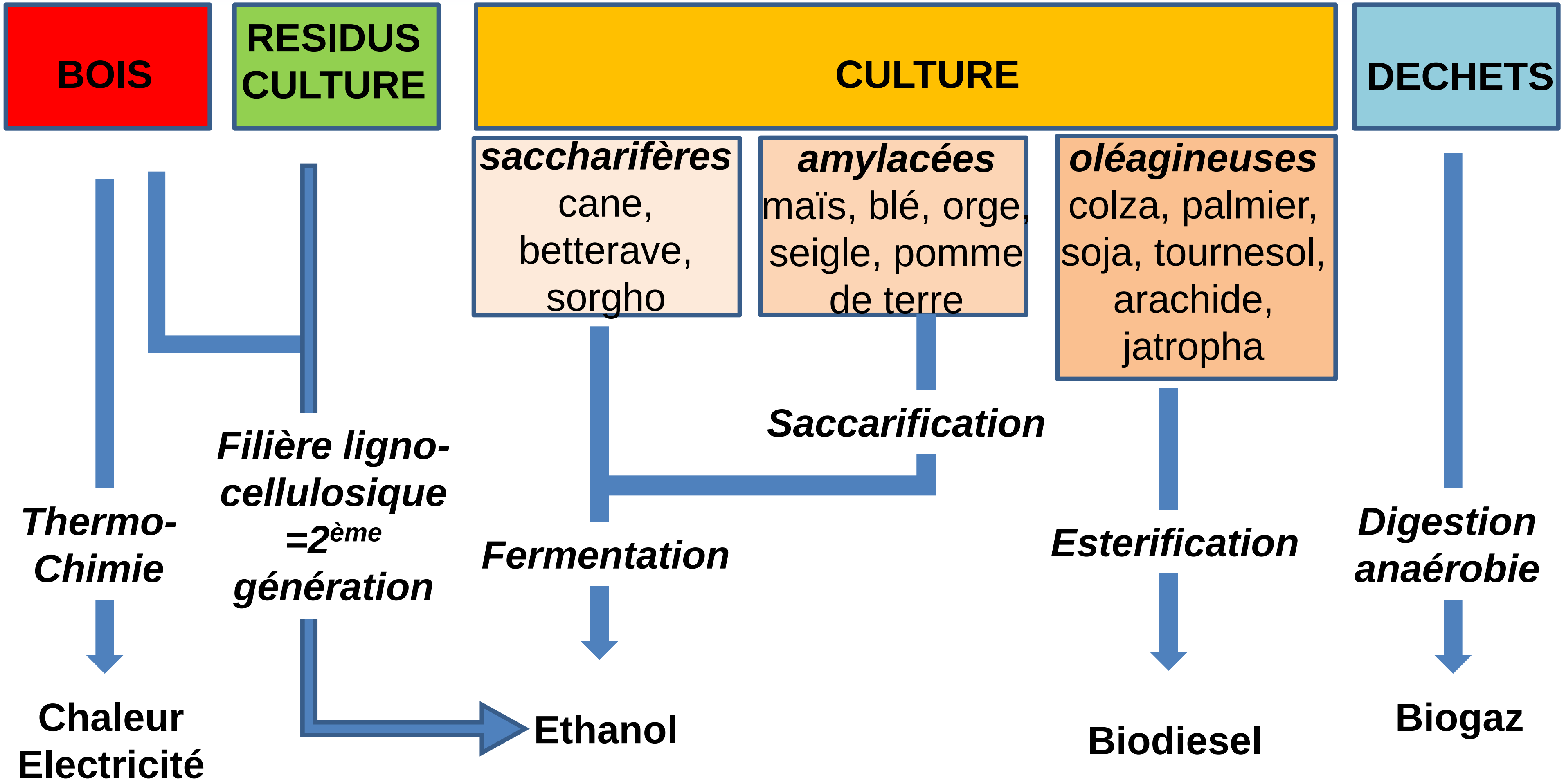


Plan de la présentation

- Etat des lieux de la production actuelle
- Quantifier l’intérêt de filières d’agrocarburants
- Les incertitudes et les risques associées au développement de filières d’agrocarburant
- Aperçu de quelques solutions ou alternatives

Etat des lieux de la production actuelle et potentiel

Les différentes filières



BOIS

RESIDUS CULTURE

CULTURE

DECHETS

saccharifères
cane, betterave, sorgho

amylacées
maïs, blé, orge, seigle, pomme de terre

oléagineuses
colza, palmier, soja, tournesol, arachide, jatropha

Thermo-Chimie

Filière ligno-cellulosique =2$^{\text{ème}}$ génération

Saccarification

Fermentation

Esterification

Digestion anaérobie

Chaleur Electricité

Ethanol

Biodiesel

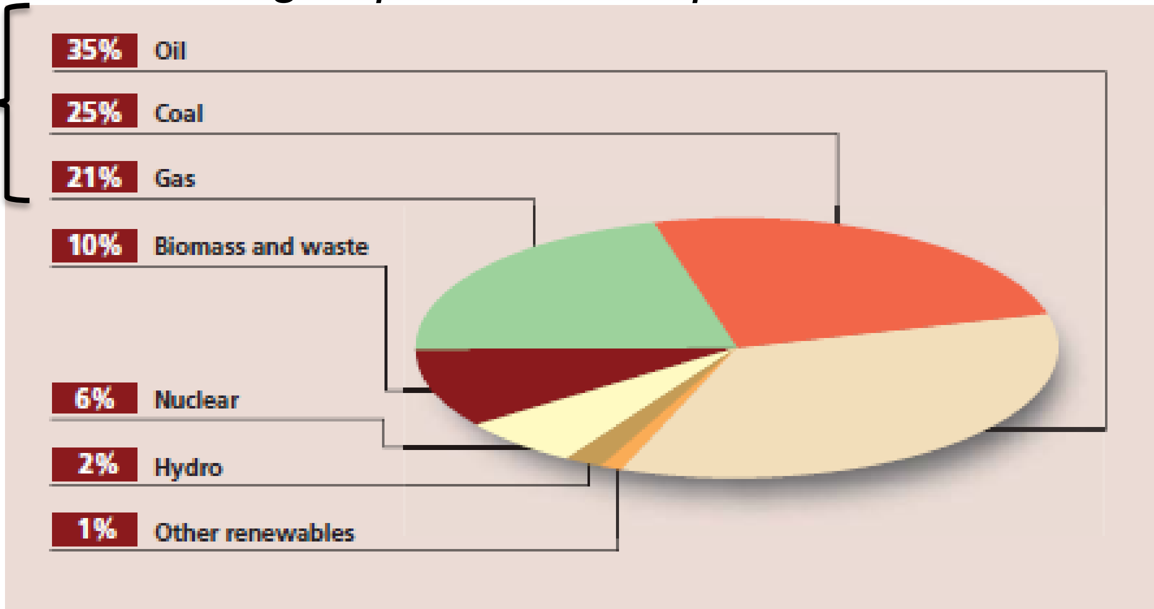
Biogaz

Les bioénergies aujourd'hui

Demande énergétique mondiale par source en 2005

81% fossiles

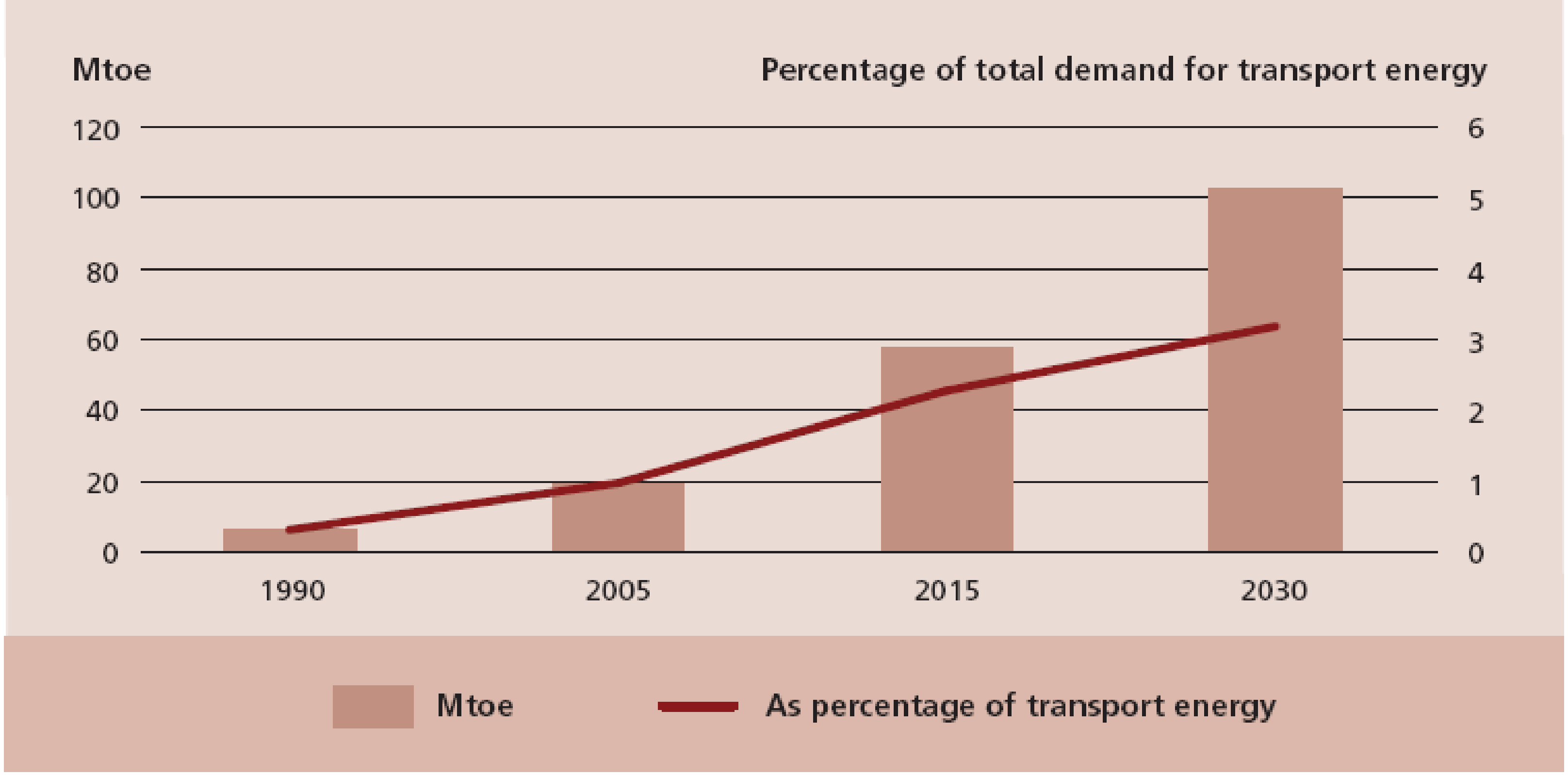
Combustibles solides 9,8%
Combustibles liquides 0,2%



Source: IEA, 2007 d'après FAO, 2008

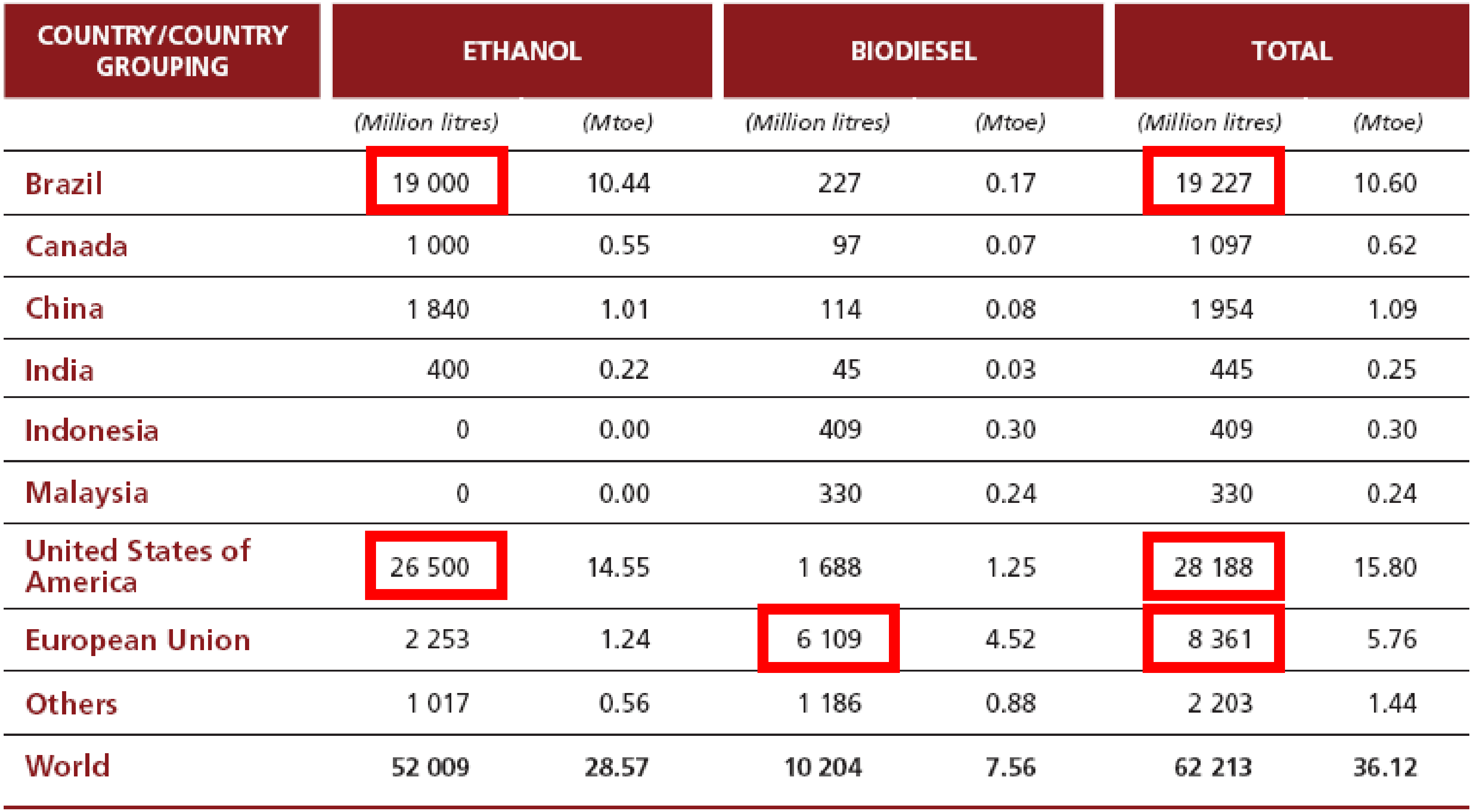
- Les bioénergies solides
  - – Majoritaires mais à effet substitutif potentiel
- Les bioénergies liquides (agrocarburants)
  - – Minoritaires mais à effet substitutif réalisé

Evolution de la production



IEA, 2007 from FAO, 2008

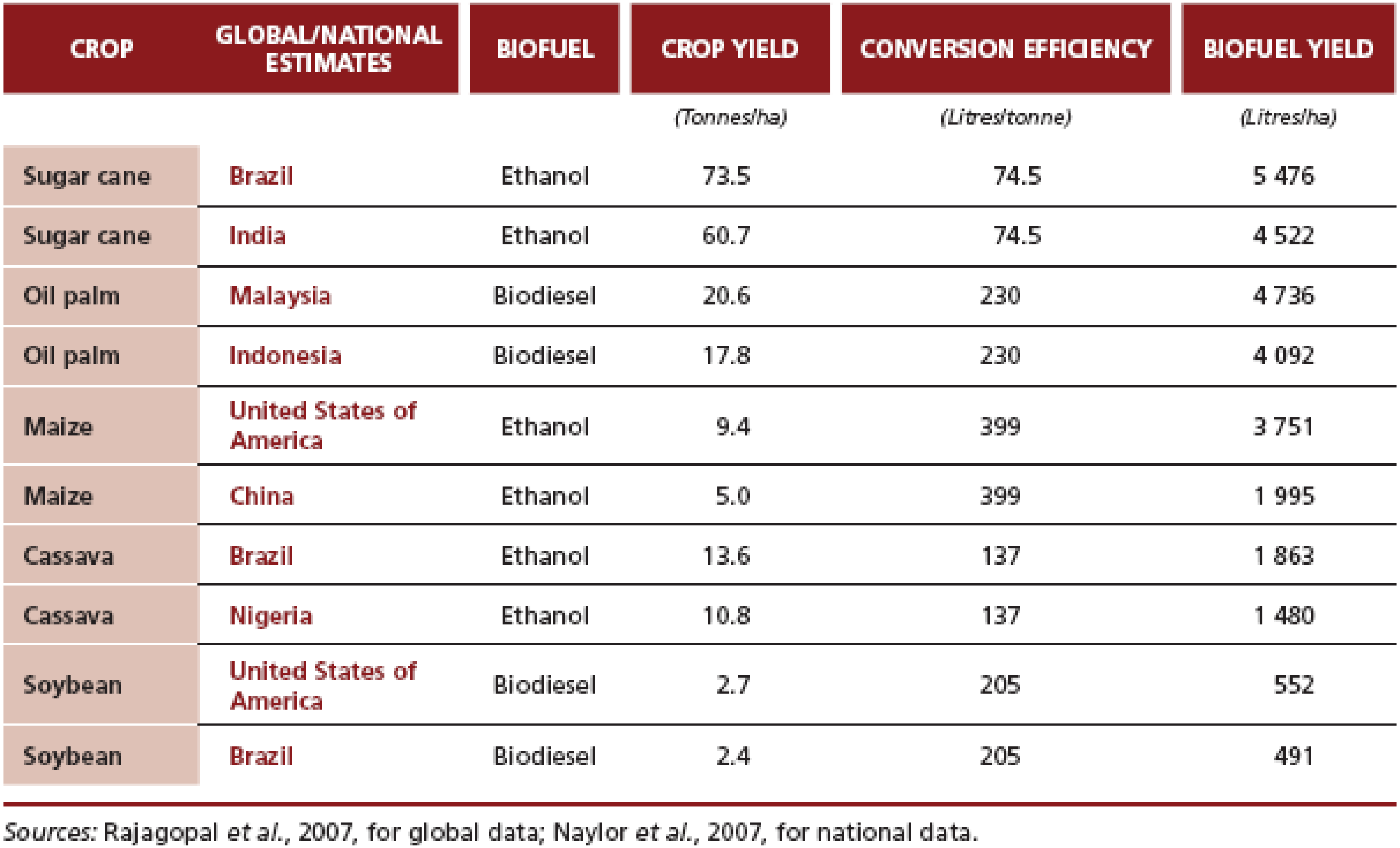
Production d’agrocarburants par pays



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

Les rendements

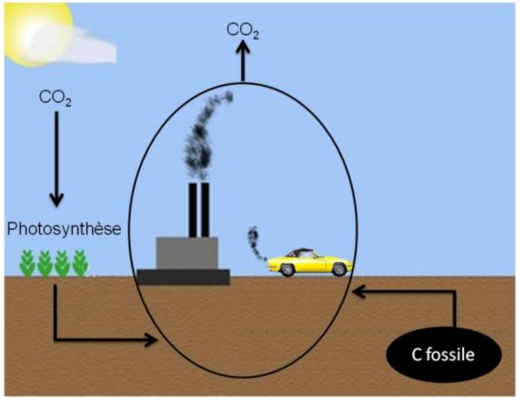


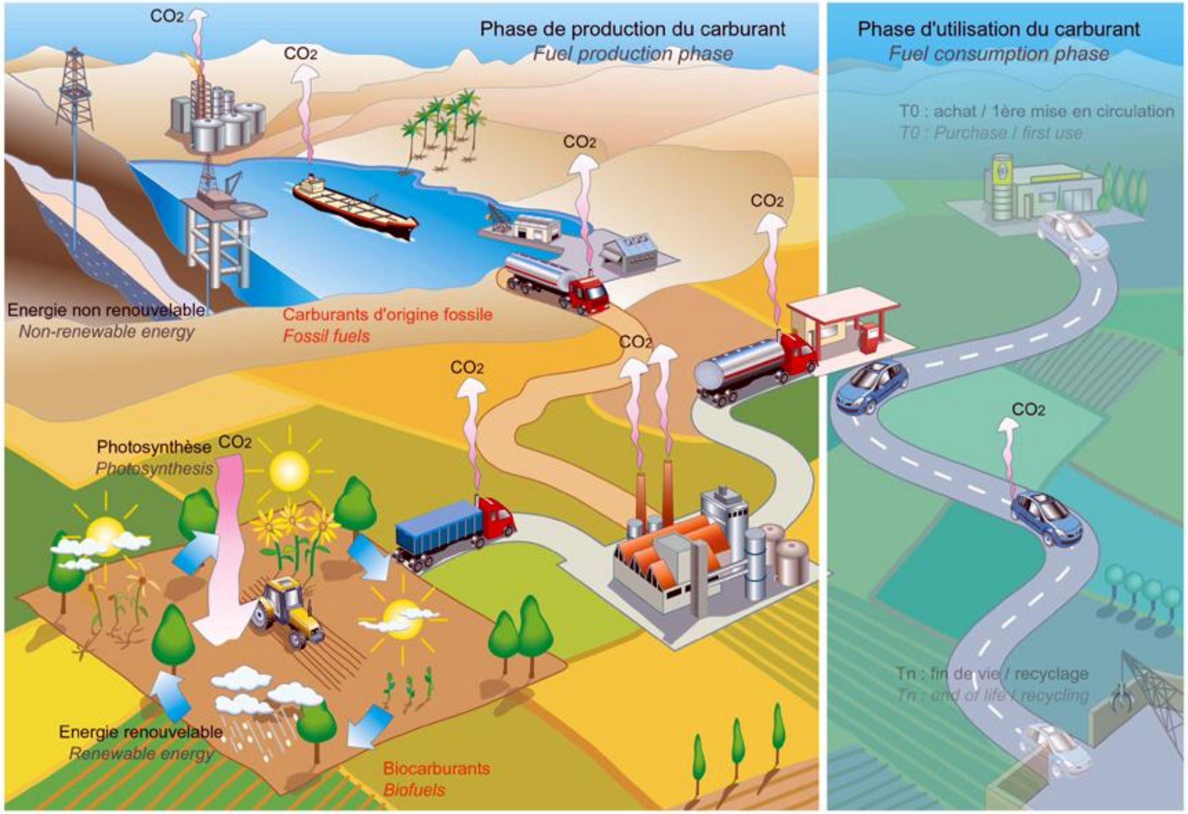
CROP	GLOBAL/NATIONAL ESTIMATES	BIOFUEL	CROP YIELD	CONVERSION EFFICIENCY	BIOFUEL YIELD
			(Tonnes/ha)	*(Litres/tonne)*	*(Litres/ha)*
Sugar cane	Brazil	Ethanol	73.5	74.5	5 476
Sugar cane	India	Ethanol	60.7	74.5	4 522
Oil palm	Malaysia	Biodiesel	20.6	230	4 736
Oil palm	Indonesia	Biodiesel	17.8	230	4 092
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.

Quantifier l’intérêt de filières d’agrocarburants

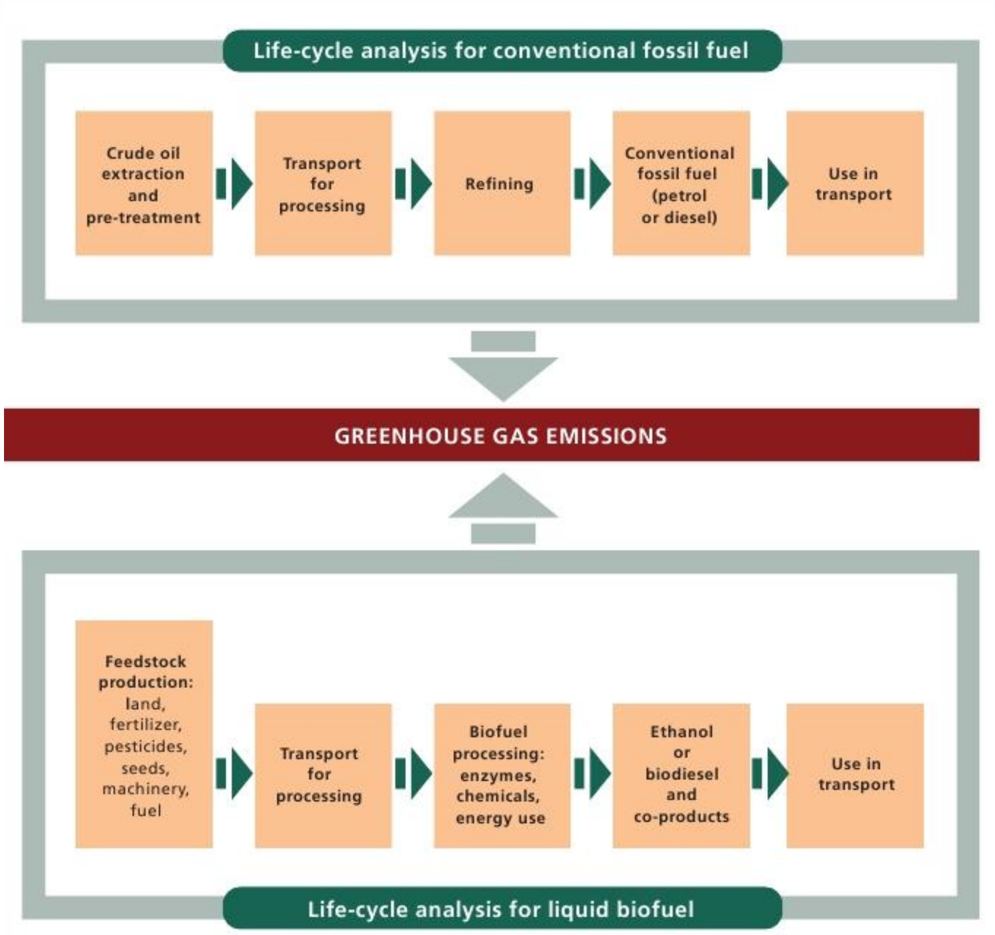
Vers une approche plus réaliste





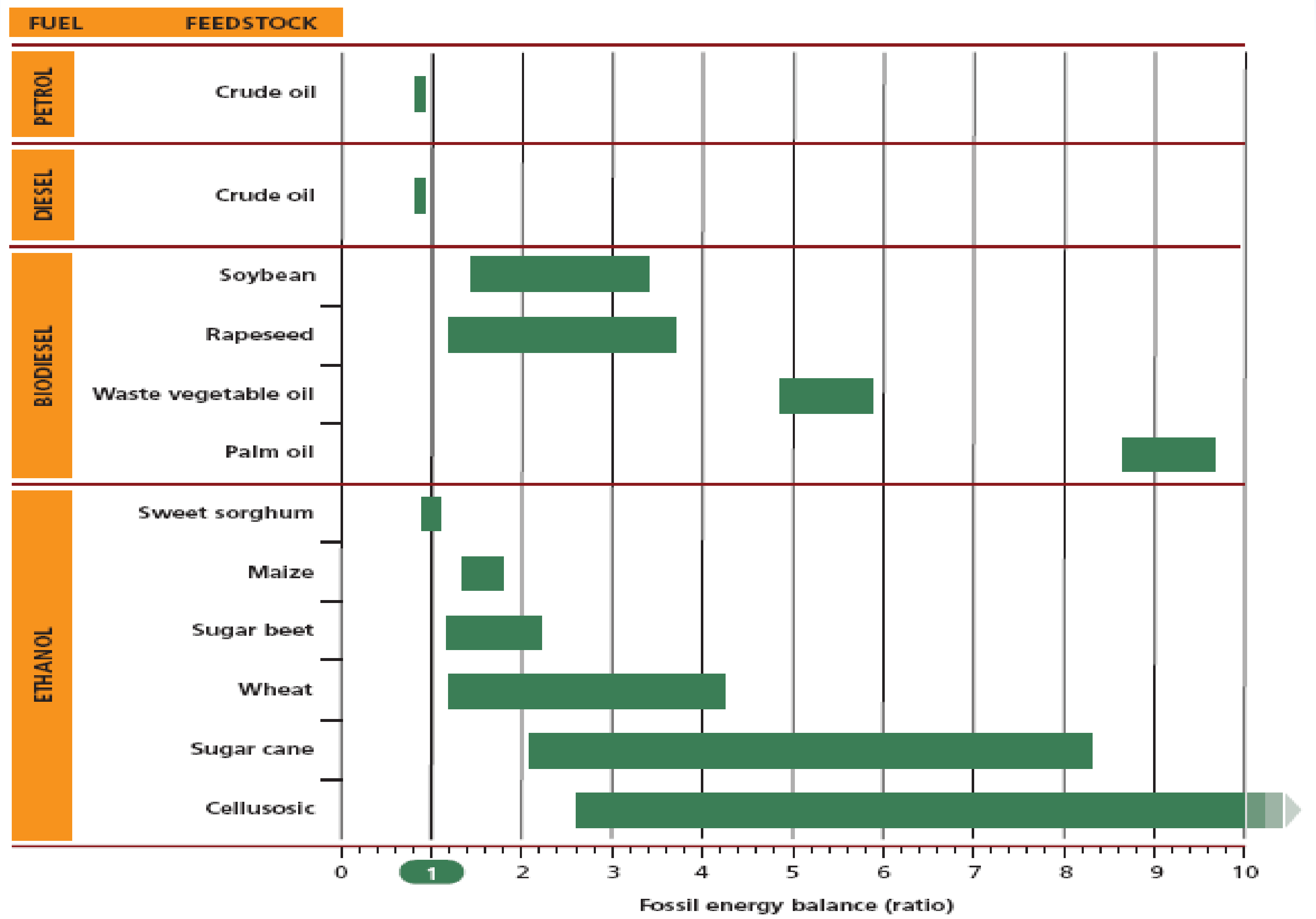
Approche du "puits à la roue"
"Well to wheels" approach

Les analyses en cycle de vie

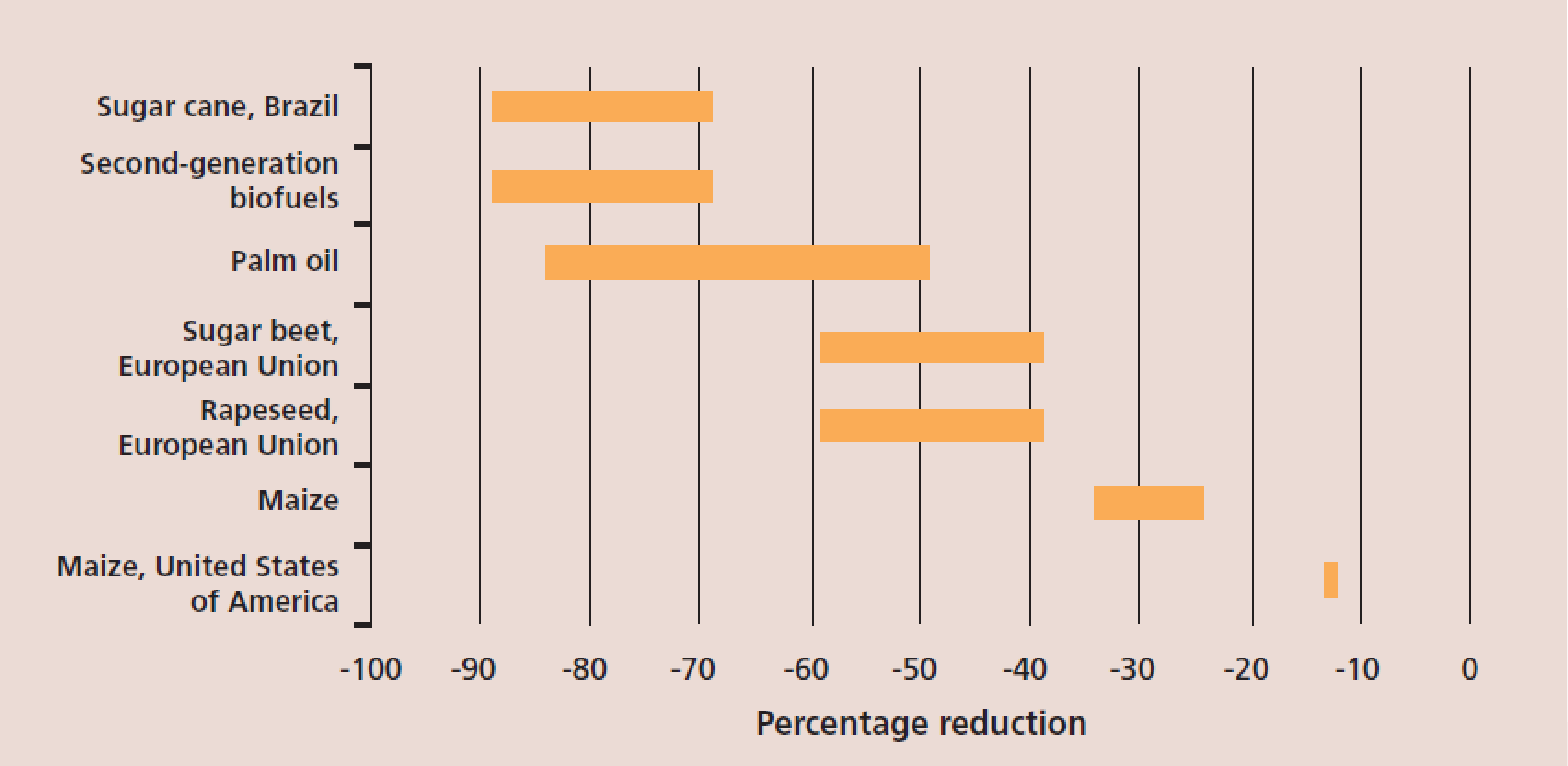


FAO, 2008

Evaluer l'efficacité énergétique



Réduction de GES de différentes filières



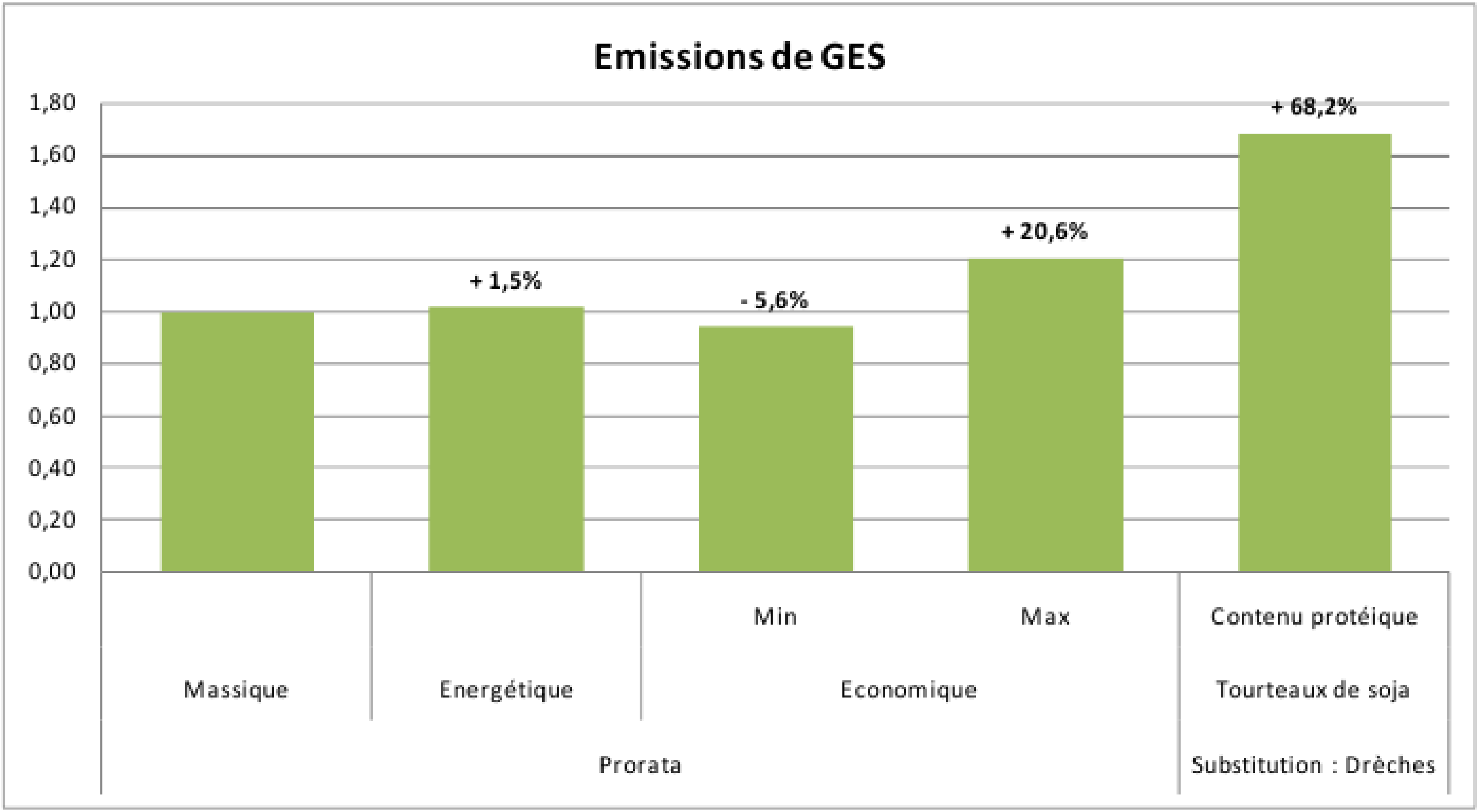
Source: IEA, 2007 d'après FAO, 2008

Pourquoi tant d'incertitude ?

- Prise en compte partielle des équipements
- Non uniformisation des facteurs d'émission
- Attribution aux co-produits
  - Par Allocation
    - Massique
    - Energétique
    - Economique
  - Par extension du système (substitution)

Le traitement des co-produits

Relative GHG emissions for ethanol from wheat in France

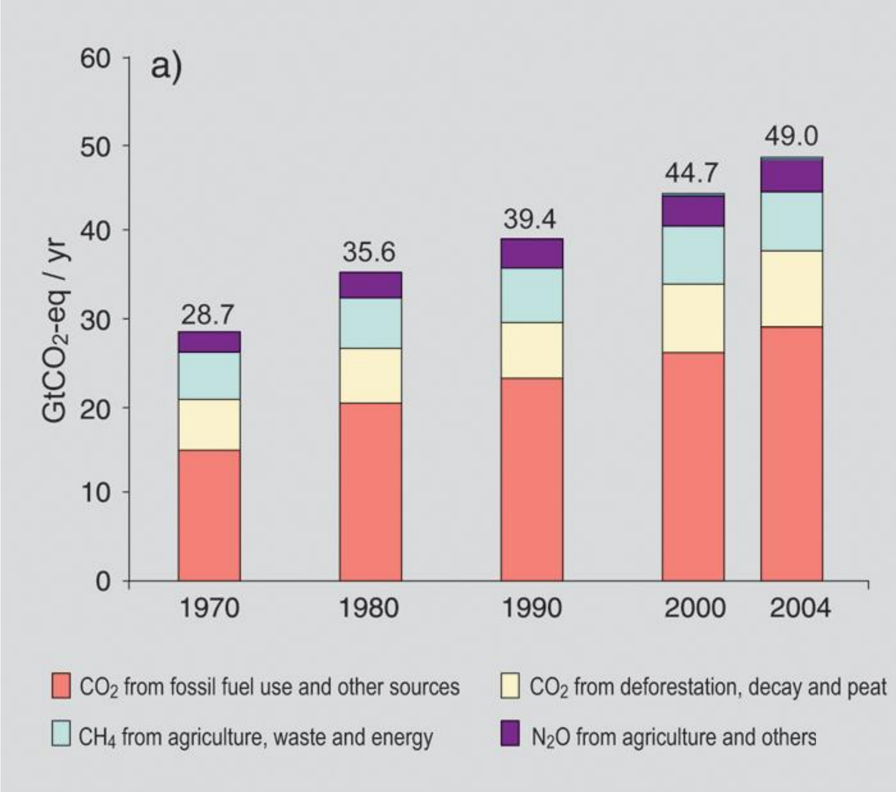


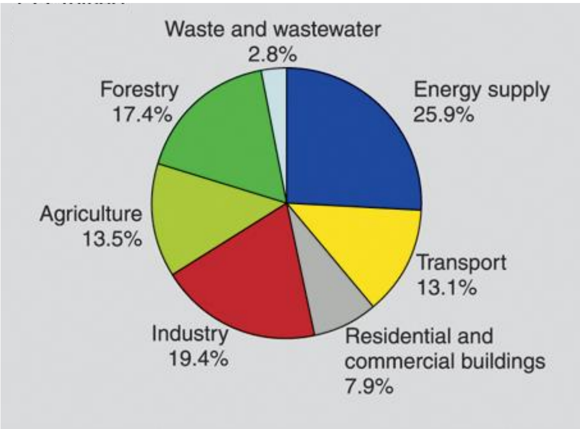
Source: Référentiel pour les ACV des biocarburants de première génération en France, BioIS/ADEME, 2008.

Effet substitutif à l'échelle globale aujourd'hui

- Production de biofuels estimée à ~ 1,5 EJ (sur 14 Mha)
- Avec une ref 'Essence' à 86 gCO_2/MJ et 90% de réduction
- Aujourd'hui, l'émission de 0,12 $GtCO_2$ est évitée par substitution

Emissions de GES à l’échelle globale

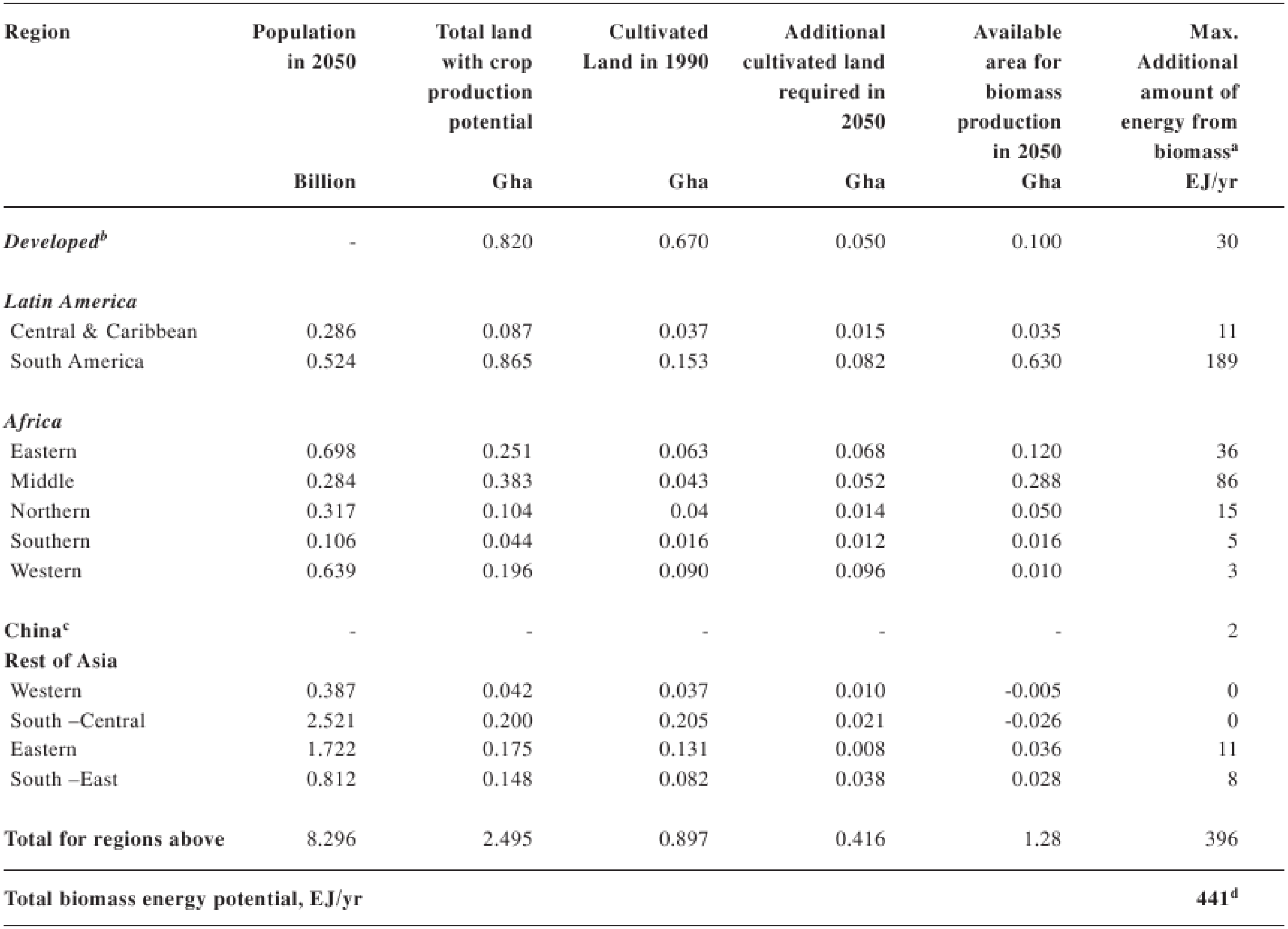




- 0,2% des émissions de GES à l’échelle globale
- 1,8% des émissions du secteur ‘Transport’

Le potentiel

- 400 EJ en 2050 ⬄ 2000 Mha (IEA Bioenergy, 2008)



Region	Population in 2050 Billion	Total land with crop production potential Gha	Cultivated Land in 1990 Gha	Additional cultivated land required in 2050 Gha	Available area for biomass production in 2050 Gha	Max. Additional amount of energy from biomass[a] 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]

Incertitudes et risques associés au développement de filières d’agrocarburants

Réduire les incertitudes des ACV

- Traitement des co-produits
- Emissions de N_2O
- La prise en compte du changement d'usage des terres (LUC)

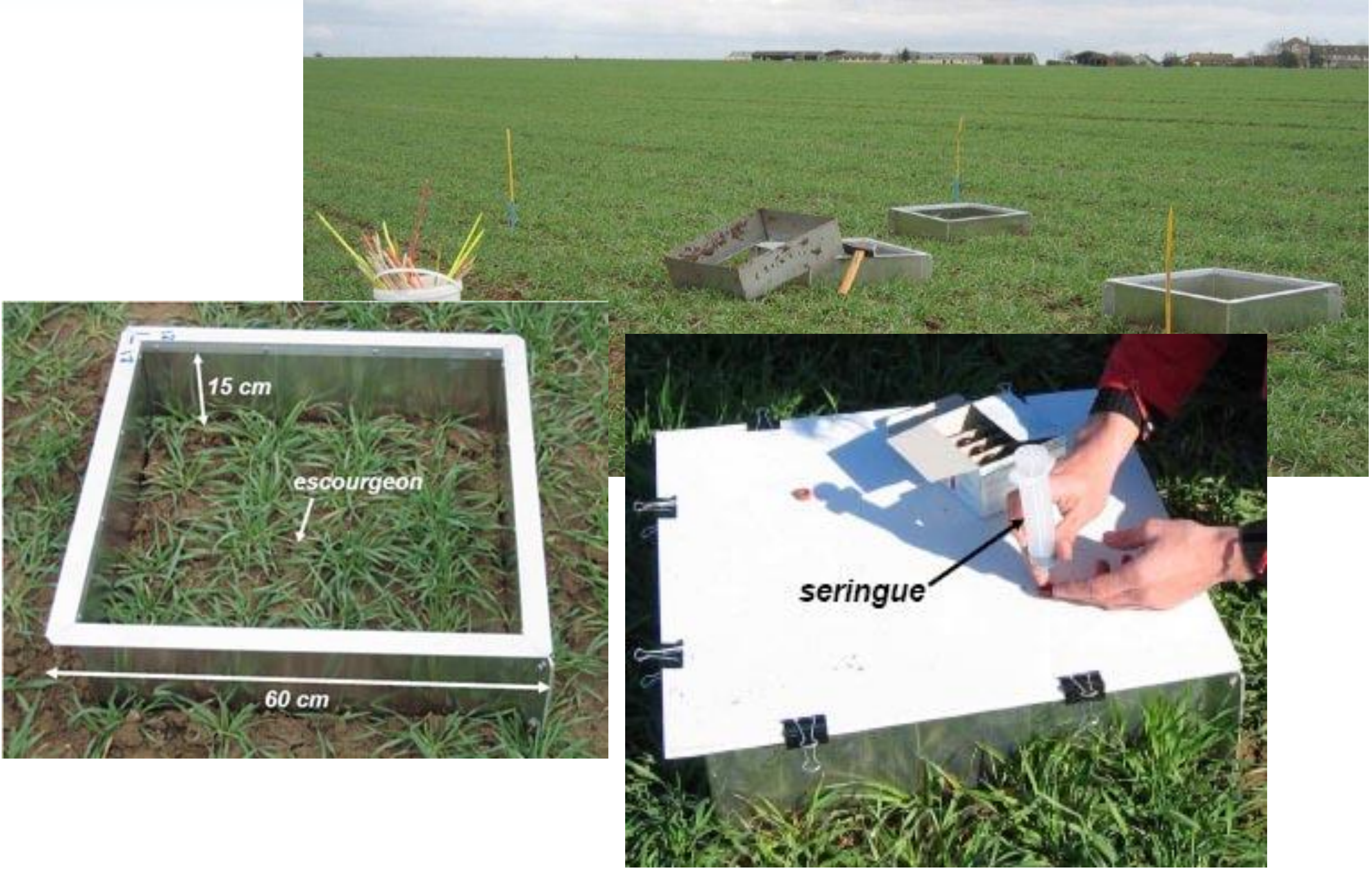
L’émission de N_2O par les sols

- GES ~300 fois plus réchauffant que le CO_2
- Nitrification
  - – oxydation de l'ammonium (NH_4^+) en nitrite (NO_2^-) puis en nitrate (NO_3^-). N_2O = produit intermédiaire
- Dénitrification
  - – processus microbien transformant des oxydes d’azote solubles (NO_3^-, NO_2^-) en composés gazeux (NO, N_2O, N_2)
- Amplitude fonction du
    - Type de sol
    - Humidité/ Température

Les méthodes de mesure

- Chambre statique ou automatique
  - – Avec mesure de la concentration par différentes méthodes:
    - Chromatographie en phase gazeuse
    - Diode laser …
- Tour à flux
  - – Avec mesure de la concentration par diode laser

Les méthodes de mesure



Forte variabilité spatiale et temporelle

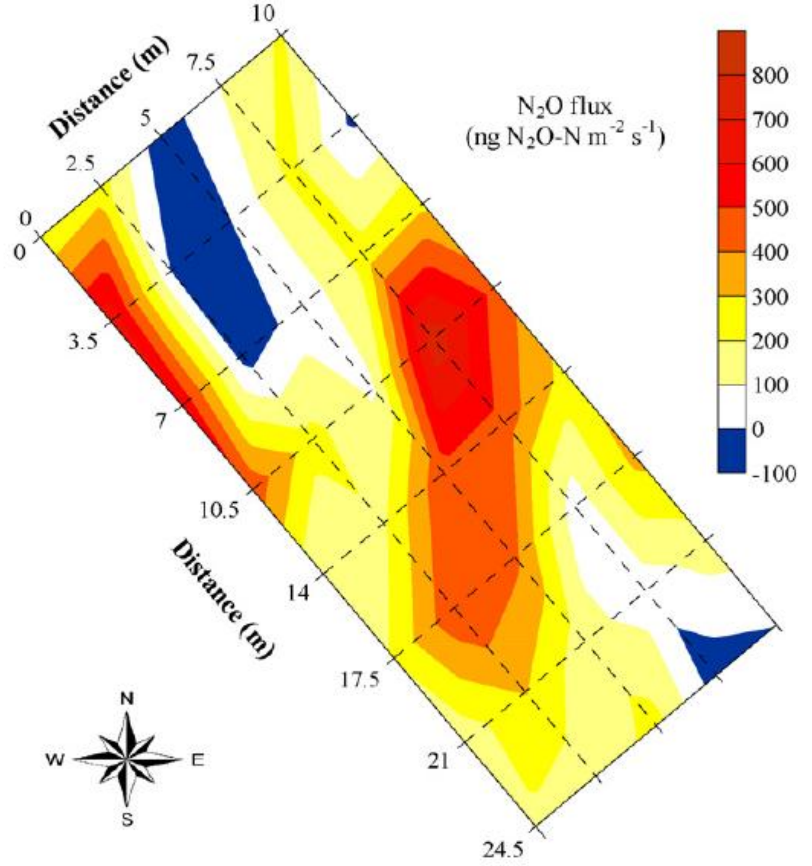
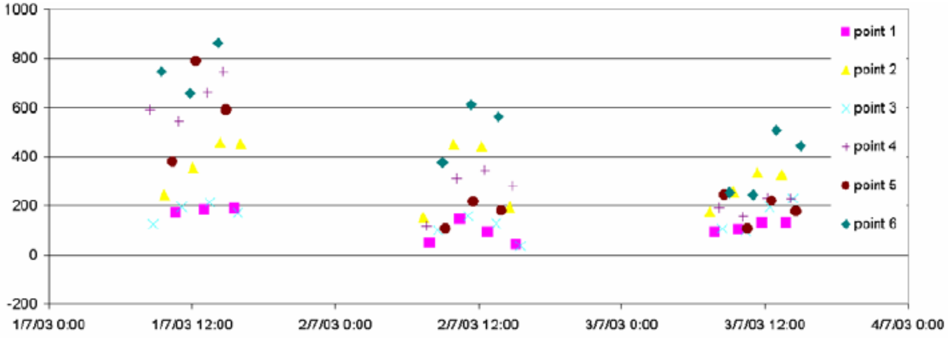


Fig. 2. Spatial variability of N_2O fluxes measured with the Fast-Box technique at Nl-LE. The contour plot is based on flux measurements at 40 points on the 25 m × 10 m grid, each sampling point being at the corner of a 2.5 m × 3.5 m rectangle.

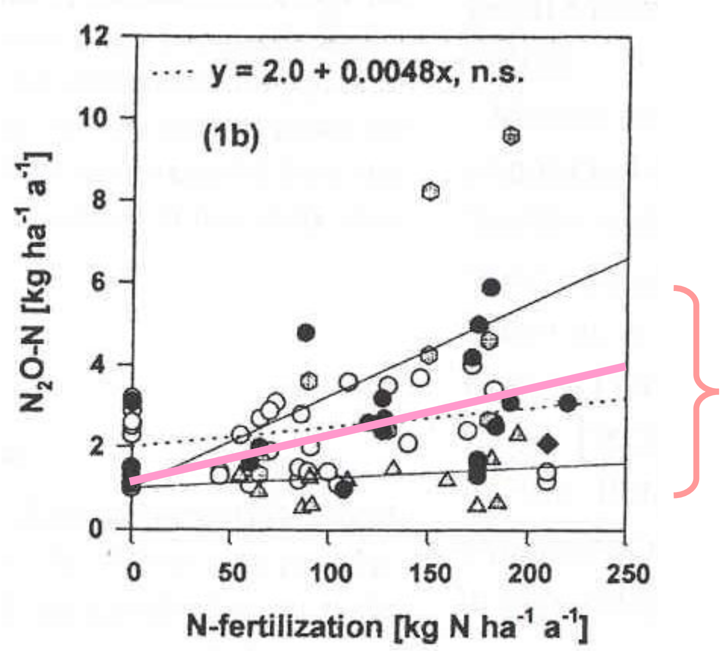
Flechard et al., 2007

Série de données (en ng m-2 s-1, FAL, Zürich) obetenue sur le site d'Oensingen (Suisse)



La notion de facteur d'émission

- Compilation de données d'émissions de N_2O ($\neq$ cultures, régions, années) en fonction de la quantité d'intrants azotés



Envelope of the 'IPCC (1996)' relationship
~1% des intrants d'azote minéral

Kaiser et al., 2000

Une approche ‘top-down’

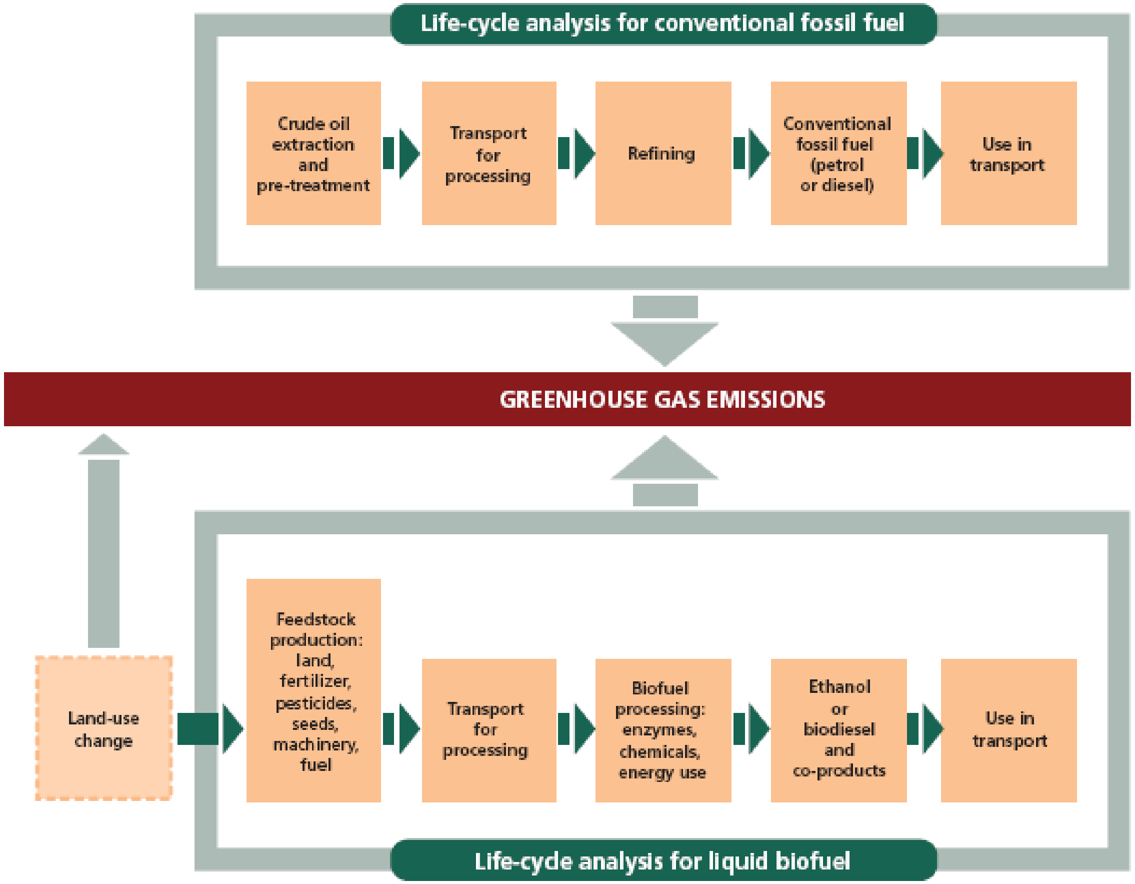
- Papier de Crutzen et al., 2007
- Calcul basé sur les puits et sources atm. de N_2O en pré-industriel et actuel.

  => Emissions actuelles : ~6 TgN_2O-N an-1
- Déduction des émissions industrielles

  => Emissions agricoles : ~5 TgN_2O-N an-1

  ~5% de la fertilisation minérale globale

La prise en compte du LUC



Life-cycle analysis for conventional fossil fuel

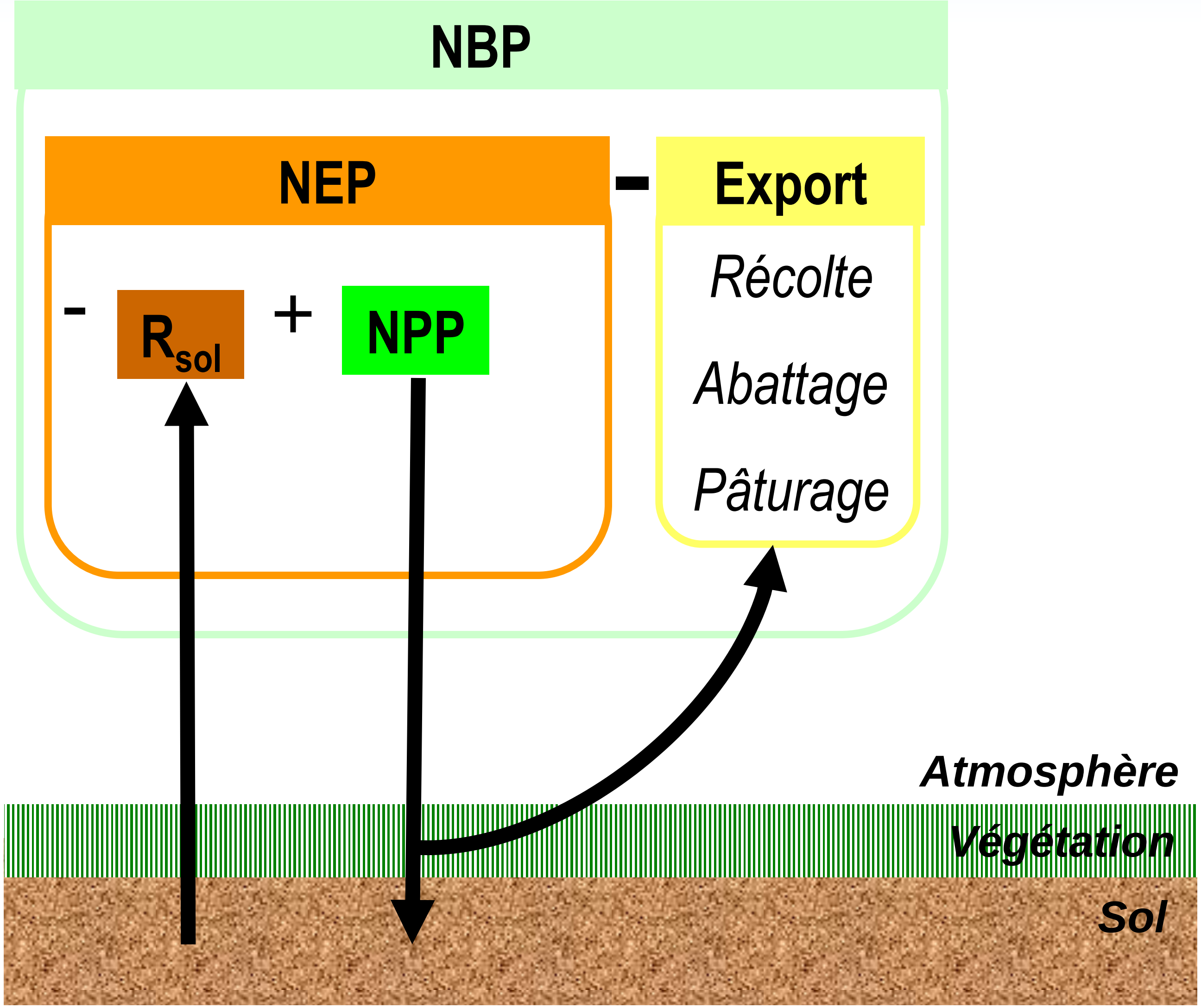
Crude oil extraction and pre-treatment → Transport for processing → Refining → Conventional fossil fuel (petrol or diesel) → Use in transport

GREENHOUSE GAS EMISSIONS

Land-use change → Feedstock production: land, fertilizer, pesticides, seeds, machinery, fuel → Transport for processing → Biofuel processing: enzymes, chemicals, energy use → Ethanol or biodiesel and co-products → Use in transport

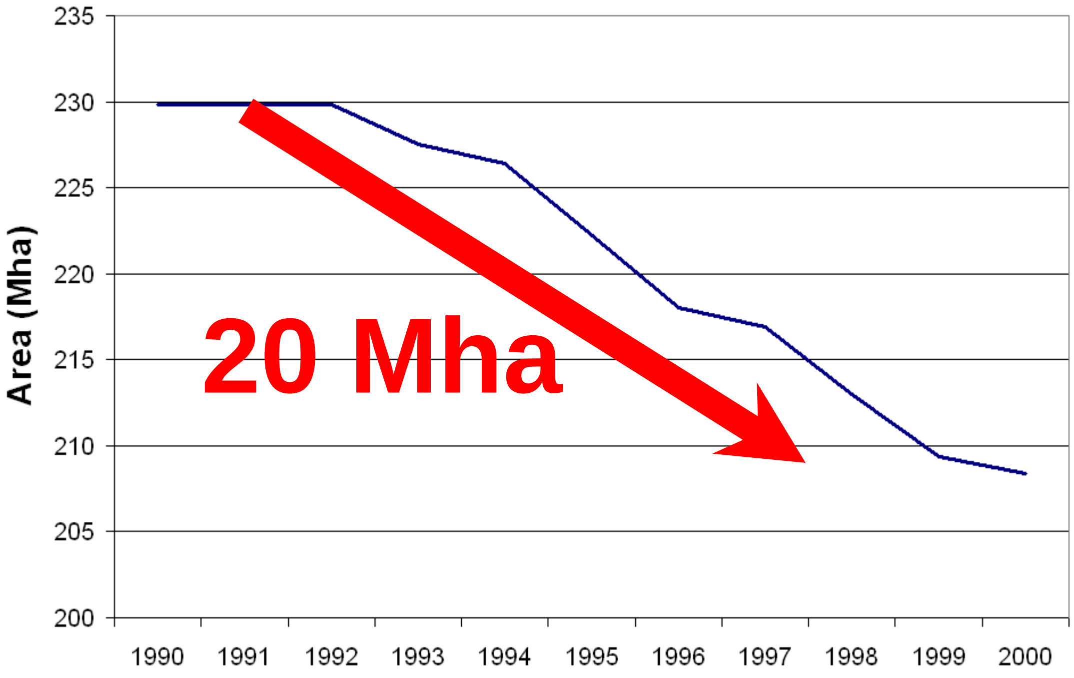
Life-cycle analysis for liquid biofuel

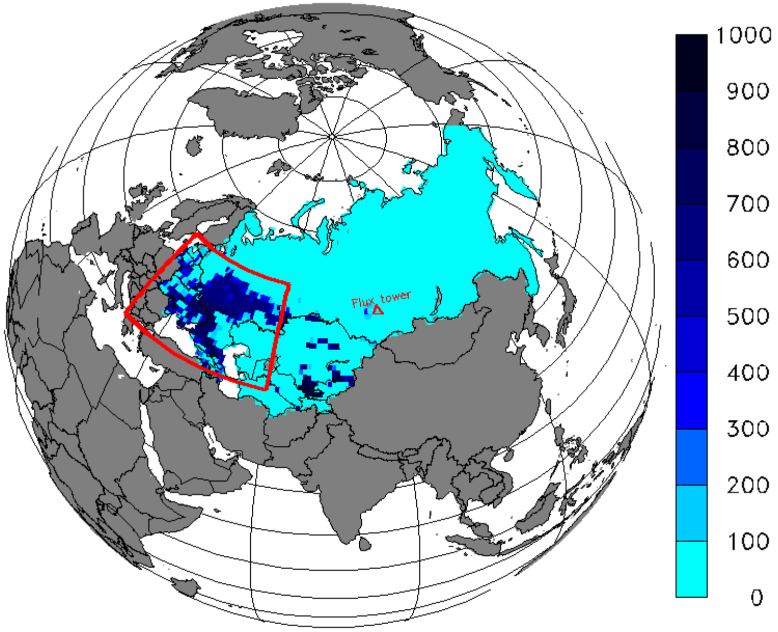
Les processus en jeu



Un exemple

- Abandon massif de terres agricoles en ex-URSS depuis 1990

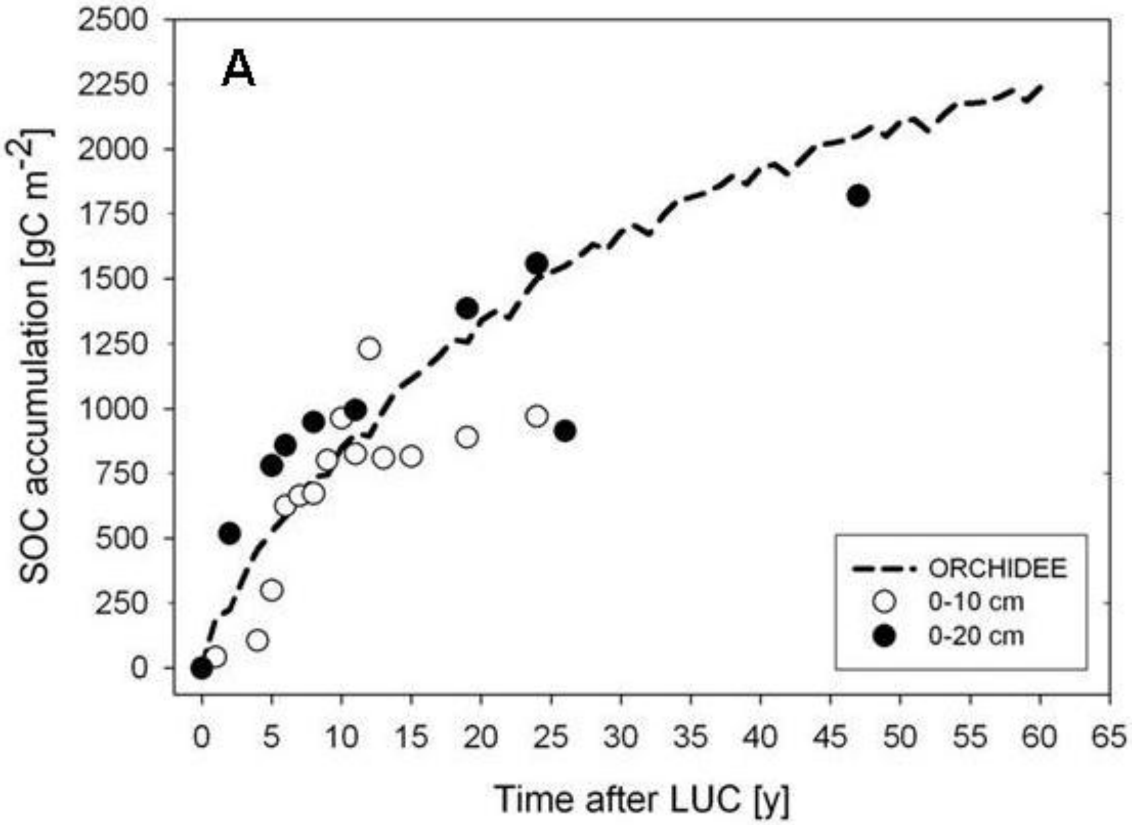




Hurtt *et al.*, Global Change Biology, 2006

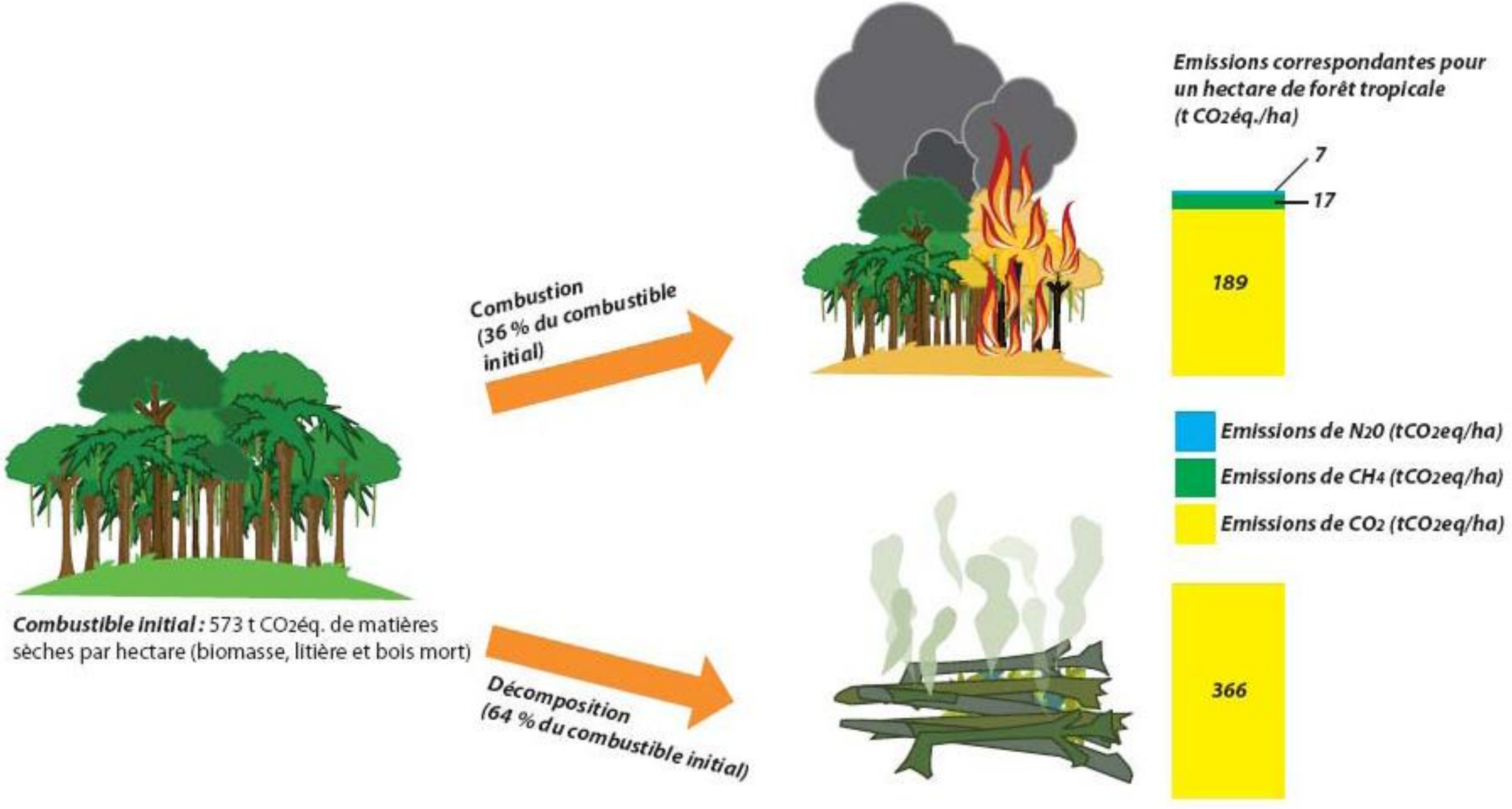
Un exemple

- Carbone dans les sols agricoles à l'abandon



From Belelli et al., soumis

La déforestation

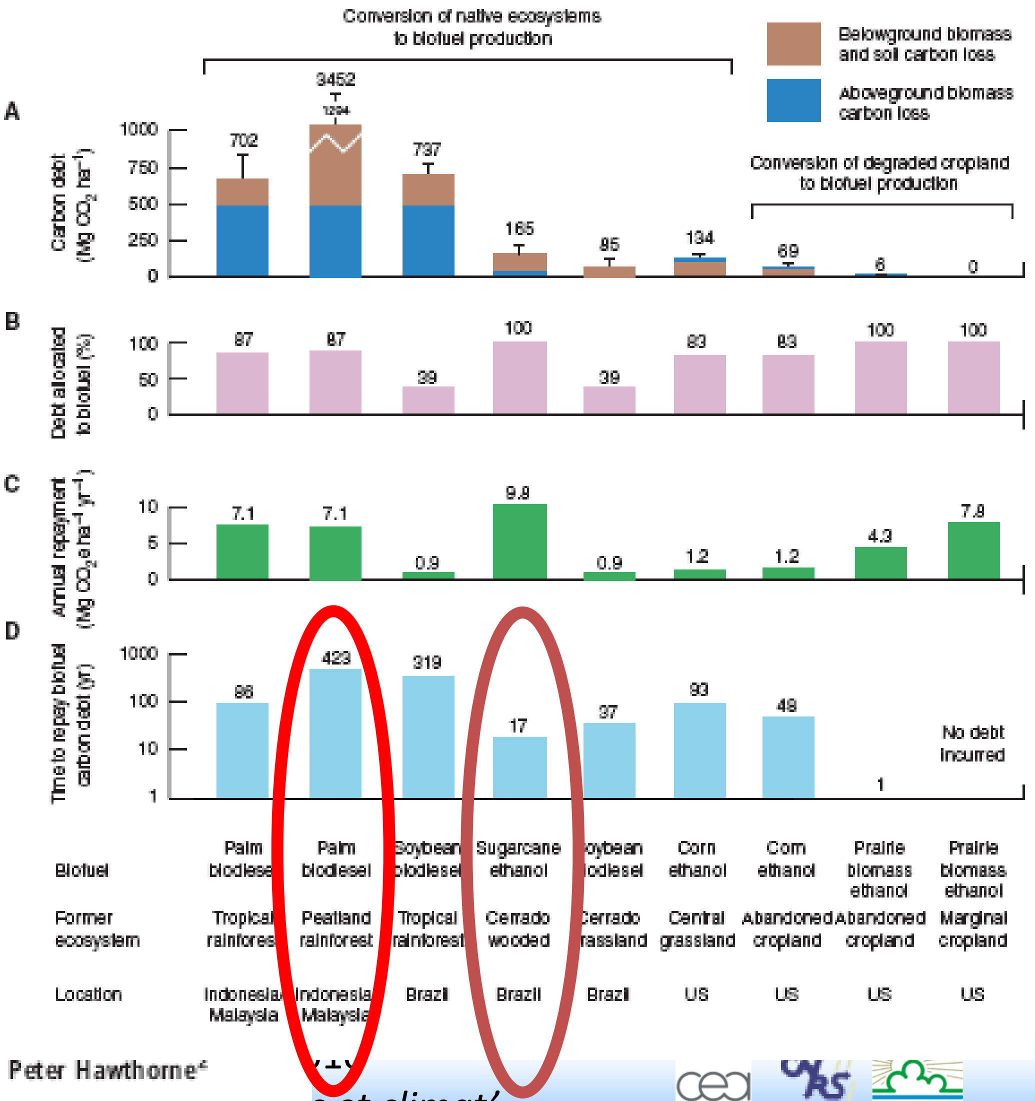


Bellassen, 2008

La notion de dette carbonée

Science, 2008

- Le changement d’usage des terres induit une perte de carbone que la culture de bioénergie met plusieurs années à compenser



Land Clearing and the Biofuel Carbon Debt

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

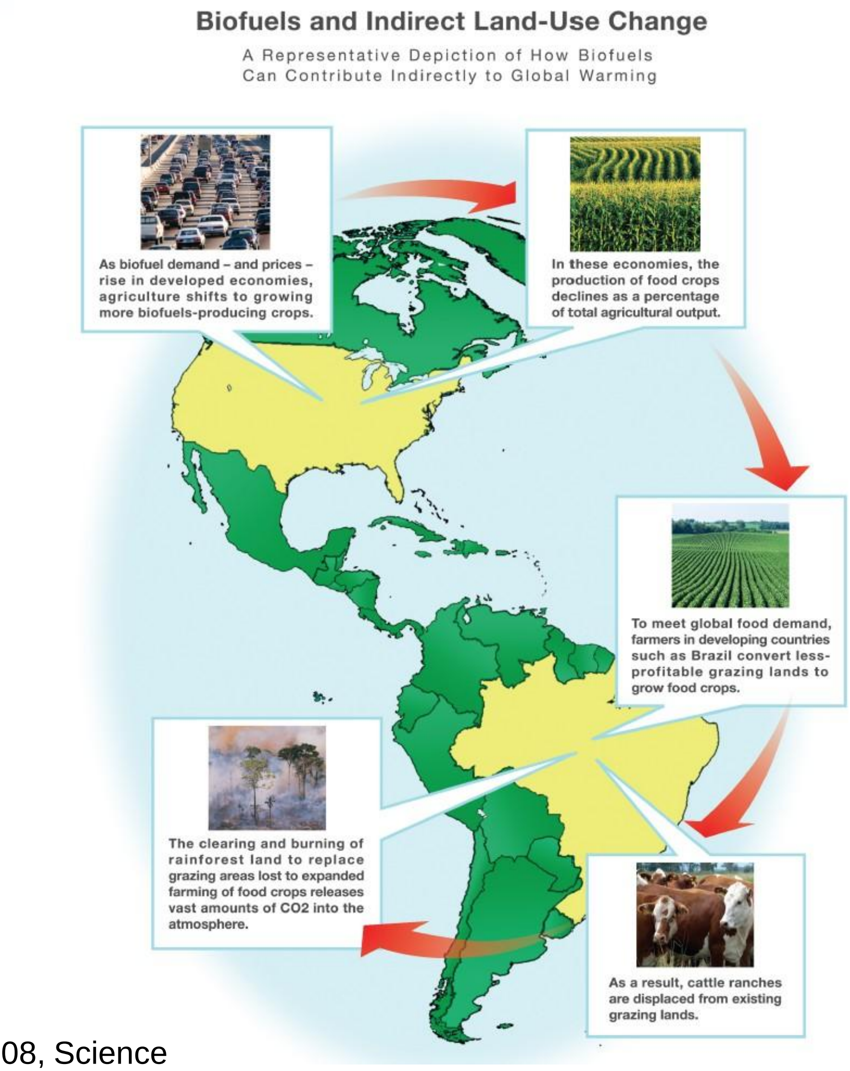
Changer d’échelle: du local au global

- L’impact des changements d’usages de terres indirects (iLUC)
  - La production d’éthanol à partir du maïs américain

réduction de 20% des GES

↓

augmentation de 100%



Biofuels and Indirect Land-Use Change

A Representative Depiction of How Biofuels Can Contribute Indirectly to Global Warming

As biofuel demand – and prices – rise in developed economies, agriculture shifts to growing more biofuels-producing crops.

In these economies, the production of food crops declines as a percentage of total agricultural output.

To meet global food demand, farmers in developing countries such as Brazil convert less-profitable grazing lands to grow food crops.

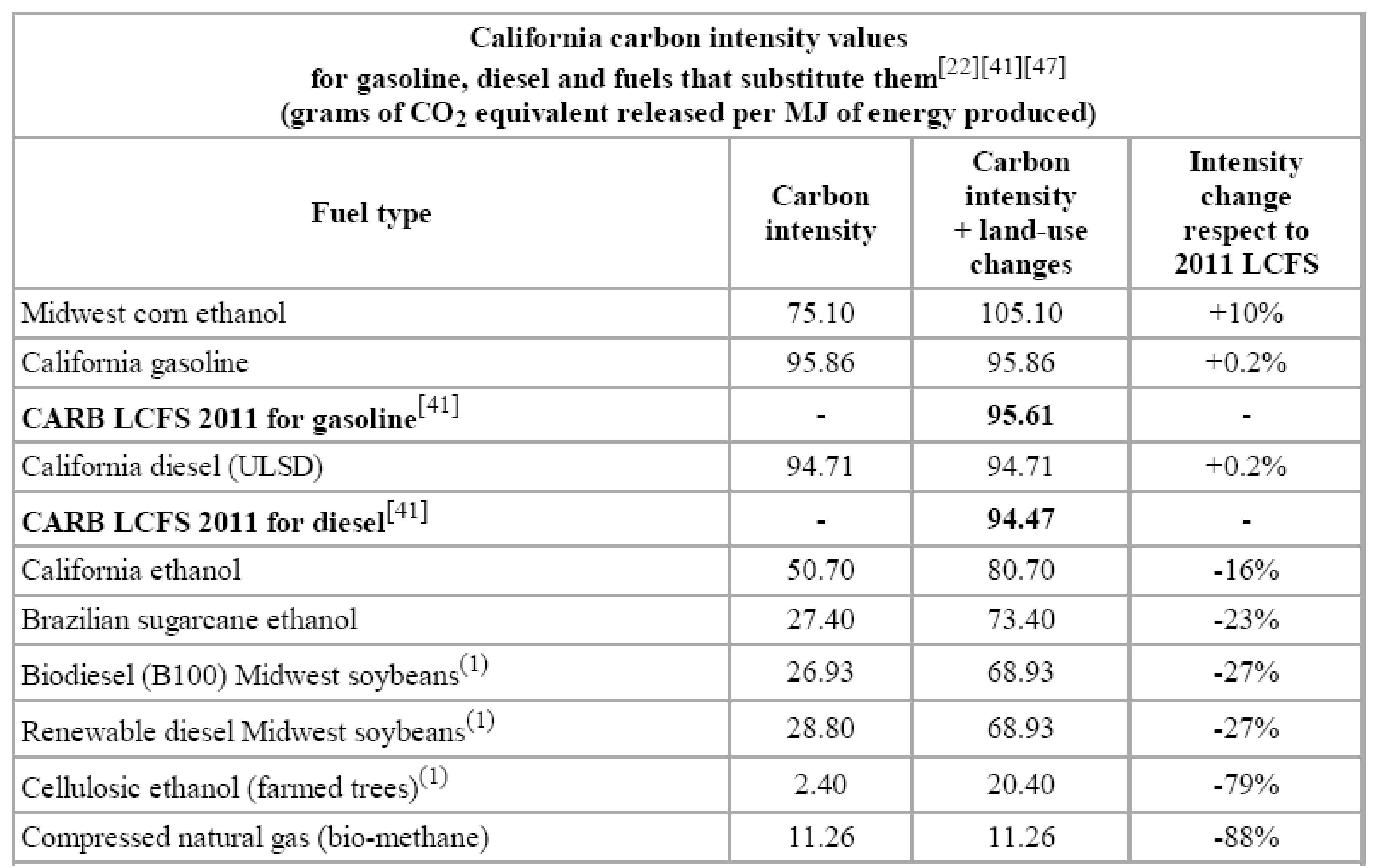
As a result, cattle ranches are displaced from existing grazing lands.

The clearing and burning of rainforest land to replace grazing areas lost to expanded farming of food crops releases vast amounts of CO2 into the atmosphere.

Searchinger, 2008, Science

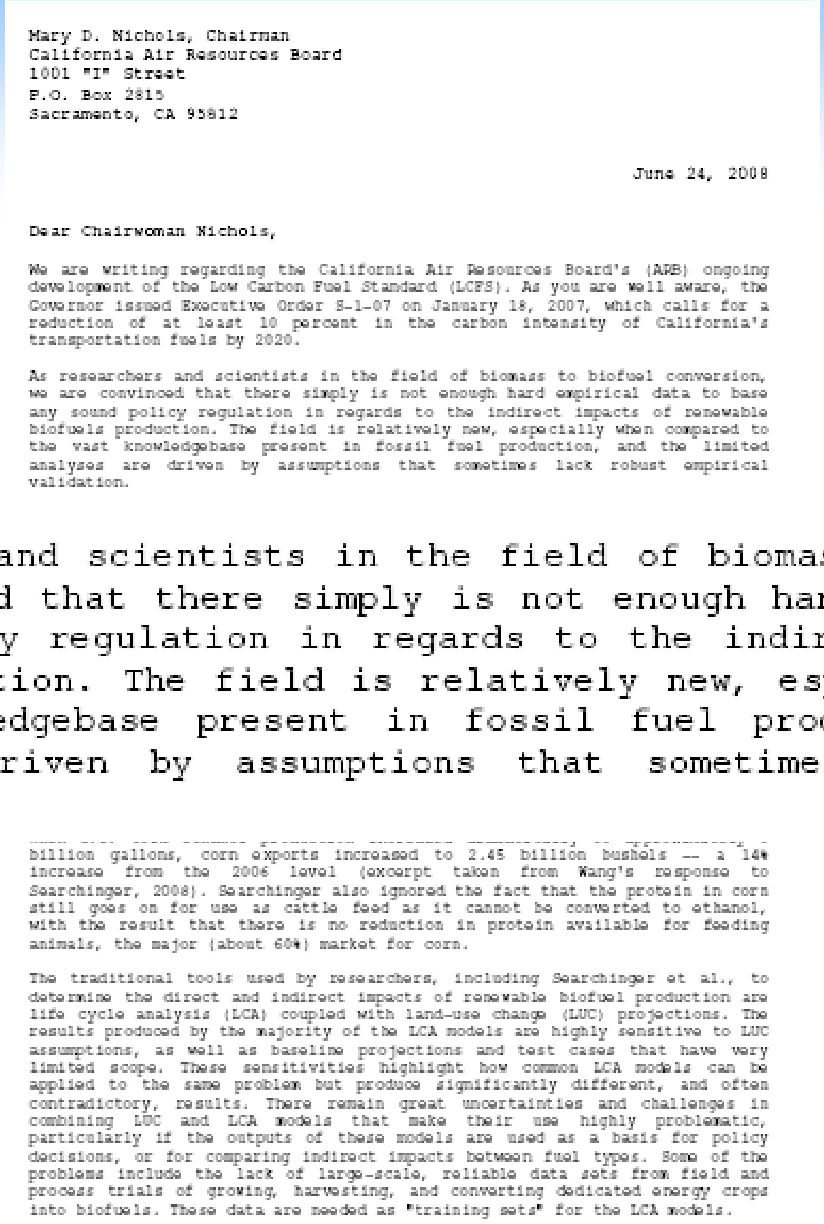
Récit d’une controverse

- Avril 2009 - Mise en place en Californie d’une réglementation sur les carburants “propres” (Low Carbon Fuel Standard, LCFS)
- Précédée d’une Consulation publique
- Une part du débat autour d’ ILUC



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,

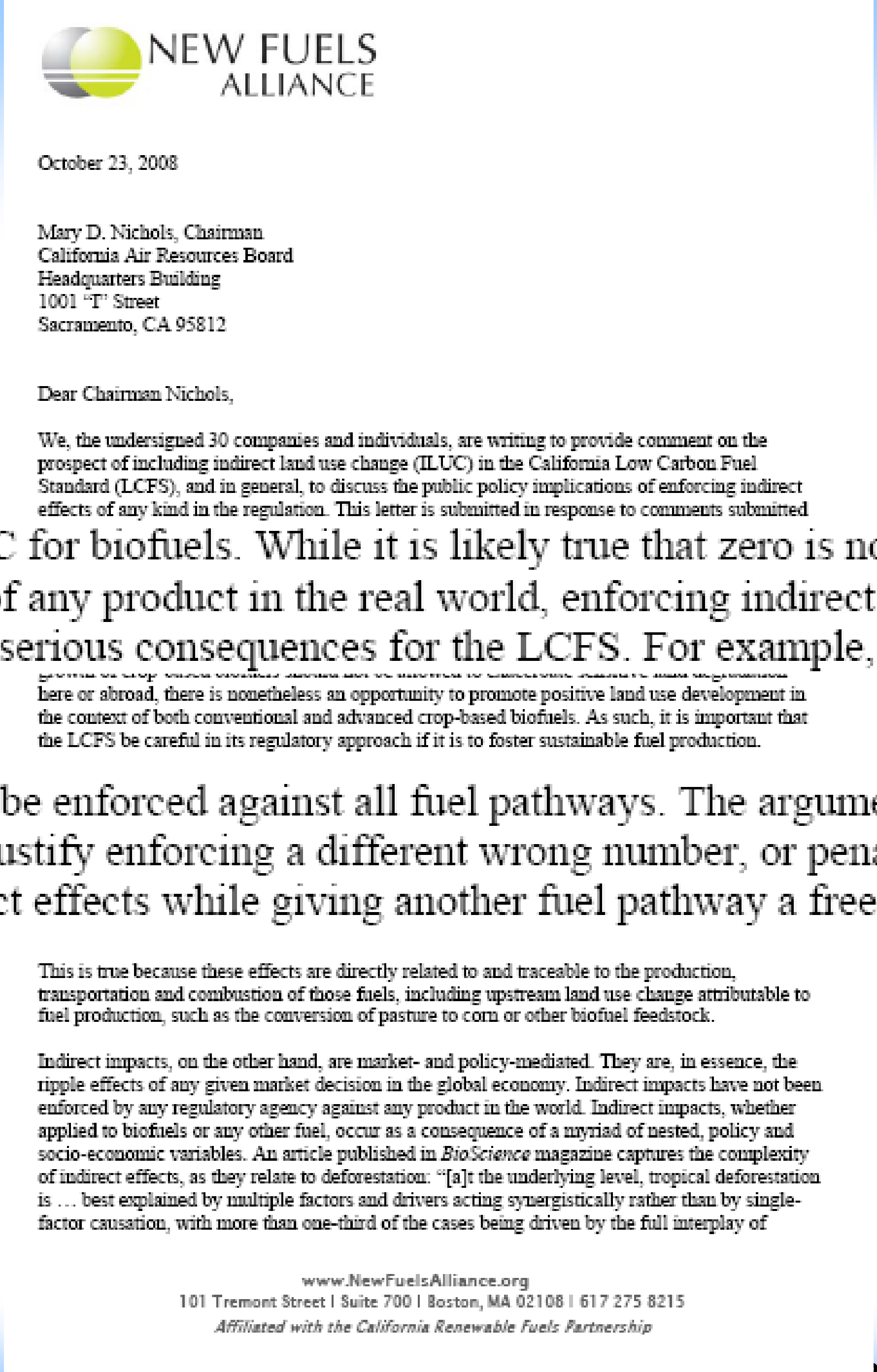
We are writing regarding the California Air Resources Board's (ARB) ongoing development of the Low Carbon Fuel Standard (LCFS). As you are well aware, the Governor issued Executive Order S-1-07 on January 18, 2007, which calls for a reduction of at least 10 percent in the carbon intensity of California's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

billion gallons, corn exports increased to 2.45 billion bushels -- a 14% increase from the 2006 level (excerpt taken from Wang's response to 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 prospect of including indirect land use change (ILUC) in the California Low Carbon Fuel Standard (LCFS), and in general, to discuss the public policy implications of enforcing indirect effects of any kind in the regulation. This letter is submitted in response to comments submitted

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

here or abroad, there is nonetheless an opportunity to promote positive land use development in the context of both conventional and advanced crop-based biofuels. As such, it is important that the LCFS be careful in its regulatory approach if it is to foster sustainable fuel production.

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.

This is true because these effects are directly related to and traceable to the production, transportation and combustion of those fuels, including upstream land use change attributable to fuel production, such as the conversion of pasture to corn or other biofuel feedstock.

Indirect impacts, on the other hand, are market- and policy-mediated. They are, in essence, the 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

Les interactions entre bioénergies et climat'

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.

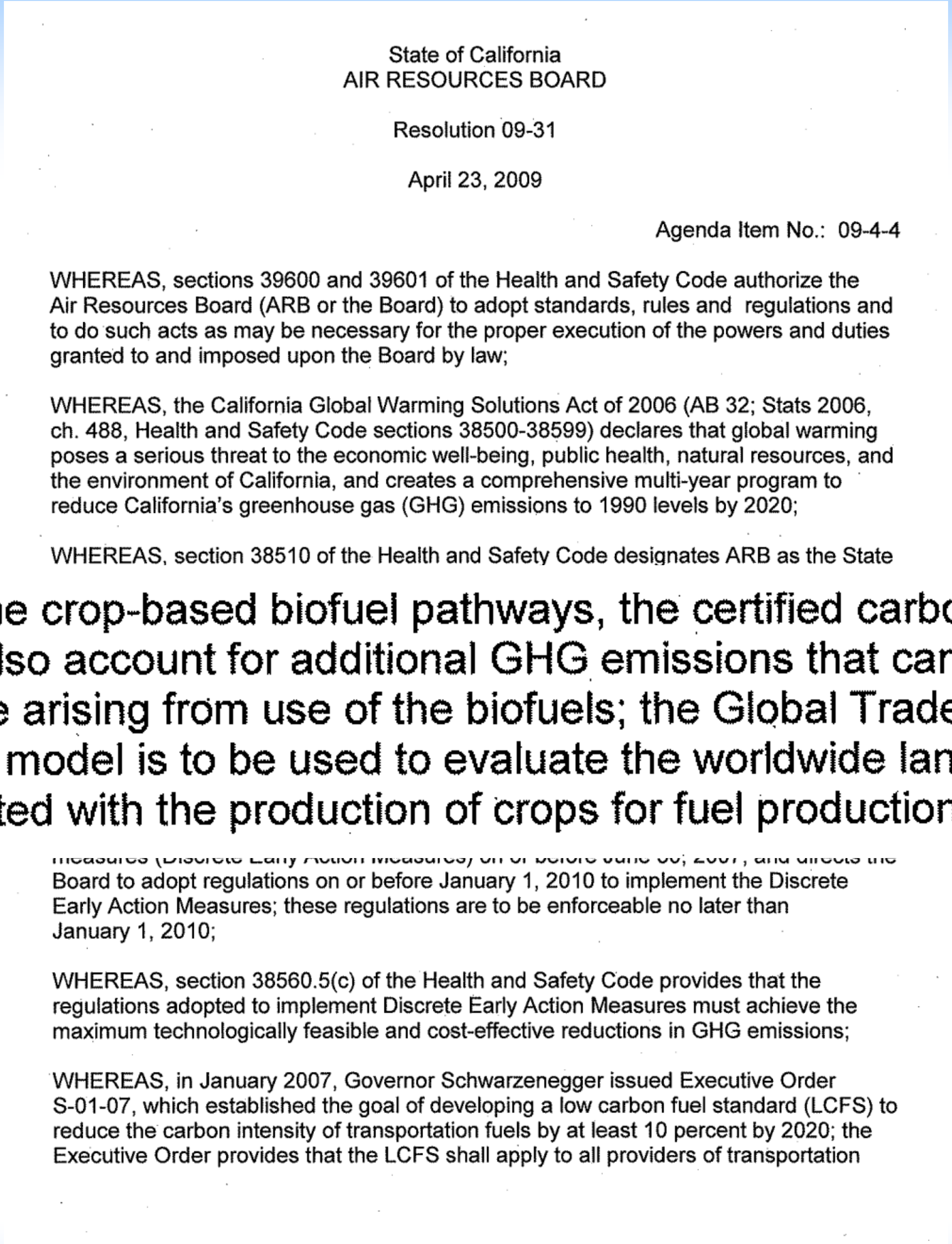
science. However, you should not delay inclusion of known sources of emissions, including indirect emissions from biofuels, pending discovery of potential effects from other fuels.

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;

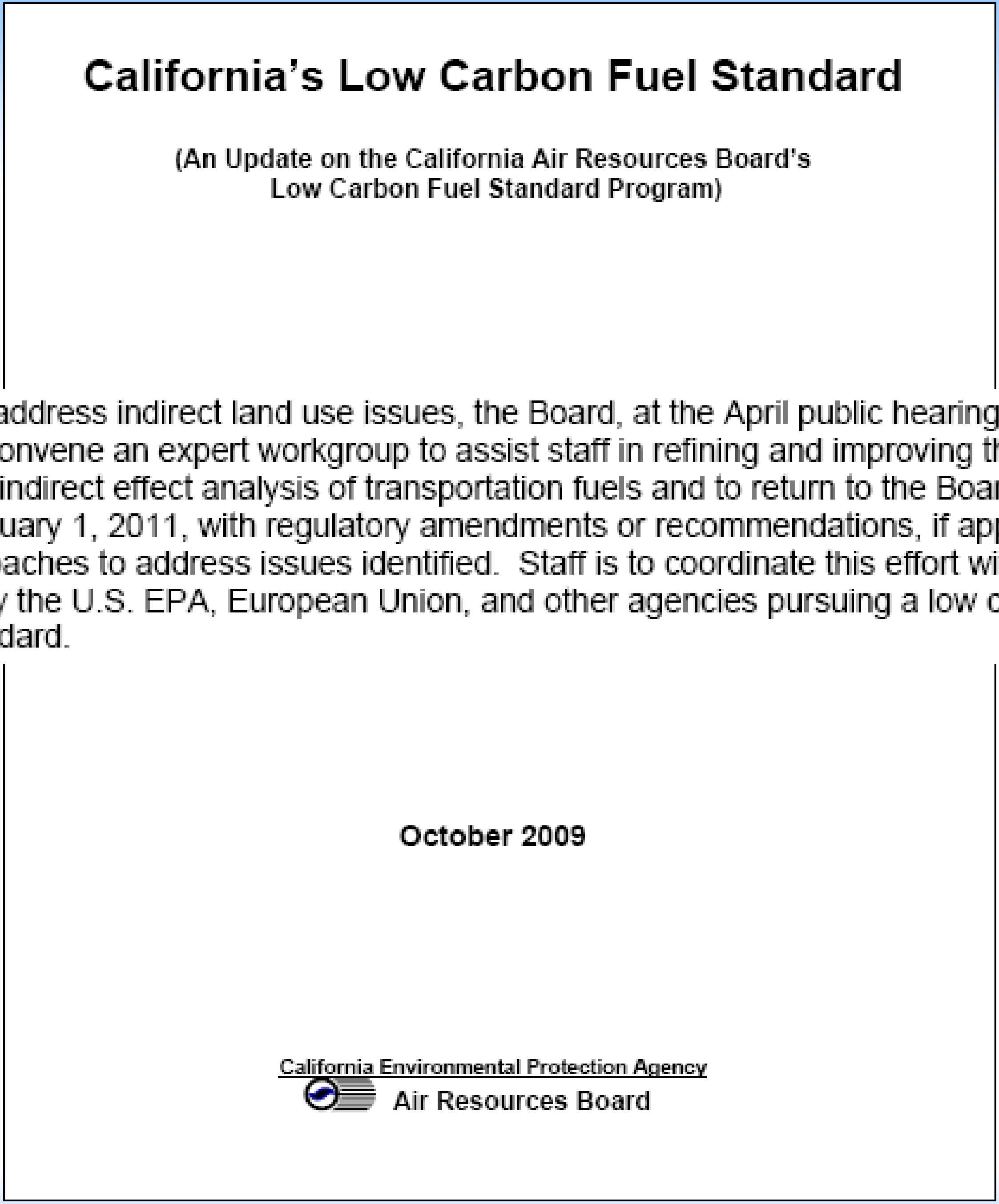
WHEREAS, section 38510 of the Health and Safety Code designates ARB as the State

measures (Discrete Early Action Measures) on or before June 30, 2007, and directs the 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

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;



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

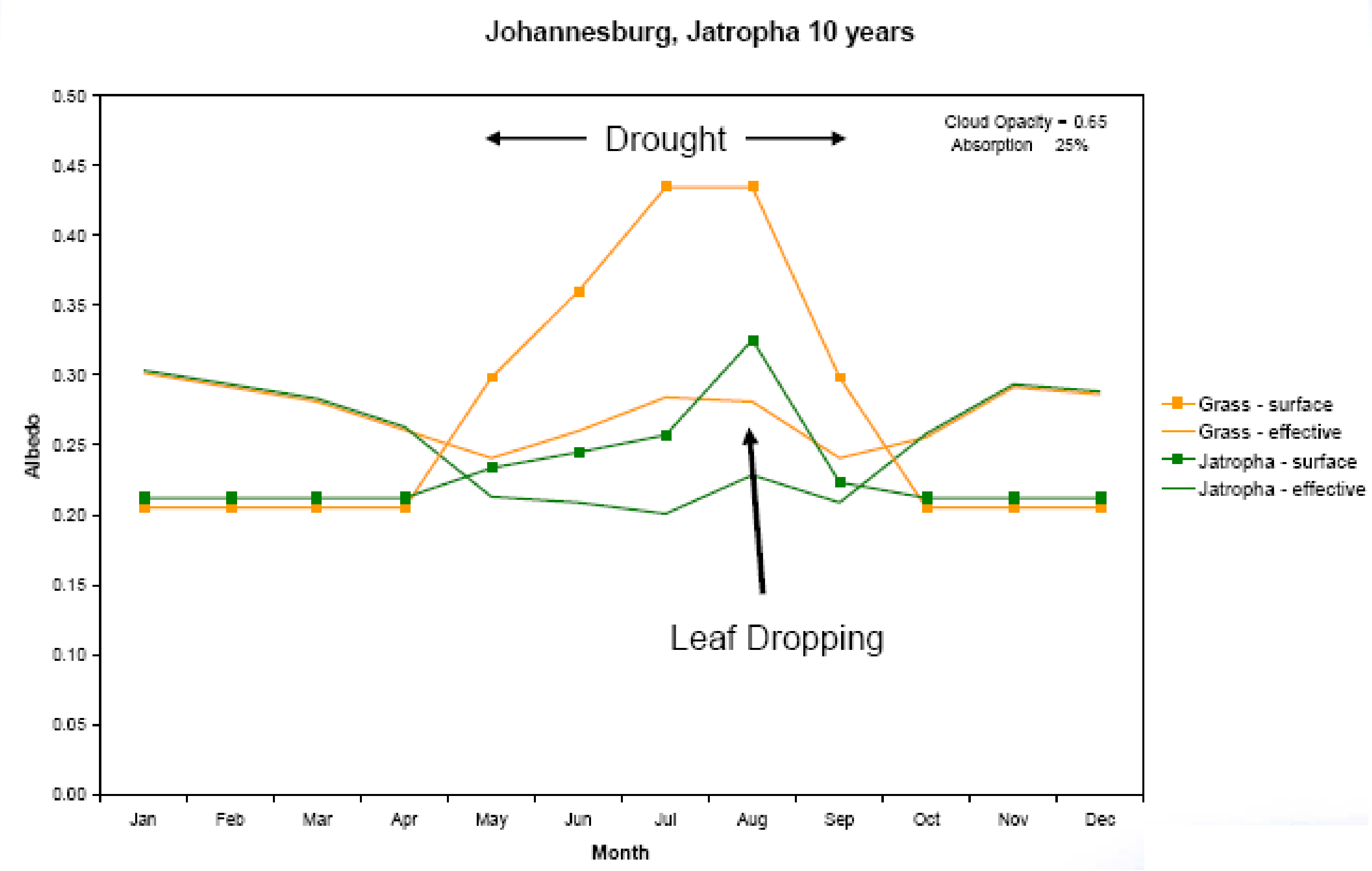
California Environmental Protection Agency
Air Resources Board

Les effets biophysiques

- Les changements d’albedo et d’évaporation vont-ils refroidir ou réchauffer le climat ?

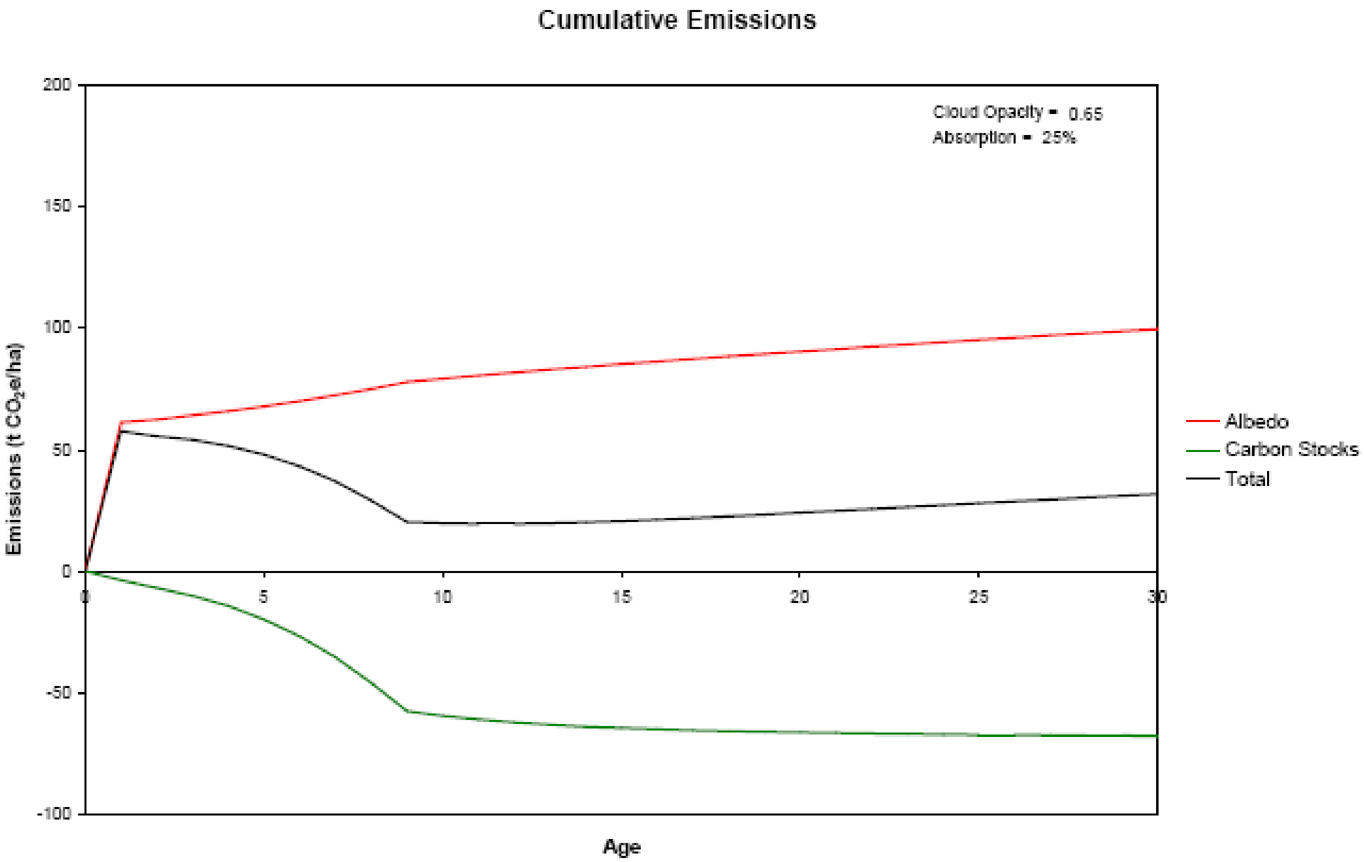
Afrique du Sud – zones sombres = plantations de Jatropha

Etude sur Jatropha



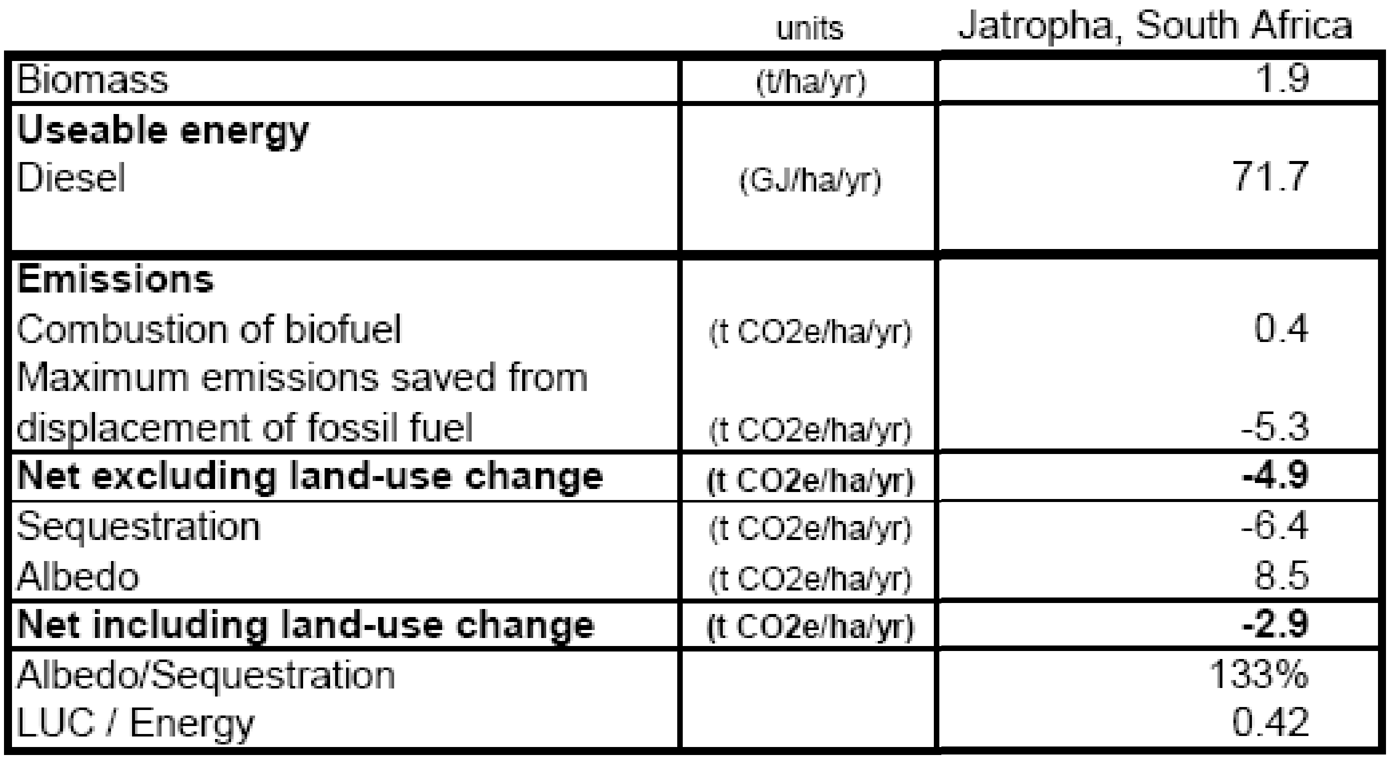
David Neil Bird, www.ceg.ncl.ac.uk/reimpact

Albedo vs. Stockage de C



David Neil Bird, www.ceg.ncl.ac.uk/reimpact

Impact en termes de GES



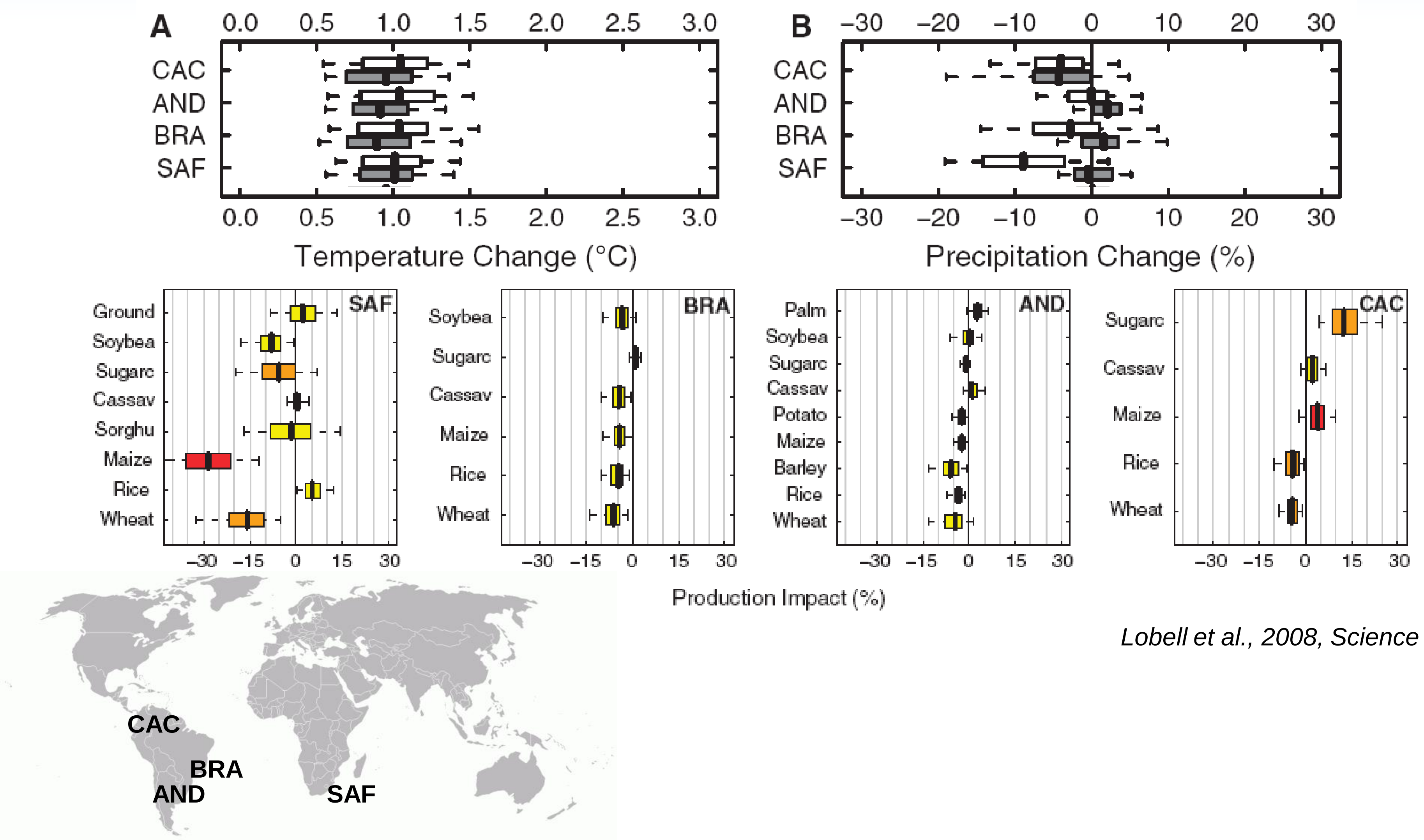
	units	Jatropha, South Africa
Biomass	(t/ha/yr)	1.9
Useable energy		
Diesel	(GJ/ha/yr)	71.7
Emissions		
Combustion of biofuel	(t CO2e/ha/yr)	0.4
Maximum emissions saved from displacement of fossil fuel	(t CO2e/ha/yr)	-5.3
Net excluding land-use change	(t CO2e/ha/yr)	**-4.9**
Sequestration	(t CO2e/ha/yr)	-6.4
Albedo	(t CO2e/ha/yr)	8.5
Net including land-use change	(t CO2e/ha/yr)	**-2.9**
Albedo/Sequestration		133%
LUC / Energy		0.42

David Neil Bird, www.ceg.ncl.ac.uk/reimpact

S'assurer de la viabilité climatique des filières

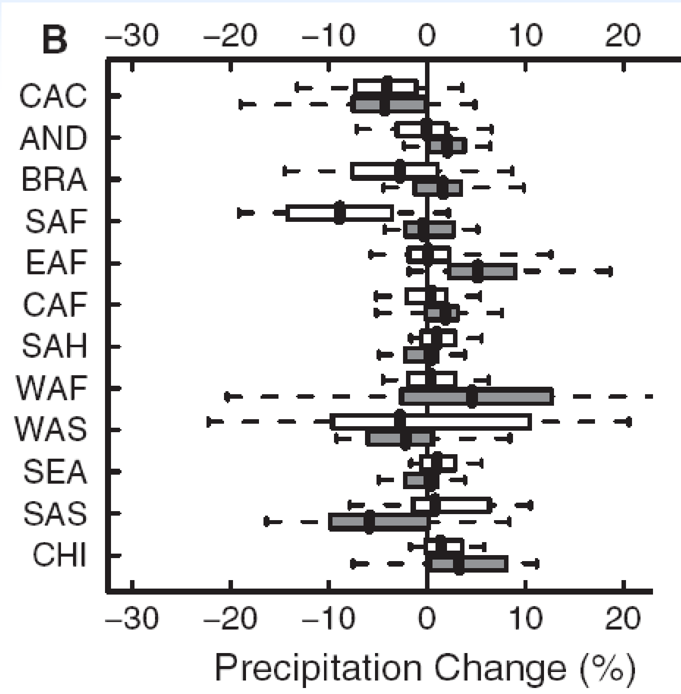
- Prédire les Rendements futurs
- Estimer les Besoins en eau

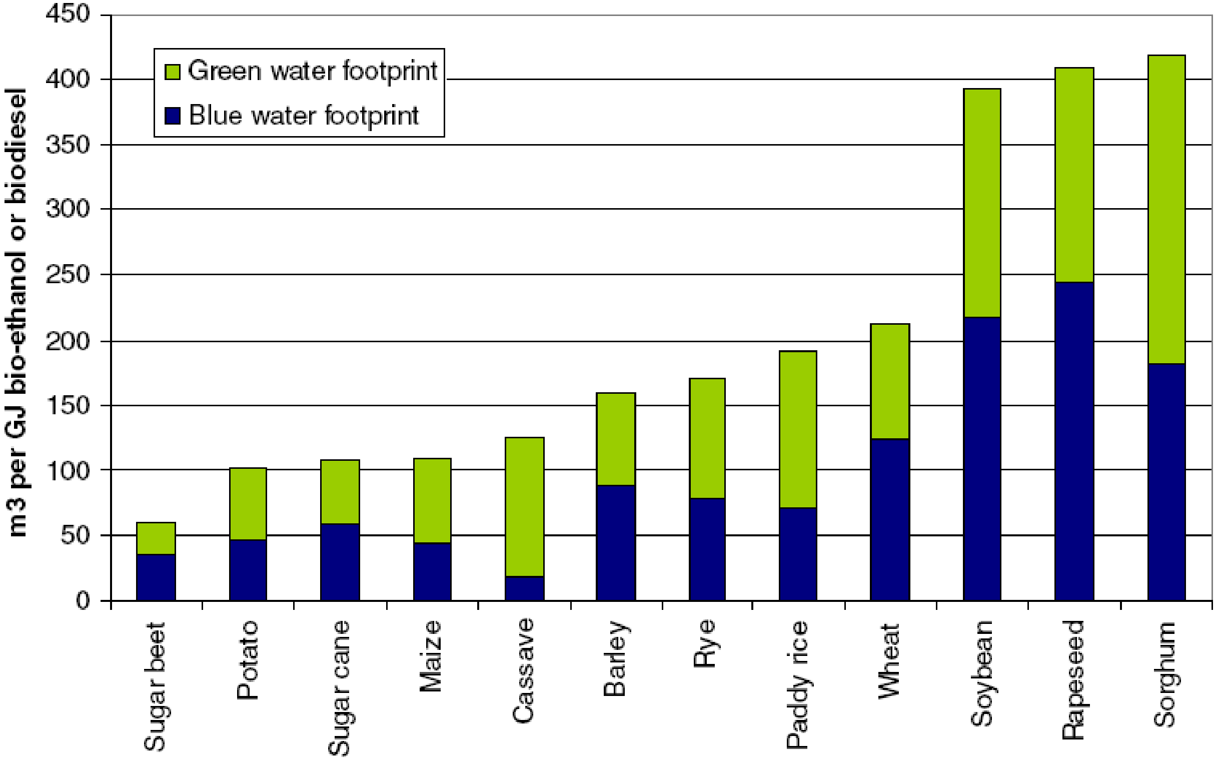
Comment le climat ‘pilote’ la productivité



Lobell et al., 2008, Science

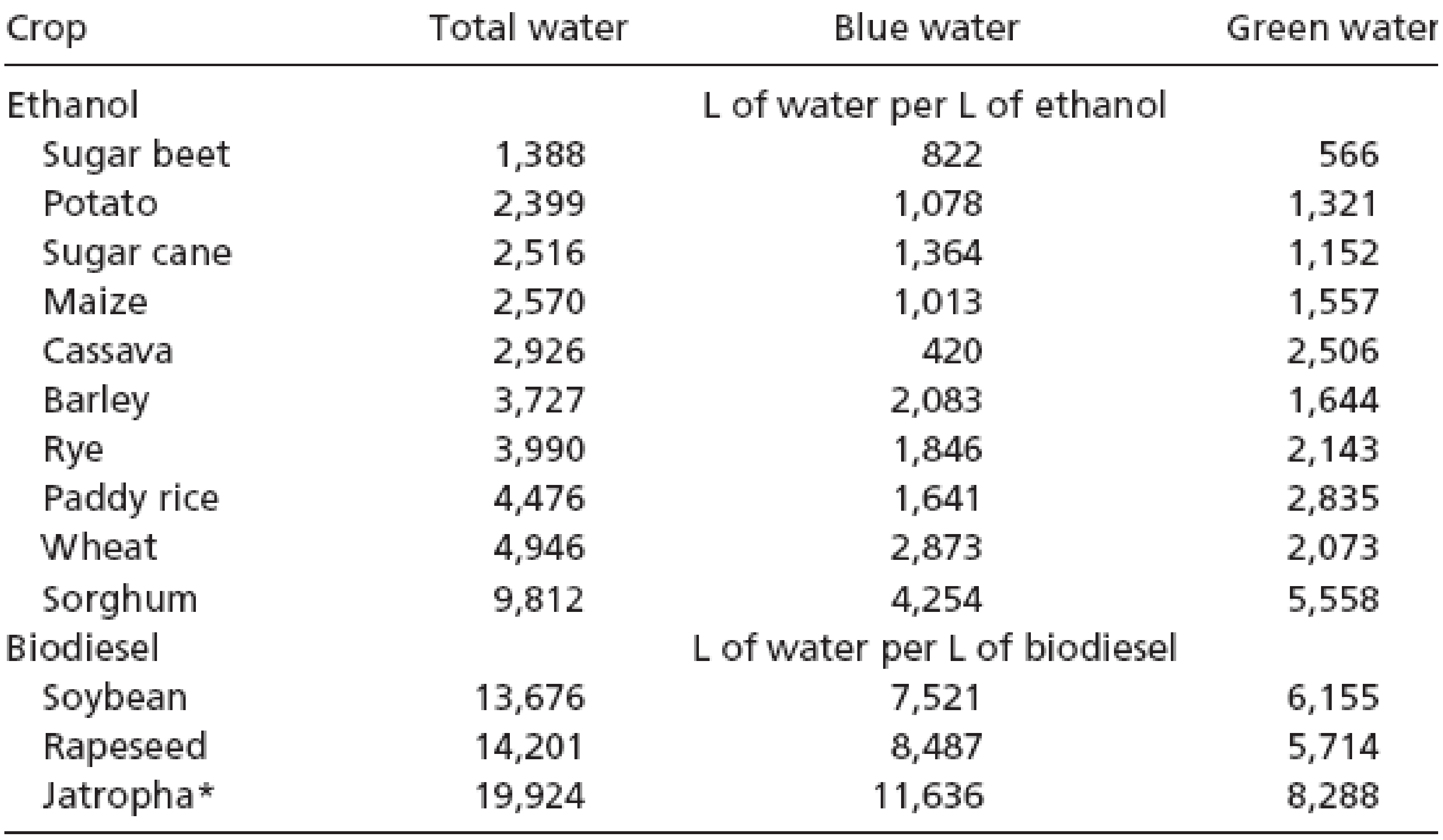
Besoin en eau de différentes cultures





Gerbens-Leenes *et al.*, *PNAS*, 2009

Besoin en eau par L d’agrocarburants

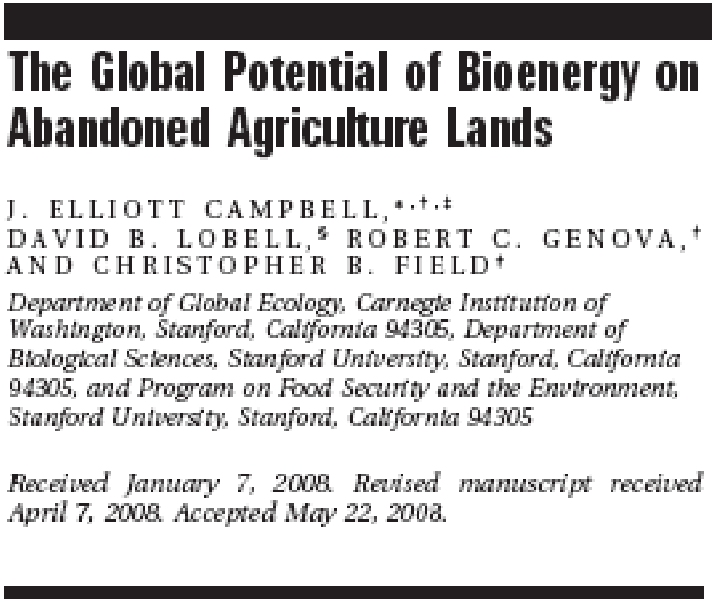


Crop	Total water	Blue water	Green water
Ethanol		L of water per L of ethanol	
Sugar beet	1,388	822	566
Potato	2,399	1,078	1,321
Sugar cane	2,516	1,364	1,152
Maize	2,570	1,013	1,557
Cassava	2,926	420	2,506
Barley	3,727	2,083	1,644
Rye	3,990	1,846	2,143
Paddy rice	4,476	1,641	2,835
Wheat	4,946	2,873	2,073
Sorghum	9,812	4,254	5,558
Biodiesel		L of water per L of biodiesel	
Soybean	13,676	7,521	6,155
Rapeseed	14,201	8,487	5,714
Jatropha*	19,924	11,636	8,288

Aperçu de quelques solutions ou alternatives

Produire sur les terres agricoles abandonnées

- Deux études



The Global Potential of Bioenergy on Abandoned Agriculture Lands

J. ELLIOTT CAMPBELL,[*,†,‡]
DAVID B. LOBELL,[§] ROBERT C. GENOVA,[†]
AND CHRISTOPHER B. FIELD[†]

Department of Global Ecology, Carnegie Institution of Washington, Stanford, California 94305, Department of Biological Sciences, Stanford University, Stanford, California 94305, and Program on Food Security and the Environment, Stanford University, Stanford, California 94305

Received January 7, 2008. Revised manuscript received April 7, 2008. Accepted May 22, 2008.

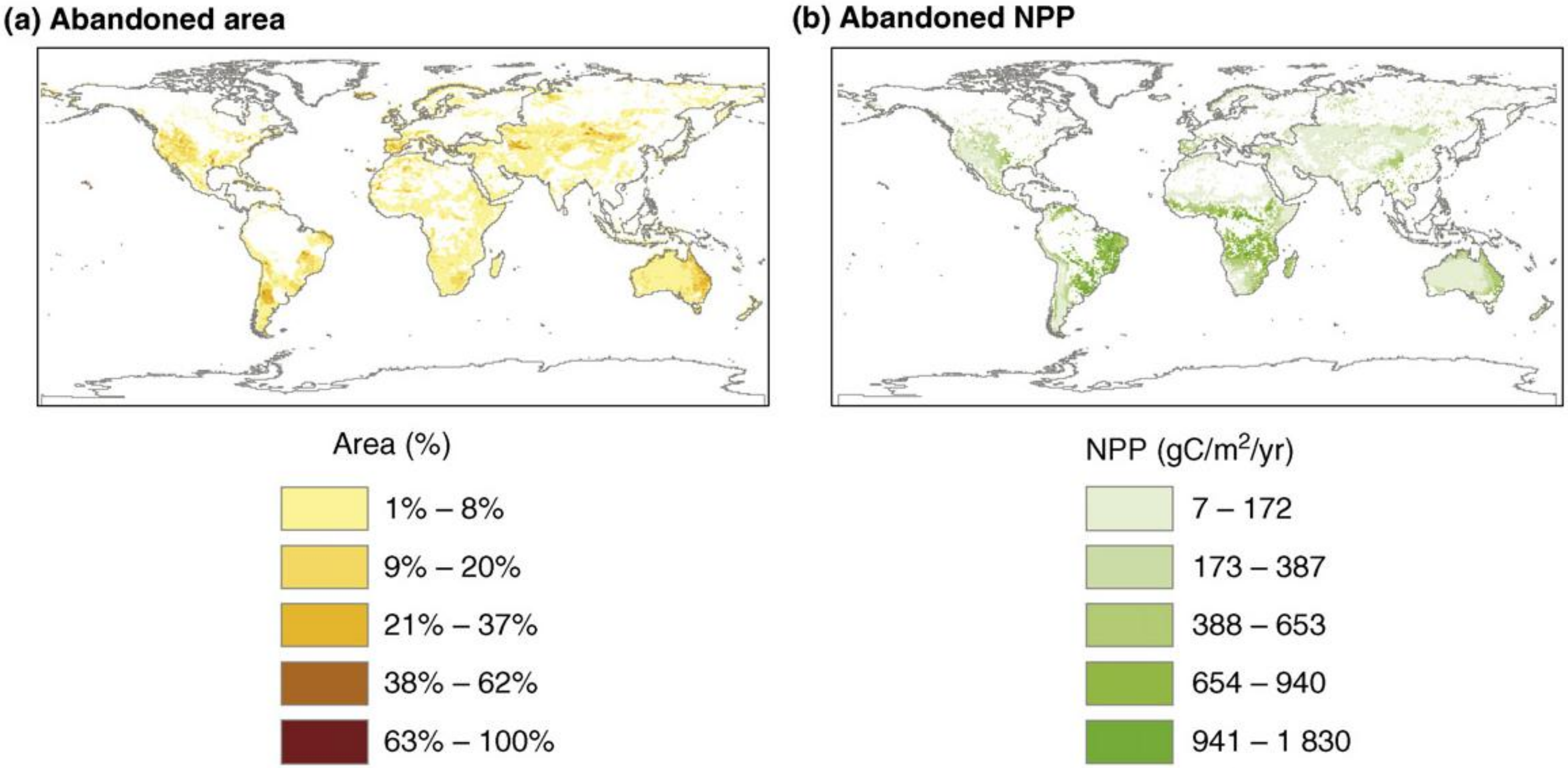
Envir. Sci. Technol., 2008

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

Surfaces concernées et NPP associée



TRENDS in Ecology & Evolution

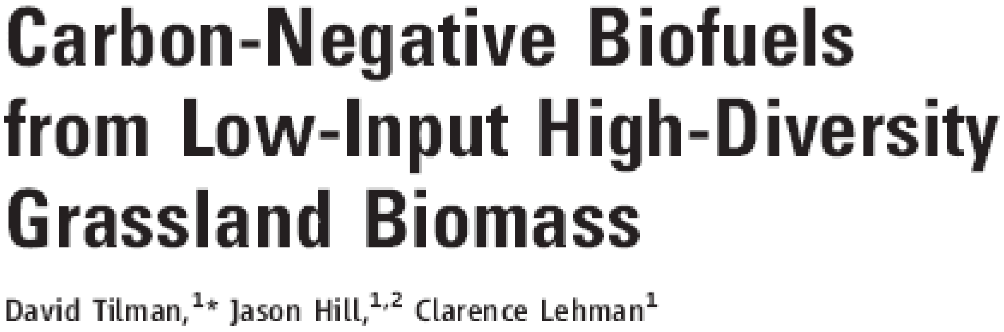
A l'échelle globale

- Quelques ordres de grandeur:
  - Surface globale estimée : ~400 Mha
  - NPP moyenne : ~3 tC ha^{-1} an^{-1}
  - 50% de biomasse aérienne, 45% de Carbone, teneur énergétique de 20 kJ g^{-1}

  => 5% de la demande énergétique mondiale
- Conclusion
  - Potentiel à ne pas dépasser
    - Sur plus de surface -> compétition énergie/alimentation
    - Avec plus d'intrants -> ↘ intérêt climatique

Agrocarburants de 2de génération

- Par ex., étude de Tilman (2006)



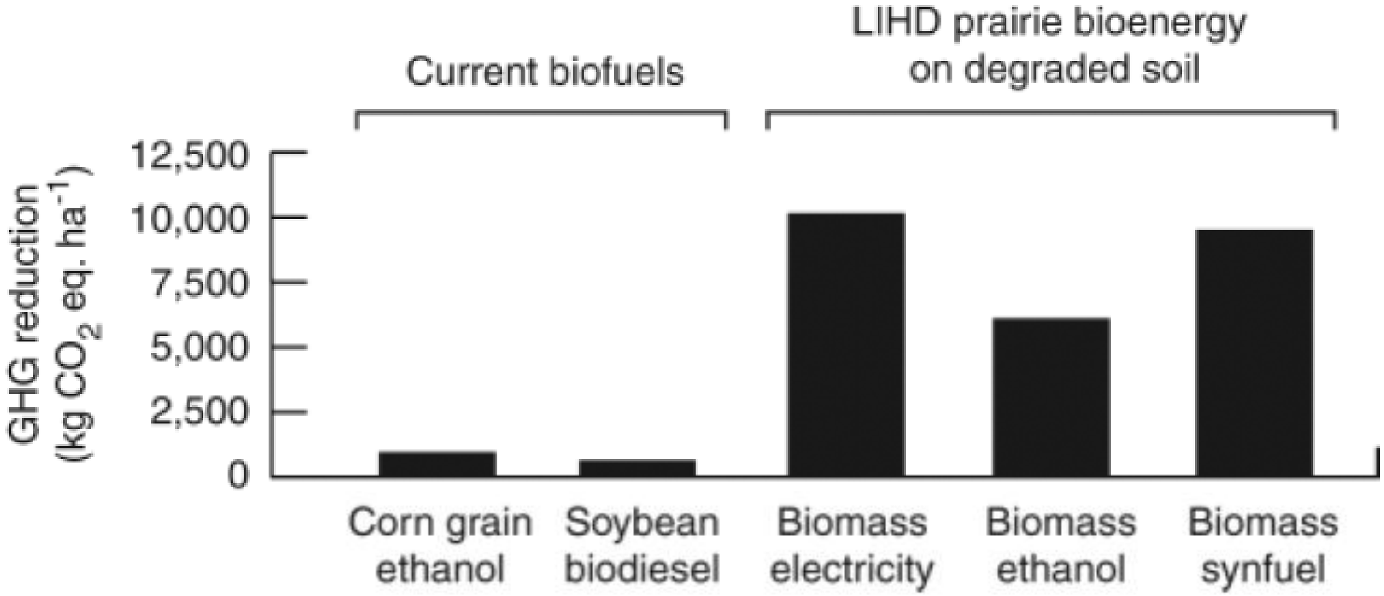
Carbon-Negative Biofuels from Low-Input High-Diversity Grassland Biomass

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

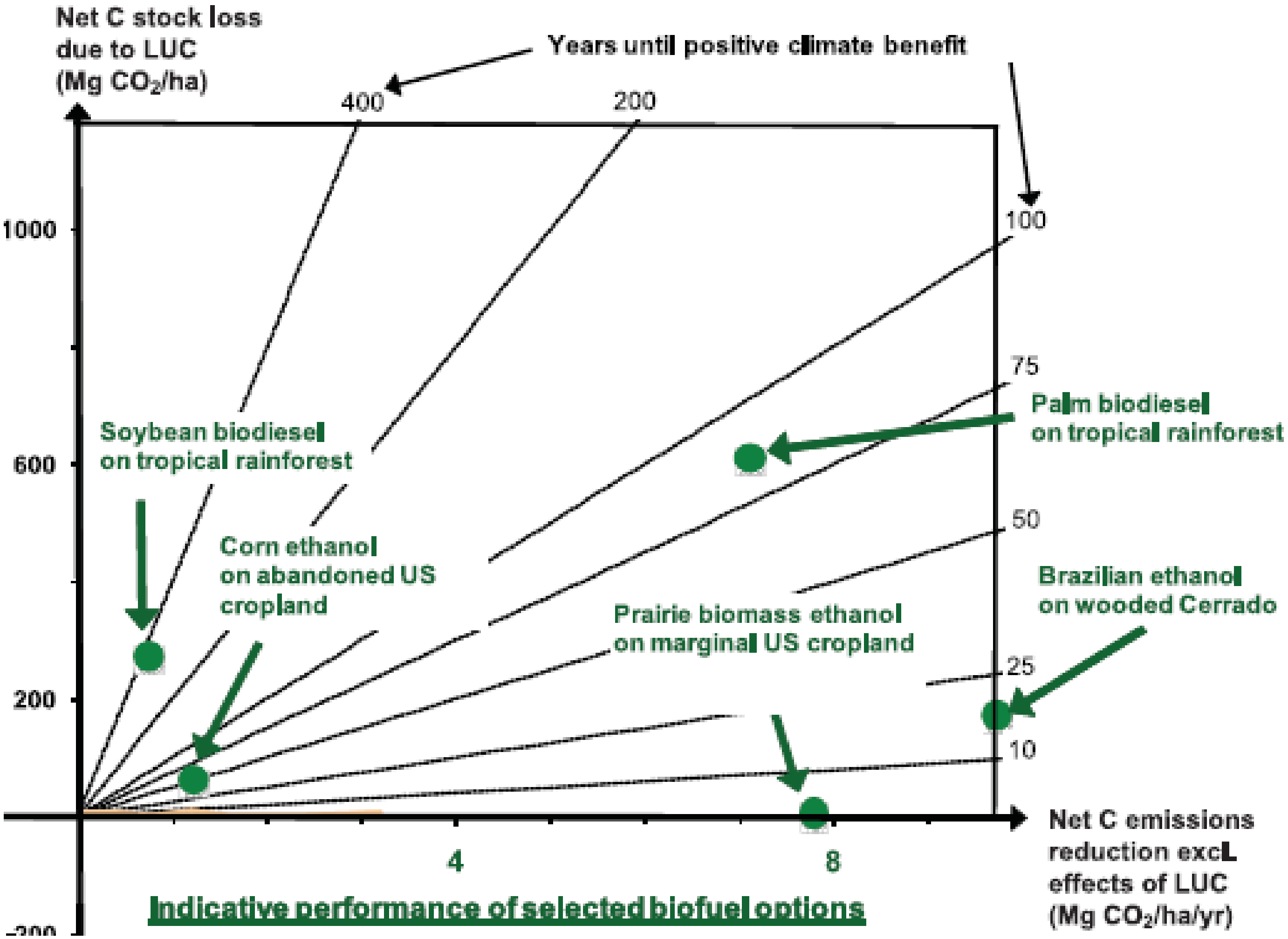
Science, 2006

- Production de bioénergie à partir de plantes herbacées pérennes (LIHD grasslands)
  - Bon rendement énergétique
  - Réduction des émissions de GES

Comparaison à des agrocarburants de 1ère génération



La contraction d'une dette carbonée



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

Planter des forêts plutôt que des cultures pour agrocarburants...

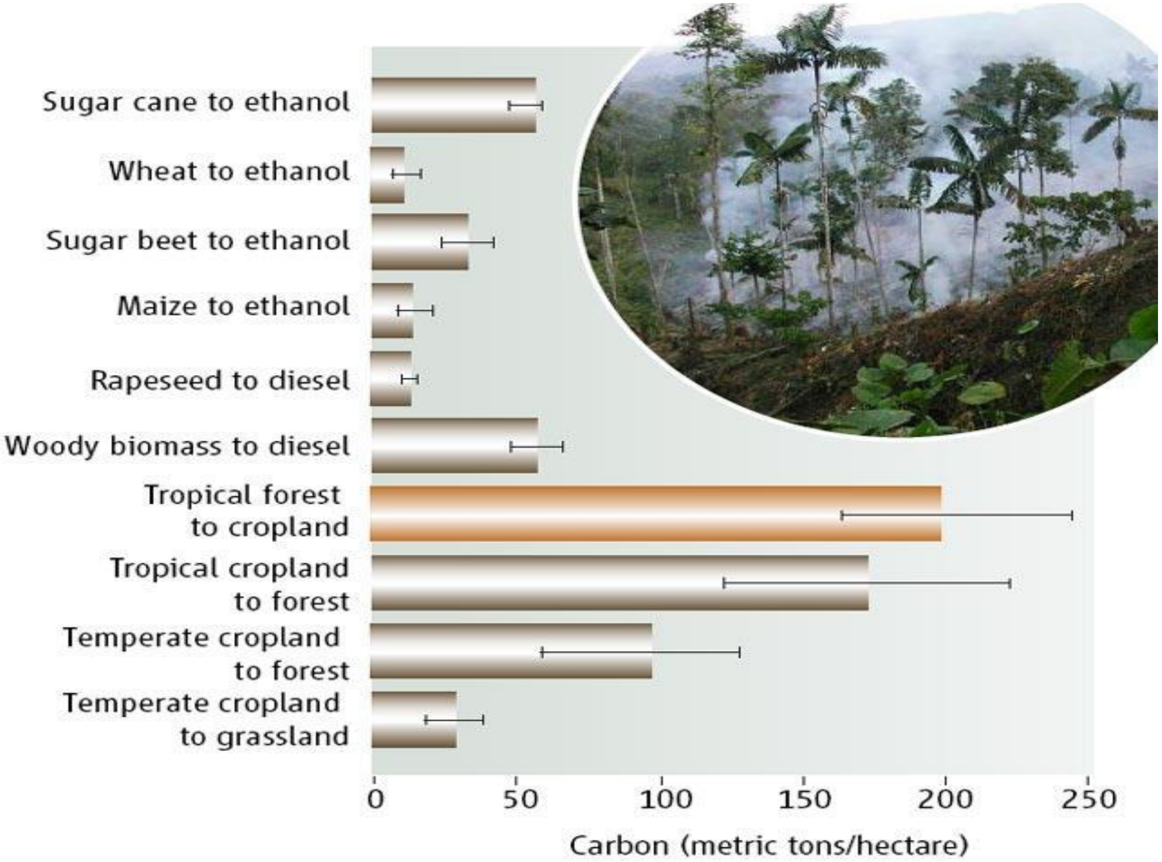
- Une étude de Righelato et al. (2007) basée sur des estimations de l'impact d'un changement d'usage des terres sur le bilan carbone

- Le gain environnemental par séquestration peut être plus grand que celui par production d'agrocarburants

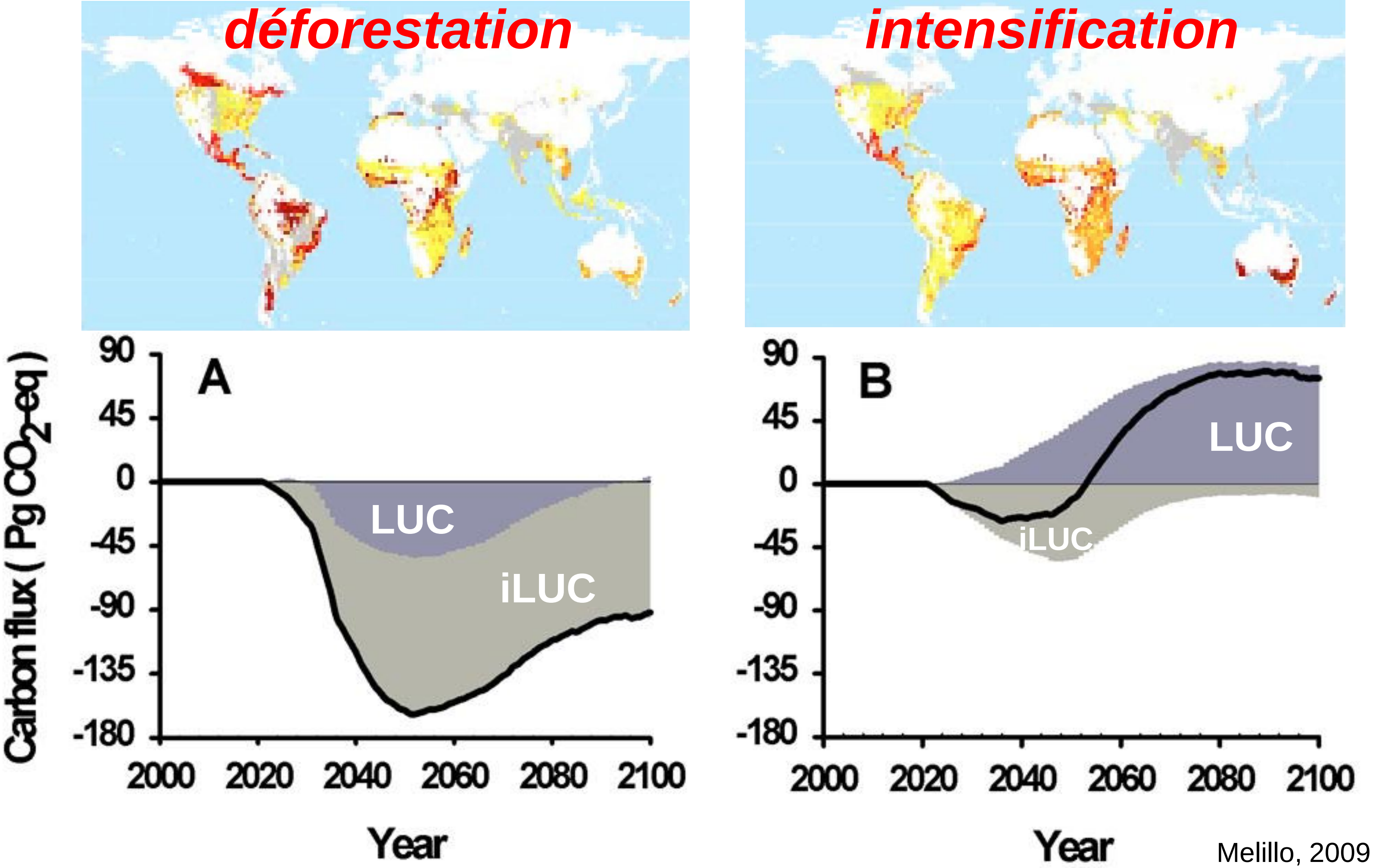
Carbon Mitigation by Biofuels or by Saving and Restoring Forests?

Science, 2007

Renton Righelato* and Dominick V. Spracklen

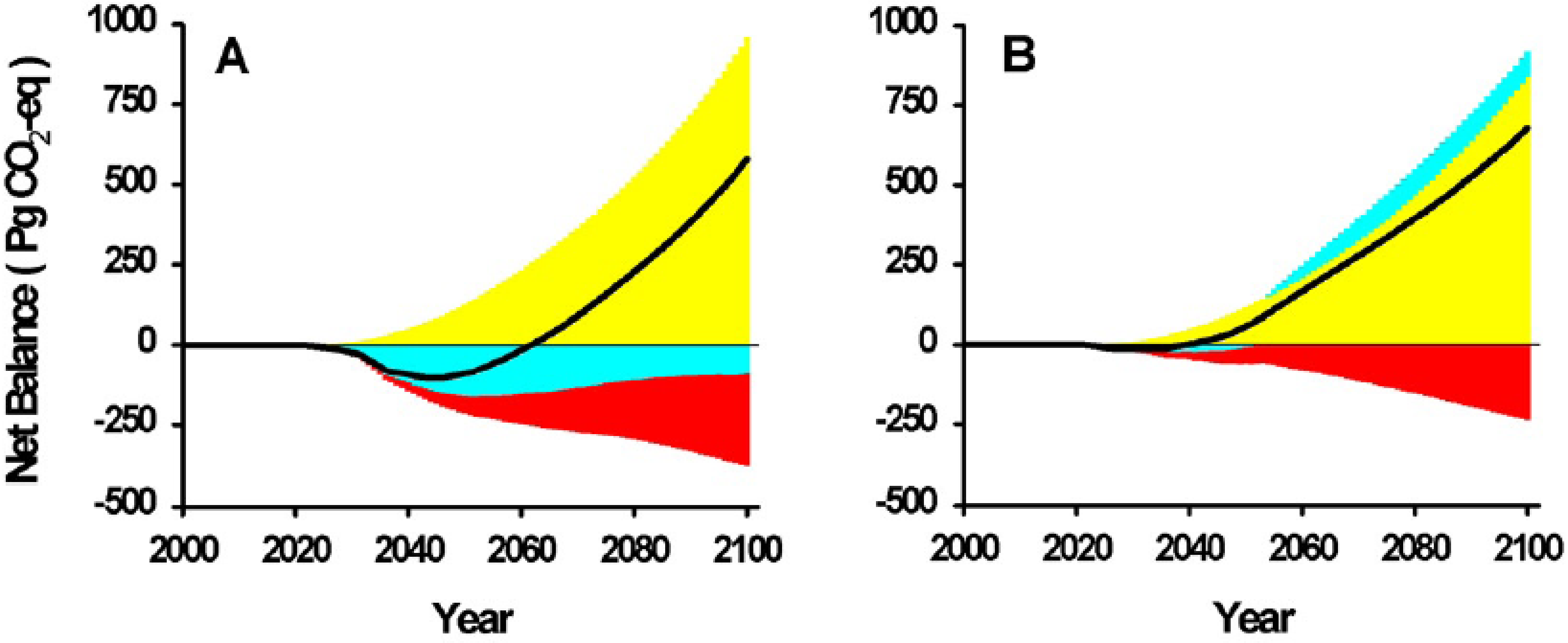


A défaut, protéger les forêts



Melillo, 2009, Science

Bilan GES net



🟨 Effet substitution

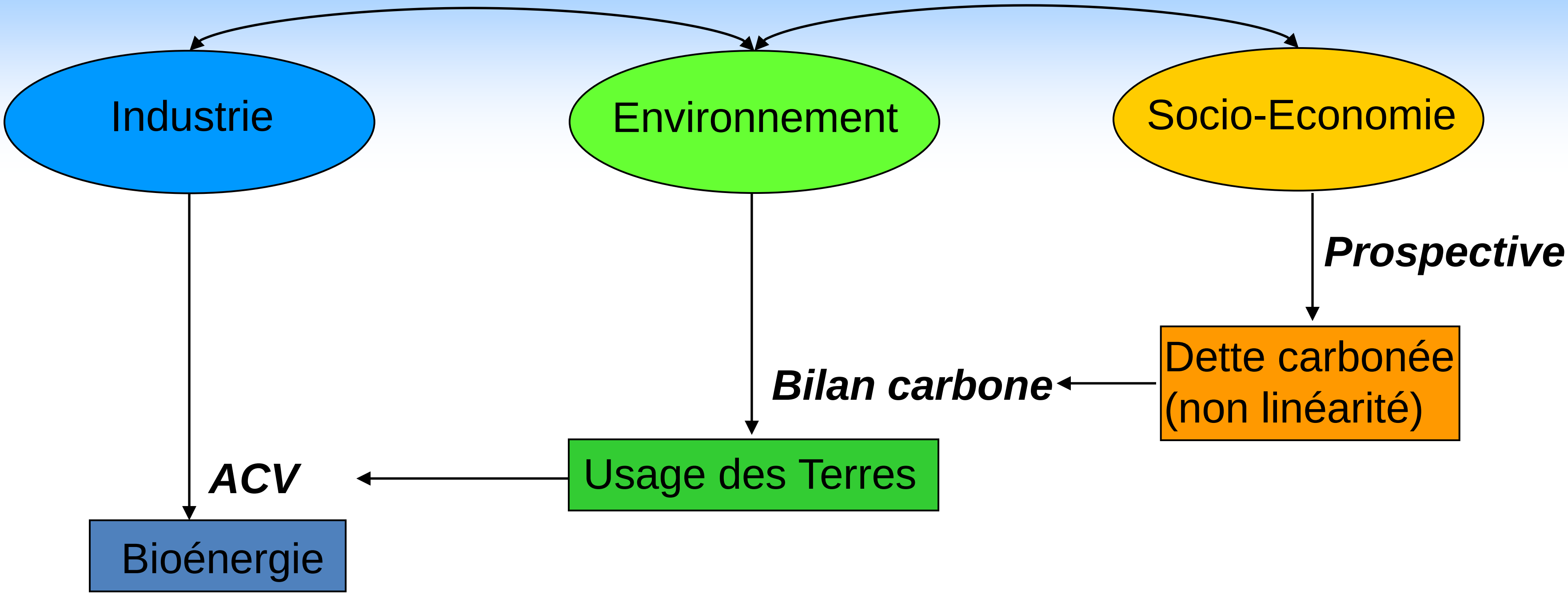
🟦 Bilan net C terrestre

🟥 N_2O emission

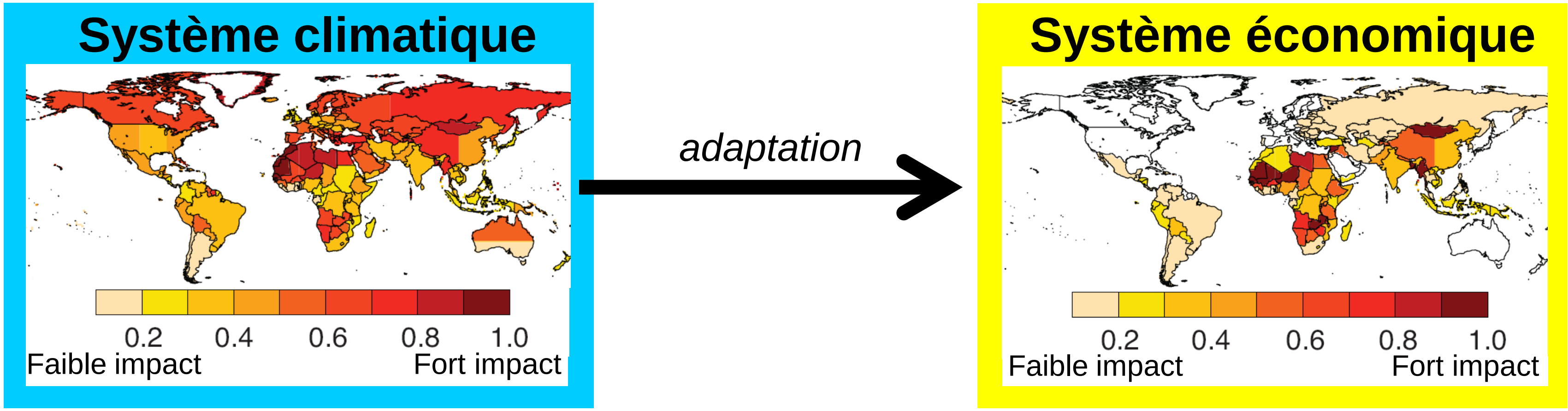
Mise en place de mécanismes

- Réduction des émissions liées à la déforestation et à la dégradation des forêts = REDD
- Sur la base d'un marché Carbone, donner une valeur aux émissions évitées associées à la déforestation
- Potentiel d'atténuation ~0.75 GtC an^{-1}

Une approche interdisciplinaire



Les capacités d'adaptation



Diffenbaugh *et al.*, *PNAS*, 2007

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