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Production de biomasse végétale au niveau mondial : potentiel de cette ressource renouvelable pour produire énergie, matériaux et molécules

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(remerciements à Laurent GAZULL du CIRAD pour l’envoi de documents)

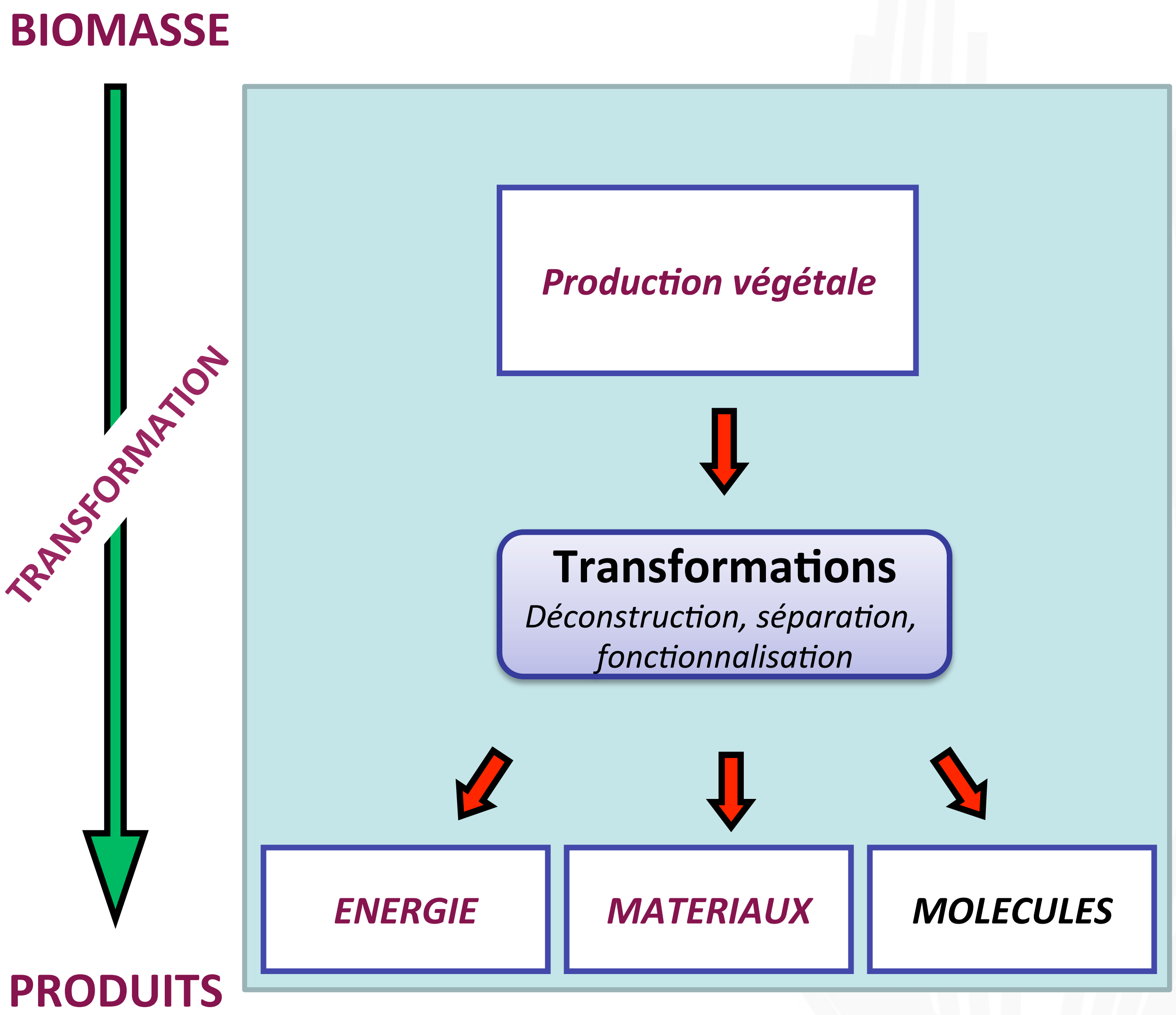
CENTRALE PARIS

LGPM Laboratoire de Génie des Procédés et Matériaux

Point de départ : quelques chiffres

- Energie solaire = 92 000 GTEP/an (1 TEP = 42 GJ)
- Energie stockée par photosynthèse 79 GTEP/an (source AIE)
- Plantes terrestres 4/5, océans 1/5
- Consommation mondiale d'énergie : 12 GTEP/an (+2,5%/an)
- Alimentation humaine : environ 2 GTEP/an

Chimie verte (acception INRA)



Taillis à courte rotation (*Salix*)

Jusqu'à 12 t/ha/ an (matière séche)

Plantations d'eucalyptus (Brésil)

4 millions ha
50 m^3/ha/an

5 à 7 ans de rotation

Plantations d'eucalyptus (Brésil)

Jusqu'à 30 m³/h

Betterave à sucre

70 t/ha/an, dont
12 t de sucre

Betterave à sucre

Betterave à sucre

Canne à sucre (Brésil)

68 t/ha/an,
dont 10 t de sucre
et 9 t de fibres

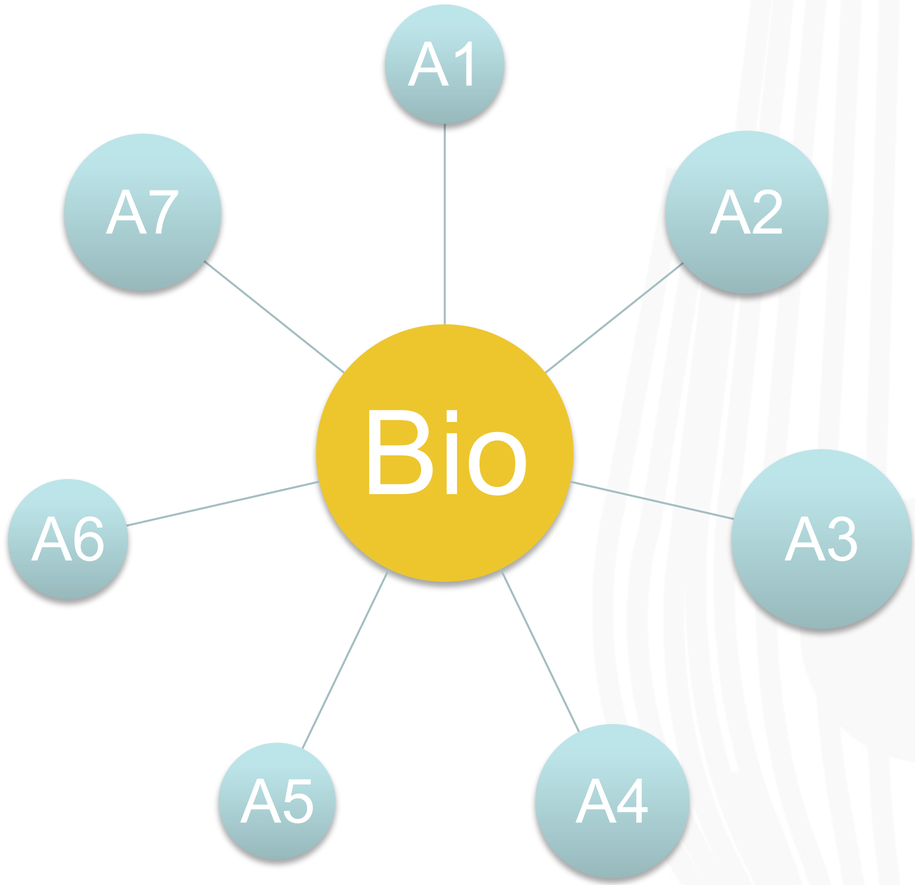
Canne à sucre (Brésil)

10 t en 8 heures

700 t par jour

Canne à sucre (Brésil)

Biorefinery/agrorefinery



Ordres de grandeur

Production	Rendement	Taille usine	Distance approvision[t]	Produits
Betterave	70 t/ha/an, soit 12 t de sucre	20 000 t/j pendant 100 jours	9,6 km	sucre, ethanol (7400 l/ha), molécules
Canne	68 t/ha/an, soit 10 t de sucre et 9 t de fibres	5 millions t/an	15,3 km	sucre, ethanol (6500 l/ha), molécules, énergie
Pâte/ papier	10 m^3/ha/an	500 000 t/an	17,8 km	Pâte et papier, énergie, liqueurs noires
Scierie résineux	12 m^3/ha/an	1 million m^3/an	16,3 km	sciages, plaquettes, sciure
Scierie feuillus	8 m^3/ha/an	20 000 m^3/an	2,8 km	sciages, plaquettes, sciure
Charbon végétal	30 m^3/ha/an	20 000 t/an, soit environ 150 000 m^3 de bois	3,1 km	charbon, énergie, pyroligneux
Bio-rafinnerie	10 t/ha/an	500 t/heure	33,3 km	matériaux, énergie, molécules

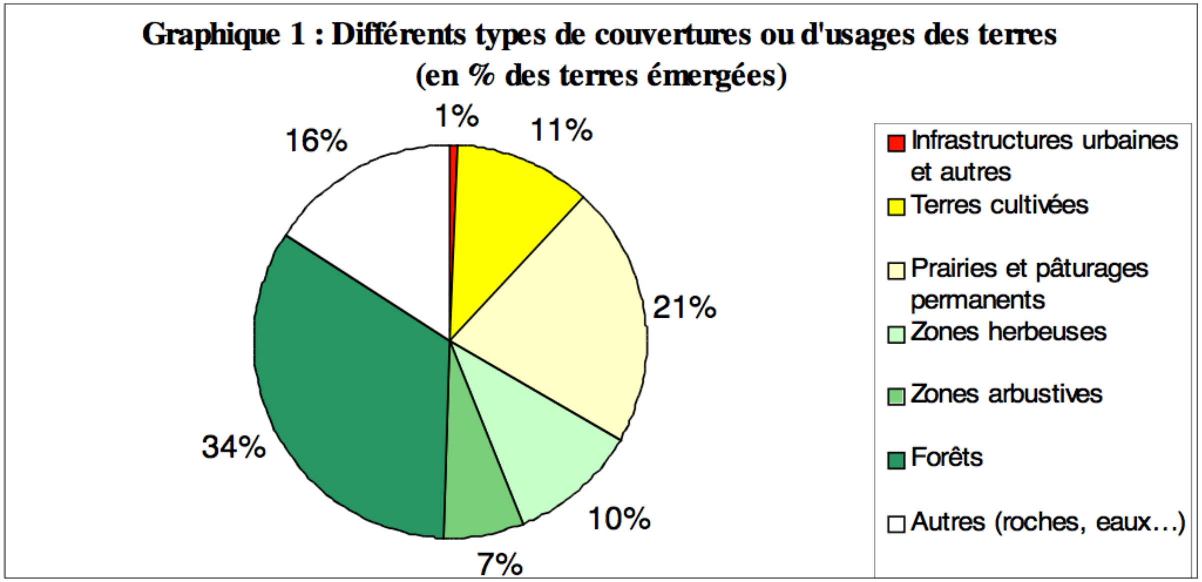
BIO-RAFFINERIES

AGRO-RAFFINERIES

Potentiel de production au niveau mondial

Les terres émergées

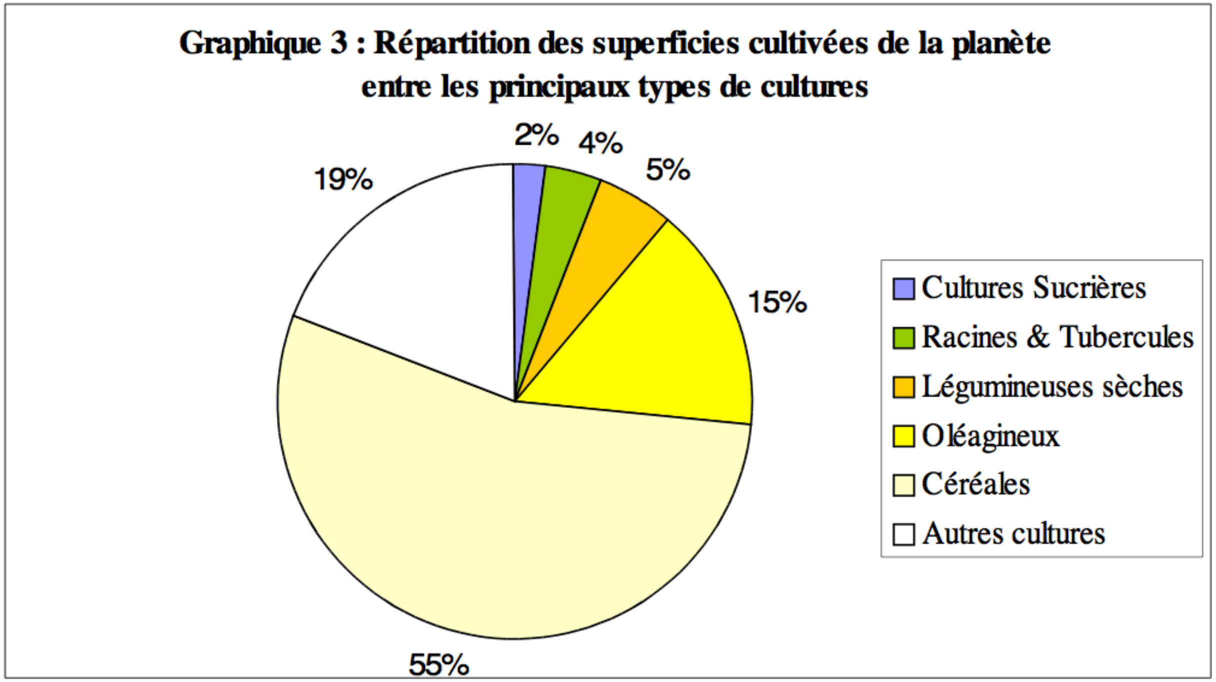
- Terres émergées (29%) : 15 milliards ha
- Terres arables et cultivées : 1,5 milliard ha
- Forêts : 4 milliards d'ha



Sources : d'après SAGE, GTAP

Rapport L. Roudart, 2008

Affectation globale des terres cultivées



Sources : d'après SAGE, GTAP

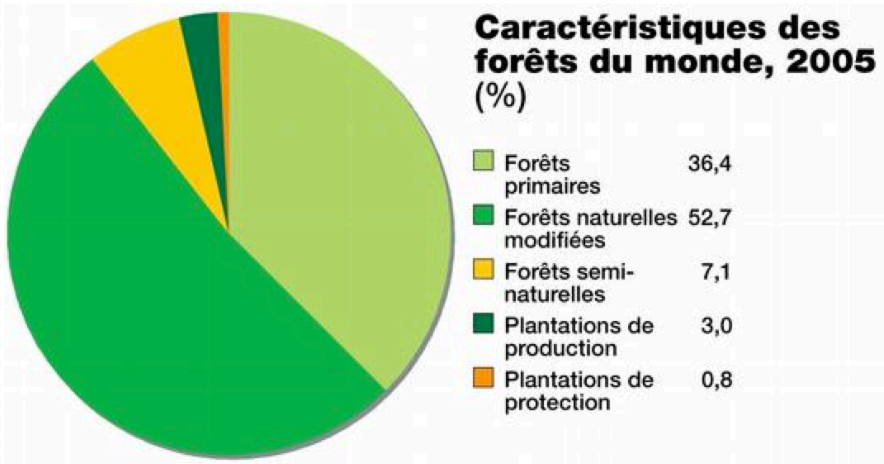
Rapport L. Roudart, 2008

Les forêts sur la planète (4000 millions d'ha)

En % de la superficie forestière mondiale

Tropicale	52 (± 2 000 millions d'ha)
Subtropicale	9 (± 360 millions d'ha)
Tempérée	13 (± 520 millions d'ha)
Boréale / Polaire	25 (± 1 000 millions d'ha)

Caractéristiques



Production : 3400 millions de m^3, soit environ 1 m^3/ha/an

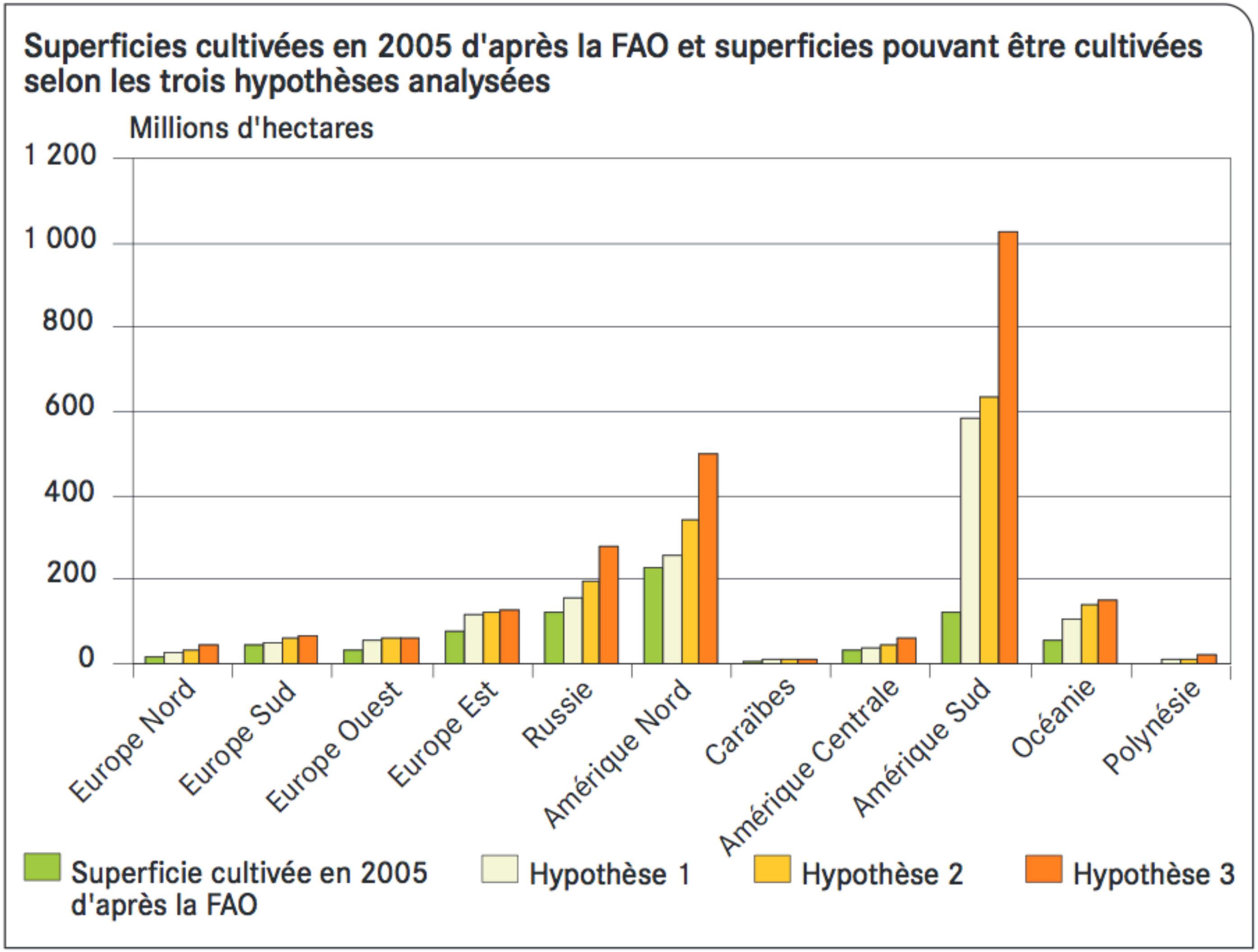
Sources : ONF et FAO

Terres arables

- Actuellement : 1500 millions d'ha
- Accroissement potentiel de
  - 1000 millions d'ha (terres jusqu'à modérément convenables, sans forêts et infrastructures)
  - 1450 millions d'ha (terres peu convenables, sans forêts)
  - 2350 millions d'ha (avec 1/3 des forêts).

CENTRE D'ÉTUDES ET DE PROSPECTIVE Analyse N° 18 - Mai 2010

Terres arables



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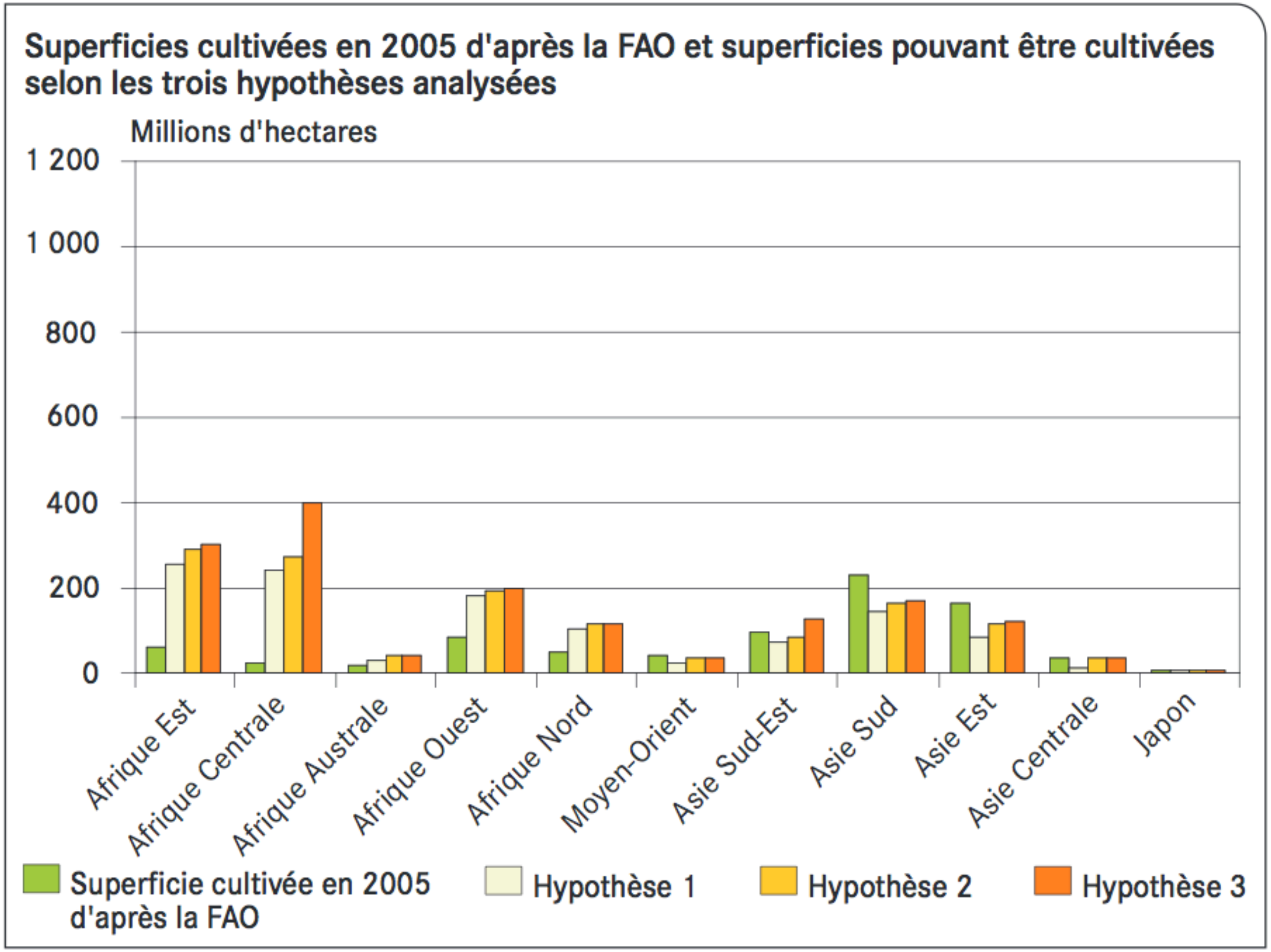
Terres arables



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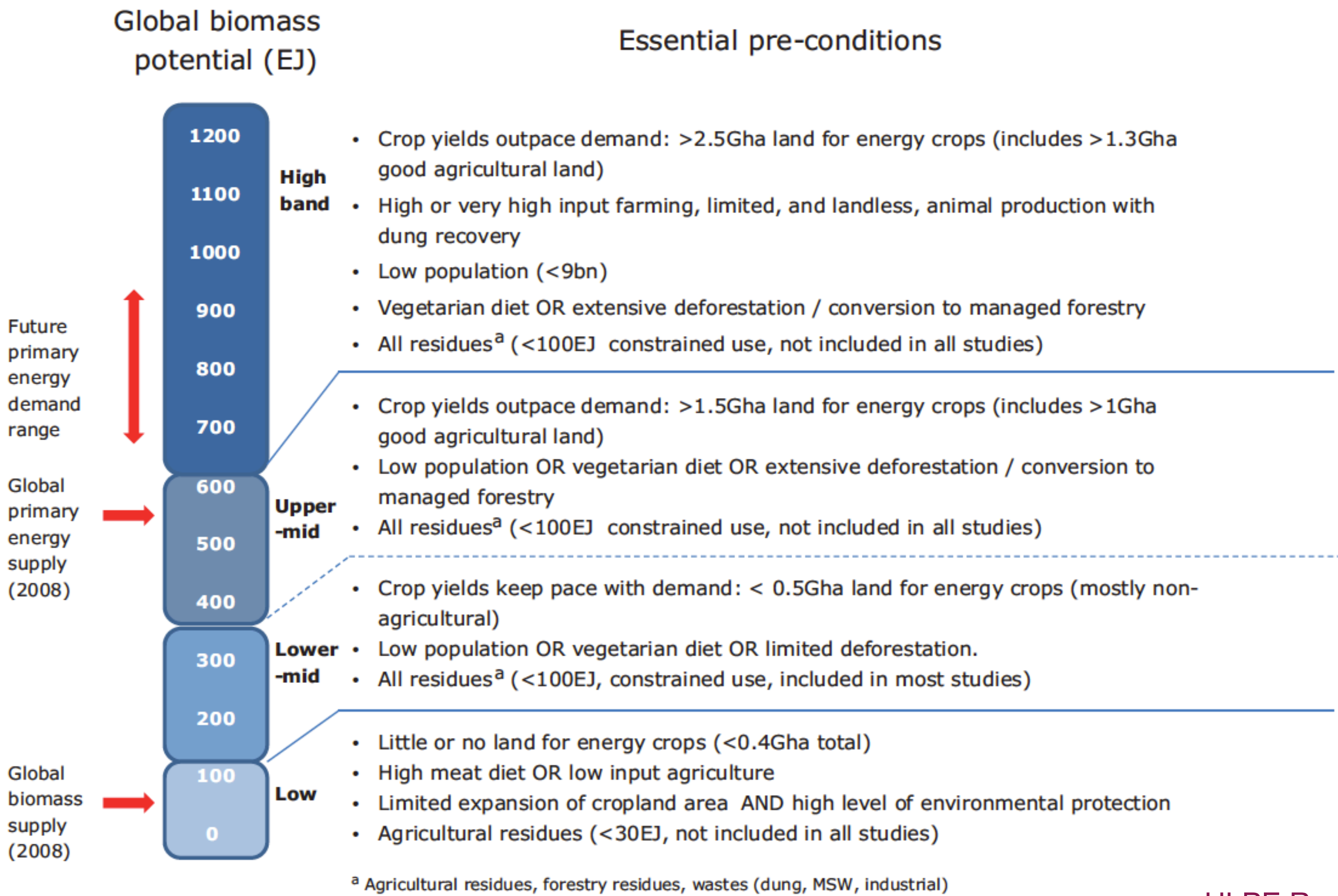
Potentiel de production au niveau mondial

Figure ES1: Common assumptions for high, medium and low biomass potential estimates



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Potentiel de production au niveau mondial

Table 1: Overview of the global potential of biomass for energy (EJ per year) to 2050 for a number of categories and the main pre-conditions and assumptions that determine these potentials [Sources: Berndes et al., 2003; Smeets et al., 2007; Hoogwijk et al., 2005a].

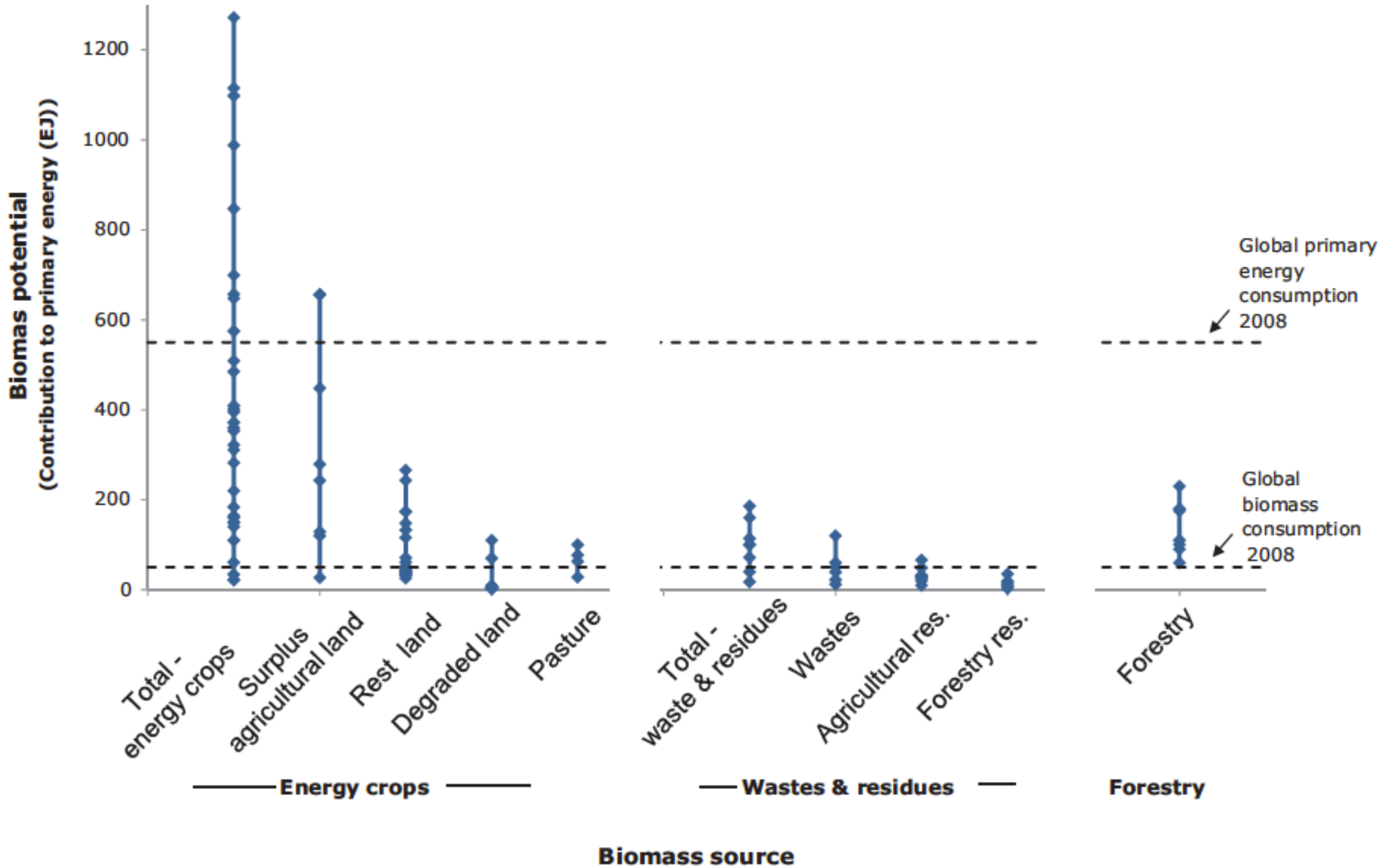
Biomass category	Main assumptions and remarks	Energy potential in biomass up to 2050
Energy farming on current agricultural land	Potential land surplus: 0-4 Gha (average: 1-2 Gha). A large surplus requires structural adaptation towards more efficient agricultural production systems. When this is not feasible, the bioenergy potential could be reduced to zero. On average higher yields are likely because of better soil quality: 8-12 dry tonne/ha/yr* is assumed.	0 – 700 EJ (more average development: 100 – 300 EJ)
Biomass production on marginal lands.	On a global scale a maximum land surface of 1.7 Gha could be involved. Low productivity of 2-5 dry tonne/ha/yr.* The net supplies could be low due to poor economics or competition with food production.	<60 – 110 EJ
Residues from agriculture	Potential depends on yield/product ratios and the total agricultural land area as well as type of production system. Extensive production systems require re-use of residues for maintaining soil fertility. Intensive systems allow for higher utilisation rates of residues.	15 – 70 EJ
Forest residues	The sustainable energy potential of the world's forests is unclear – some natural forests are protected. Low value: includes limitations with respect to logistics and strict standards for removal of forest material. High value: technical potential. Figures include processing residues	30 - 150 EJ
Dung	Use of dried dung. Low estimate based on global current use. High estimate: technical potential. Utilisation (collection) in the longer term is uncertain	5 – 55 EJ
Organic wastes	Estimate on basis of literature values. Strongly dependent on economic development, consumption and the use of bio-materials. Figures include the organic fraction of MSW and waste wood. Higher values possible by more intensive use of bio-materials.	5 – 50 EJ
Combined potential	Most pessimistic scenario: no land available for energy farming; only utilisation of residues. Most optimistic scenario: intensive agriculture concentrated on the better quality soils. In parentheses: average potential in a world aiming for large-scale deployment of bioenergy.	40 – 1100 EJ (200 - 400 EJ)

* Heating value: 19 GJ/tonne dry matter.

IEA BIOENERGY: EXCO: 2007:02

Potentiel de la production de la biomasse

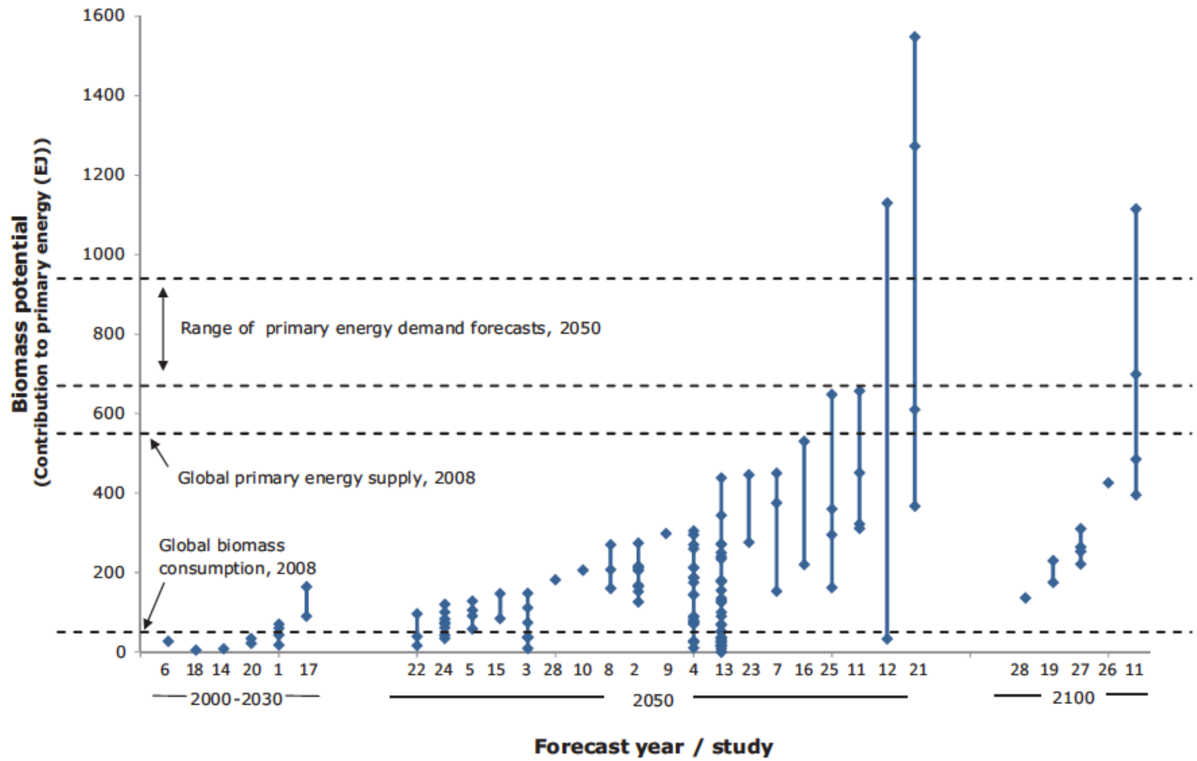
Figure 4.2: Indicative contributions to global biomass potential estimates from different biomass sources and land classes



La variabilité des projections

Figure 4.1: Biomass potential forecasts by individual study and timeframe.

(NB: figures are those reported in the original study and incorporate different definitions of potential (theoretical, technical, economic, etc.); studies also differ in terms of the range of resources included.)



1 -Bauen04	6 -Field08	11 -Hoogwijk05	16 -Lysen08	21 -Smeets07	26 -Yamamoto99
2 -Beringer11	7 -Fischer01	12 -Hookwijk03	17 -Moreira06	22 -Thrän10	27 -Yamamoto00
3 -Cannell02	8 -Haberl10	13 -Hoogwijk04	18 -OECD/FAO08	23 -WEA00	28 -Yamamoto01
4 –deVries07	9 -Hall93	14 -IEA08	19 -Rotiyanskiy07	24 -WGBU09	
5 -Erb09	10 -Johansson93	15 - IEA10	20 -Sims06	25 -Wolf03	

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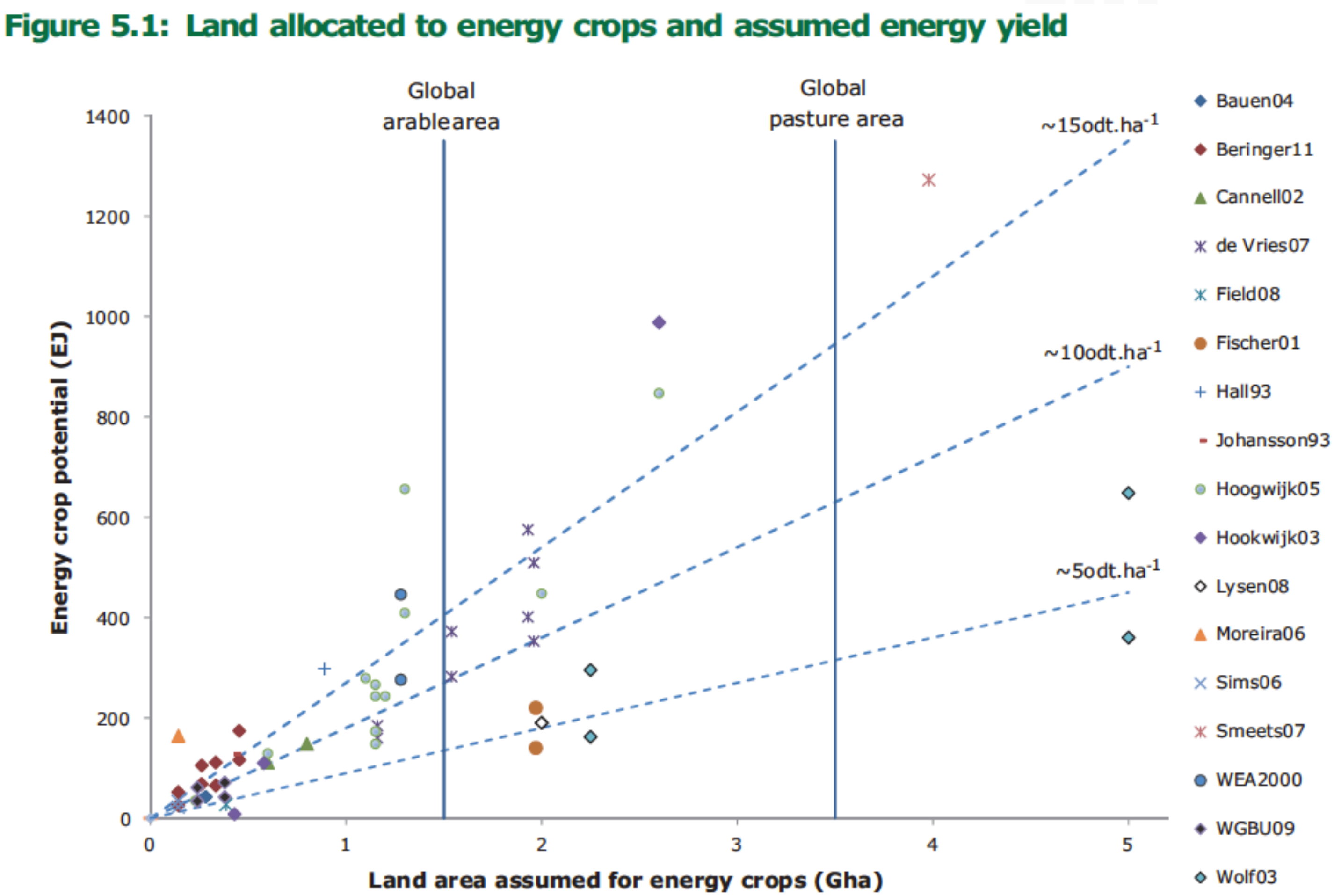
Explication des écarts de prédiction



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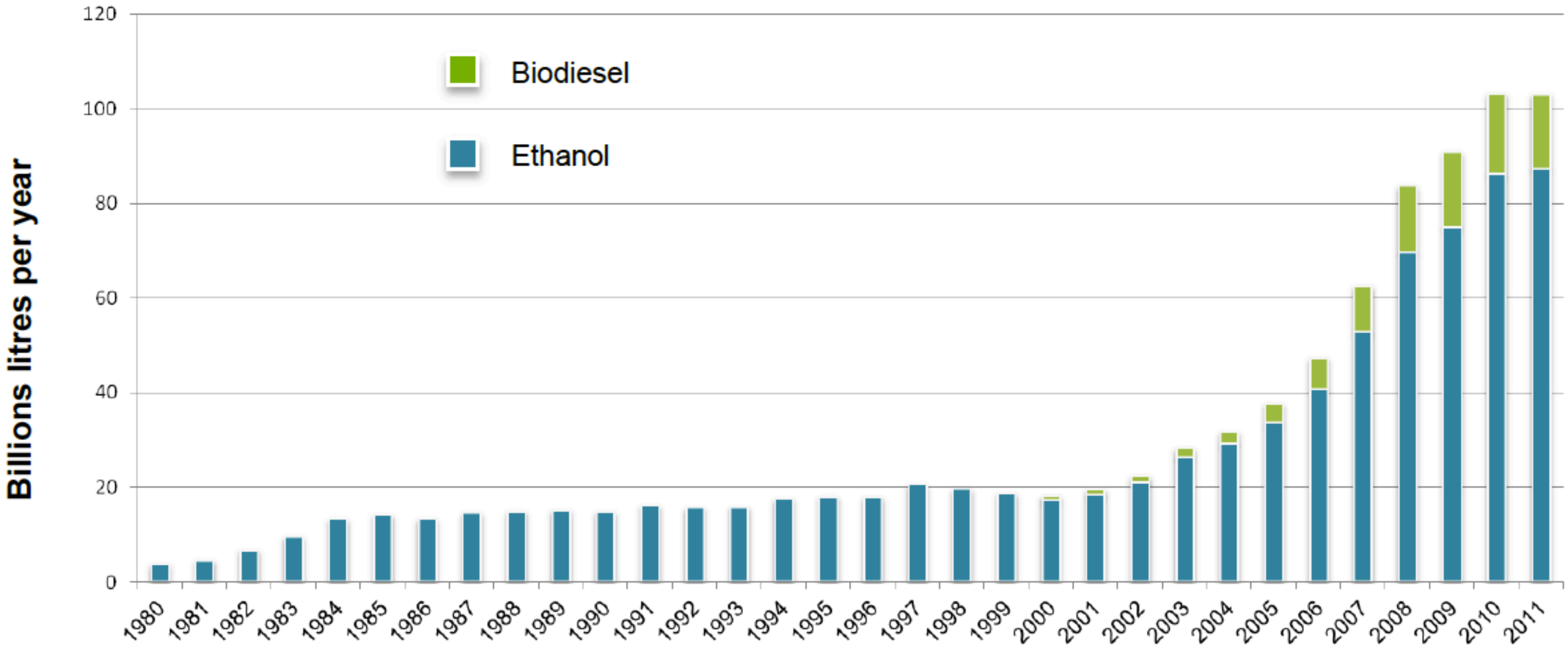
Quelques données sur les biocarburants

Production de biocarburants

Figure 2 Biofuel production, 1980–2011



Source: HLPE, 2012a.

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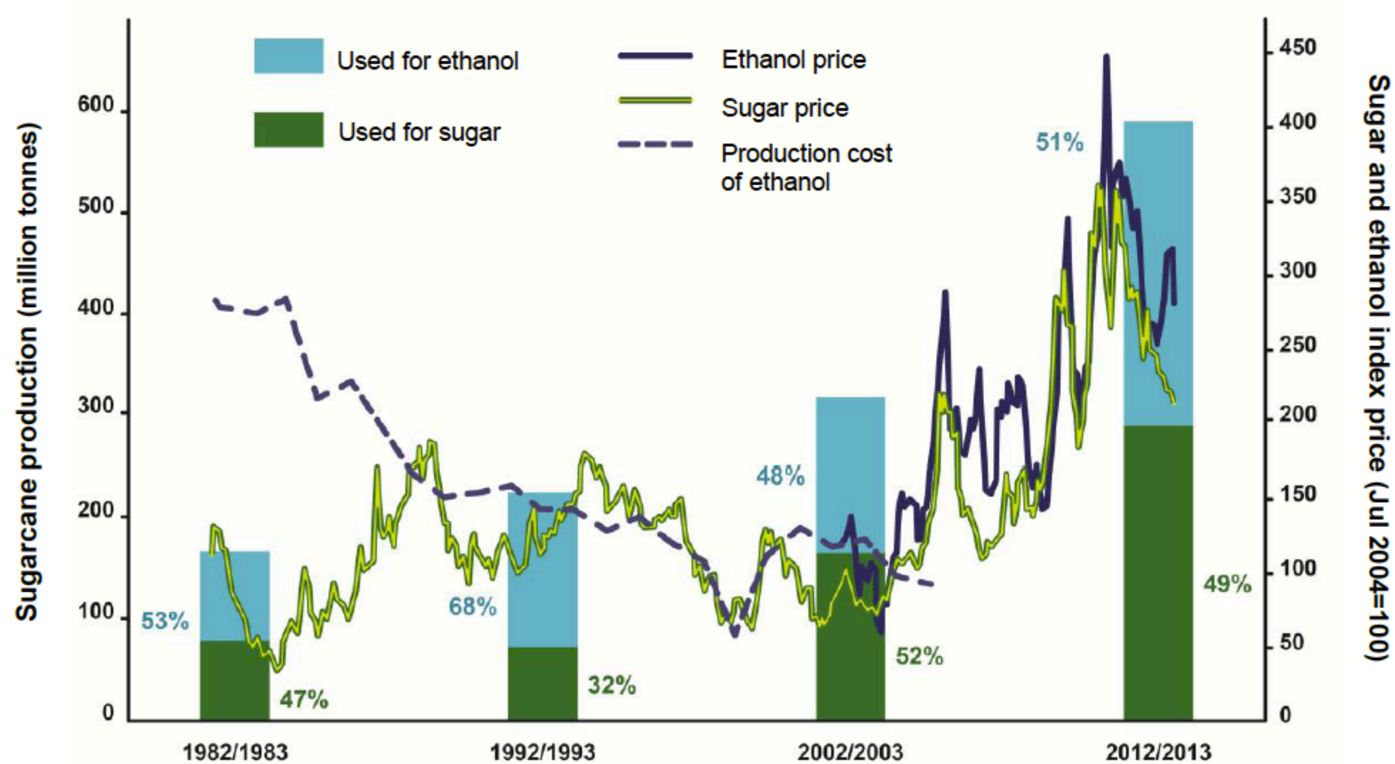
Couplage prix aliment/prix énergie

Figure 11 Sugarcane production, ethanol and sugar production and prices in Brazil



	1982/1983	1992/1993	2002/2003	2012/2013
Sugarcane	166.1 Mt	223.4 Mt	316.1 Mt	588.4 Mt
Ethanol	5.82 Mm^3	11.73 Mm^3	12.49 Mm^3	23.21 Mm^3
Sugar	8.86 Mt	9.26 Mt	22.38 Mt	38.24 Mt

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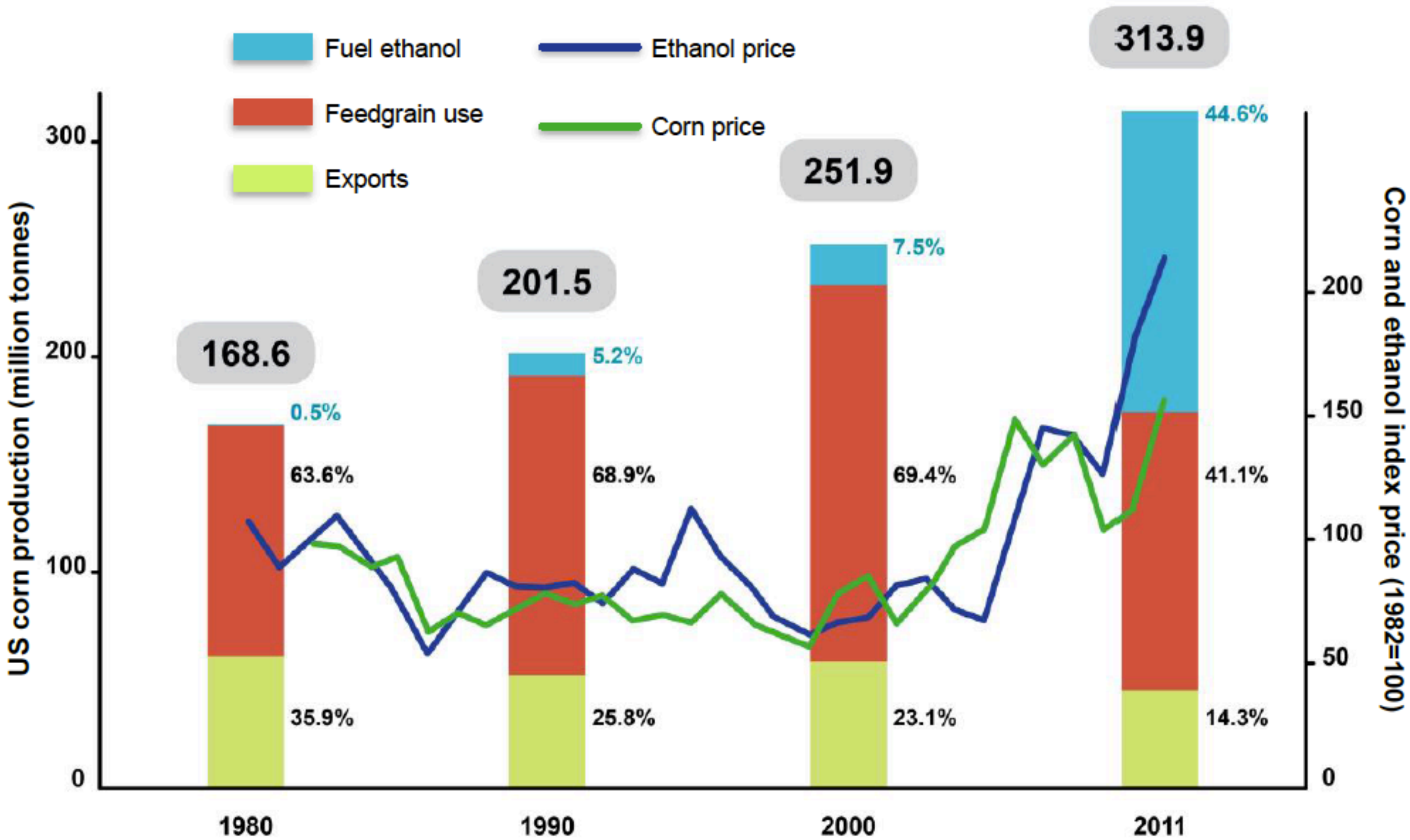
Couplage prix aliment/prix énergie

Figure 10 Ethanol and corn prices, and US corn production for fuel, feed and exports



Source: Adapted from Bastianin, Galeotti and Manera (2013). Data from http://faostat.fao.org for corn production. Corn and ethanol prices, shares of fuel, food and export uses from Batianin, Galeotti and Manera (2013)

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Efficacité de la production de biocarburants

Table 3 Net energy return on investments for different fuel types

Fuel	EROI	Countries/regions included in the evaluation
Cellulosic ethanol	2–36 (5.4)	United States (switchgrass)
Corn ethanol	0.8–1.7	United States, Colombia, China
Wheat ethanol	1.6–5.8	United Kingdom, Netherlands, Switzerland, Australia
Sugar-beet ethanol	1.2	United Kingdom
Soybeans biodiesel	1.0–3.2	United States, Argentina, Brazil, China, South Africa
Sugar-cane ethanol	3.1–9.3	Brazil, Mexico, Southern Africa
Molasses	0.6–0.8	Thailand, Nepal
Cassava	1.3–1.9	China, Thailand
Sweet sorghum	0.7–1.0	China
Rapeseed biodiesel (Europe)	2.3	United Kingdom
Waste vegetable oil biodiesel	5–6	
Palm oil biodiesel	2.4–2.6	Southeast Asia, Thailand
Jatropha	1.4–4.7	China, India, Thailand, Africa
Algae	0.01–7.01	

Source: Compilation by authors, based on WWI (2006); Pimentel and Patzek (2005); Shapouri *et al.* (2004); Quintero *et al.* (2008); Kim and Dale (2008); Hill *et al.* (2006); Royal Society (2008); Grant *et al.* (2008).

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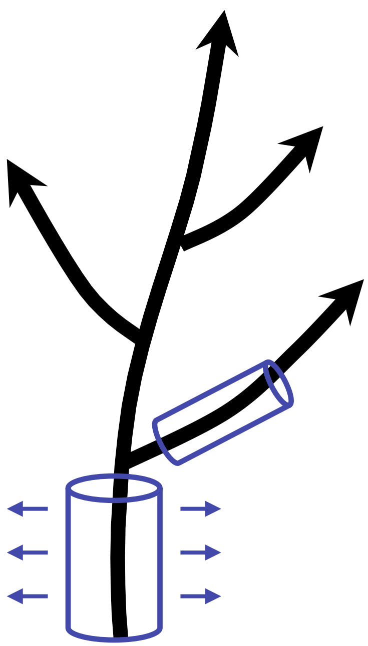
Valorisation plante entière : tiges pour le non-alimentaire

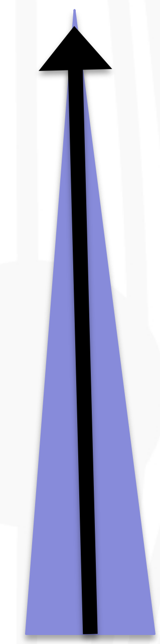
Rôles de la tige dans les plantes

- Système vasculaire
- Support mécanique
- Adaptation du support mécanique
- Résistance aux agressions

Croissance primaire

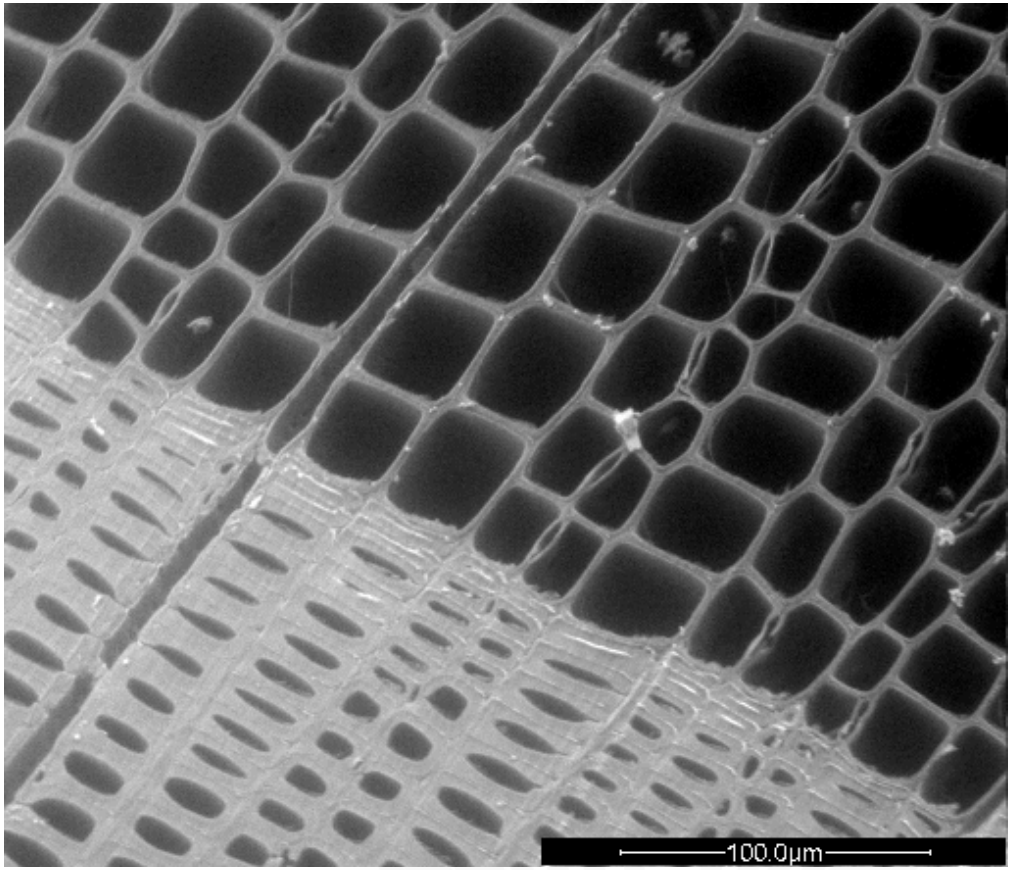


Croissance secondaire

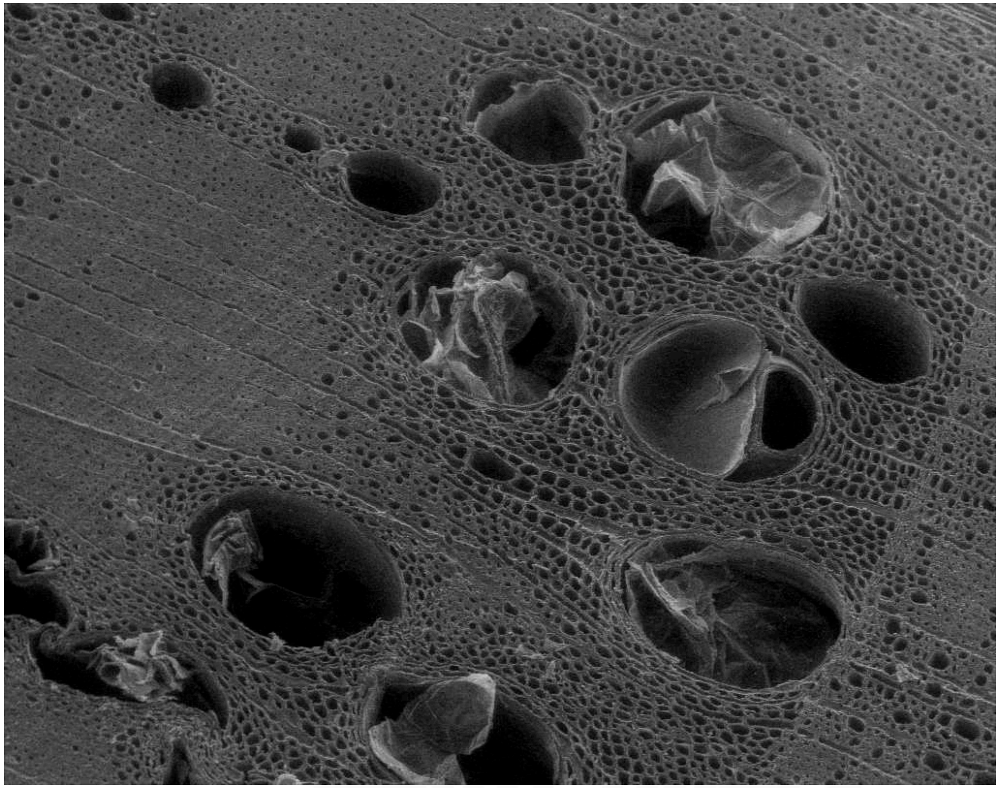


Arbres

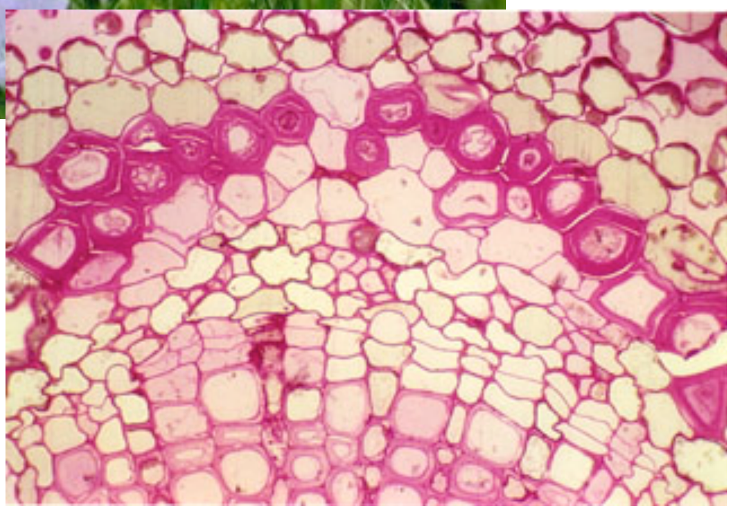
Plantes annuelles



ESEM image of Spruce, P. Perré



ESEM image of Oak, P. Perré



Lin (*Linum sp*)

Chanvre (*Cannabis sativa*)

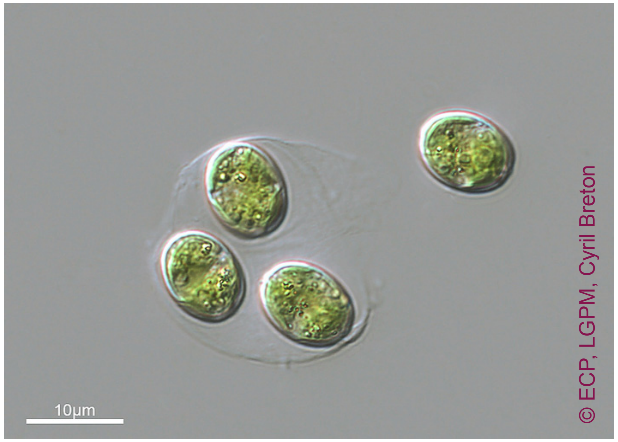
Sources : *http://www.snv.jussieu.fr/bmedia/textiles*
http://www.chanvre.com/

Ne pas oublier les micro-algues

Micro-algues

	Microalgues	Plantes C4	Plantes C3
Productivité maximale ($T.ha^{-1}.an^{-1}$) **Rendement photosynthétique**	150-180 **~ 6 - 7.5 %**	60 **~ 2.5 %**	30 **~1.25 %**
Productivité observée ($T.ha^{-1}.an^{-1}$)	50-70	10-30	10-15
Productivité en lipides potentielle ($T. ha^{-1}.an^{-1}$)	75-90		
Productivité en lipides observée ($T. ha^{-1}.an^{-1}$)	15-20	3	1.5
Coûts de production ($\$.kg^{-1}$)	0.4 - 40	0.04	0.04

Site ANR, Projet Algomics ANR-08-BIOE-002



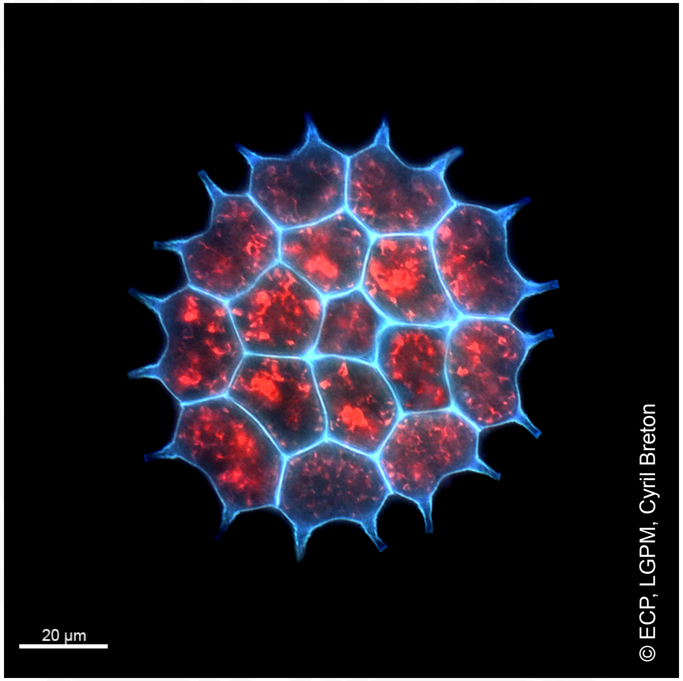
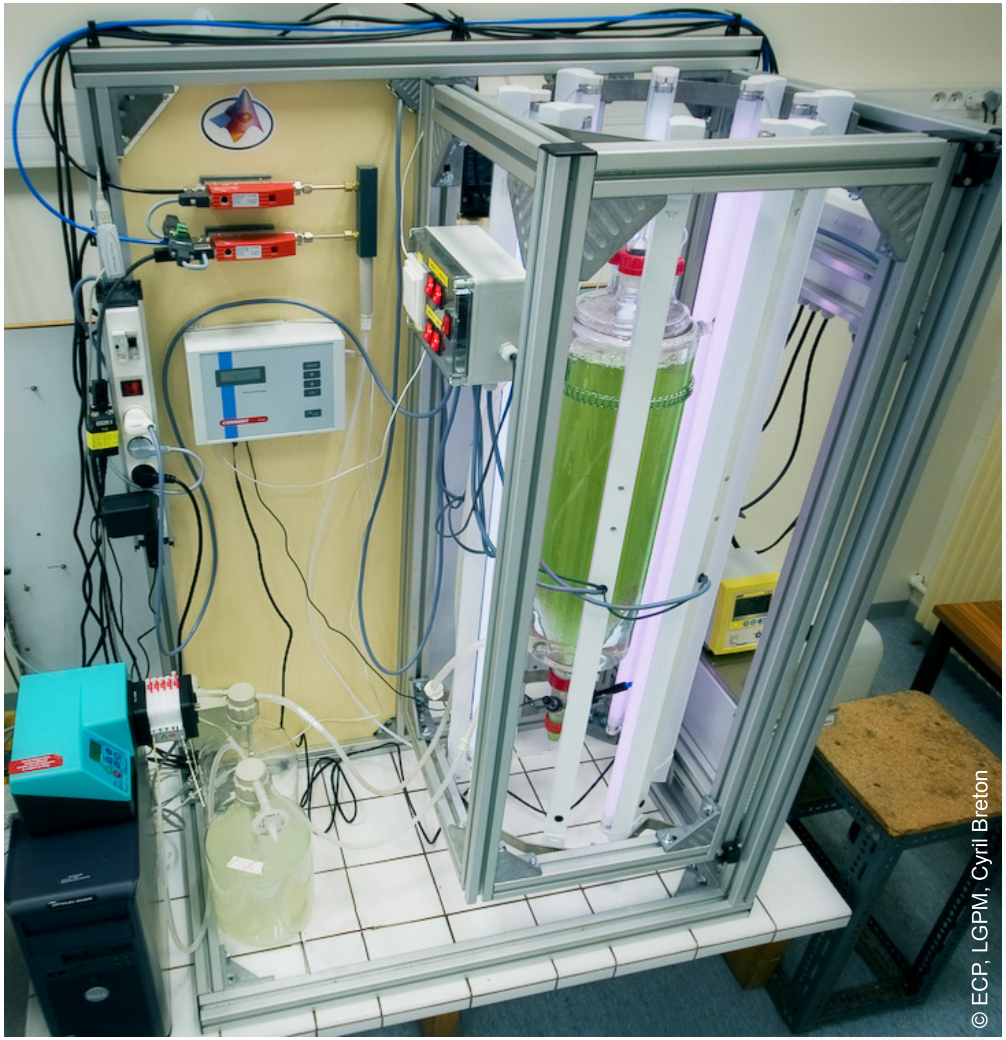


Photo-bioréacteur de laboratoire (LGPM)



Production de biocarburant par micro-algues (Alicante)

Photo-bioréacteur urbain

Source : site société Ennesys

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Merci pour votre attention

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