November 2007

Biofuel thematic paper – Biofuel potential

The potential for biofuel production/usage is assessed below. The assessments cover: EU, the U.S., China, Brazil, Denmark and the whole world; they are made for the years 2010, 2020 and 2030.

The assessments are made on the basis of the following assumptions:

- No effect on food, feed and export demands.
- Second generation technologies are not utilized in large scale until after 2010.

This note refers to 2 types of potentials:

- Maximum: The potential to produce biofuels if all the biomass which can be removed without harming the environment is used to produce biofuels.
- Realistic: The potential to produce biofuels while taking into account the fact that the available biomass can also be used for other purposes (e.g. food and "heat and power"). It requires active government support to realize these levels of biofuel production.

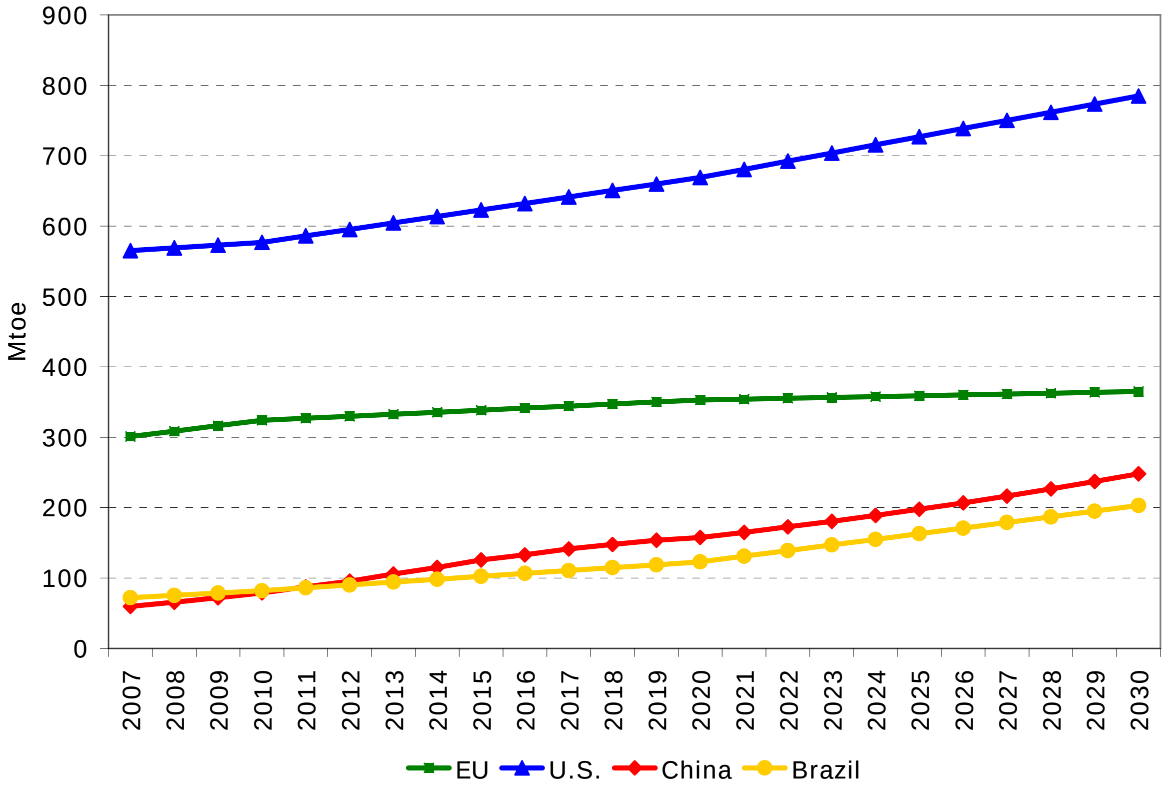
Issues related to the discussion of "food vs. fuel," environmental impacts, socioeconomic impacts and developing countries are covered in other thematic papers.

The potentials are referred to in Mtoe (million tons of oil equivalent, 1 Mtoe = 41.87 PJ = ~ 0.5 billion gallons of ethanol) – on an energy content basis.

Energy demand for road transport

Energy demand for road transport is a key factor for biofuel demand. Over the past many years, energy demand for passenger and freight transport has grown steadily in most regions of the world. The main underlying factor for growth in energy demand for road passenger transport is income growth coupled with a tendency to spend more or less the same percentage of disposable income on transport. Increasing wealth among citizens gives more people the option to buy a car and use the added flexibility that it provides. Additional income therefore means additional travel budget, which allows more frequent, faster, farther and more luxurious traveling. Likewise, more wealth increases the demand for goods, thereby increasing energy demand for freight transport. The projected increase in energy demand for road transport is shown in the figure below.

Figure 1 Energy demand for road transport by region



Sources: EU – European Commission, U.S. – EIA, China – A.T. Kearney, Brazil – Petrobras.

Current biofuel targets

The current targets for biofuels usage in the EU, the U.S., China, Brazil and Denmark are listed in Table 1.

The EU has defined its biofuel target as "10% of the energy demand for road transport by 2020". Given the projected energy demand for road transport (as shown in the figure above), this equals 35 Mtoe of biofuels (or 18 billion gallons/70 billion liters of ethanol if all biofuels are ethanol[1]).

In 2007 President George Bush launched his plan to reduce U.S. gasoline usage by 20% in the next ten years (named: Twenty In Ten). Part of this plan is to increase the supply

[1] Biodiesel will play an important role.

of renewable and alternative fuels to 35 billion gallons in 2017 (~67 Mtoe). This is equivalent to approx. 10% of the projected energy demand for road transport by 2017.

China expects biofuels to meet 15% of its transportation energy needs by 2020 equivalent to approximately 24 Mtoe of biofuels.

In Brazil, all gasoline sold for road transport must contain 20-25% ethanol. Depending on the availability of ethanol, the Brazilian government changes the percentage of ethanol in the gasoline. Currently the mandatory percentage is 22.5%.

In 2007 Denmark is expected to commit to a 10% biofuel share by 2020, in line with current EU targets.

Table 1 Biofuel targets and need for biofuels by region (definition of target is written in italic red text)

Country/ region	Year	Mtoe	Billion gallons (ethanol)[c]	Billion liters (ethanol)[c]	Share of energy demand for road transport[d]
EU	*2020*	35	18	70	*10%*
US	*2017*	67	*35*	133	10%[a]
China	*2020*	24	12	47	*15%*
Brazil	*2006*	7	3.7[b]	14	10% (*22.5% of gasoline*)
Denmark	*2020*	0.4	0.2	0.8	*10%*

Notes: [a] Equivalent to approx. 15% of projected gasoline consumption in 2017. [b] Domestic use, in addition to this approx. 1 billion gallons of ethanol was exported. [c] For illustration, if all biofuels/alternative fuels are ethanol, which will not be the case in reality.

Potentials - EU

First generation biofuels

The Joint Research Centre (JRC) of the European Commission has assessed the EU's "realistic" potential to produce first generation biofuels in the "Well-to-wheels" report. Their estimates are summarized below.

For most crops, production and consumption of agricultural products are today roughly in balance in the EU. Biomass for the first generation biofuels by 2010 therefore has to come from:

- Land released from the recent sugar reform: This will increase the 2010 potential by 2.4 Mtoe of biofuels compared to today.
- Land currently set aside: If all set-aside land is used for biofuels this could add 5.0 Mtoe of biofuels.

- Increased yields: It is expected that yields will continue to increase in the future. This will allow a production of an additional 3.2 Mtoe of biofuels by 2010 compared to today.
- Existing energy crops: 2.2 Mtoe of biofuels are today produced in the EU.

In summary, JRC estimates that it is realistic that the EU can produce 12.7 Mtoe of first generation biofuels by 2010. This equals 3.9% of the projected energy demand for road transport. Hence it appears to be necessary for the EU to import biomass/biofuels to meet the current 5.75% biofuel target for 2010.

The results are summarized in Table 2.

Second generation biofuels

The European Environmental Agency has likewise assessed the long-term "maximum" potential of the EU to produce biomass for second generation biofuels in the report "How much bioenergy can the Europe produce without harming the environment?".

The estimated biomass potential is sufficient to produce approximately 120 Mtoe of biofuels – equivalent to 33% of the energy demand for road transport in the EU by 2030 - if all available biomass is used for biofuel production (see table 2).

However, in reality the available biomass will also be used for other purposes. Hence it is not realistic that the EU can cover 33% of the future energy demand for road transport from domestically produced biofuels.

The Biofuel Research Advisory Council of the European Commission envisages a 25% biofuel target for 2030 (requires 91 Mtoe of biofuels) with half of the biofuels being produced domestically (~46 Mtoe) and half imported (~46 Mtoe).

This requires that close to 40% of the available biomass is used for biofuels by 2030 (46 Mtoe/120 Mtoe=38%).

Overview

Table 2 Potential biofuel production and usage in the EU (in Mtoe)

Potential if the following types of land are used for growing crops for first generation biofuels: Land currently used for energy purposes, set-aside land and land released from sugar reform. Further increased yields add to the potential.

Source: EU, Joint Research Centre – "Well-to-wheels" report

		2010	2020	2030
Type of scenario		Realistic	Maximum	Maximum
Energy for road transport		324	354	365
Biofuel potential	First generation	13	(16)	(20)
	Second generation	-	98	120
	Total	13	98	120
	% of energy demand	3.9%	28%	33%
Realistic biofuel target	% of energy demand	5.75%	10%	25%

Realistic potential. Not additive to second generation potential, as the "same land" is used for growing second generation biomass.

Source: Simple extrapolation of 2010 estimate from EU, Joint Research Centre – "Well-to-wheels" report (based on increased yields).

Existing targets

Realistic biofuel target for 2030; half of it produced domestically and half of it imported. Requires that ~40% of the available biomass is used for biofuels.
In line with vision of *European Commission – Biofuels Research Advisory Council*

Potential if all available biomass is used for biofuels.

Source: Based on data the European Environmental Agency's report "How much bioenergy can Europe produce without harming the environment?".

Potentials - The U.S.

First generation biofuels

FAPRI[2] (2007) estimates that the U.S. is capable of producing 13.3 billion bushels[3] of corn in 2010/11, of which 4.3 billion bushels will be available for ethanol production (compared to 2.2 billion bushels in 2006/07).

This implies that by 2010 the U.S. should be capable of producing roughly 12 billion gallons of ethanol (assuming an energy content of corn of 18 MJ/kg and a conversion factor of 47% from corn to ethanol). This equals roughly 24 Mtoe of ethanol or roughly 4% of the U.S. energy demand for road transport by 2010 (see Table 3).

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[2] The Food and Agricultural Policy Research Institute (FAPRI) is a dual-university research program with research centers at Iowa State University and the University of Missouri-Columbia.

[3] 1 bushels of corn=25.4 kg.

Second generation biofuels

The U.S. Department of Agriculture and the U.S. Department of Energy (2005) estimate in the report "Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply" that the land resources in the U.S. in the long run will be capable of producing 1.3 billion dry tons of biomass per year.

The estimated biomass potential is sufficient to produce approximately 264 Mtoe of biofuels – equivalent to 34% of the energy demand for road transport in the U.S. by 2030 - if all available biomass is used for biofuel production (see Table 3).

Again, some of the available biomass will be used for other purposes.

The Biomass Research & Development Technical Advisory Committee (2002)[4] envisages that 20% of the energy demand for road transport by 2030 can be covered by biofuels (~ 157 Mtoe of biofuels). This requires that:

- 50% of the available biomass for second generation biofuels is used (125 Mtoe of biofuels);
- The potential to produce first generation biofuels is realized (16 Mtoe of biofuels)[5];
- 10% of the needed biofuels are imported (16 Mtoe).

It is important to note that the "realistic biofuel targets" for the U.S. are based on a lower share of imports than the target for the EU (the argument of supply security seems to be more important to the U.S. than to the EU).

[4] Referred to in U.S. Department of Energy and U.S. Department for Agriculture (2005).

[5] In reality this estimate from 2005 most likely underestimates the potential to produce first generation biofuels in the U.S. Today it is commonly agreed upon in the industry that first generation will generate at least 15 billon gallons ethanol (~30 Mtoe) in the U.S.

Overview

Table 3 Potential biofuel production and usage in U.S. (in Mtoe)

FAPRI (2007) estimates that 4.3 billion bushels of corn will be available for ethanol production by 2010/11. This is sufficient to produce roughly 12 billion gallons of ethanol (~ 24 Mtoe of ethanol).

Source: FAPRI (2007), U.S. and World Agricultural Outlook 2007.

		2010	2020	2030
Type of scenario		Realistic	Maximum	Maximum
Energy for road transport		577	669	785
Biofuel potential	First generation	24	n.a.	16
	Second generation	n.a.	n.a.	248
	Total	n.a.	n.a.	264
	% of energy demand	n.a.	n.a.	34%
Realistic biofuel target	% of energy demand	n.a.	n.a.	20%

Vision of The Biomass Research & Development Technical Advisory Committee (2002). Requires that 50% of the available biomass for second generation biofuels is used, The potential to produce 1st generation biofuels is realised (16 Mtoe of biofuels) and that 10% of the needed biofuels are imported (16 Mtoe).

Maximum long-term potential, including agricultural and forest resources. Potential for 1st generation biofuels is lower compared to 2020, as large areas of land are used for growing perennial crops.

Source: Based on data on biomass potentials from U.S. Department of Agriculture and U.S. Department of Energy.

Potentials - China

A “realistic” scenario for ethanol production (note - only ethanol) in China in 2010 and 2020 is outlined in Table 5 on the basis of data from A.T. Kearney (HL scenario).

Furthermore, the long-term (2030) “maximum” potential is shown, assuming that all available biomass is used for ethanol production. The long-term “maximum” potential is assessed on the basis of data from the U.S. Department of Agriculture and the Chinese Ministry of Agriculture.

A.T. Kearney estimates that it is realistic that China will produce 3.1 Mtoe of ethanol in 2010 (including 1.5 Mtoe of second generation ethanol) equivalent to approximately 3.9% of the energy demand for transport in China. This increases to 9.2 Mtoe of ethanol in 2020 or 5.8% of the projected energy demand for road transport in China.

These estimates are to be considered as rather conservative, as they are based on the assumption that a rather small share of the domestic biomass resource is used for ethanol production (see Table 4). For example, it is assumed that only 5% of the available second generation biomass is used for ethanol production by 2020. The low share of corn used for producing first generation ethanol reflects China's limited potential to produce first generation biofuels due to strong domestic demand for corn for food.

Table 4 Share of domestic biomass resource used for bioethanol

Biomass resource	2010	2020
Corn (first generation)	2%	2%
Sweet sorghum (generation 1.5)	45%	55%
Cassava (generation 1.5)	20%	30%
Corn stover and 'other biomass' (second generation)	3%	5%

The U.S. Department of Agriculture and the Chinese Ministry of Agriculture have, as mentioned, assessed China's long-term maximum biomass potential.

These data show that China has great potential to increase the production of ethanol. It is estimated that in the long run China could cover more than 50% of energy demand for road transport if all available biomass (wood, rice straw and crop straw – not including waste) is used for ethanol production.

This is not realistic as there are a number of alternative uses of biomass in China, and because it is not economically feasible to collect all the biomass which can potentially be removed, but it underlines the fact that the potential for future ethanol production could be higher that the figures from A.T. Kearney indicate. If 25% of the potentially available biomass is used for ethanol production, ethanol could cover 14-15% of the energy demand for road transport in China.

Table 5 Potential ethanol production in China (in Mtoe)

Share of biomass resources used for bioethanol in 2010/2020:
- 2% / 2% of corn used for ethanol (G1)
- 45% / 55% of domestic Sweet sorghum (G1.5)
- 20% / 30% of Cassava (G1.5)
- 3% / 5% of corn stover and 'other biomass (G2)

Source: A.T. Kearney , 'Most preferred scenario'/HL-scenario

Forecast by A.T. Kearney

		2010	2020	2030
Type of scenario		Realistic	Realistic	Maximum
Energy for road transport		79	158	248
Ethanol potential	First generation	0.6	0.8	-
	Generation 1.5	1.0	1.8	-
	Second generation	1.5	6.7	144
	Total	3.1	9.2	-
	% of energy demand	3.9%	5.8%	58%
Realistic ethanol target	% of energy demand	4.1%	6.2%	-

Long-run potential if all available biomass (wood, rice straw, crop straw) is used for biofuels (not including waste).

Source: Based on data on biomass potentials from U.S. Department of Agriculture and Ministry of Agriculture, China

Including 0.2 Mtoe of imports

Including 0.6 Mtoe of imports

The potential for China to produce other types of biofuels will be added in a later version.

Potentials – Brazil

Brazil has the potential to become a major producer of second-generation ethanol and to increase its production of first-generation biofuels substantially (see Table 6). Brazil therefore has the potential to become a major exporter of ethanol, thereby supporting other countries in meeting their biofuel targets.

First-generation biofuels

Brazilian ethanol producers expect that ethanol output will increase to 10 billion gallons of ethanol in 2013 from 4.7 billion gallons in 2006 based on the following assumptions:

- Land use for sugarcane production increases by roughly 60% to 10.3 million hectares.
- Number of plants operating increase by 27% (from 325 in 2006 to 412 in 2013).
- Yields increase by 4.6% from 2006 to 2013.

Today ethanol production accounts for 13% of the total fuel consumption in the transport sector in Brazil (equivalent to 4.7 billion gallons, of which 3.7 billion gallons are consumed domestically and 1 billion gallons are exported). Assuming linear growth, this implies that by 2010 Brazil should be capable of producing 7.7 billion gallons of ethanol or 15 Mtoe of first-generation ethanol, which is equal to 18% of the projected energy demand for transport fuels in Brazil.

In the longer term, McKinsey estimates the “maximum” potential of Brazil to produce first-generation ethanol in 2020 to 86 Mtoe. This requires an additional 24 million hectares of land used for sugarcane production (6.3 million hectares were used in 2006) and that 100% of this additional sugarcane (24 million hectares) is converted into ethanol.

Second-generation biofuels

Sugarcane bagasse is the second-generation feedstock in Brazil with the largest potential.

McKinsey estimates that 30 million hectares of land can be used for sugarcane production in 2020.

If this is feasible, the maximum potential for second-generation ethanol production from bagasse would be another 86 Mtoe in 2020 based on the following assumptions:

- Yield per hectare of land = 25 tons of bagasse
- 100% conversion of C5/C6 sugars
- Yield of ethanol per ton of bagasse is approximately 75 gallons

Hence, the total ethanol production potential for 2020 amounts to 172 Mtoe, which is close to 55 Mtoe more than Brazil's own energy demand for road transport. (Note that this almost equals the total need for biofuels in the U.S. to meet its 2017 biofuel target.) Consequently, Brazil has substantial potential to become a major exporter of biofuels.

It is important to note that these theoretical potentials require that other energy sources, for example sugarcane residuals, replace bagasse for heat and power generation so that almost all bagasse can be used for ethanol production. The use of other energy sources for heat and power generation will substantially limit the CO_2 reduction potential for ethanol produced from sugarcane (first-generation ethanol) and could even present a barrier to exploiting the full potential for second-generation ethanol production from bagasse. The estimate of 172 Mtoe should therefore be considered theoretical.

<u>Overview</u>

Table 6 Potential ethanol production and usage in Brazil (in Mtoe)

Based on the assumption that 30 million hectares are used for sugarcane production (6.3 million hectares were used in 2006) and all sugar cane is used for ethanol (roughly 50% is used today).

Source: McKinsey

Based on short-term forecast by Brazilian ethanol producers

Extrapolation based on 2020 data and an estimated increase in yields of ~1.5% p.a.

		2010	2020	2030
Type of scenario		Realistic	Maximum	Maximum
Energy for road transport		75	117	183
Biofuel potential	First generation	15	86	100
	Second generation	-	86	100
	Total	15	172	200
	% of energy demand	18%	147%	109%
Realistic biofuel target	% of energy demand	~16%	(100%)	(100%)

Based on the assumption that 30 million hectares are used for sugar cane production (6.3 million hectares was used in 2006) and all bagasse is used for ethanol (including the 90% which today are burned for energy).

Sources: McKinsey (land availability) and Unica, São Paulo's representative in the sugar and alcohol industry (potential ethanol output from bagasse per hectare).

Domestic production less 10% for exports

Brazil can more than cover its own demand for energy for road transport.

Potentials – Denmark

<u>First-generation biofuels</u>

The Danish Board of Technology has assessed the possibility to reach the EU's 5.75% biofuel target for 2010 by domestic first-generation biomass resources, and concludes that there are plenty of Danish resources to cover a considerable share of the energy demand for transport. The 5.75% target can be reached using:

- 1.4% of the agricultural land (37,000 hectares) for growing sugar beets for ethanol
- 3.8% of the agricultural land (100,000 hectares) for growing rape for biodiesel (equivalent to the area used today for growing rape, two thirds of which are used for biodiesel exports)

The actual maximum potential is not estimated by the Danish Board of Technology.

Second-generation biofuels

The Danish Board of Technology has also assessed the Danish second-generation biofuel potential on the basis of the following assumptions:

- 15% of the agricultural land (approx. 400,000 hectares) is used for growing energy crops for biomass production – mainly ethanol production
- 2 million tons of straw are used (1 million tons unutilized today plus the 1 million tons currently used for energy production)
- Animal fat is used for the production of 110 million liters of biodiesel

On the basis of these assumptions, estimates show that biofuels can meet in the region of 25% of current energy demand for road transport (approx. 1 Mtoe).

Potentials – Global

The potential for growing biofuels feedstock worldwide is an area where many aspects are highly uncertain. Nonetheless, several reports issued over the last couple of years have tried to assess the potential.

OECD (2007) estimates that up to 245 EJ per year of biomass will be available for energy production (heat, electricity, and transport) by 2050. This is at the lower end of the wide range of 125-760 EJ referred to in fourth report from the Intergovernmental Panel on Climate Change (IPCC, 2007).

OECD estimates – based on their 245 EJ estimate – that the total biofuels production can amount to 43 EJ (approx. 1,000 Mtoe) fuel by 2050, assuming only half of the available biomass is used for biofuels production and the conversion efficiency rate is 35%.

This is sufficient to meet roughly 25–30% of the projected global energy demand for road transport by 2050. The broader range of estimates from IPCC (2007) indicate that by 2050 biofuels can cover between 14% and 90% of the projected demand for energy for road transport (again assuming that half of the available biomass is used for biofuels production and the conversion efficiency rate is 35%).

The potential to reduce GHG emissions

The need for reduced GHG emissions

The GHG concentration in the atmosphere has increased from about 280 ppm in pre-industrial time to a current level of 375 ppm. Consumption of fossil fuels has been the major contributor to the increased atmospheric concentrations of CO_2, with an annual contribution of approximately 5.9 GtC during the 80's and 90's (see Fig. 2).The emission of non-CO_2 greenhouse gases is also significant. The annual emission of methane is estimated to be between 2.1- 3.8 Gt C-equivalents and that of nitrous oxide to be between 1.0 and 2.1 Gt C –equivalents (see table 7). These data are highly uncertain as is the understanding of the magnitude of the mechanisms which act as sinks for these greenhouse gases.

Figure 2 The overall carbon cycle

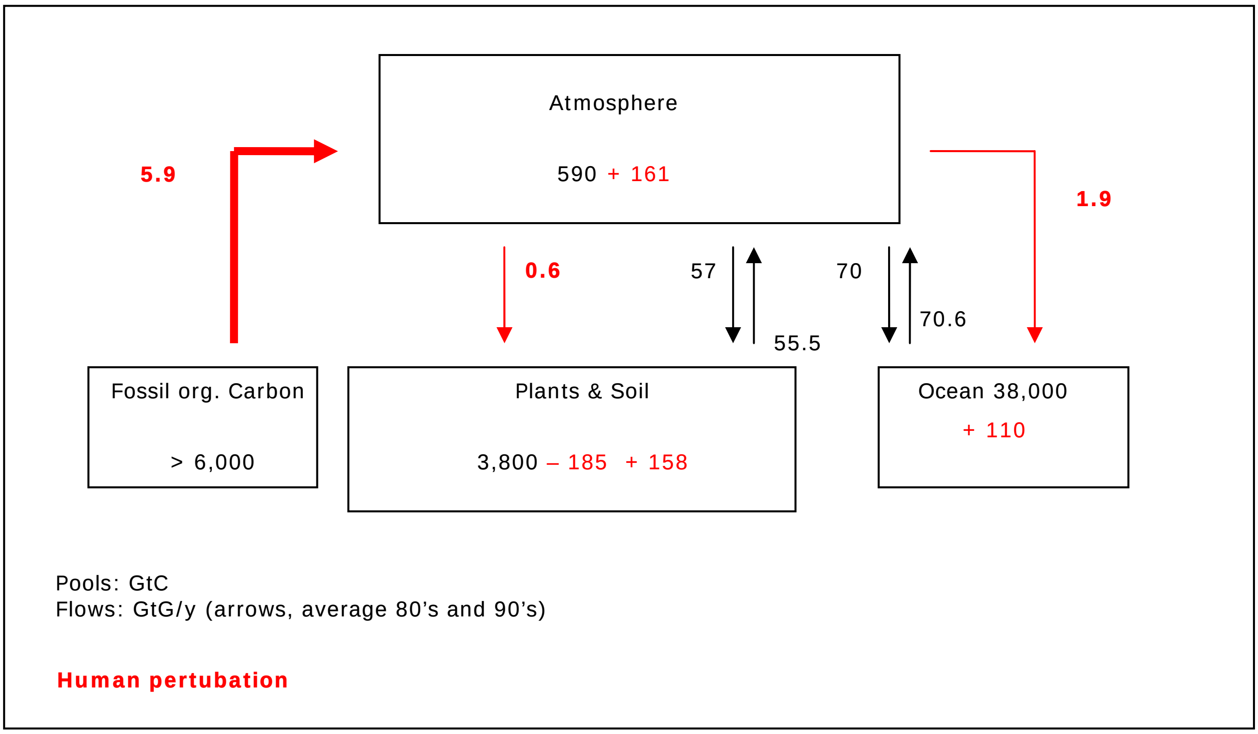

Table 7 The emission of greenhouse gasses

Source of emission	GtC-eq./y	Main contributors	GtCeq/y
Fossil fuel combustion	5.9	Oil	2.6
		Coal	1.7
		Natural gas	1.6
CH_4	2.1-3.8	Enteric fermentation	0.59
		Rice	0.25
		Landfill	0.25
		Burning of biomass	0.21
N_2O	1.0-2.1	Soil	0.53
		Animal waste	0.27

Figure 2 shows that the C-stock of the terrestrial vegetation has not changed very much in the 80's and 90's, as deforestation in the tropics has been balanced by an increase of net primary production (NPP) at higher latitudes due to CO_2 fertilization (increased growth caused by higher concentrations of CO_2).

Estimates indicate that to limit the global temperature increase to 2 °C it is necessary to stay below 450 ppm GHG. This requires actions that will deliver 7 GtC-eq./y emission reductions in 2030 compared to a business-as-usual scenario.[6,7]

<u>The potential of biofuel to contribute to closing the 7 GtC gap</u>

Substituting 1 MJ of gasoline with 1 MJ of bioethanol should reduce CO_2 emissions between 17 g of CO_2 (corn, conservative estimate) and 83 g of CO_2 (second generation) (see Thematic paper on Environmental impacts).

To estimate the potential of biofuels, consider two scenarios:

- A assumes a reduction of 40 g CO_2 per MJ (using a mixture of first- and second-generation biofuel technologies)
- B assumes a reduction of 80 g CO_2 per MJ (exclusively second generation)

As mentioned previously, OECD (2007) estimates that total biofuel production can amount to 43 EJ/year in the future. Based on this estimate, the potential saving is 0.46 GtC in A and 0.92 GtC in B. These figures show that using biofuels can close between 6%

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[6] McKinsey (2007).

[7] Pacala S. & Sokolow R. (2004) also refer to a 7 GtG gap (but in 2050, and based on GHG stabilization at 500 ppm)

and 13% of the total gap of 7 GtC by 2030. It does, however, require ambitious political initiatives to exploit this potential.

For comparative purposes, McKinsey (2007) estimates that the transportation sector (biofuels + improved vehicle efficiency) has the potential to contribute 0.8 GtC.

Extra potential – Carbon sequestration

In addition to the positive effects indicated above, carbon sequestration can increase the possibilities to reduce GHG emissions.

The potential is uncertain, but its possibilities are illustrated by this example:

Based on current yields of bioethanol from corn (Farrell *et al*, 2006) and a CO_2-emission reduction of 40 g CO_2/MJ, the substitution of gasoline with biofuel will deliver a reduction of 2.2 t CO_2/ha, or approximately 0.6 tC/ha. If biofuel biomass production involves changing cropland to grassland (for example, using switch grass instead of corn), an additional 0.8 tC/ha should be added to this figure[8], given the enhanced carbon binding of switch grass compared to corn.

This indicates the possibility to obtain carbon sequestration effects that could double the CO_2 mitigation effects of using biofuel. Note, however, these effects would last only for a limited period of time.

Overall, we estimate that using biofuels can make a significant contribution to counteract climate change. Biofuels can be an important component in a multi pronged approach, because no single technology can close the 7 GtC gap alone.

[8] Al-Kaisi M.M. & Grote J.B. (2007) Soil Sci Soc Am J 71: 1381-1388: Switch grass has 14 t/ha greater root biomass than corn.

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