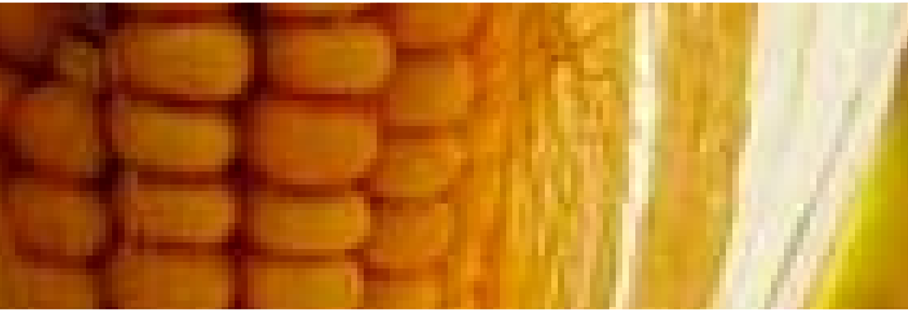

Biomass, food & sustainability:

Is there a dilemma?

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Member of the Supervisory Board of Rabobank Nederland

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UPDATED VERSION, AUTUMN 2007

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In January 2007, thousands of demonstrators marched through Mexico City in protest at a rise in the price of the maize flour used for tortillas. Many believed the higher price was caused by American demand for ethanol which had pushed up the price of maize on which Mexicans depend for their basic food. Similarly, consumers in Italy went on strike to protest against the increasing price of their daily pasta.

The tortilla crisis is one example of the many recent concerns about the impact of biomass production on food production, the stability of food and feed prices and the availability of food for the poor. Other concerns include the possible adverse effects on nature and biodiversity and the net energy savings and CO_2 emission reductions that can be realised with bio-energy[2] compared to conventional, fossil energy. Combined with high subsidies paid for making transport biofuels competitive, consumer confidence as to whether bio-energy is the right thing to do is declining. Moreover, governments now face divergent pressures from environmental groups, some of them hailing bio-energy as a solution to climate issues, other denouncing it as a future cause of inequality and hunger.

But are these concerns justified? Is the tortilla crisis the direct effect of US policy on transport biofuels? Will bio-energy improve energy security and mitigate CO_2 emissions, or will it simply lead to new problems in other areas, such as food security, biodiversity and even air pollution?

Trends in energy, agriculture and bio-energy

After tens of thousands of years of daily struggle for food, it is breathtaking that a farmer today can cultivate hundreds of hectares single-handedly to produce sufficient food to feed thousands of families on the other side of the planet. In spite of a threefold increase in world population since the Second World War, the fastest increase ever in human history, available calories per capita have grown by nearly 25%. This truly remarkable feat is the combined result of academic research, government policy and private investment. It shows that agricultural research has been one of the most rewarding economic sectors, with rates of return of 40-78%[3]. We can draw an important lesson from this: human capacity to innovate is great and allows us to be confident that collectively we are capable of innovation and rapid change.

In the same period, since the Second World War, global energy consumption has increased more than six fold to the current level of 470 EJ[4]. Population growth and rising welfare were the main drivers. In the same period, per capita energy demand has more than doubled from 28 GJ to 68 GJ, with averages for the US standing at more than six times those of China. With 3.6% growth, 2004 had the fastest energy demand growth rate since 1978, despite record oil prices. Global primary energy demand is expected to grow more than 50% to 700 EJ in 2030[5]. The demand for liquid transport fuels and electricity is increasing especially rapidly. By 2030 China and India together will account for 30% to 40% of global energy demand, i.e. about 16% of oil demand (now 10%); 5% of natural gas demand (2% now) and 48% of coal demand.

The strong growth in energy demand in the past and the expected continuation of this growth has caused many concerns. Emissions from fossil fuels are widely believed to be one of the main contributors to climate change; growing dependency on politically less stable regions to supply the world markets with sufficient oil has fuelled energy security concerns. The geopolitical situation in the Near East and the Gazprom confrontation in 2006 and subsequent incidents where energy supply was manipulated for political purposes, have added to the growing concerns about the security of energy supply. Even rumours about energy supply disruptions can cause energy prices to spike virtually overnight. The world economy is very vulnerable when it comes to physical supply of fossil energy and energy price hikes; moreover, these risks cannot be hedged.

The concerns about energy security and, more recently, climate change, have resulted in various efforts around the globe to address both the supply side and the demand side of the energy system and to set up worldwide climate policy frameworks. A key turning point in that respect was the United Nations Conference on Environment and Development, the 'Earth Summit', in 1992, which led to the adoption of Agenda 21. This agenda, reaffirmed in 2002 at the Johannesburg Summit on Sustainable Development, provided an overarching agenda for sustainable development, linking the worldwide development challenges with the challenges in the areas of energy, environment and conservation of natural resources.

The development agenda was further reinforced by adoption of the Millennium Declaration and the Millennium Development Goals (MDGs), at the Millennium Summit in 2000 in New York. These MDGs aim to eradicate extreme poverty, but do not include energy-related goals or explicit references to agricultural production targets.

There is general agreement that there is a huge potential for reducing energy demand through energy efficiency improvements in all main sectors such as residential buildings, transport and industry[6]. Oil use could be used twice as efficiently by end-use energy efficiency improvements[7]. Still, energy efficiency improvements have thus far been unable to curb the rising demand for energy and are unlikely to do so in the future. Supply side options include renewable energy, such as wind and solar power, as well as controversial forms of energy, such as nuclear energy and exploitation of tar sands. These supply options invariably gain more attention in policy strategies, RD&D support and investments than options for increasing energy efficiency.

Despite worldwide attention for renewable energy, its share in total energy demand is, on average, still low. In 2004 it was approximately 13% (62 EJ) [8] of global primary energy supply. However, the vast majority thereof was 'biomass and waste'[9] (49 EJ), much of which (10% out of 13%) is traditional biomass, e.g. direct combustion of wood in developing countries. It should be noted that the data on traditional bio-energy use is particularly unreliable. In any case, modern bio-energy, referring to the conversion of primary biomass into secondary energy forms such as heat, power or transportation fuels (see Box 1), accounts for only a small part (approximately 2%, or 8 EJ) of global energy consumption. Some countries have been able to reach considerably higher shares of renewables in the energy mix, often as the combined result of government policy and favourable conditions to explore hydropower, wind energy or geothermal power. In Brazil, for instance, hydropower accounts for about 35% of the nation's energy demand[10].

Although the share of the renewable energy market is small, the sector has experienced enormous growth in recent years. Due to rising prices for fossil fuels (especially oil, but also natural gas and to a lesser extent coal) the competitiveness of renewables has improved considerably over time. In addition, the development of CO_2 markets (emission trading), as well as ongoing learning and subsequent cost reductions for renewable energy systems have strengthened the economic drivers for increasing production, use, and trade of renewable energy. Total installed capacity for wind energy increased from less than 5 GW worldwide in 1990 to nearly 73 GW in 2006. In the same period the installed capacity of solar power grew from 0.2 GW to over 8 GW[11]. Renewable energy now represents a serious and often preferred option in national energy policies.

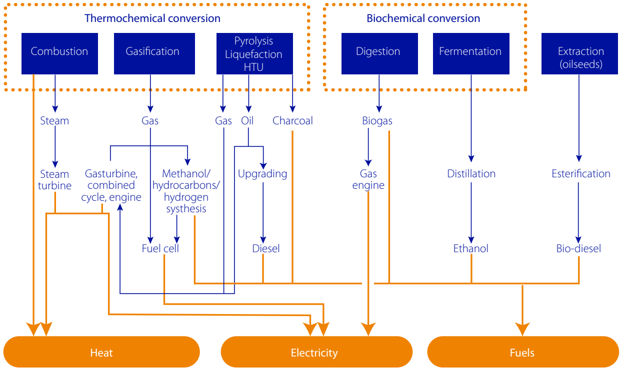
Among the various forms of renewable energy, liquid transport biofuels have seen the strongest growth in recent years. Transport biofuels stand out because at present they represent the only scalable renewable alternative to fossil fuels for transportation and are welcomed by the automotive industry because little adaptation is needed to the distribution infrastructure. Transport biofuels come in two forms: biodiesel and ethanol[12]. Biodiesel, mainly used in the EU, is made of vegetable oils, such as rapeseed, soybeans and palm oil, or from animal fats and waste oils.

Ethanol, primarily used in the US and Brazil, is made of starch, sugar and cereals, amongst other feedstock (see Box 1). In 2006, worldwide biodiesel production reached 7.2 million tonnes, or 0.28 EJ. Ethanol production, destined for fuel use, reached 40 billion litres, or 0.67 EJ[13].

Box 1 **Bio-energy conversion routes**

Conversion routes for producing energy from biomass are plentiful, all with different efficiencies. Figure 1 illustrates the main conversion routes currently used or under development for production of heat, power and transport fuels. Key conversion technologies for production of power and heat are combustion and gasification of solid biomass, and digestion of organic material for the production of biogas. Liquid bio fuels are also used for heat and power production in reciprocating engines. The main technologies available or developed to produce transportation fuels are fermentation of sugar and starch crops to produce ethanol, gasification of solid biomass to produce syngas and synthetic fuels (like methanol and high quality diesel) and extraction of vegetal oils from oilseed crops, which can be esterified to produce biodiesel. The various technological options and routes are in different stages of deployment and development[14].

Figure 1 **Main conversion options for biomass to secondary energy carriers**

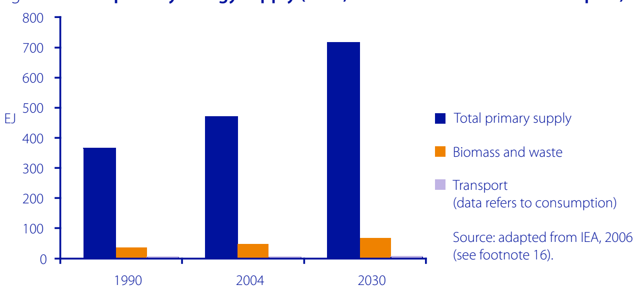


Source: Adapted from World Energy Assessment, 2000[15].

Future bio-energy use

As the world population is expected to continue to grow, reaching just over 8 billion in 2030 (compared to more than 6 billion now), and the level of energy consumption per capita to increase by a factor 1.2 on average worldwide, energy demand is likely to increase by over 50%[16]. This will further challenge energy security and climate change concerns. In an effort to curb the energy trends, ambitious targets for renewable energy have been set by many administrations, many of them aiming at renewable energy shares of 20% or higher. It is uncertain if, and how, these targets are to be met: will it be bio-energy, or more specifically transport biofuels, or will it be another form of renewable energy (wind, solar)? As there is no silver bullet, governments are cautious about picking a particular technology and adopt broad strategies to stimulate development of alternative energy forms, allowing markets to decide on the basis of costs, convenience and other criteria.

Figure 2 **World primary energy supply (total, biomass and waste and transport)**



In the 2006 World Energy Outlook of the International Energy Agency (IEA) it is estimated that modern and traditional bio-energy use could reach 69 EJ per year by 2030 (from 49 EJ in 2004), corresponding with an average annual growth rate of about 1.3% to 1.4%. As overall energy demand grows (see Figure 2), the share of bio-energy in total energy supply remains stable towards 2030, while the share of modern bio-energy grows (from about 2% in 2004 to 3% in 2030). Transport accounts for a fairly small part of total bio-energy use, but is by far the fastest growing. Growth rates for transport biofuels are expected to reach on average 12% towards 2015 and 7% thereafter towards 2030, reaching nearly 4 EJ in 2030. These expectations reflect that bio-energy in the transport sector is well positioned to offer a cost effective alternative to fossil fuels in the medium to long term. Based on current installed capacity and announcements made by the sector it is estimated that biodiesel capacity could increase more than fourfold, and ethanol capacity more than twofold by 2012[17].

In an alternative policy scenario by the IEA, assuming that governments around the world implement their plans[18] to counter oil dependency and climate change, bio-energy could reach as much as 11% of global supply by 2030 (4% modern bio-energy) as a result of higher growth rates of the bio-energy sector and less growth in overall energy demand. The alternative policy scenario assumes stronger energy conservation policies and measures resulting in a 10% lower energy demand by 2030. Such scenarios reflect a major shift in thinking.

Whatever scenario materialises, bio-energy is expected to play a substantial role in the energy mix in 2030, providing around 70 EJ per year compared to 49 EJ in 2004; for modern bio-energy, expectations range from 15 to 18 EJ compared to 8 EJ in 2004. This requires substantial amounts of biomass.

Agricultural production is expected to double by 2030 to meet rising demands for food, feed, shifting dietary patterns (more dairy products and meat), and rising bio-energy needs. Production increases can be realised through yield improvements worldwide, even without expanding arable land. While the agricultural technologies to achieve the required yield improvements already exist, their application is an important challenge and should by no means be taken for granted everywhere, especially not in Africa and in ecologically disadvantaged regions.

The extent to which bio-energy related demand for biomass will add to the total demand for agricultural products depends on many variables, amongst which the type of biomass suitable for bio-energy and the efficiency with which a particular type of biomass can be converted into energy as well as on factors inherent to overall agricultural demand such as shifting dietary patterns (demand for animal proteins) and trade factors such as subsidies.

With respect to transport biofuel conversion technologies it is essential to differentiate between the so-called first and second generation technologies. First generation technologies, already used on a large scale worldwide include the conversion of sugar cane and wheat into ethanol through fermentation of sugars and starches, and the conversion of vegetable oils such as palm oil and rapeseed through transesterification in to bio-diesel. Second generation technologies, not yet commercially viable, include the conversion of cellulosic inputs such as straw, stover and woody material into ethanol or biodiesel. These technologies are believed to reach higher conversion efficiencies than first generation technology and, even more importantly, bring into play other sources of biomass, such as by-products of agricultural production. As such, second generation conversion requires less biomass, and biomass that does not necessarily compete with food and feed crops.

Promising new technologies are under development for improving the conversion ratio of biomass to energy, or for developing biomass resources that do not affect the agricultural sector. One of the most interesting scientific areas today is the biological engineering of E. coli and other bacteria to ferment the breakdown products of cellulosic products[19].

Lignins, hemi-cellulose and cellulose together form the most abundant biological material on earth.

In terms of other non-plant species, there are indications that algae and fungi may present promising and non-land based options that would also be far less demanding in terms of phosphate, potentially the main limiting factor on land. The French research institute for exploitation of the sea has compared oil yields of various algae species. They report 23 tonnes of oil per hectare realised in a project in the Loire region in France. This is significantly more than the 6 to 8 tonnes per hectare commonly achieved with palm oil, one of the most efficient perennials. In addition to oil (50% of the weight), algae produce valuable other products[20]. Despite these promising developments it remains to be seen when these will become economically viable.

Whether or not new technologies become viable, global demand for bio-energy will continue to grow. As a result, concerns are being expressed that bio-energy could have a huge impact on agricultural markets and consequently on food prices. In addition, some are also questioning the rationale for bio-energy, and even more so of transport biofuels, on the grounds that the energy efficiency of converting solar radiation into useable forms of energy by plants is about one order of magnitude lower than in the case of e.g. photovoltaic solar energy schemes[21]. Although this is true, the position of competing energy options in the market will always be determined on the basis of cost and convenience. So far bio-energy seems well positioned to offer a cost effective alternative in several end-use markets under specific conditions. The impact of the bio-energy sector on nature and biodiversity is yet another target of criticism despite its contribution to climate mitigation. Past intensification of agriculture has led to high environmental and social costs, and so the fear exists that with rising agricultural demand, the environmental and social costs could rise as well.

Bio-energy and sustainability: more than food for fuel

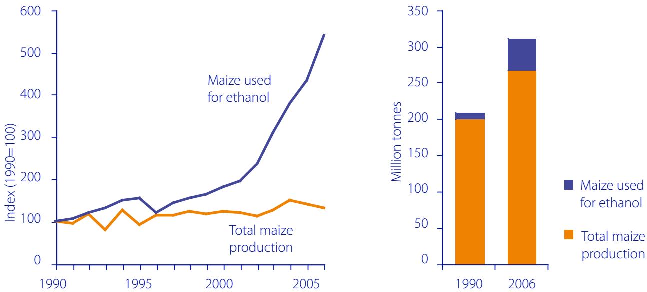
There are many impacts of bio-energy and related concerns about those impacts. The best way to take these seriously is to carefully review the existing evidence on biomass production and bio-energy use and to put it in a wider agricultural, energy, environmental and economic perspective.

The food, feed and fuel dilemma

The first concern to address in more detail relates to the effects of rising bio-energy demand on food prices, which could affect in particular the poor and the least developed countries that have to buy food on the international market. This dilemma is often referred to as the 'food for fuel' dilemma, but probably more aptly named 'food, feed and fuel', as the main energy crops – maize, soybean – are also feed crops. A major displacement of food and feed by energy crops is not expected as farmers can potentially switch on an annual basis (with the exception of perennials) between food, feed and energy crops. The dilemma is therefore about the competition between food, feed and energy crops and its impact on food prices. The effects of such competition are difficult to determine, as there are many different factors that may play a role. The complexity in determining the effects of bio-energy demand on food and feed prices can be illustrated for transport biofuels.

The share of maize dedicated for biofuel production in total maize production reached approximately 7% on average worldwide in 2006. For sugar cane this figure reached 17%, for oilseed 6% and palm oil it was just over 3%. Biofuels thus represent a significant share in total demand for various crops. Feedstock use for biofuels has grown most substantially since the late 1990s, as illustrated for maize in the US in Figure 3. This rising demand has contributed to the price rise of maize in the US. However, so have other factors; e.g. in the same period maize production in the US did not follow market demand, and in fact even declined since 2004, as a result of poor harvests and declining subsidies. This obviously contributed to the upward trend in maize prices in the US.

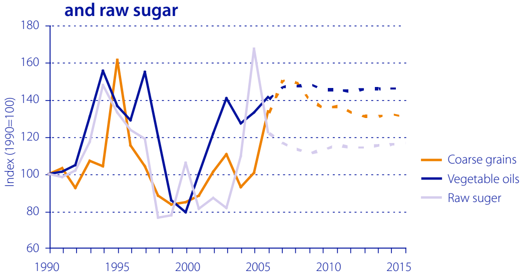
Figure 3 **Trend in maize production and maize demand for ethanol in the US (left) and absolute demand in 1990 and 2006 (right).**



Source: Statistics from the Food and Agriculture Organisation (FAOSTAT) and own analysis.

Even before the transport biofuel sector became significant, average world prices of coarse grains, cereals and vegetable oils were volatile, as illustrated in Figure 4. The reasons for this are changing oil prices and stock reserves, fluctuations in harvests, speculation and changing demand for feedstocks due to changes in consumption patterns. It was when food and feed prices were at historically low levels, at the turn of the century, that the biofuel sector started to grow rapidly. This led those opposing bio-energy to draw (erroneous) conclusions from the correlation between a rapidly growing biofuel sector and increasing feedstock prices. This is not to say that there is no causal relation between rising demand (for biofuels) and prices. It is argued here that the market response to the new entrant (biofuel) might be of temporary nature as the agricultural market can and likely will adapt, as it has before. Short-term price volatility has always been there and there is no reason to assume that it will cease to exist.

Figure 4 **Trends in past and future prices of coarse grains, vegetable oils and raw sugar**



Source: OECD-FAO, 2007[22]

It is worth considering whether bio-energy will have a structural effect on agricultural commodity prices. It is still too early to draw final conclusions with respect to structural price effects of bio-energy demand. History shows that when demand for commodities goes up, so does supply. The uncertainty is embedded in the worldwide capacity to offset additional demand by productivity increases and changes in demand. The recent decision by the EU to reduce fallowing of agricultural land is a case in point. With the advent of second generation transport biofuels and other high-tech forms of bio-energy (e.g. algae) as well as by-products of food and feed production, such as stalks and stubbles, bio-energy applications could be enlarged, thus reducing the demand for feedstock that competes with food demand.

Despite uncertainties in future developments, most experts assume that the price of agricultural commodities will decrease slowly over time because efficiency improvements are expected to be greater than the increasing demand for food, feed and energy crops[23]. In the much longer term, towards 2050 and beyond, when population has reached over 9 billion people and income levels and associated energy and food needs have risen substantially, the question arises whether bio-energy can still be produced in quantities sufficient enough to cover a significant share of the energy needs without endangering food supply. However, by that time, higher yields, more efficient technologies and other feedstocks are likely to become available, as well as other renewables.

It is worth noting that higher commodity prices, and bio-energy in itself, could also be an opportunity, not least for poor countries. Africa, for instance, has huge potential for agricultural production. The African economy, in which agriculture still plays a key role, could benefit from higher production revenues, allowing greater cash flows and hence greater investments in the rural sector. This opportunity does not specifically arise from biomass production destined for bio-energy use, but in principle arises from all agricultural commodities[24]. Caution is needed, however. While in developed countries competition between food, feed and bio-energy crops can easily be prevented by strong government policy, government intervention in poor countries could be more difficult, because there may be a lack of capacity, resources, or willingness to ensure that certain crops are available at reasonable prices for domestic consumption, and the investment climate may not be conducive.

Balancing the equation: land use and nature

One important element in the food, feed and fuel equation is land use for agriculture and its effects on nature. Producing more and more from an equal amount of agricultural land requires yields to rise, which has been the very successful strategy in the developed countries, while in developing countries production increase has mainly resulted from area expansion. Concerns about the destruction of tropical forests for palm oil or cattle are increasing as the price of nature is hard to quantify and nature is seldom protected by any other means, such as enforceable conservation measures. This could have serious effects on biodiversity and perhaps also climate.

Currently, transport biofuel production accounts for just 1% of the world's available arable land, according to the IEA. This figure could rise to 2.5–3.8% by 2030[25]. Obviously, the land claim of biofuel feedstock production is only part of all biomass being produced for bio-energy (especially given the large role of traditional biomass which is expected to reduce sharply on this time scale), so the overall land claim could be higher. The challenge here is to facilitate this additional land claim without expansion of total agricultural area. There is no reason to assume that for bio-energy crops this challenge is any different from the challenge posed by rising demand for other agricultural commodities. In that case, bio-energy crops compete for space with food and feed crops, as discussed earlier. If natural ecosystems with high biodiversity values were destroyed for the sole purpose of energy production, either directly or indirectly, this would fall into the same realm as the destruction of rain forests for cattle grazing and other (agricultural) purposes, and should be strongly discouraged.

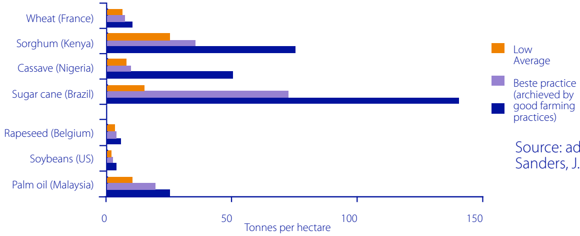
From an ecological point of view, no land use in the humid tropics is more destructive than low yielding annual crops. Plantations are a much better alternative even if biodiversity impacts are still considerable. In other words, the greatest potential to safeguard biodiversity lies in good agricultural practice and new cropping and livestock systems in order to intensify agriculture on the most productive lands and reduce the pressures on natural ecosystems. This is especially relevant in the vast but currently rather unproductive rural areas in the developing world, in order to avoid further nature and habitat loss due to expansion of agricultural land.

But how can agricultural productivity per hectare be raised? The only real option for improving yields is a process of sustainable intensification, with due regard to the lessons learnt from irrational and poor use of agrochemicals and water in the past. Sustainable intensification is defined as an increase in the efficiency of the use of land, water and chemicals (fertilisers and pesticides), using modern husbandry techniques to tend new genotypes of crops and animals, while avoiding environmental degradation. This boils down to what has been called a second or doubly Green Revolution, boosting land, water and labour productivity and enabling greater diversification of diets and income generation in rural areas.

The extent to which crop yields can be raised is considerable, in particular in poor countries. To cite just one example: average cassava yields in Nigeria are less than 10 tonnes wet weight per hectare (t/ha), compared to 50 t/ha at the best farms in Nigeria and 100 t/ha at the best farms in Brazil. Other examples are shown in Figure 5.

An uncertain factor is presented by climate change induced weather changes, which may influence biomass production both in a positive and negative way. The latest report of the Intergovernmental Panel on Climate Change (Working Group II) indicates that crop productivity will increase slightly at mid- to high latitudes with a temperature increase of 1–3 °C, whereas at lower latitudes, especially in seasonally dry and tropical regions, crop productivity is expected to decrease, even with small temperature increases (1–2 °C)[26]. The causes for decreasing yields include recurrent droughts, late onset of the rainy season, and higher night temperatures. Increased CO_2 rates and above all the expansion of climate belts towards higher latitudes, have positive effects on overall production.

Figure 5 **Examples of the potential of crop yield improvements**



Source: adapted from Sanders, J., 2007[27].

Another way to relieve the pressure on bio-energy related land needs is to improve efficiencies through choice of feedstock. When, for example, second generation transport biofuels become economically viable and technically perfected, cellulosic feedstocks such as grasses and fast growing trees such as willow or eucalyptus can be used as feedstock. This feedstock does not require fertile land and can be grown on degraded and waste lands, of which vast amounts are available, although water and phosphorus may become limiting factors in some areas. This feedstock can be supplemented by other types of organic waste. It is estimated that the annual 1.3 billion tonnes of bio-waste in the US could be sufficient to replace 40% to 50% of conventional transport fuels used[28].

Even without second generation technologies, promising developments are emerging. One is the possibility to use energy crops that can rotate with annual food crops, such as food crops (cereals, legumes) and non-food crops (cotton, sunflower) to increase the benefits of additional investment in biofuel crops (e.g. fertiliser and preparation).

Another possibility is the use of species adapted to marginal conditions[29], or to apply improved husbandry methods in grazing systems, now often one of the lowest yielding agricultural systems in the world. This would allow the freeing up of degraded land to grow crops like Jatropha, a plant that can grow under harsh conditions on soils that are unsuitable for most food or feed crops. Innovative concepts, such as the use of algae and single cell protein, may lead to substantial efficiency increases in protein production and land requirements. Although not yet economically viable, besides intercropping schemes, these techniques would allow biomass production for bio-energy without threatening food security. The challenge will be to reduce production costs, and, for Jatropha and the like, to minimise water needs whilst guaranteeing sufficient production. Today, many of these species are often very low in yield and major breeding efforts are still needed to increase their productivity under harsh conditions. Land shortage, in other words, is unlikely to be the major long term factor in the biomass for food and fuel debate.

Energy efficiency

Another major concern relates to the efficiency of bio-energy, often expressed as net energy balance. This is the ratio between the energy embodied in a unit of bio-energy divided by the fossil energy required to produce that same unit. When higher than one, it is efficient, at least from an energy point of view, to use bio-energy instead of conventional energy.

Determining the net energy balance of bio-energy is a difficult and challenging task. It requires a life-cycle approach accounting for all energy needs throughout the entire production process. In the case of biomass used for electricity generation such an approach includes e.g. the energy needs for the production, harvesting and transportation of the biomass to the electricity plant. These energy needs should then be compared with the energy needed to explore, process and transport coal, gas or oil. In the case of transport biofuels the calculation becomes even more complex, as the energy needed to convert biomass into fuels, and to refine crude oil into transport fuels, is also to be accounted for. For each crop used and conversion technology applied, the net energy balance will be different. Net energy balances also greatly depend on the definition of system boundaries, i.e. on the decisions with respect to what is and is not considered to be energy use associated with the production. For example: are the energy needs for fertiliser production, plant construction and machine manufacturing taken into account, or not?

This explains why there is much debate about the net energy balance of bio-energy and thus about avoided CO_2 emissions; one of the reasons for making use of bio-energy. The discussion often focuses on transport biofuels, where emission reductions are much lower than some would contend, depending on crops used, soil type, agricultural practice and actual processing conditions. The theoretical maximum amount of avoided CO_2 emissions from substituted mineral oil is about 3.3 ton CO_2 per tonne oil equivalent (toe). This is based on the amount of CO_2

released upon burning of mineral oil (2.9 tonnes CO_2 per toe) with an additional 10% to 15% to account for fossil energy use in exploration, refining, transport and distribution[30]. According to Reijnders and Huijbregts[31] the life cycle emissions of South Asian palm oil correspond to 2.8 to 19.7 tonnes CO_2 per ton of palm oil. The higher figure corresponds to plantations on cleared natural forest on peaty soils, implying net emissions of CH_4 (methane, a strong greenhouse gas). Given the fact that the calorific value of palm oil (40 GJ/tonne) is comparable to that of mineral oil (41.8 GJ/tonne), the lower figure would suggest that emission reductions by palm oil based biodiesel are zero at best. Other studies suggest that palm oil based biodiesel requires 9 times less energy to produce than it delivers; sugar cane based ethanol approximately 8 times less[32].

All in all, the energy content of most common transport biofuels exceeds the energy required to produce them[33]. However, exactly how much energy can be saved should be determined on a case-by-case basis. In particular, the efficiency of the agricultural production phase is crucial, and depends on the type of crop used, fertiliser use, agricultural practice, among other things (see Box 2).

Box 2 **Improving the efficiency of converting crops to energy**

The efficiency of converting a crop into some form of energy depends on many variables. Disentangling these helps to identify how the overall efficiency of using biomass for energy purposes can be improved. The total energy yield, in GJ/ha that can be derived from one hectare of biomass could be calculated by means of the following formula:

$$E = Y_a * \Sigma_i W_i * (1 - M_i) * [S_i * C_i + \Sigma_{i,j} B_{i,j} * CB_{i,j}]$$

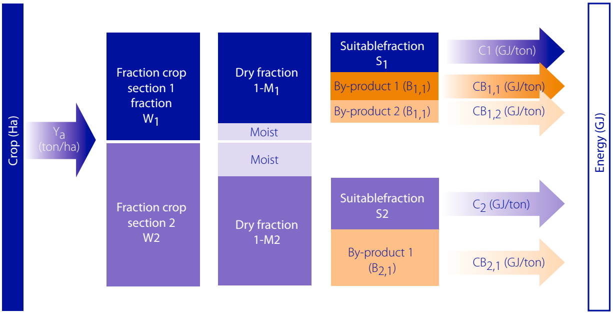
Y_a is the total agricultural yield in tonnes per hectare (the fresh, or wet, weight of the harvest). Usually, a harvested crop comprises several 'crop sections' (i). The main section is denoted with i=1, and refers to e.g. the kernel of maize or tuber in sugar beet. The other section(s), denoted by i=2, i=3, refer to e.g. leaves and stems. Theoretically, roots or underground biomass should be included as well, although they are rarely used for biomass. W_i indicates the weight fraction of each crop section in Y_a. In sugar cane (stalks) or sugar beet (tuber) W_1 approaches 100%. In case of palm oil, W_1 refers to the weight of the fruits and W_2 to the weight of the empty bunches.

As Y_a refers to the wet weight of the harvest, the moisture fraction (M_i) must be subtracted. Only part of the dried crop section is suitable for a particular conversion process, which is denoted by S_i for conversion process C_i. In the case of sugar cane, S_1 refers to the weight fraction of sugar in the cane and C_1 to the efficiency (in GJ/tonne) of ethanol production from cane sugar. In the case of palm oil, the oil fraction is S_1 and the process efficiency (GJ/tonne) of making biodiesel through transesterification is given by C_1.

The by-product fractions of each crop section are denoted by ($B_{i,j}$). The main by-product is denoted by j=1. Some by-products can be converted into energy. For example, sugar cane processing provides two by-products: the biomass residue baggase ($B_{1,1}$) and molasse, which is the residue from which it is too difficult to extract sugar ($B_{1,2}$). The former can be used for energy generation ($CB_{1,1}$), whereas the latter can be used for ethanol production, albeit with a much lower efficiency compared with sugar ($CB_{1,2}$).

The weight fractions are crop specific and relatively invariant, although research is ongoing to obtain a higher W_1 compared to the other fractions. The moisture fraction is variable, depending on crop and climate specificities. Efficiency improvements can be obtained by breeding varieties containing less moisture, or by applying energy efficient drying. Efficiencies can be further improved by increasing the fraction of the suitable material in a crop, i.e. getting S_i as close to 100% as possible, e.g. by breeding maize varieties that are high in starch. Efficiency improvements in the conversion process, or development of new technologies for converting by-products, are further options to increase overall energy yield. When cellulosic ethanol production becomes economically viable this would allow an efficient conversion of e.g. crop section 2 (stems and leaves) of maize to be used for ethanol production (C_2).

Figure 6 **Pathways to convert crops into energy.**



Source: Rabobank, 2007.

Other environmental impacts: nutrients, water and soil

The production of bio-energy crops not only impacts agricultural commodity prices, land use and net energy balances, but also water use, soil quality and nutrient availability. Nutrient deficiencies should not be overestimated as they can be remedied by efficient fertiliser use. Increased efficicency in production and use of fertilisers, will also increase the efficiency of agricultural production (and thus biomass) in energy terms, even if there may be constraints in developing countries with poor soil fertility.

Water scarcities, in contrast, can be a serious matter. Water availability, mostly locally and regionally specific, can constitute a great barrier in semi-arid and arid areas to agriculture in general and hence to biomass production as well. Adequate agricultural (water) management techniques exist in many cases and efforts are already ongoing to promote higher efficiencies through specific temporal and spatial applications ('water the plant when the fruit is developing, not before') and using e.g. drip irrigation ('water the plant root, not the soil') and so-called deficit irrigation. Dramatic improvements in recycling run off and percolated water can be achieved, so that the only water consumption is in evaporation from the soil and transpiration from the plant (evapotranspiration). In some cases biomass crops can contribute to improved water management and retention functions, especially in reforestation schemes. The use of untreated waste water available in developing countries to grow bio-energy crops is a new alternative that would be cheaper and safer than cleaning the water or using it to grow crops for human consumption; the first experiments in Egypt in this regard have been encouraging.

Apart from water concerns related to the production of the crop, its processing may also be a source of concern. The waste products resulting from the harvesting and processing of palm fruits into oil, for example, may cause severe pollution especially if the residue is discarded into the surface waters. The residue itself is of course a source of biomass as well as of plant nutrients, if properly used.

The impact of bio-energy feedstock production on the soil is, just as it is for any other form of arable farming, a function of the type of crop or tree and the agro-ecological environment and practices. Much depends on how long the crop covers the soil and how much the soil lies fallow and is exposed to erosion. Annual crops, such as soybean, canola or wheat, are generally less favourable than perennial crops such as oil palm, or semi-perennials such as sugar cane, cassava, bananas, or grasses. Once they are established tree crops do not require ploughing, provide better ground cover in terms of time and space, less soil disturbance and erosion, better carbon fixation and have some positive effects on hydrology. So the balance seems to be in favour of perennials and tree crops. What is specific for bio-energy is that it creates a market for agricultural residues. When these residues are used for bio-energy purposes rather than for replenishing the soil, this could have an effect on soil quality, especially soil organic matter.

Soil impacts are not simply a matter of crop and use of agricultural residues. If prime forest is cut in order to plant oil palm, the environmental costs may be very high and often can be unacceptable. This is exacerbated if forest clearing is combined with widespread burning leading to loss of soil organic matter, changes in top soil chemistry, carbon emissions and loss of biodiversity. If forests growing on swamp lands are cut and the land drained, the result may be disastrous because of the substantial methane emissions caused by drainage. The cutting of forests should be strongly discouraged, not only because of the loss of forest biodiversity and sequestered carbon, but also because of the widespread disruption of the ecosystem caused by heavy machinery and the decrease in biomass.

Competitiveness and subsidies

Finally, there is a need to address some of the concerns related to the assumed competitiveness, or lack of it, and the subsidies to the bio-energy sector.

At present, competitive performance of bio-energy compared to fossil energy is possible, as mature, efficient, and reliable technology is already available to turn biomass into power. Competitive power generation from biomass can be mostly found in co-generation plants using (cheap) agricultural residues to co-fire power plants, such as Brazilian mills using bagasse (the left-over of sugar-cane based ethanol production) to power the mills or to sell electricity surpluses to the net. The availability of low-cost feedstock or agricultural residues is crucial for the profitability of biomass-based power generation.

Transport biofuels are in general not competitive with fossil transport fuels, with the Brazilian sugar cane based ethanol as a notable exception. Generally, the economics of first generation transport biofuels from e.g. cereals and sugar beet in temperate climate zones are poor and unlikely to reach competitive price levels even in the longer term. Therefore, the sector is largely subsidised, through excise duty exemptions, support to transport biofuel production processes and agricultural subsidies, etc. In view of concerns about the food, feed and fuel dilemma, the net energy balance and other environmental impacts, the appropriateness of these subsidies must be questioned.

With rising oil prices the competitiveness of bio-energy could improve. However, it can be argued that barring the effects of major subsidies and other imperfections, the interaction of the bio-energy market with the conventional energy market creates both a floor and a ceiling price mechanism for agricultural commodities which can be used as feedstock for bio-energy production[34]. Obviously, when total costs of bio-energy production from a particular agricultural feedstock are lower than the prevailing oil price, demand for this feedstock for conversion into bio-energy will increase and the price will go up. Inversely, if the price of the bio-energy alternative exceeds the oil price, demand for the underlying commodity for energy will fall and prices will decline. The price range for agricultural commodities thus created also depends on the underlying cost dynamics of the various bio-energy alternatives as well as on CO_2 prices as the latter can augment the relative competitiveness of transport biofuels vis-à-vis fossil energy alternatives. Additionally, bio-energy also has to compete against other renewable energy options such as solar and wind power.

When second generation transport biofuels become available on a large scale, costs could decline substantially, offering much better perspectives and competitive fuel prices in the longer term (between 2010 and 2020). Partly, this is because of the inherently lower feedstock prices and versatility of producing lignocellulosic biomass under varying circumstances. Furthermore, the advanced gasification and hydrolysis technologies under development have the potential for efficient and competitive production of fuels, sometimes combined with co-production of electricity. Comprehensive research and development strategies for such technologies are required in order to focus not only on development of technologies but also on the long-term deployment and (re-)building the infrastructure and markets required. Development of second generation technology is important, because there are few if any long term unsubsidised economic perspectives for the use of food crop derived transport biofuels in the temperate climate regions of the world, and only very specific ones in tropical countries (sugar cane and palm oil)[35].

Is there a dilemma?

Bio-energy has the potential to be produced in a sustainable manner, that is to say providing a net energy gain, having higher environmental benefits compared to fossil fuels, being competitive economically and available in large quantities without endangering food supply. The applicability and soundness of bio-energy depends on what energy feedstock is used, how and where it is grown and how it is processed. In itself, bio-energy should not present a dilemma with regard to safeguarding food production or the environment. In fact, it may help to diversify agricultural and forestry activities and attract investments in agricultural production. However, it is dangerous to generalise.

Bio-energy projects are to be judged on a case-by-case basis

Bio-energy projects should be judged on a case-by-case basis taking into account the various sustainability implications as discussed. Above all, bio-energy must be part of a broader energy diversification and development policy which includes not only supply side options but also energy demand savings and incentive frameworks. Given the huge differences between the various biomass sources and conversion technologies it is of crucial importance that the right priorities are set, nationally and internationally, in supporting bio-energy options. In this respect it is regrettable that the current US and EU bio-energy support schemes do not differentiate between net energy balance and the environmental impact of the various bio-energy alternatives. Providing government support to promote bio-energy with other motives than widening the energy options will undoubtedly create negative externalities and skewed competition curves.

Risks and opportunities

Bio-energy could also give an impetus to the development of more rational and productive forms of agriculture, especially in developing countries and in marginal areas, by generating additional income in the farming industry and help nations to save on their energy bills. As such, bio-energy could provide opportunities for rural development. In addition, more productive agriculture would free up land for food and energy crops. A policy that integrates bio-energy farming and food and feed farming can potentially solve both local food shortages and increase the income of the world's poorest people. This will only work if governments and donors develop coherent policies including bio-energy as part of a broader approach to energy and rural development. This is all the more urgent given that the bio-energy sector will, according to IEA projections, absorb 15% (USD 2.4 trillion) of total global energy sector investments until 2030. The new popularity of bio-energy in investment and development circles should not lead to isolated projects benefiting a few, to the detriment of long term sustainable rural development.

The crucial importance of agricultural efficiency

Yield increases are of crucial importance in whether or not bio-energy will be a viable opportunity. Rational modernisation of food and livestock production is a precondition for the introduction of biomass production for bio-energy, and shall need to be demonstrated for different agro-ecosystems around the globe. This should demonstrate how biomass can fit into overall sustainable rural development. There is a clear if not yet articulated need for an international clearing house of best practices with an associated technology transfer programme. A programme for bio-energy could benefit greatly if it were integrated with official development assistance (ODA). ODA in agriculture and rural development has dropped more than 50% in the last twenty years[36]. This is particularly striking when considering the importance agricultural yields for the possibilities of supplying the world with sufficient food, feed and agri-based fuel.

The importance of technological breakthroughs

The condition that no new land is taken into production, to safeguard biodiversity, implies that the short term attraction lies in the use of (semi) perennials such as oil palm, sugar cane and cassava for bio-energy feedstock. The greater promise is held by the massive uses of municipal and forest waste streams (pellets and other solid biomass). In the longer term, as second generation technologies come on stream, cellulosic resources become the promising feedstock, which can potentially be grown on unused land. And perhaps the future will also see combinations of land and ocean based biomass production systems, further diminishing the pressure on agricultural land.

Emerging sustainability criteria and consumer concerns

The international policy arena is still slow to ensure that the bio-energy sector develops in a sustainable manner. This may have an adverse effect on public support for bio-energy as a whole. It seems that this is already happening, given the many instances of concerns by NGOs and citizens. Ever better informed and more critical consumers, in developed and developing countries, are becoming aware that their purchase decisions can make a difference in reducing environmental impacts or preventing social injustice. Massive energy crop plantations may meet with public aversion, even though the environmental problems of monocultures pertain to all monocultures and are not specific to bio-energy.

It is important that environmental problems due to land use change, processing and monoculture are avoided, as they can be. In order to appease fears about a food and fuel dilemma, the development of bio-energy may require the development and broad international acceptance of appropriate sustainability criteria and certification schemes[37]. We are already seeing several European countries moving in that direction. Producers of biomass would, however, be well advised to document the environmental impact of their production processes in order to comply with sustainability criteria. It is not unlikely that biomass traceability will become an issue, both at national level and possibly also under the World Trade Organisation (WTO).

In fact, bio-energy could emerge as an important area of debate in the context of WTO. Recent evidence from the WTO suggests that environmental concerns could play a greater role in future trade and thus may also affect bio-energy[38]. It is not unthinkable that countries may refuse market access for bio-energy products on the basis of environmental, or more broadly, sustainability criteria. This would put pressure on the international policy community to develop internationally agreed criteria and monitoring systems as soon as possible, in order to prevent a jungle of different criteria systems from emerging.

To conclude

We are now witnessing tight markets in some commodities and regions due to a variety of reasons, such as bad harvests, low stocks and speculation. In the short term price volatility in some regions and for some commodities could persist. Being a nascent sector, the rapidly growing bio-energy sector will add to this volatility and may even suffer from it.

In the medium term one may expect that markets and governments will adjust and respond to the new reality. We already see the signals: the EU has decided to give up temporarily the set-aside obligation to boost wheat production instead of giving premium for fallow land which was recently en vogue. Eventually farmers will also choose more efficient crops or breed better crops, and apply various technologies to boost production, as this could raise their revenues. There is still a large potential for productivity increases.

In the longer term competitive second generation and other technologies will become available, which could bring into play non-food cellulosic feedstocks and high-yield cultivation of algae. This will permanently change the food and fuel discussion. On the demand side one may expect higher efficiencies and in the longer term a system-change away from engines as we know now, to hybrid or all electric cars.

Considering this perspective, the key challenges for the next decades can be summarised simply as the provision, in a sustainable manner, of food, income and energy to a growing world population. Formulated in this manner, this is nothing new and has been the focus of our collective attention in the latter half of the 20th century. However, the recent emphasis on energy does point to a new balance in our efforts. In a world where fossil fuels can no longer be taken for granted for reasons of climate change and geopolitics, the relationship between food and energy takes on a new dimension. This is not only the case because energy is an important cost factor in agri-food chains, but above all because several renewable forms of energy are directly linked to agricultural land.

The future of bio-energy, whatever shape it takes, is closely linked to that of agriculture and food, and in the future of agriculture, bio-energy is likely to play an increasing role. Moreover, bio-energy could potentially reconcile the priorities of the richer part of the world (security of energy supply and addressing climate change) with those of the poor (access to energy, income generation and opening up new markets).

Governments aiming at a significant role for bio-energy in the near future, must formulate realistic targets based on correct production levels and conversion rates. Thus far, policy choices in this area have obviously not been driven by economic efficiency but by strategic and geopolitical considerations such as increased energy self reliance. The US and EU have now put in place import quota or import levies which impede free international trade of biofuels. Under such conditions the risk of price induced competition between food and fuel increases..

It is worth noting that the opportunities for biomass to replace conventional oils go beyond the domain of bio-energy. Petrochemicals could also be replaced by chemicals based on biomass feedstocks. Besides providing an efficient alternative to petrochemicals such biobased chemicals are also biodegradable. In this way they contribute to diminishing oil needs as well as to reducing non-reusable waste streams. Bio-chemicals are already a reality and as its market share grows, the demand for biomass also increases.

Above all, the challenge lies in diminishing inefficient land-use to facilitate the growing demand for food, feed, fuel and other use of biomass e.g. as feedstock for the chemical industry. Although agricultural development is one of the success stories of the modern world, extensive parts of the world have thus far benefited too little from this progress. Poverty often leads to low agricultural output and environmental damage. Beyond a plea for more ODA, particularly aimed at boosting agricultural output in the least developed regions, the need for a true partnership between the public and the private sectors to innovate the rural sector needs to be underlined. Poverty can be tackled, as we know from many success stories of communities lifting themselves out of poverty through a combination of investment, modern and ecological sound technology and government policy. This remains the true challenge of our world, and, under the right conditions, bio-energy can be a key factor in this.

Endnotes

1 This booklet is an updated version of the extended published text of the Duisenberg lecture given by Louise O. Fresco on September 17, 2006, in Singapore. With hindsight, the subject of biofuels and the dilemmas surrounding its use turned out to be very timely, as a wealth of new data and points of view and even controversies have emerged in the course of the last twelve months. I am grateful therefore to the Rabobank for making a second, extended edition possible. I gratefully acknowledge the inputs from Rabobank staff and in particular the 2006 and 2007 reports, respectively entitled 'Financing and the Emerging Bio-energy markets, the Rabobank view' and 'Agri-based Alternative Energy: Risks and Opportunities for the Farming Industry – Developed Nations and Emerging Markets'. Unless otherwise referred to, data is quoted from these Rabobank reports. Errors of fact and judgment are, of course, entirely mine. I am especially most thankful to Daan Dijk for his relentless assistance in reviewing and collecting data and the many discussions we have had, and to Wouter de Ridder who joined us with data, insight and editorial advice, as well as to André Faaij for providing additional references.

2 I follow FAO definitions. Bio-energy: energy from bio-fuels. Bio-fuel: fuel produced directly or indirectly from biomass such as fuel wood, charcoal, bio-ethanol, bio-diesel, biogas, or bio-hydrogen. Biomass: material of biological origin (excluding material embedded in geological formations and transformed to fossil), such as energy crops, agricultural and forestry wastes and by-products, manure or microbial biomass. Bio-energy includes all wood energy and all agro-energy resources. Wood energy resources are fuel wood, charcoal, forestry residues, black liquor and any other energy derived from trees. Agro-energy resources are energy crops, i.e. plants grown for energy such as sugar cane, sugar beet, sweet sorghum, maize, palm oil, seed rape and other oilseeds and various grasses. Other agro-energy resources are agricultural and livestock by-products such as straw, leaves, stalks, husks, shells, manure, droppings and other food and agricultural processing and slaughter

by-products. Source: FAO, 2004, Unified Bioenergy Terminology (UBET), Rome.

3 Lele, U., 2003, Partnering to promote technology transfers. World Bank Operations Evaluation Department (OED), Washington.

4 BP statistical review: data series 1965-2005 based on commercially traded fuels only hence excluding renewables and nuclear. This can be used as a good proxy for energy demand growth over this period. The Worldwatch Institute has synthesised time series (for fossil fuels only) based on United Nations, US Department of Energy and International Energy Agency data that goes back to 1950. This data leads to a multiple of 5.2 over the period 1950–2004. By inference (assuming 6% growth between 1945 and 1950), energy demand over the entire 60 year post-war period has thus increased by a factor of 6.6.

5 International Energy Agency (IEA), 2006, World Energy Outlook 2006, Paris.

6 On the basis of best available technology a 2–4 fold energy reduction has been reported for the transport sector, whereas in industrial processes a 1.5–2 fold reduction is on average achievable. The sector with the largest, low cost, energy savings potential is the residential and commercial building sector. Especially heating and cooling demand can be greatly reduced. A number of zero energy buildings have been built and more are currently under construction. Obviously, the impact on global primary energy demand depends crucially on the speed of replacement of the existing capital stock. Sources: Blok, K., E. de Visser, 2005, Ecofys report ECS05066 commissioned by the Netherlands Environmental Assessment Agency.

7 Lovins, A, et al., 2004, Winning the Oil end Game, Rocky Mountains Institute, US.

8 IEA, 2006, World Energy Outlook 2006, Paris: Table 2.1, p 66.

9 The IEA, from which this data is derived, combines biomass and waste, which refers to 'solid biomass and animal products, gas and liquids derived from biomass and the renewable part of municipal waste'. Source: IEA, 2006, World Energy Outlook 2006, Paris.

10 Energy Information Administration (EIA), 2004, International Energy

Annual 2004. Official Energy Statistics from the US government, Washington.
11 Data from New Energy Finance.
12 Experiments are also under way with biofuels as an alternative to kerosene in air transportation.
13 Rabobank, 2007, 'Agri-based Alternative Energy: Risks and Opportunities for the Farming Industry – Developed Nations and Emerging Markets', Utrecht.
14 A. Faaij, personal communication, 2007.
15 UNDP, UN-DESA and World Energy Council, 2000, World Energy Assessment: energy and the challenge of sustainability. José Goldemberg (editor), New York.
16 These are the assumptions used in the reference scenario of the IEA. Source: IEA, 2006, World Energy Outlook 2006, Paris.
17 Rabobank, 2007, 'Agri-based Alternative Energy: Risks and Opportunities for the Farming Industry – Developed Nations and Emerging Markets', Utrecht.
18 'The Alternative Policy Scenario analyses how the global energy market could evolve if countries were to adopt all of the policies they are currently considering related to energy security and energy-related CO_2 emissions. The aim is to understand how far these policies could take us in dealing with these challenges and at what cost.' Source: IEA, 2006, World Energy Outlook 2006, Paris: p. 161 and details on p 165-169.
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21 Reijnders, L. and M.A.J, Huijbregts, 2006, Life cycle greenhouse gas emissions, fossil fuel demand and solar energy conversion efficiency in European bioethanol production for automotive purposes, Journal of Cleaner Production, 15(18): 1806-1812.
22 Organisation for Economic Co-operation and Development (OECD)

and Food and Agriculture Organisation (FAO), 2007, Agricultural Outlook 2007–2016, Paris.
23 OECD-FAO, 2007, Agricultural Outlook 2007–2016, Paris/Rome.
24 See also Rabobank, 2007, Agri-based Alternative Energy: Risks and Opportunities for the Farming Industry – Developed Nations and Emerging Markets, Utrecht.
25 IEA, 2006, World Energy Outlook 2006, Paris: p. 385.
26 IPCC, 2007, Summary for Policymakers. In: Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge.
27 Sanders, J., 2007, Wageningen University (personal communication).
28 Holmgren, J., 2007, Speaking at the 'Next Generation Biofuels Markets' in Amterdam, 4–5 October.
29 Bio-saline agriculture for instance, may bring into play large areas of saline waste land. The Organisation for Agriculture in Saline Environments is developing pilot projects in the Colorado delta in Mexico with active involvement of local communities. Source: http://www.oasefoundation.eu/
30 Calculated on the basis of statistics from EIA (http://www.eia.doe.gov).
31 Reijnders, L. and M.A.J. Huijbregts, Palm oil and the emission of carbon-based greenhouse gases, forthcoming in the Journal of Cleaner Production, article in press, corrected proof.
32 For a recent review of overall life cycle efficiencies see: Hill, J. et al, 2007, Environmental, economic and energetic costs and benefits of biodiesel and ethanol biofuels, PNAS 103(30); and Von Blotnitz, H. and Mary Ann Curran, 2007, A review of assessments conducted on bio-ethanol as a transportation fuel from a net energy, greenhouse gas, and environmental life-cycle perspective, Journal of Cleaner Production 15(7): 607-619; and Reijnders, L. and M.A.J. Huijbregts, 2007, Life cycle greenhouse gas emissions, fossil fuel demand and solar energy conversion efficiency in European bioethanol production for automotive purposes, Journal of Cleaner Production, 15(18): 1806-1812.
33 Fossil energy balances: cellulosic ethanol: 2-36 (theoretical).

Biodiesel from palm oil: ~9; from waste vegetable oils: 5–6; from soybeans: ~3; from rapeseed: ~2.5; from sunflower: 3; from castor: ~2.5. Ethanol from sugar cane: ~8, from wheat: ~2; from sugar beets: ~2; from maize: ~1.5; from sweet sorghum: ~1. Source: Worldwatch Institute, 2006, Biofuels from Transport: Global Potential and Implication for Energy and Agriculture, Washington, p. 162.

34 Schmidhuber, J., 2007, Impact of an increased biomass use on agricultural prices, markets and food security, in the proceedings of the seminar 'Food, Fuel or Forest? Opportunities, threats and knowledge gaps of feedstock production for bio-energy', Anton Haverkort et. al. (ed.), Wageningen University.

35 Hamelinck, C. and A. Faaij, 2006, Outlook for advanced biofuels. Energy Policy 34(17): 3268–3283.

36 Worldwide assistance to agriculture decreased continuously from more than USD 5 billion at its peak level in 1988 to USD 3 billion in 2005 (in current prices). Source: OECD, 2007, Statistics Portal (http://www.oecd.org/statsportal/).

37 Certification could mean that, in order to qualify as a biofuel or to meet the fiscal specification for biofuels, there would need to be a minimum carbon saving. Practically, that may mean that all biofuels sold in the world will need to be carbon-certified in future. It is essential that the private sector follows suit and organises itself in a 'coalition of the willing', committed to truly sustainable biofuels production and trade.

38 With respect to compatibility of such certification schemes with WTO rules on technical barriers to trade it should be noted that decision of the appellate body of the WTO give grounds to expect that environmental regulators can refuse imports of goods based on information on how they were produced. See e.g. Howes, R. The Appellate Body Rulings in the Shrimp/Turtle Case: A New Legal Baseline for the Trade and Environment Debate, Columbia Journal of Environmental Law, 272(2002): 489-519.