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Department of Technology and Society
Environmental and Energy Systems Studies

SUSTAINABLE VEHICLE FUELS – DO THEY EXIST?

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Lars J. Nilsson, Max Åhman

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Sustainable vehicle fuels - Do they exist?

Abstract

Our aim with this report is to discuss vehicle fuels from a wide perspective of sustainability. Biofuels and electricity are analyzed and compared to fossil vehicle fuels. Our goal is to try to point out the circumstances under which vehicle fuels can be reasonably perceived as sustainable, and which systems we should develop and which we should avoid. The all-embracing conclusion of this study is that one can not establish how sustainable fuels will develop in the future without simultaneously taking into consideration both *scale* and *pace of growth*. Today's biofuels produced in Sweden are sustainable, given the present production volume, and promote further development of new fuel systems. However, in the case of increased production volumes, strict requirements should be established for the energy- and climate efficiency of the entire fuel chain (from cultivation to tank). High priority should be given to the development of fuel-efficient cars. In this field hybrid electric technology and electric cars will grow in importance. Any long-term strategy for biofuels should include investments in technology for both thermal gasification and biological conversion methods of lignocellulose, since these are complementing as much as competing technologies, and increasing the flexibility as well as decreasing the risk of conflicts. Biogas from waste products has great environmental advantages and the sector can be expanded with only small risks of conflicts. Certification (if correctly formulated) is an important and necessary tool on the way towards more sustainable vehicle fuels and increased production volumes, but certification systems should not be overrated since they can not cover all sustainability aspects. Socio-economic aspects such as working conditions, local rural development etc. must be dealt with through general measures such as national legislation, distribution policies, programs and plans, all of which should be supported by international agreements and cooperation on development at all levels. Irrespective of the development in Sweden or the EU, global production of biofuels will increase, not least in the developing countries. It is therefore important to exploit the opportunity we have today to participate in the development and implementation of sustainability criteria. Renewable vehicle fuels can lead to a positive as well as sustainable development in both industrialized and developing countries, when the framing and guidance for an adequate pace of growth and production volumes are given.

Keywords

Vehicle fuels, sustainable development, environmental aspects, socio-economic aspects

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Executive summary

Increased use of fossil fuels pushes the development towards the use of more non-conventional fossil raw materials (tarsand, CtL), which in its turn leads to an increase in CO₂ emissions when compared to “normal” gasoline/diesel. At the same time, we have a big technical potential for biomass, but its exploitation will be limited by economic and practical factors. Bioenergy can only form part of the solution to the climate issues originating from the transport sector, and should be seen as complementary to more efficient vehicles as well as a measure to encourage a reduction of as well as more efficient transport operations.

Biofuel systems are significantly more complex than today’s fossil fuel system with many more possible combinations. It is therefore important to take the entire production chain into consideration, especially since it is much more difficult to generalize regarding biofuels than regarding fossil fuels. This applies, for instance, to the analysis of how biofuel systems (including electricity) comply with given sustainability criteria.

One sustainability criterium is the energy balance for biofuels, which can be calculated in different ways. Which method being most relevant is decided by how the actual system is shaped and the local conditions. There is no general “right” or “wrong” method. Since there is competition for farmland, energy efficient biofuel systems with a high yield of fuels per hectare should be prioritized, for example fuels from gasified energy forest, sugar cane ethanol (not requiring artificial irrigation) etc. There is also a potential increase in area efficiency for the 1st generation biofuels of today. Area efficiency is of limited importance when biofuels are produced from forest raw material, above all waste products, and from biomass cultivated on previously unused marginal land.

The production of biogas from biological waste products has good energy efficiency and leads to no increase in the competition for farmland. The same also applies to the use of waste products from forestry, for example, in the production of ethanol and fuels by means of gasification. Today’s Swedish production of ethanol from wheat and RME from rapeseed has a good energy balance thanks to the by-products being used in an efficient way as protein feed, replacing soy protein feed imported from Brazil, i.e. these factories should be seen as combined fuel and feed factories. In the future we may see a rise in energy efficiency for current as well as future biofuel systems thanks to the development of different sorts of energy combinations, or bio-refineries. The general efficiency will increase greatly by future electric hybrid vehicles, compared to the vehicles of today. However,

to transform bioenergy into electricity in order to fuel plug-in hybrids or electric cars gives very little efficiency gains compared to a developed electric hybrid, running on biofuels.

To ensure that biofuels from crops lead to substantial climate benefits the prerequisites are that: 1) fuel-producing factories run on biofuels, not fossil fuels, 2) cultivation is avoided on “carbon rich” farmland, for example, peat land with permanent pasture etc., 3) possible by-products are utilized efficiently in order to maximize their (indirect) energy- and climate benefits and 4) nitrous oxide emissions are minimized by effective fertilization strategies and by the use of commercial nitrogen fertilizers produced in factories with nitrous oxide gas purification. The second generation fuels based on forest raw material lead to substantial climate benefits. A “double” climate benefit can be gained when waste products, for example, manure, are used in biogas production, due to the reduction of methane emissions from conventional handling.

If increased biofuel production implies cultivation on new farmland with a high carbon content, the climate benefits from the use of biofuels could be lost. Climate benefits, on the other hand, can be enhanced if cultivation takes place on marginal lands with low carbon content. The binding of carbon dioxide in the soil diminishes eventually while the climate benefit of replacing fossil fuels by biofuels continues. It is very doubtful to charge biofuels with long-term indirect effects on land use as “displacement effects” by assuming that increased biofuel production always leads to cultivation of new farmland. Possible displacements of existing cultivation also apply to increased food and fodder production. However; “sustainable fuels” require “sustainable planning” of land-use.

Electricity use in the transport sector, in the form of small electric cars or plug-in hybrids, leads to substantially lowered emissions of greenhouse gases when renewable electricity is used. Depending on the calculations used, the environmental benefits from electricity can vary substantially. However, in a coherent climate policy strong reasons advocate the use of electricity in the transport sector as an excellent solution for the future, since it is a CO₂-free energy carrier and the production has very good potentials of becoming carbon dioxide efficient. In the future, biofuels will, to a large extent, be produced in combination with electricity and heat; the extent of the combinations is decided by the heat sink available (locally and nationally). Today’s debate regarding whether biomass should be used for electricity and heat production or for transport fuels is therefore in part irrelevant.

Normally, gaseous fuels emit lower quantities of regulated substances compared to conventional diesel and gasoline, as do also, to a certain extent, liquid biofuels. This distinction, however, should

not be exaggerated since emission levels today are decided primarily by regulations based on available technology for engine construction and for emission control. Future plug-in hybrids, electric cars and fuel cell vehicles are the only ones which can have “zero-emission” on the street. However, these emissions are being shifted “upwards” in the system to the power station or hydrogen production plant. For all that, emissions are usually easier and cheaper to purify in a large, centralized plant than in all vehicles.

For certain new fuels (for example hydrogen) security issues are involved in their handling, but these seem manageable. Biofuels have the advantage over fossil fuels in case of spillages on land or water, being biologically degradable.

Today’s production and use of ethanol, RME and biogas provides advantages, rather than inhibiting the development of new and more efficient biofuels. In order for the transport sector to profit by the great potential for biofuels in the long term, better systems than those of today are needed. This development requires broad investments on (i) gasification technology, (ii) enzymatic hydrolysis and (iii) efficient electrical drivelines. Both today’s as well as future production systems will consist of bio-refining plants, where also platform chemicals will be produced, such as ethylene or ethanol for the chemical industry.

The ability of biofuels to compete with fossil fuels will in the future be decided primarily by environmental taxes as, for example, CO₂ taxes and by the price of crude oil. With increased competition for raw materials, the biofuels production will align itself towards the use of cheaper raw materials, such as waste products from forestry and agriculture as well as households, called 2nd generation biofuels, as well as biogas. The development of production technology for 2nd generation fuels requires a substantial improvement in technology and the market in order to gradually obtain learning effects and thereby reduce production expenditures. Higher prices of raw materials entail risks associated with expansion and intensified land use.

Possible effects on biological diversity depend on the farmland being used. If existing arable land is utilized the effects are often marginal and even positive, while they can be substantial and negative if new land with high natural values are being farmed. Farming of untouched land is, however, a general problem which includes food-, fodder- and wood production. This requires new and general measures, covering all land use, in order to prevent the loss of biological diversity.

Influence on regional water access and water consumption must be monitored when biofuels are based on irrigated crops (above all sugar cane and maize) since irrigation is resource-demanding and therefore not always sustainable. Increased biofuel production can impact on the need for

irrigation, depending on which crops are cultivated, in which region the cultivation is being undertaken, and the amount of rainfall. Hence, the “right” crop should be cultivated in the “right” region, in order to avoid water shortage in vulnerable regions.

The price increases of food products in recent years stem from a variety of factors, among which increased biofuel production has a certain, limited influence. Thus far the production of raw materials for biofuels takes up only about 1.5% of the world arable land, and 4.4% of the global grain production goes to fuel production. Other factors which have contributed to the price increase are: i) increased demand for food, not least meat and dairy products, ii) increasing oil prices, which increased the costs of cultivation and freight, iii) reduced grain stocks, iv) drought, v) trade and agriculture policy and vi) speculation in the market for agricultural products.

There are ample possibilities for producing considerable amounts of bio raw material, while at the same time securing food supply and safeguarding untouched land, for example through utilizing waste products from farming and forestry and increasing the cultivation on marginal land and fallow farmland. The rise in volume of agricultural produce in recent decades was brought about by higher yields rather than by increased land use. The actual acreage of tilled land has even diminished in many countries.

Price increases on food products improves the profitability of production, increasing investments in the agricultural sector, not least in economically poor regions, which again leads to increased production without the need of an increase in acreage of tilled land. Population increase, diet and productivity are decisive factors for the acreage required in the future to cover the requirements of food. Climate changes may have substantial effects on future harvest yields, but there are great uncertainties regarding how these effects will be felt in different regions. When agricultural crops become competitive on the energy market, it will strengthen the link between the two sectors, energy and agriculture, since the energy sector will become an alternative market, next to the food sector.

There are both opportunities and risks involved in the increased demand for biofuels for developing countries. The effects of high food prices are very different depending on which group of people is being considered, for example, urban poor or poor farmers, different countries, for example, net-importers or net-exporters of food, as well as whether the perspective is short or long term, before or after adaptations in the agricultural sector have been implemented. High food prices have worrying distribution effects, but this is a general problem. Famine and malnourishment are not due to a lack of food in the world, but to poverty.

Biofuels have put globalization issues on the map, but there is a large variety of products which claim farmland, implying that these questions are equally relevant to all areas of our consumption. With new markets for biofuels and higher prices of agricultural products the options for poverty reduction increase by means of new ventures within agriculture and rural development in many countries, especially in southern Africa and South America. In order to attain a positive development, strict requirements are needed for a policy leading in the right direction, both for the developed and the developing countries.

Aspects of sustainability dominate the current debate on biofuels, and decisive for a continued expansion is how the sector complies with the given requirements. Certification is an important tool which is currently under development by many actors at many levels, but above all from a euro-centric perspective. However, not even this tool can guarantee that all sustainability requirements are met. Limitations and problems of certification include the handling of social- and work-environmental aspects, as well as indirect aspects arising from changed land use. Apart from this, many countries lack developed institutions and can therefore be unfairly disadvantaged by complicated regulations. Certification tools therefore must be complemented by different measures as well as by national laws, by monitoring compliance and political bilateral and multilateral agreements. Today we have the opportunity to implement sustainability criteria for biofuels at a global level, a possibility we should make use of. Even without these sustainability criteria the production of biofuels will increase, above all in developing countries, with the inherent risk of the development of less sustainable systems.

In conclusion, we can establish that it is impossible to ascertain the sustainability of biofuels without at the same time taking the *scale* and *pace of growth* into consideration. The amount of different fuels that can be produced “sustainably” depends in large part on general factors such as legislation, agricultural development, trade policy etc, which impact on social and economic sustainability criteria. There is a risk that growth at too fast a pace can lead to sub-optimization and consequently the development of less sustainable systems. A suitable pace of growth, on the other hand, could lead to an increase of the potential for sustainable vehicles fuels systems by optimizing agricultural production on existing farmland (which reduces the risk of land competition), effective biofuel production combinations could develop and synergies between current and future technical platforms (for example 1st and 2nd generation fuels) could be handled effectively.

To sum up, these are our recommendations:

- High priority should be given to the development of fuel-efficient cars. In this field electrical hybrid technology and electrical cars will grow in importance.
- Any long-term strategy for biofuels should include investments in technology for both thermal gasification and biological methods for the transformation of lignocellulose since these are complementing as much as competing technologies which increase flexibility as well as decrease the risk of conflicts.
- Today's biofuels in Sweden are sustainable at the current production volume and promote the further development of fuel systems, but we need precise requirements for the energy- and climate efficiency in the entire fuel chain (from cultivation to tank) in the case of increased production volumes.
- Biogas from waste products has great environmental advantages and can expand with little risk of conflict. Today it is furthermore well suited for regional car fleets, pending further development of the infrastructure.
- Certification (correctly framed) is important and necessary on the way towards more sustainable fuels and increased production volumes, but these systems should not be overrated as they can never contain all sustainability criteria.
- Socio-economic aspects such as working conditions, rural development etc. must first be solved by general measures such as national laws, distribution policy, programs and plans, all of which should be supported by international agreements and cooperation in development at different levels.
- Irrespective of development in Sweden or the EU, global production of biofuels will increase, not least in the developing countries. It is therefore important to deal well with the opportunity we have today to participate in the development and implementation of sustainability criteria.
- Renewable fuels can, with the correct policy instruments and guidance for an adequate pace of growth and production volumes, lead to a positive as well as sustainable development in both industrialized and developing countries.

Foreword

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Lund, November 2008

The Authors

Contents

Sustainable vehicle fuels- Do they exist?	1
Executive summary	4
Foreword	10
Contents	11
1. Biofuels for transport – an overview of the debate	13
2. What role can alternative fuels play in the energy system?	15
2.1 Biofuels globally and in Sweden	15
2.2 Energy systems for vehicles	17
3. What about energy balance and land use?	22
3.1 Energy balance	22
3.2 Area efficiency	26
3.3 Increased efficiency via electrical cars	30
4. Do biofuels lead to climate benefits?	33
4.1 Greenhouse gases from cultivation	33
4.2 Emissions from fuel plants and use of waste products	35
4.3 Emissions from land use change	38
4.4 Fuelling the car from the electricity grid	43
4.5 Electricity and heat instead of fuels	45
5. How are other emissions being affected?	50
5.1 Regulated and unregulated emissions	50
5.2 Fuel handling	51
6. Are today's systems leading towards better biofuel systems?	53
6.1 1 st and 2 nd generation biofuels	53
6.2 Development of 2 nd generation biofuels	54
7. Can renewable fuels be economically sustainable?	56

7.1 The long-term oil prices	57
7.2 The long-term biofuel costs	57
7.3 How far can the price on biofuels fall?	59
8. Are biofuels a threat to biological diversity and access to water?	61
8.1 Biological diversity	61
8.2 Water access	64
9. Have biofuels caused increased food prices?	66
9.1 Increased production of biofuels	67
9.2 Increased food demands	68
9.3 Increasing oil prices, falling cereal stocks, speculation and drought	69
9.4. Trade and agricultural policy	70
10. Is there enough land for food and fuel?	72
10.1 A stronger connection between the energy and agricultural sectors in the future	73
10.2 Land requirements for food and fodder production	73
10.3 Fallow land and residues	76
11. Threat or opportunity for developing countries?	79
11.1 The effects of increased food prices	79
11.3 Case – study Mozambique	83
12. Is today's policy with its policy instruments leading us in the right direction?	86
12.1 Strategies for sustainable fuels	86
12.2 Current initiatives for sustainable biofuels	87
12.3 Important remaining questions	89
13. What are the conclusions and the recommendations?	93
14. References and tips for in-depth reading	100

1. Biofuels for transport – an overview of the debate

In the past five years, the use of ethanol and biodiesel (e.g. fatty acid methyl esters, FAME, which can be made, among other things, of rape methyl ester, RME) in the transport sector has increased rapidly, albeit from a generally low level, both globally and in Sweden. Most biofuels are still dependent on government subsidies which are given for several different reasons, among others to decrease the dependence on foreign oil, supporting rural communities and farmers and industrial development. Recently, mitigating climate change has become an increasingly strong driving force for biofuel development. In the US farm subsidies and decreased oil dependence have been the foremost reasons for investment in biofuels, while Brazil and other tropical countries see industrial development as a prime reason. In Sweden and Europe the climate argument is becoming increasingly important for the continued support for biofuels.

As an effect of recent years in global expansion of biofuel production, and the plans for a continued expansion (above all within the EU and the US) many reports, articles and analyses have been published treating the growing global biofuel market and whether this growth is to be seen as a threat or an opportunity. Biofuels have shifted from being painted as one of several important solutions to the climate problem, both in the EU and Sweden, to a new media picture focused on the risks and possible threats. At times, different reports reach very different conclusions, even if they employ very similar scientific bases and statistics.

The lack of consensus can be explained by the fact that the current expansion of biofuels has repercussions on several different sectors in society as well as in different parts of the world. Therefore, the angles as well as the aims of analysis vary considerably. Different actors will weight the importance of issues such as climate, development, trade or economic efficiency differently and will have basically different views on free-trade, appropriate climate measures and the relation between the North and the South. Different results can be explained by important issues such as the choice of time frame, the extent and scale of biofuel production as well as the knowledge of, and belief in, future solutions on climate and poverty issues. Even the term “biofuel” entails great variations of production systems using different raw materials and transformation processes to varying effect. Thus, generalizations are difficult to make.

The current global increase of biofuels has brought the term “sustainable development” to a head, and the debate reflects exactly how difficult, if not impossible, it is to reach an unambiguous decision as to what the term entails. At the same time, the blossoming of the biofuel debate has clearly emphasized the effects of globalization, where anything we consume can be seen to have

effects far beyond our own borders. The question regarding the start and ending of our responsibility has become of immediate importance with the ethanol- and biodiesel debate. The debate about the future of biofuels is both healthy and a sign of maturity. After the expansion in recent years it is unavoidable to question how long this growth can continue, and at what rate it should take place in order for parallel adaptations in the community to be able to occur.

Our aim with this report is to discuss biofuels from a wide perspective which as far as possible aligns the term “sustainable development” with the definition given by the Brundtland report in 1987. Our analysis will include future energy carriers within the transport sector, such as electricity and 2nd generation biofuels, but it will focus mainly on the *use* of biofuels in Sweden, and will hence include Swedish production and even the production caused by imports to Sweden. As point of reference we use current and future fossil fuels.

In the report we discuss energy efficiency, climate benefits, effects on biological diversity and water resources, increased food prices, land use, lock-in effects or bridging technologies, as well as implications for developing countries. Current and future means of control, such as the EU biofuels’ directive and certification requirements are discussed from the point-of-view of whether they lead towards a more sustainable energy system in the transport sector. Finally, recommendations regarding what line we should take regarding to the different production systems are given, both for those already existing and for those which could develop in the near future. Our aim is to point out the circumstances under which fuels can be justifiably perceived as sustainable, which systems we should develop and which systems we should avoid. By way of introduction, we give a short outline of the role the alternative fuels can have in the energy system.

2. What role can alternative fuels play in the energy system?

2.1 Biofuels globally and in Sweden

About ¼ of Sweden's total energy use goes to the road transport sector (90 TWh of a total of 402 TWh) and it is expected to increase concurrently with increasing transport needs, which in turn are driven by economic growth and globalization. Current global energy use within the transport sector of approximately 84 EJ¹ of fossil energy is expected to grow to 132 EJ by 2030², if current trends persist. The transport sector is entirely dependent (96%) on fossil fuels.

Concerns for future climate changes are the main arguments in Sweden and the EU, as to why we need to reduce consumption of fossil fuels in the transport sector. Other important issues are energy security and oil dependence. While Sweden as a whole has succeeded in reducing emissions of greenhouse gases by 8% since 1990, the transport sector has moved in the opposite direction and has increased its emissions by 9%³. This has happened in spite of an increasing energy efficiency in the vehicle fleet in recent years.

One reason for this negative development is the substantial increase in traffic, while simultaneously it has proved difficult to find competitive alternatives to conventional fossil fuels. The transport sector's energy system (from well to wheel) has been developed over a long period of time and with very high demands on energy density, purity and compatibility with the existing vehicle technology. The development is furthermore characterized by long lead times on both vehicles and fuels. In the short term, this will impose relatively high costs on the replacement of fossil fuels for transport compared to other sectors in society, i.e. heating.

Since 2004, Sweden has granted tax exemptions to the use of renewable fuels as a means to reduce greenhouse gas emissions from the transport sector. As a result, large quantities of ethanol and biodiesel have been introduced onto the Swedish market. Further forms of support include the so-called "pump-law", which requires all gas stations over a certain size to supply at least one renewable alternative (which has mainly stimulated the development of ethanol), and a subsidy of 10 000 SEK (~1000 Euros) to be paid to all buyers of new, environmentally classified vehicles.

¹ Global energy data are often given in EJ while Swedish statistics usually are reported in TWh – 1 EJ (Exa joule) = 278 TWh (Terra watt hours).

² IEA 2007

³ Official reporting from Naturvårdsverket (National Environmental Protection Agency), 2008

In 2007 Sweden consumed approximately 2.1 TWh of ethanol, 1.2 TWh of biodiesel (RME) and 0.3 TWh of biogas⁴. This should be compared to the consumption of 46 TWh of gasoline and 40 TWh of diesel. A large share of the ethanol (68%) and all biodiesel (>96 %) were used for low percentage blends in normal gasoline and diesel. The remaining ethanol supplied approximately 100 000 E85 vehicles, while the biogas fuelled approximately 10,000 bi-fuel vehicles (gasoline/gas). Approximately 1,200 busses and 2,900 trucks, running on either ethanol (E85) or biogas, should be added to these numbers.

The ethanol used as fuel in Sweden comes mainly from Brazil (approx. 80%). The rest is produced in the EU and Sweden. The largest production facility in Sweden is based on grain and is located in Norrköping. Ethanol is also produced in Örnsköldsvik from sulfite compounds and in smaller quantities by way of hydrolysis (2nd generation ethanol). Biodiesel in the form of RME is produced in Stenungsund and Karlshamn. This production is complemented by a number of smaller production facilities and imports from the EU. Early in 2008, the facility in Karlshamn and the majority of the smaller plants closed down due to poor profitability. Biogas is produced and used locally in over 55 municipalities in Sweden.

Global production of ethanol has increased many times over in recent years, most substantially in the USA and Brazil, followed by China and the EU. Even the production of biodiesel, concentrated in the EU, has increased substantially. Global ethanol production is dominated by ethanol from maize and sugar cane, while biodiesel is based on rape methyl ester. Global trade in biofuels is rising but is still relatively limited.

Bioenergy – only part of the solution

In the US, Brazil, India, China and EU plans for the continued increase in biofuel production towards the years 2020-2025 already exist, or are under preparation. If these plans are implemented, biofuels will constitute between 4-8% of the global gasoline- and diesel consumption by 2020 or 2030. This share will comprise mostly 1st generation biofuels. 2nd generation fuels (thought to yield even greater volumes), will have been only marginally developed for the market within this period.

An increase in the share of biofuels after 2020-2030 is possible but uncertain. Even though the theoretical potential for future bioenergy production is substantial, both in Sweden and globally, in

⁴ Energimyndigheten (The Energy Agency), 2008

reality it is being hindered by practical, technological and not least economic difficulties. The IPCC (2007) indicates a bioenergy potential of between 125- 760 EJ⁵ by the year 2050. Most assessments of a long-term technical potential assume between 400-500 EJ, with a *practical/economic* potential of about 170-250 EJ. This potential should furthermore be shared with the heating- and electricity sector where it is often, in the short-term, cheaper to replace, for example, coal by bioenergy, see chapter 4.5. To this we should add the losses of transforming bioenergy into fuels. 100 EJ bioenergy adds up to a maximum of 50-60 EJ of fuels using the best future techniques available and assuming that no combination solutions are employed. In spite of this, and of all the uncertainty surrounding the sector, it can be established that the prerequisites exist for future biofuel production to cover part of the energy requirements of the transport sector. The exact amount of bioenergy that will be utilized in the future is very uncertain at this point in time, and the quantity used for biofuels will be decided by the technological development and future economic factors.

Biofuels should not be seen as the climate “silver bullet” for the transport sector , solely as a part of the solution. A general strategy for reducing the transport sector’s contribution to climate change is by (i) the increased efficiency of the vehicle fleet and the transport operations (ii) a limitation on the increase of transport demand and (iii) an increased use of renewable energy. Recently a number of studies⁶ have ascertained that all of these strategies are needed in order to solve the challenges facing the transport sector.

2.2 Energy systems for vehicles

The energy system for the running of a vehicle includes the entire chain, from production and extraction of feed stock , the fuel production process to the vehicle technologies for the utilization of the fuel. These systems differ for fossil fuels, biofuels and electricity.

⁵ The total global energy consumption in 2006 was approx. 464 EJ of which 40-45 EJ was “traditional bioenergy” and 9% EJ was “modern bioenergy” (IEA 2007a)

⁶ For example, a report for the Parliamentary Committee on Transport and Communications, see Åkerman and Åhman 2008

Feed stock

The high, and increasing demand for fossil fuels force up the prices of crude oil and stress the question of how much “conventional” oil⁷ is remaining (the peak oil debate). Increased prices on the world market and a limited access to conventional oil lead to an increased production of gasoline and diesel from “non-conventional” fossil sources such as tar sand (e.g. Canada) or synthetic fuels from coal in, for example, China and South Africa, called coal-to-liquids (CTL).

Fuels manufactured from non-conventional fossil resources have a considerably higher emission of CO₂ per litre of fuel than ordinary fossil fuel and is often associated with serious ecological consequences at extraction. In the case of coal-to-liquids the greenhouse gas emissions are doubled compared to normal gasoline/diesel.

Biomass for fuel production is not a uniform feed stock. It is often divided into sugar/starch, lignocellulose and vegetable oil. Biomass can also be classified as coming from farmland in production and hence directly competing with food production, or from the cultivation of surplus land, not in production (for example wooded land), marginal land not suitable for food production, or from waste flows. Biomass can furthermore be divided into wet and dry fractions, of which the wet fractions can decompose, becoming biogas. Current liquid biofuels come from the starch-rich part of grain plants (e.g. wheat seeds and maize corns), from sugar (e.g. sugar canes) or oil-rich plants (e.g. rape or palm oil).

In the future it is hoped instead to exploit the entire biomass of the plant, also the lignocellulose. A substantial amount of biomass is found in the form of lignocellulose in the waste products from forestry, farming and households⁸. Lignocellulose could also be produced from dedicated crops of energy plants on farmland, e.g. Salix, hybrid aspen, switchgrass, elephantgrass and eucalyptus. Certain bioenergy crops can be grown in fields not suitable for growing food, e.g. the oil-rich plant jathropa, or plants with high cellulose- content e.g. elephantgrass and switchgrass. The waste flows of wet biomass, e.g. manure, some household waste, waste products from ethanol production (spent wash), as well as remains from purifying plants, can decompose and produce biogas. Biogas can

⁷ The term conventional oil is often used to denote crude oil which can be pumped directly from the ground and be refined. Non-conventional oil is fossil resources which need pretreatment (e.g. to be boiled) in order to become crude oil.

⁸ According to the IEA the long-term potential of bioenergy from waste flows is between 55-300 EJ which should be compared to the current global energy use of 467 EJ.

also be produced from crops such as pasture grass, maize etc. Other by-products such as waste fat, animal fat and pine oil can be exploited and refined to produce biodiesel.

The fuel process

The processing systems for the production of biofuels from different types of biomass are more complex and require more energy than the refining of crude oil to gasoline-diesel-and paraffin-fractions. Today's ethanol and biodiesel have in common that they are produced by relatively simple procedures, namely, fermentation or pressing, from raw materials already available on the agricultural market⁹. Even biogas is produced by a relatively well-established and simple method, namely, decomposition of wet biomass from household waste, purifying plants and manure. The main barrier to biogas has been to develop cost- efficient production and infrastructure systems for the fuel.

Future biofuels based on lignocellulose can be converted into fuel via two different processes, hydrolysis (and fermentation) or gasification. By hydrolysis the cellulose decomposes to sugar and is later fermented into ethanol. In principal, all kinds of biomass can be gasified to synthesise gas (hydrogen and carbon monoxide) and from the synthesised gas one can then produce a number of different fuels, see figure 2.1 below. Neither hydrolysis nor gasification of biomass is today commercially available.

Electricity will be an important energy-carrier in the future. The supply of electricity is seen as a lesser problem compared to the possible effects of this increased electricity use and how this should be reckoned environmentally. The results vary significantly depending on the perspective and this will be treated later in the report.

⁹ These biofuels therefore often go under the name of 1st generation biofuels.

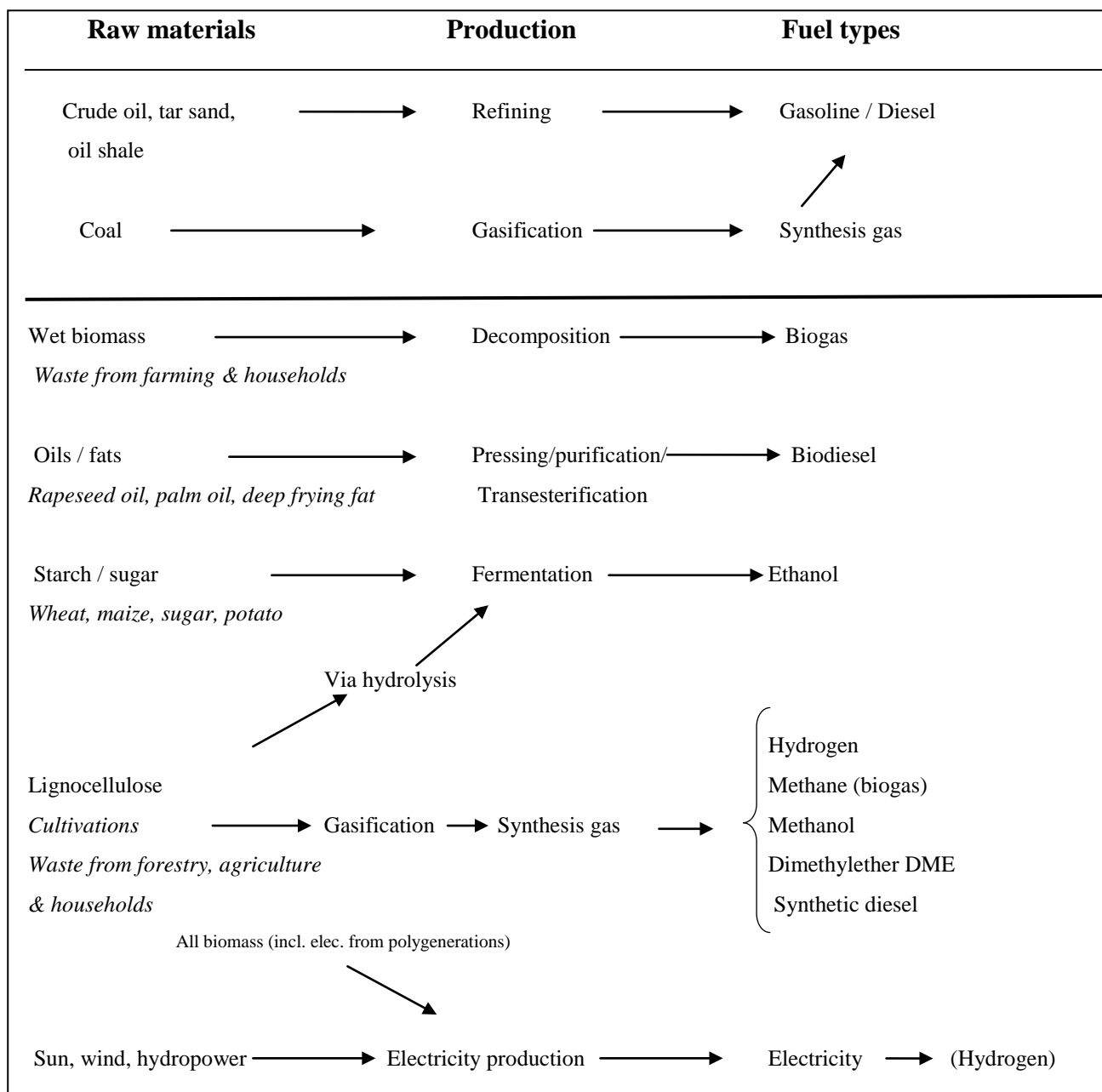


Figure 2.1. Transformation paths from renewable feedstocks to current and future transport fuels

Vehicles

In general, the differences between vehicle systems for liquid biofuels and gasoline/diesel are relatively small. Certain adaptations in engines and distribution systems are needed and for some fuels technological development is required (e.g. for DME¹⁰ in trucks)

Significant differences, compared to gasoline and diesel vehicles, can be seen in favour of vehicles for gaseous fuels (biogas, natural gas or hydrogen) and of electric cars, either plug-in hybrids or purely electric. Gaseous fuels require a more expensive infrastructure and have a higher degree of energy loss at the point of distribution than liquid fuels. This is, above all, a problem for future investments in hydrogen. An increased electricity use by, for example, plug-in hybrids and electric cars requires infrastructural investments, for example fuelling-stations etc.

Conclusions

- Increased use of fossil fuels pushes the development towards the use of more non-conventional fossil raw materials (tarsand, CTL), which in turn will lead to an increase in CO₂ emissions compared to “normal” gasoline/diesel.
- There is a relatively substantial technical potential for biomass, but its exploitation will be limited by economic and practical factors. Bioenergy can only form part of the solution to the climate issues of the transport sector, and should be seen as complementary to more efficient vehicles as well as to measures to reduced and more effective transport demand.
- Biofuel systems are significantly more complex than today’s fossil fuel system since they have many more possible combinations. Therefore it is important to take the entire production chain into consideration, and it is therefore also much more difficult to make a general conclusion about the sustainability of biofuels than it is for fossil fuels.

¹⁰ DME: Dimethylether ; diesel fuel produced by gasification of lignocellulose

3. What about energy balance and land use?

3.1 Energy balance

Efficient utilization of fossil as well as renewable energy is an important criterion for sustainability. The energy balance for different biofuels indicates how much fuel is obtained per unit energy input. In biomass cultivation there are direct energy inputs in the form of diesel for tractors etc., as well as indirect energy inputs in the form of commercial fertilizers, production and maintenance of machinery etc.. Energy inputs are also needed for transport and in fuel conversion plants. Comparisons between Swedish and international studies on the energy balance of, for example, ethanol show very big variations, from negative energy balances to a gain of 3-5 times the energy input¹¹. These variations in results can be explained by a number of factors, which can be divided into physical, technical, as well as calculation factors. Examples of physical and technical factors are the crops and raw material used, the geographic area, cultivation methods, harvest yields, the technique used in the conversion plants, biofuel return, the source of the heat and electricity used, transport distance etc. The calculation factors rely above all on how the system boundaries are set, for example, whether by-products are included or not, and how the energy input is divided between fuels and possible by-products usable for other purposes.

In figure 3.1 an overview is given of the quantity of biofuels that can potentially be produced from one hectare of farmland per year from different crops and for different types of fuel. The production is based on current technology (and estimated technology for 2nd generation fuels) and average farmland in northern Europe, which is to say that the actual production can be both higher or lower depending on local and regional conditions¹². Apart from biofuel return, the amount of energy gained from by-products from some biofuel systems is also shown, for example, from the production of ethanol and biodiesel. By-products can come either from the cultivation process – e.g. straw, tops and leaves, or from the fuel conversion plant – e.g. distiller's waste from grain ethanol production, rapeseed meal from RME production, and lignin material from wood-based ethanol (e.g. energy crops, or forestry raw material). In the figure, the energy input needed by the different systems for cultivation (direct and indirect energy inputs of different forms), for the transport of the raw material, as well as for the conversion into the vehicle fuel (fossil as well as renewable energy

¹¹ Börjesson, 2006

¹² Börjesson and Tufvesson, 2008

such as biomass) is also shown. In the production of biogas the by-product can be used as a fertilizer to replace commercial fertilizer. This is considered an indirect energy return and is also taken into consideration.

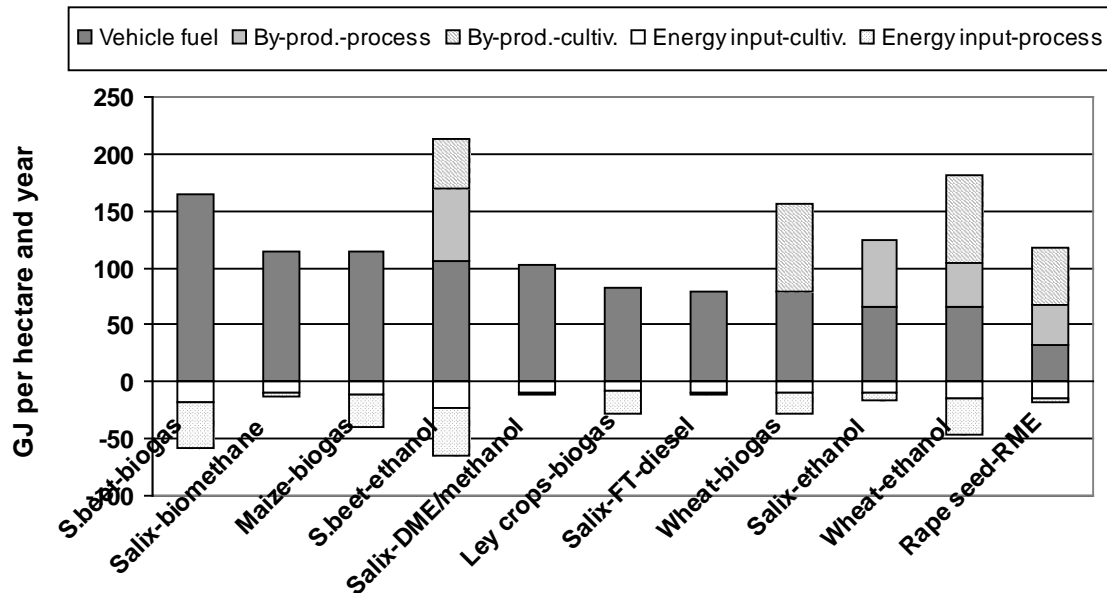


Figure 3.1. Output of fuels and by-products per hectare and year for different biofuel systems as well as energy inputs in the cultivation and transport of crops, and in the fuel factory process. Also included is the indirect energy return when decomposition waste from biogas production is used instead of commercial fertilizer. The production is from average quality farmland in northern Europe (after Börjesson and Tufvesson, 2008).

The energy input shown in Figure 3.1 is converted into primary energy, which is to say that the energy needed in, for example, diesel production, electricity generation etc. including distribution losses. On the other hand, the figure does not show the type of energy in use, being liquid fuels, electricity, solid fuels etc. Sometimes energy analyses are criticised for not clearly indicating energy carrier, since the quality of carriers can vary greatly. Diesel is primarily used in cultivation, while solid biomass of a lower energy quality is used in the fuel-producing plants. Berndes et al. (2008) give a more detailed description of the different energy carriers used in the production of biofuels. One conclusion is that the distribution of different energy carriers is fairly equal for different biofuel systems, and that the use of fossil fuels has a maximum of 25% of the entire energy input under current Swedish conditions.

The biofuel systems with the highest energy balance are those with the highest positive bars (return of bioenergy) and a low input of energy (low negative bars). The 2nd generation fuels, based on wood raw material and produced by thermal gasification, have a high energy balance (energy output

in relation to energy input), often between 8-10, which is illustrated by the bars in the Figure. When forestry-based waste products, for example branches and tops (called logging residues) from selective logging and final felling of forests, weak stemwood, from selective logging and clearance etc. are used, the energy balance is at least as high as when woody energy crops are used. The same goes for straw from grain cultivation used in gasification, and for ethanol production based on straw and forestry waste, compared to energy forest. Production systems for biogas from crops often have an energy balance of about 3 (see Figure 3.1), and if waste from farming and food production etc. is used, it is often higher (see for example Berglund and Börjeson, 2006). When it comes to ethanol and biodiesel, their energy balance is dependent on how the by-products are included and calculated. If, for example, the by-products of grain ethanol are not included, the energy balance is about 1.3. If the distiller's waste energy return is included, then the energy balance increases to 2.1, and if the energy return of the straw is also included (excluding the part which is left on the field to maintain its fertility) the final result is 3.6. The conclusion is therefore, that for biofuel systems which generate by-products, the final energy balance can vary significantly depending on how these are calculated.

As a comparison, Brazilian sugar cane ethanol is thought to have an energy balance of about 7 in domestic use, thanks to very efficient cultivation methods and an efficient use of the by-products (bagasse) in the ethanol process¹³. When transport to Europe is included (as well as truck transport from plant to harbor) the energy balance is reduced to about 5. The energy balance for maize ethanol in the US is calculated somewhat lower than European grain ethanol, which, among other things, depends on the rather inefficient use of by-products today¹⁴. In other words, there is a potential for improving the energy balance of both maize ethanol and grain ethanol by the improved utilization of the by-products, for example, straw. As discussed above, Figure 3.1 shows only biofuels from cultivated crops, but there is also a significant, unused potential from waste products within the agricultural sector, for example, for biogas production which often has an even higher energy balance. The potential for forest raw material in Sweden is substantial (logging residues, thin stemwood etc) and is estimated to be higher than those for woody energy crops. The use of these forest-based systems for the production of 2nd generation fuels indicates an even higher energy balance.

¹³ Egeskog and Gustavsson, 2007

¹⁴ Börjesson, 2006

The energy balance for gasoline and diesel are higher than for biofuels since transformation losses are relatively small when crude oil is refined. When coal is gasified into liquid fuels the energy balance will be approximately the same as for gasified biomass. The extraction and refining of fuels from “non-conventional” fossil fuels such as tar sand and oil shale require relatively large energy in-puts, up to 30% of the energy return from the oil, which gives a low energy balance.

Allocation of by-products

The distribution of the energy input between the vehicle fuel and its by-products based on the energy content of the products is called “physical allocation”. If the economic value of the specific biofuel and its by-products varies greatly it may be more correct to distribute the input of energy based on the price of the various products. The price of straw is, for example, only about 1/8 of the price of ethanol and the price of distiller's waste is intermediate. If an economic allocation is used the energy balance of grain ethanol will be about 1.7 when the by-products are included (3.6 at physical allocation). For RME it will be 3 (physical allocation about 6) and for ethanol of wood raw material about 4 (physical allocation almost 6)¹⁵. Through economic allocation the varying quality of the energy carriers is also taken into consideration, which is not done by physical allocation. Liquid fuels such as ethanol are, for example, a considerably higher quality energy carrier than, for example, straw fuels (see above).

As a complicating factor there is yet another method for including possible by-products in the energy- and life-cycle analysis, by system expansion. Through expanding the system boundaries one takes into consideration the alternative products which the actual by-products replace and the indirect energy – and environmental benefits this entails. The distiller's waste and the rapeseed meal which are produced in ethanol and RME plants in Sweden are used mainly as protein feed for dairy cows and often replace imported soy protein feed from Brazil. This entails both energy – and climate benefits since the production of soy meal (including the transport to Europe) requires more energy and causes greater carbon emissions, than the production of distiller's waste and rapeseed meal.¹⁶

In the international standard of life-cycle analysis (ISO 14044) it is recommended that system expansion be used whenever possible and should always be preferred over allocation. In the

¹⁵ Börjesson and Tufvesson, 2008.

¹⁶ Flygsjö et al., 2008.

European well-to-wheel study compiled by Concawe et al. (2007), the systems expansion is used to calculate the energy efficiency, the climate impact and fuel costs. In order to perform a system expansion it is required that life-cycle data are available for the replaced alternative products, which is not always the case. Another limitation for system expansion is that the market for the alternative, replaced products has to be known, this means, one must know to what extent a commercial outlet exists for products such as protein feed made from distiller's waste and rapeseed meal. Regarding distiller's waste from grain ethanol, the Swedish market is thought to be sated at production levels of approximately 2-3 TWh ethanol, which equals roughly 5% of current gasoline use.¹⁷ Thereafter, the distiller's waste must be used for other purposes, for example for biogas production or as pellets, which can lead to an altered energy and climate benefit. The European market for distiller's waste as protein feed is thought to be of an equivalent size. This means that ethanol equating approximately to 5% of current gasoline use within the EU can be produced simultaneously as the distiller's waste can be sold as feed.¹⁸ Regarding the production of RME from rapeseed the limitation consists, above all, on possible cultivation areas and not on the protein feed market for rapeseed meal. An estimate is that the maximum quantity of RME that can be produced in Sweden is about 1 TWh with current cultivation methods. Larger volumes would mean that the cultivated area would become too large and problems with crop diseases would increase.¹⁹ This amount of RME equates approximately to 2-3% of current diesel usage. When systems expansion is applied the energy balance of Swedish grain-based ethanol increases to approximately 5.²⁰

3.2 Area efficiency

Since the competition for arable land is increasing (see chapter 9), as well as the fact that biofuels can only be part of the solution for the climate issue (see chapter 2), it is important to choose a production system which gives maximum return of fuel per hectare of cultivated land. The use of area efficiency will therefore become all the more relevant as a sustainability criterion, especially for first generation fuels, which are based on agricultural crops. Area efficiency is in certain cases less relevant for 2nd generation fuels such as ethanol from lignocellulose as well as liquid and gaseous fuels from thermo-gasification, e.g. when waste products from forestry are used.

¹⁷ SOU, 2007.

¹⁸ Concawe et al., 2007.

¹⁹ SOU, 2009.

²⁰ Börjesson, 2008.

Figure 3.1 illustrates how the fuel output, expressed as GJ per hectare per year, varies between different production systems. The production systems in the figure are, from left to right, given in decreasing order of return of vehicle fuel. Highest return of biofuel comes from biogas from sugar beet (including tops and leaves), about 5 times higher than RME from rapeseed which gives the lowest return. Ethanol from grain gives approximately twice as much vehicle fuel per hectare as RME, and energy crops from gasification give approximately 3 times more fuel. In Figure 3.2 these outputs have been transformed to describe how many miles a car can run on the biofuel from one hectare. Here the energy input or the possible by-products are not included; the numbers include only the gross production of biofuels.

Figure 3.2 also shows ethanol from sugar cane and maize, produced in Brazil and the US, respectively (average return). In the figure different climate zones and production areas are included, which should be taken into consideration in making comparisons. If, for example, fast growing deciduous trees are cultivated in Brazil and are gasified to form methanol, this would be the system with the highest return. Furthermore, an example of both ethanol and biogas production from grain in an energy combination is shown, where the distiller's waste is digested into biogas instead of being dried to supply feed. This system is already being tested today and could come to the fore in future ethanol plants, if, for example, the outlet for distiller's waste as protein feed is limited. There are a number of other examples by which different kinds of biofuels can be produced, together with, for example, district heating and pellets²¹. By the development of energy combinations (bio-refineries) in the production of 2nd generation fuels from lignocellulose, the total energy efficiency for the production system can be increased, but simultaneously this could reduce the return yield of biofuels, which can have a negative impact on the area efficiency.

²¹ See for example Ericsson and Börjesson, 2008

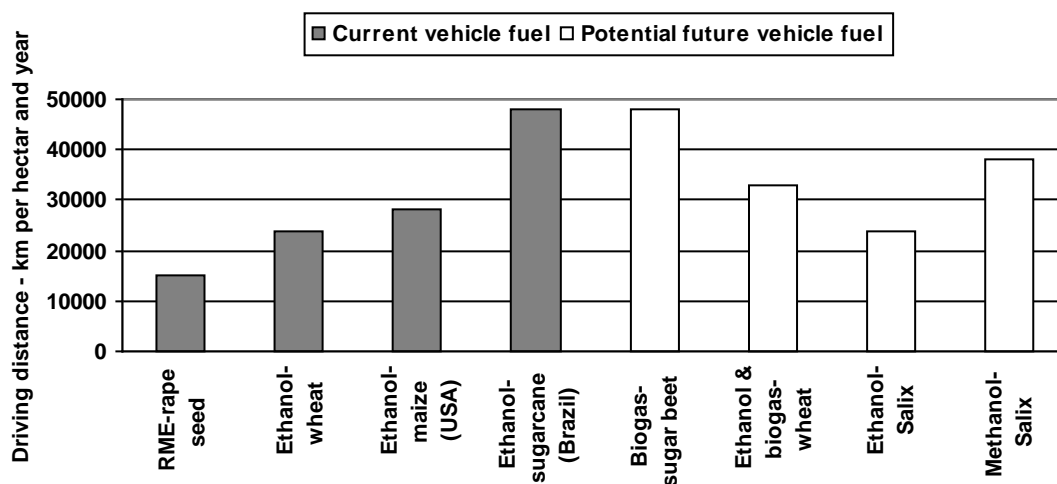


Figure 3.2. Possible yearly mileage per hectare and year of energy cultivation with different biofuel systems in use today and potential future systems (shows the gross return, fuel consumption is assumed to correspond to 0.9 liters of gasoline per 10 km). If biofuels are used in electric hybrid cars it could almost double the mileage per hectare (see figure 3.3). The area efficiency for 2nd generation fuels has partly limited relevance here as these will be based primarily on forest raw material and not agricultural crops in the future.

As is seen in figure 3.2, one hectare of rapeseed transformed to RME could supply a car with fuel for about one year (15,000 km). In the figure the varying efficiency of the cars is taken into consideration, which, for example, implies that RME (in diesel cars) becomes more advantageous than in earlier comparisons with ethanol (in gasoline cars). Ethanol from wheat and maize can run 1.5 - 2 cars and ethanol from sugar cane, approximately 3 cars. Even in Sweden the potential exists for a similarly area-efficient system as the Brazilian sugar cane ethanol, in the form of biogas from sugar beet (incl. tops and leaves). Today, however, technological developments are required before biofuels from sugar beet can become cost-efficient. Besides, current sugar beet cultivation requires good soil and a suitable climate, which limits a potential increase in areas for cultivation. If current sugar beet cultivation in southern Sweden were to be used for biofuel production, theoretically 1.5 TWh of ethanol or approximately 2 TWh biogas could be produced, corresponding to approximately 3 - 5% of current gasoline utilization²². Plant breeding of energy beets is on the way, and is expected to yield a much higher output than current sugar beet, and these could be grown globally and in regions with limited water supply, as an alternative to sugar cane. The water

²² SOU, 2007

requirements are considerably lower for energy beets than for sugar cane, which limits sugar cane cultivation to tropical regions.

If both ethanol and biogas are produced from wheat, one hectare of grain can supply approximately 2 cars with fuel, which implies an increase of about 40 % compared with when only ethanol is produced. When ethanol is produced from woody energy crops (Salix) it can supply approximately 1.5 car, and if the woody energy crops are gasified to form methanol, this produces enough fuel to supply approximately 2.5 cars with fuel. Methanol from woody energy crops requires about 35-40% less arable land than ethanol from wheat or Salix in order to supply a similar amount of energy (DME from gasification gives an even longer mileage due to the higher efficiency of the diesel engine). An important aspect in this connection is the potential for improving current annual food crops for biofuel production, for example, through higher biomass yields and the altered chemical composition of seed and grain (increased starch and oil content). The area efficiency for today's 1st generation biofuels can then also be seen to increase in the future.²³ Another way of increasing the area efficiency is to utilize fuel-efficient vehicles. If biofuels are used in an electric hybrid car, the potential mileage increases by between 70-100%, which then implies only half the acreage for the same mileage (see section 3.3).

Currently there are unexploited potentials of biological waste products which could be used for energy purposes, such as raw material for biogas production which can be used as fuel for vehicles. Examples of waste products include manure, organic waste from households and the food industry, crop residues from agriculture etc. The use of waste products is often more energy efficient than the use of cultivated crops and does not lead to any competition for farmland²⁴. On the contrary, the more food that is produced, the more waste products are available for biogas production. Also within forestry there are different kinds of waste products, for example branches and tops of timber from felling and cutting etc., which can be used for biofuel production through gasification. For these kinds of fuel systems the area efficiency is then not a relevant sustainability criterion.

There are also other situations where area efficiency has limited relevance. One example is energy cultivation on marginal land of low productivity on which particularly hardy crops can grow and where food production is not an alternative. One example in Sweden would be old, disused farmland, not in use for forest production either, where there is a potential to grow fast-growing

²³ Börjesson, (2007)

²⁴ Berglund and Börjesson, 2006

deciduous trees, such as poplar and hybrid aspen for energy purposes²⁵. Another example is jathropa, a drought-resistant bush with oil-rich seeds which can be used for biodiesel production and can be cultivated in semi-dry conditions, for example in India and Africa where options are limited. In the western parts of USA and northern China, pilot cultivations have been set up using a drought-resistant crop, namely, switchgrass, for energy purposes.

3.3 Increased efficiency via electrical cars

With today's speedy vehicle development it is possible that we will see plug-in hybrid and small electric cars on the Swedish market in only 5- 10 years. A good plug-in hybrid running on electricity, with a reach of approx. 50 km would typically be able to substitute about 40-60% of the fuel of a private car. Plug-in hybrids could even in time be expected to replace a part of light, weight truck traffic in cities.

An important argument for plug-in hybrids and electric cars is the high energy efficiency in electric engines. This is correct, but in order to make a fair judgment, the calculations should be based on the same primary energy source (coal or biomass). In figure 3.3 below, we start out from biomass (Salix) and compare potential efficiency for future electric cars, plug-in hybrids, developed hybrids and current conventional vehicles. The uncertainties in the diagram stem, above all, from the assumptions made concerning the future efficiency in fuel production (incl. the electricity production).

²⁵The Oilcommission, 2006

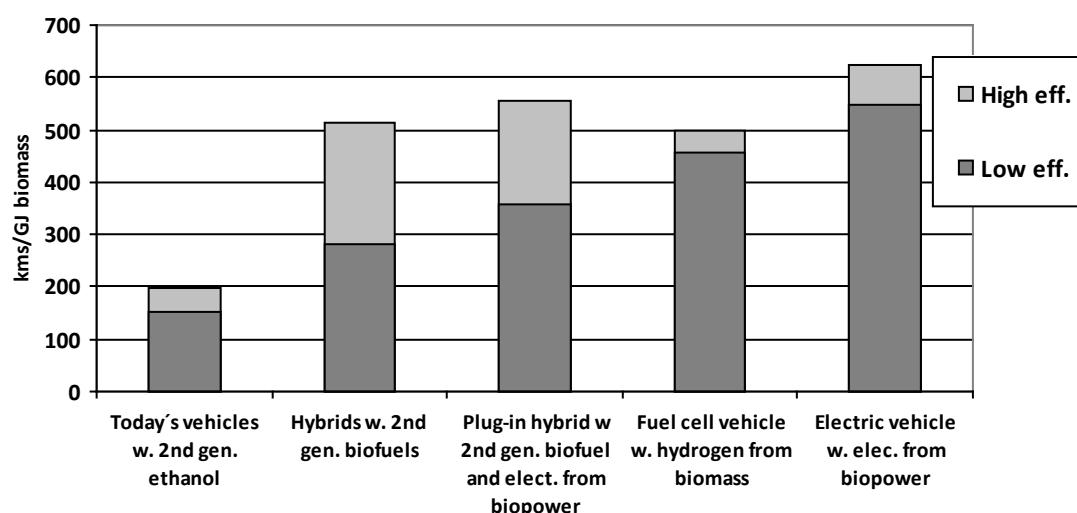


Figure 3.3. Driven km per GJ biomass with today's vehicles and 2nd generation biofuels as well as a number of possible, future vehicles and fuels. Revised and updated from Åhman 2001.²⁶

In figure 3.3 the significance of higher efficiency in bioenergy use within the transport sector is shown. With more efficient vehicles and an increased efficiency in fuel production, potentially only a third of the biomass is needed for covering the same distance in the future²⁷. Comparing the different future alternatives in figure 3.3 it can be seen that the variations in the primary energy efficiency between a developed hybrid and a plug-in hybrid, a hydrogen cell car or a purely electric car, are small given the substantial uncertainties. If bioenergy is implemented in the transport sector, the profit gained by electricity can then be seen to be quite small. The advantage of electricity lies instead in the zero emissions locally, and the flexibility concerning primary energy sources, which it offers.

²⁶ Standard four door, middle-sized car and compensated for the additional weight of the battery etc. (100-300 kg).

²⁷ The most cost-efficient way of reducing the use of gasoline/diesel in the short term, is to reduce the weight, air resistance and wheel resistance. In the long term, hybrids will give considerable efficiency gains.

Conclusions

- The energy balance for biofuels can be calculated in different ways, the relevant options being decided by how the actual system is designed and the local conditions. There is no general “right” or “wrong” method.
- Since there is competition for farmland, energy-efficient biofuel systems with a high return of fuel per hectare should be given priority, for example, fuels from gasified energy forest, sugar cane ethanol (not requiring artificial irrigation) etc.
- There is also a potential for increased area efficiency for the 1st generation fuels of today, and for the use of forest raw material, above all waste products, and with cultivation of unused marginal land the area efficiency is of limited importance.
- The production of biogas from biological waste products has good energy efficiency and leads to no increase in competition for farmland. The same also applies for the use of waste products from forestry, used, for example, in the production of ethanol and fuels by means of gasification.
- Today’s Swedish production of ethanol from wheat and RME from rapeseed has a good energy balance as the by-products are used in an efficient way, namely as protein feed, replacing soy protein feed imported from Brazil, i.e. these plants should be seen as combined fuel and feed plants.
- In the future we may see a rise in energy efficiency for current as well as future biofuel systems in conjunction with the development of various energy combinations (bio-refineries).
- Average efficiency will increase greatly through the electric hybridization of future vehicles, compared to vehicles today. However, to transform bioenergy into electricity in order to fuel plug-in hybrids or electric cars gives little efficiency gain compared to a developed electric hybrid, running on biofuels.

4. Do biofuels lead to climate benefits?

The debate concerning the climate benefits of biofuels has been lively lately. Several reports have been presented in the media showing a limited climate benefit, or even increased emissions compared with conventional fossil fuels. Until recently biofuels were described as almost climate neutral. Presumably these differences are due to how the system boundaries are set, the assumptions made and how the calculations are done. In particular, four factors are of primary importance to the outcome of the calculations. These four factors are 1) the efficiency and the greenhouse gas emissions of cultivation, 2) the type of fuels used in the fuel conversion plant, 3) the efficiency in the use of by-products and how this is accounted for, and finally 4) the type of land used for cultivation.

4.1 Greenhouse gases from cultivation

During the cultivation process there are three main contributors of greenhouse gases; carbon dioxide (CO₂) from diesel tractors, CO₂ from the production of artificial fertilizers, and nitrous oxide (N₂O) from nitrogen-based fertilizers. Nitrous oxide is 300 times more aggressive than CO₂ and often constitutes half or more of all greenhouse gas emissions from cultivation²⁸. The substantial greenhouse emissions from nitrous oxide have been known to soil scientists for a long time but have not reached the general public until now. This may be the explanation for the increased interest and focus on N₂O lately, and why it has been presented as “news” in the media as a huge disadvantage of biofuels.

Nitrous oxide is formed partly during the production of nitrogen fertilizers, partly from the nitrogen found in the soil (biogenic N₂O), which implies that the more nitrogen a crop requires, the greater are the emissions of nitrous oxide. Annual crops, such as rapeseed and wheat, give rise to more nitrous oxide than perennial crops, such as energy grass and woody energy crops, since annual crops require more nitrogen fertilizers. Second generation biofuels based on, for example, woody energy crops produce lower greenhouse gas emissions compared to 1st generation fuels based on annual food crops due to lower emissions of nitrous oxide. Forest raw materials generate even less nitrous oxide than woody energy crops.

The fertilizer industry in Europe is aware of the issue of nitrous oxide emissions and is installing catalytic converters in the production plants of nitrogen fertilizer. Catalytic cleaning reduces nitrous

²⁸ Börjesson and Tufvesson, 2008

oxide emissions by up to 80% and thus leads to a clear improvement of the climate benefits of biofuels²⁹. The biogenic emissions of N₂O from soils are often estimated as somewhat larger than those from the production plants (without catalysers), but they are also known to vary greatly due to local conditions. The IPCC has prepared a calculation model to estimate average nitrous gas emissions from different crops grown in different regions. This model is continually updated and developed, and is today the most accepted and widely used for life-cycle assessment of biofuels.

However, there are exceptions and studies using their own calculation methods. One example of such a case, which received much media attention, was a study done by the Nobel Prize winner Paul Crutzen et al. (2006) which stated that biodiesel from rapeseed and ethanol from wheat and maize caused higher emissions of greenhouse gases than diesel and gasoline due to high emissions of nitrous oxide during the cultivation process. However, this so-called “top-down” report was quickly called into question by many researchers, who showed that Crutzen had used incorrect conversion factors for the ability of plants to absorb nitrogen, for how much of the nitrogen re-circulates in the field etc. These mistaken assumptions were corrected and Crutzens results agreed approximately with those of the IPCC, i.e. more or less one third the size³⁰.

One source which limits the use of nitrogen as fertilizer (thus producing less nitrous oxide), is their ever, increasing price. Emissions from tractors are also thought to decrease in the future due to more fuel-efficient engines and less driving in the field, for example, by the use of plowing-free tillage systems etc. Furthermore, diesel can be replaced by biofuels. The production of nitrogen fertilizers is also assumed to become more energy efficient and hence less of a strain on the environment, via the increasing costs of natural gas, its primary energy source.

Summing up; emissions of biogenic nitrous oxide from the cultivation of energy crops, and especially regarding annual crops, represent a large share in the total greenhouse emission from energy crops. This will also have a substantial impact on the overall greenhouse gas performance of biofuels. Concurrently there are large uncertainties regarding the levels of nitrous oxide gas emissions, which are thought to vary greatly between different cropping systems, their geographic location as well as over time. How nitrous oxide gases can be included in a certification scheme, and how the uncertainties are handled in a system requiring emission reductions can have a

²⁹ Börjesson and Tufvesson, 2008

³⁰ See, for example, Rauh, 2007; Ammann et al., 2007. Among other things Crutzen uses a very low figure for the efficiency of the up take of nitrogen in the plants based on the soil's total nitrogen pool, and not on the mineral nitrogen present, as would be correct in this case.

significant influence on how different biofuels are seen to meet these same requirements. More knowledge is needed on this aspect.

4.2 Emissions from fuel plants and use of waste products

The climate benefits from biofuels can vary greatly depending on the energy source used in the fuel plants. This is illustrated in the European well-to-wheel study mentioned in chapter 3, the results of which are shown in Figure 4.1. In this study it is stated that greenhouse emissions from a large number of biofuel systems have been investigated, for example from ethanol when the ethanol plant uses bioenergy, natural gas or coal for production of the required heat and steam. The emissions of greenhouse gases from cultivation are also included, as well as the possible climate gains when by-products replace alternative products (see system expansion in chapter 3). When bioenergy is used in grain ethanol production, the climate benefit is approximately 70% compared to gasoline, when natural gas is used, it is approximately 50% and if brown coal (lignite) is used there is no climate benefit and the emission of greenhouse gases can even increase up to 10% above the emissions from gasoline (see fig. 4.1). Brazilian sugar cane ethanol has an even higher climate benefit, approximately 85-90 % compared to gasoline, this thanks to high harvest yields, relatively low energy inputs in the cultivation process and the use of the waste product bagasse to run the ethanol plants³¹.

³¹ See for example Concawe et al 2007

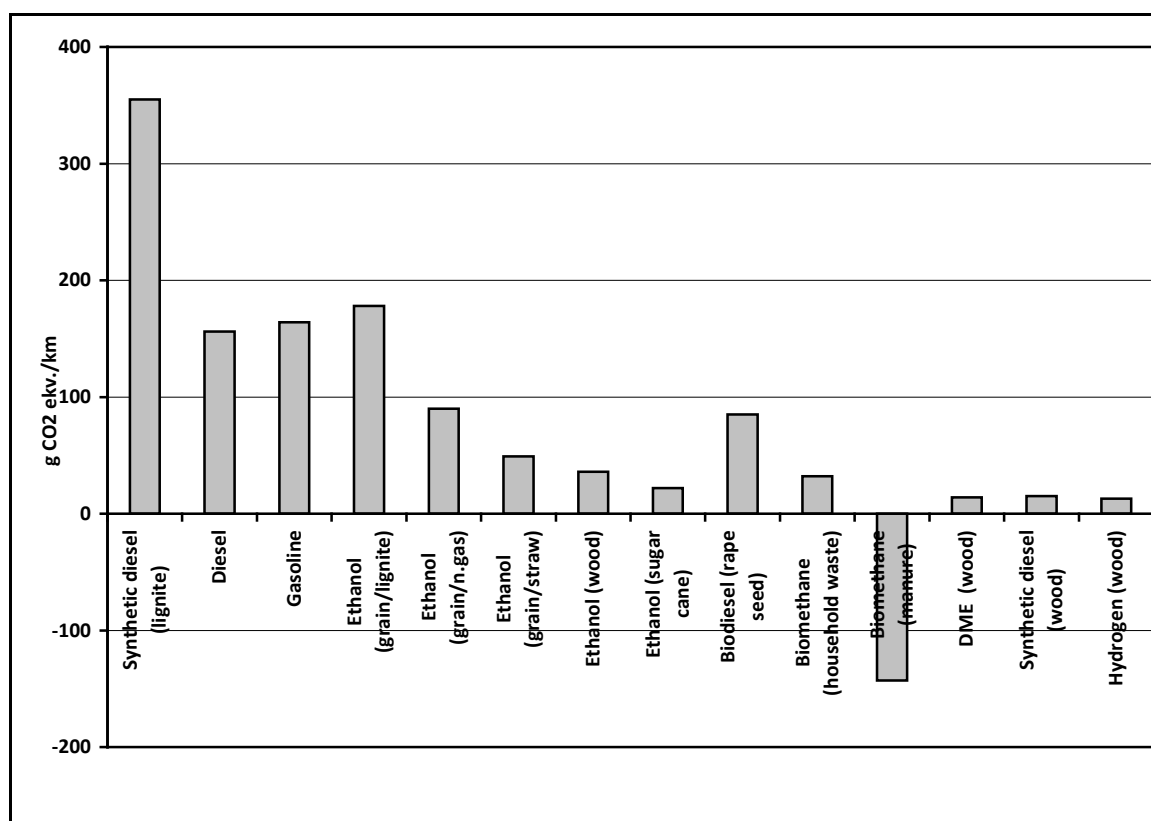


Figure 4.1. Life-cycle emissions of greenhouse gases for different biofuel systems. Source : Concauwe et al. (2007), assuming the technology in conventional vehicles and fuel processes for the year 2010.

In the media, maize ethanol from the US is often presented as “bad” ethanol because of its limited climate benefits compared to Swedish and Brazilian “good” ethanol³². The reason for American maize ethanol being considered “bad” is that many ethanol plants use fossil fuels, such as coal and natural gas. Furthermore, the cultivation of maize requires a relatively high energy input and amount of nitrogen fertilizer, which increases the nitrous oxide gas emissions. One estimate of the average climate benefit of American maize ethanol is about 15-20%, compared to gasoline³³. The types of ethanol plants in the US are, however, many, ranging from old, poor plants based on coal, increasing the net contribution of emissions slightly, to new, efficient plants using bioenergy (for example wood chips) with a 50% climate benefit. There are also variations in how efficiently by-products are used, for example as animal feed, which influences the life-cycle emission of greenhouse gases. The same must be said for European grain ethanol. When distiller’s waste

³² See Börjesson, 2008

³³ Wang et al, 2007

replaces imported soy meal for protein feed, as is being done in the Norrköping ethanol plant, an extra climate benefit is gained from grain ethanol, which implies that the total reduction of greenhouse gases is close to 80%³⁴. This stems from the estimate that the greenhouse gas emission from imported soy meal is twice as high as from dried distiller's waste from grain ethanol production³⁵. That Swedish grain ethanol has such a high climate benefit is also due to the fact that the plant in Norrköping uses forest wood chips as fuel.

The climate benefit from RME is estimated to be about 50%, which is to say somewhat lower than that for grain ethanol, see figure 4.1. One reason for this is the higher requirement of nitrogen fertilizers in rapeseed cultivation and hence the higher emissions. The by-product, rapeseed meal is, on the other hand, a higher quality protein feed than distiller's waste and as such heightens the indirect climate benefits by using rapeseed meal as protein feed instead of distiller's waste.

For biogas systems based on energy crops such as maize or lye crops the climate benefit is often about 80%. Also here we have an indirect climate benefit gained through the use of the digestion residues from the biogas production as a fertilizer replacing the commercial fertilizers which would otherwise have been used³⁶. Ethanol from woody energy crops is estimated to give approximately the same reduction in greenhouse gas emission as biogas from energy crops, but in this case the utilization of the by-product, lignin, has a great impact on the size of the climate benefit. Lignin can, for example, be used in the production of heat or for pellets which can replace fossil fuels. The greatest climate benefit, approximately 90%, is gained by 2nd generation fuels based on thermal gasification of energy forest crops. Examples of these are; methanol, DME and methane. The reasons for this lie partly in the low greenhouse gas emissions from the cultivation of forest energy crops, partly from the energy-efficient conversion process for which the energy input is largely supplied "internally" from the biomass. When forest waste products are used for the production of ethanol, methanol, DME, methane etc. there is often a greater climate benefit to be gained than when woody energy crops such as Salix are used. The reason for this is that the production of forest raw material is at least as energy efficient as the production of Salix and normally does not require any nitrogen fertilizer, thus reducing the emissions compared to cultivation of Salix.

If solid fossil fuels are used for the gasification instead of biomass, coal-to-liquid (CTL), it increases the emissions of greenhouse gases drastically. As seen in figure 4.1 the emissions are then

³⁴ Börjesson 2008

³⁵ Flysjö et al, 2008

³⁶ Börjesson and Tufvesson, 2008

estimated to be twice those of gasoline and diesel. These systems are very bad from a climate point-of-view. The same goes for fossil fuels based on tarsand and oilshale which can give rise to higher emissions than even CTL³⁷. A possible method in the future for improving the climate performance of fuels from coal, tarsand and oilshale is through the separation of the CO₂ at the production stage and sequester this in depleted oil and natural gas depositories. This is, however, not a commercial technique today and requires continued investments on development and demonstrations. One assessment made by the IPCC is that the separation of CO₂ has a maximum capacity of 20-40% of the total reduction of greenhouse emissions in the future and can only be fully developed in about 2050. It is also possible in biofuel production to separate and deposit CO₂.

There are also fuel systems with a “doubled” climate benefit instead of the “doubled” climate pollution load as in the case of CTL. When, for example, liquid manure is used for biogas production, the spontaneous emissions of methane occurring in the traditional handling and storage of manure can be substantially reduced. Since methane is an approximately 20 times more aggressive greenhouse gas than CO₂ this indirect climate benefit is significant³⁸. Indirect gains through reduced methane emissions are also won from the use of other waste products in biogas production, but these are often not as substantial as that from liquid manure. From a climate point-of-view, biogas from organic waste products and, above all, liquid manure, make the most efficient biofuels system.

4.3 Emissions from land use change

Large amounts of CO₂ are tied up in biomass below and above ground in the form of soil carbon and in vegetation. If these “carbon deposits” are altered in connection with the production of raw material for biofuels, the climate benefit may be altered drastically. Changes of the soil carbon content is included in the Concawe study in figure 4.1 but since the cultivation of biofuels is assumed to take place on existing farmland the differences are small. Apart from the fact that the production of biofuels can lead to direct land use changes, by new energy crops replacing existing cultivation, the long-term effects of indirect land use change due to increased biofuel production is also discussed. One such long-term, indirect effect may occur via displacement effects, by which increased production of biofuels can lead to an increase in competition for land and thereby

³⁷ WWF, 2008

³⁸ Börjesson and Berglund, 2007; Concawe et al., 2007

cultivation of new farmland in a following step. Such indirect displacement effects are not included in the Concawe study.

Two American studies which were published in the spring of 2008 in the scientific journal *Science*, received much media attention³⁹. The results showed that biofuels would need between 20-400 years in order to achieve climate neutrality, due to their large indirect emissions of biogenic CO₂ from the soil and natural vegetation from an increased cultivation of energy crops. These studies assumed that all cultivation of biofuels would require new farmland, since all existing farmland is needed for food and feed production. The longest “repayment-period” was for biofuels produced from palm oil on former rainforest land in Malaysia and Indonesia and the shortest period was for ethanol produced from sugar canes on the former forested area of Cerrado in Brazil⁴⁰. An increased production of maize ethanol in the US was calculated to have a “repayment-period” of 167 years before increased emissions of CO₂ from the soil and natural vegetation would be compensated by the reduced emissions of ethanol replacing gasoline. These calculations from Searchinger et al. are based on an economic model for how the increased production of ethanol in the US influences the requirements for new farmland, both in the US and in other parts of the world.

The conclusions of these two articles are that investments in biofuels from agricultural crops such as palm oil, soybeans, maize and sugar cane are counterproductive from a greenhouse gas perspective. The production of biofuels from unutilized waste biomass and perennial crops such as energy grass and woody energy crops, cultivated on marginal land where food crops can not be grown, on the other hand, are seen as advantageous from a greenhouse point-of-view.

Objections to Fargione’s and Searchinger’s conclusions have been raised. First of all, most of the cases described in the two studies are hypothetical and not a reality today, which means that they do not reflect current production of biofuels. On the other hand, in the case of sharply increased biofuel as well as food and feed production, certain of the cases could become a reality. Today arable land not fully exploited but lying fallow is still available due to the surplus of grain and other food crops we have had on the world market over decades. The global production of wheat, for example, has diminished by approximately 10% during this period. Moreover, there has been a general reduction in the intensity of agriculture due to low profitability. In other words, there is the potential of increasing production on existing farmland before the need of new land arises (see chapter 9).

³⁹ Searchinger et al. 2008; Fargione et al. 2008

⁴⁰ Fargione et al. 2008

Furthermore, some studies have shown that the cultivation of land, through, for example, the deforestation in tropical regions, depends on a variety of factors of local character and only little on actual prices for agricultural products.

Another objection is the assumptions made in the two studies is that “all” new cultivation of land is used for the production of biofuels. Today approximately 1.5% of all arable land, worldwide is used for biofuel production and around 4% of the total grain harvest⁴¹. The rate of increase of grain production is estimated by the OECD/FAO to be higher for food and feed production than for biofuels, at least for the next ten years. The cultivation of new farmland should therefore also burden an increased production of food grain, and above all grain for feed, which is estimated to increase considerably more than food grain due to a global rise in meat consumption (see further in chapter 9).

One further objection to the two studies is that they predict a very modest climate benefit when only the production of biofuel is taken into account. Their assumptions are based on current ethanol production in the US which is seen to have an average climate benefit of only 15-20% compared to gasoline, due to the use of fossil fuels in the production plants and often poor utilization of by-products (see paragraph 4.2). The assumption that these inefficient systems will be in use in the future can be questioned since there will be an increase in knowledge about the climate benefits of biofuels, increased costs on CO₂ emissions, the implementation of certification schemes etc. which will encourage development toward systems more beneficial to the climate, even in the US. If, for example, the Swedish ethanol production system would have been chosen as the reference system, the “repayment period” would have been shortened by 3-4 times.

Fargione’s and Searchinger’s other conclusion, namely that systems exist which can lead to an increased binding of carbon, for example the cultivation of perennial crops such as energy grass and woody energy crops on marginal land where food crops can not be grown, is uncontroversial and in accordance with other sustainability criteria (however the profitability in these cultivations is often low and therefore possibly in need of direct subvention). This is, therefore, a direct effect on land use, in contrast to the long-term, indirect displacement effects on which their first conclusion was based. For Swedish conditions these direct effects can lead to a reduction of greenhouse gases by more than 100% for biogas from pasture grass and 2nd generation biofuels from woody energy crops, if these are replacing annual grain crops whose cultivation leads to successively diminished

⁴¹ OECD/FAO 2008

binding of soil carbon⁴². Figure 4.2 illustrates how important the type of soil is in the calculation of the climate benefits of biofuels, using as an example the case of bioethanol production based on Swedish conditions⁴³. Peat soil makes up 7-9% of Sweden's current farmland, and how these will be cultivated in the future will have a significant impact on the greenhouse balance. The cultivation of annual energy crops on peat land soils leads to large emissions due to the intensive annual cultivation of the fields, while the cultivation of perennial crops will lead to low emissions.

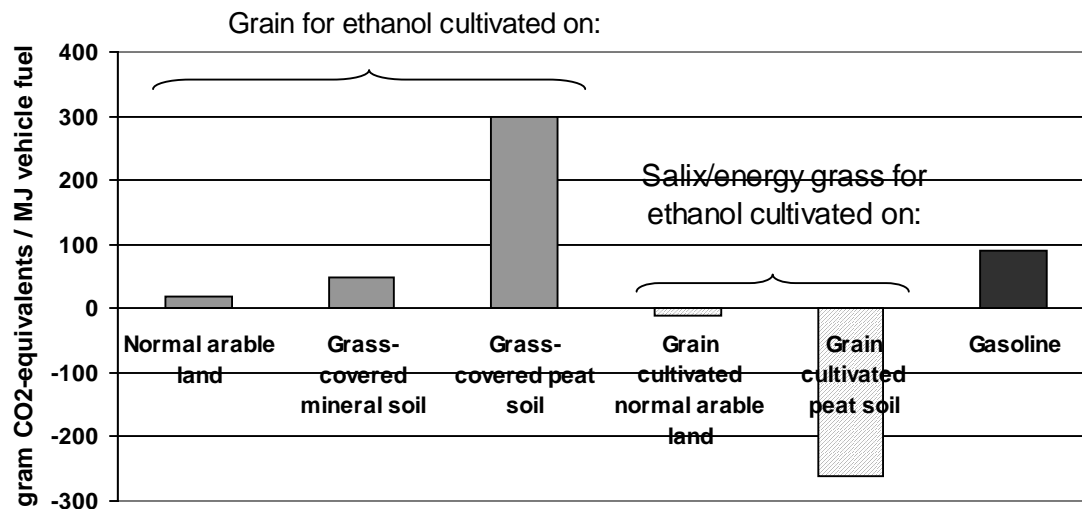


Figure 4.2. Life-cycle emissions of greenhouse gases for different ethanol systems, based on the type of crop and soil utilized (considering economic allocation). Revised data from Börjesson, 2008 and Börjesson and Tufvesson, 2008

A general problem in including changes in the binding of carbon in farmland and vegetation, in calculations of the greenhouse gas balance of biofuels, is that the time perspective is crucial to the outcome. Changes in carbon levels in both soil and vegetation, diminishes over time and eventually reaches a new state of equilibrium. In a mature forest there is a balance between absorption and emission of CO₂ and when there is a land use change the binding of carbon continues in the soil for a period (30-50 years). However, the reduction of greenhouse gases is continuous when biofuels replace fossil fuels, which means that there is no time limit. Figure 4.3. is a schematic presentation of this, where changes in the carbon content of the soil and in the vegetation in certain situations can lead to an initial increased greenhouse gas emission. However, the climate benefit of biofuels increases over time. In other words, in the short term (some years or decades depending on the

⁴² Börjesson and Tufvesson 2008 (changed content of soil carbon has historically depended on changing plowing depth)

⁴³ Börjesson 2008

ecosystem) it is seen as more climate efficient to store carbon in soil and vegetation, but in the long term it is always more efficient to harvest the biomass continuously and replace fossil fuels.

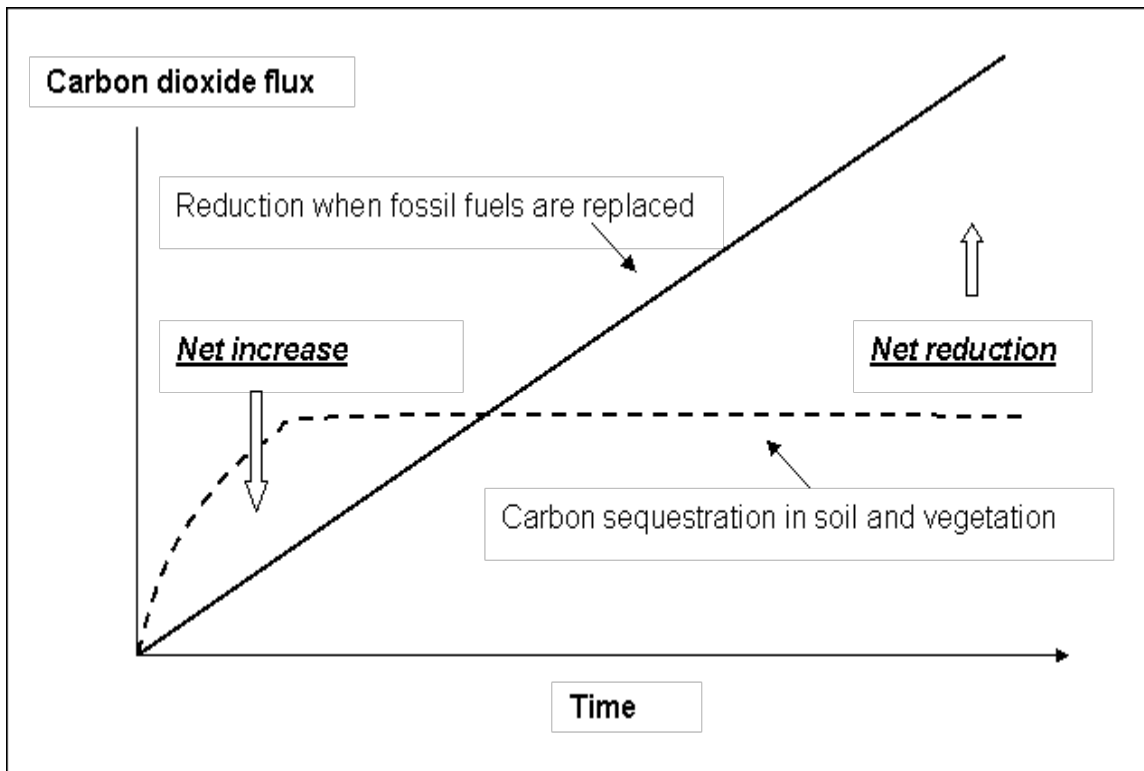


Figure 4.3. Schematic outline of how the net flux of CO₂ is changed over time when biomass is used to replace fossil fuels compared to when soil and vegetation only is used to bind carbon to reduce CO₂ emissions.

Summing up, effects of land use change, directly or indirectly through displacement of food and feed production to new farmland, can have a very substantial influence on biofuels greenhouse gas performance. At present, it is in principle impossible to connect indirect land use changes to a specific production system for a particular biofuel. Indirect land use changes in the form of new cultivation of farmland due to displacement effects are a consequence of every type of production, even food and feed production. This implies that possible negative consequences should be attributed to all types of production, not only biofuels. If only biofuels are being attributed the negative consequences, this leads to a “marginal thinking” where biofuel production is assumed always to lead to indirect land use changes in the form of new cultivation of farmland (a parallel can be made with the following paragraph where marginal electricity and average electricity are being discussed). Furthermore, it is very difficult to include indirect effects of land use due to

displacement effects in certification systems as discussed in Chapter 12. These aspects need to be handled with more general policy instruments.

4.4 Fuelling the car from the electricity grid

As earlier discussed it is likely that we in the future will fuel a certain proportion of our cars from the electricity supply system. Electricity is being produced from a wide variety of sources and is being distributed to the customer via the common electricity grid. How different sources of electricity production are allocated to different users has substantial influence on which effects an increased electricity use within the transport sector is thought to have. Electricity production can be allocated to users as (i) marginal production, (ii) dynamic marginal production, or (iii) electricity mix.

Marginal production is the electricity produced in order to cover a temporary increase in electricity demand and therefore comprises electricity from plants with the highest variable costs. If, however, the electricity demand increases on a permanent basis this will lead to an expansion of the electricity system. The long-term affect of this increase is then the “dynamic marginal”, which means the difference between the “old” electricity system and the new expanded system⁴⁴. The entire electricity production can be distributed proportionately to all users, from the current or a future, assumed mix of electricity. The choice of allocation method is dependent on the time frame as well as the purpose of the calculations.

Calculations on marginal electricity production are used for the study of effects of small increases over a short period. In Sweden and within the EU the marginal electricity is often produced by coal-powered condensation plants with high CO₂ emissions.

This, however, is not relevant if the aim is to study the effects of a permanent increase within the transport sector. Instead, calculations should focus on long-term dynamic effects which this increase will cause in the entire electricity system. In this case one should also consider whether the increase within the transport sector reflects a general policy on climate and energy in the society at large. A further increase of energy consumption of 2-4 TWh can not be covered by marginal electricity (coal) but will be covered by new types of energy production, which means wind power and biomass-based combined heat and power, or, if prices increase, by improved energy efficiency. The

⁴⁴ Here it can be noted that the increase of electricity use within one sector can increase the price and hence make more efficient approaches more profitable in other sectors, thus limiting the need to generate more electricity.

growth of exactly these new power sources is due to Swedish energy- and climate policy limiting the emissions of CO₂ from electricity production, by methods such as electricity certificates, aimed subsidies favoring renewable energy and efficiency programs. When investments in electricity in the transport sector are viewed as something apart from Swedish climate policy, it is still clear that renewable energy, with the current Swedish subsidy system, will continue to grow. Without environmental policy restrictions it can be assumed that marginal electricity will be produced from natural gas or an increased use of coal-based power.

With an upper limit on CO₂ emissions for the electricity sector, and a concurrent increase of electricity use within the transport sector, the pressure to stay below the CO₂ limit increases on the remaining actors in the electricity sector. It is therefore not obvious that one should continue to calculate with marginal perspectives at all, either on a long- or a short-term basis. The EU commission often uses the electricity mix as a basis for their environment assessments. This can be motivated by the fact that all users share the same “right” to “count in” renewable electricity as well as having the same responsibility for the coal-powered condensation plants used in the marginal electricity to cover larger fluctuations in consumption. The mix of electricity is very different in Sweden, Scandinavia and the EU. In Sweden and in Scandinavia it is for the most part based on either hydro or nuclear power, while within the EU almost half the electricity mix is based on fossil fuel.

In figure 4.4 the effects of different allocation methods for electricity production with reference to a future electric car, are demonstrated. It is difficult to compare electric cars to conventional cars since the technology for electric cars is still lacking in both comfort and performance. Here it should be noted that even if an electric car is considerably more energy-efficient than a conventional one, the CO₂ emissions will remain higher if electricity from current coal-based power plants is used in the calculations (e.g. for marginal electricity production). Much lower CO₂ emissions are observed if calculations are instead made with the dynamic marginal (bio power plants and CO₂-free electricity) as well as for calculations including the Swedish electricity mix. There are, however, substantial differences between the Swedish electricity mix and that of the EU.

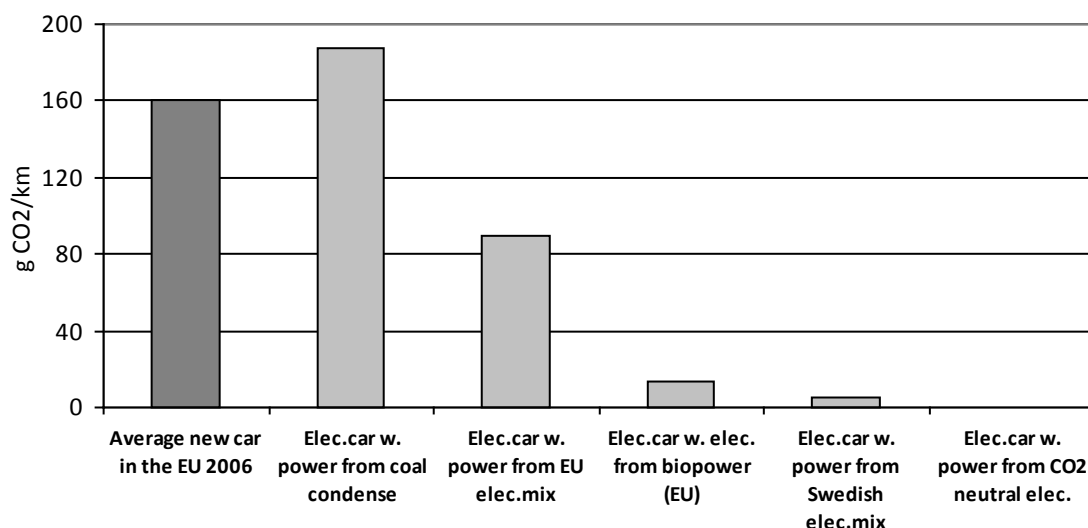


Figure 4.4. Effects on CO₂ emissions from electric cars in the future, based on differences in the origin of electricity production.

The conclusion is that “electricity” can be calculated in many different ways depending on which question needs to be answered. The important thing is to choose the “right” method for the specific question. Advantages can be gained by using several methods, illustrating climate benefits on the short- and long-term basis and even including assumptions of a certain development within the electricity sector. The important issue is that the calculation methods and the results are transparent.

From a long-term strategic point-of-view there are several factors advocating electricity as a very good energy carrier for the transport sector. One big advantage is the local zero- emissions of dangerous gases, another important aspect is the flexibility in the electricity production (the use of many different primary sources) and finally it is important from a climate perspective that the energy carrier in itself is CO₂ free. Furthermore, only electricity and hydrogen allow the transport sector in the future to use substantial amounts of hydro-, sun- or wind energy. Electricity shares many advantages with hydrogen as an energy carrier. Expensive batteries with too low performance are still the main obstacle for the introduction of electric vehicles. Still, electric cars are considered much closer to market production than hydrogen fuel cell cars. For fuel cell cars the obstacle lies in the expenses involved in the production of fuel cells of a sufficient quality.

4.5 Electricity and heat instead of fuels

One argument often heard against biofuels, is that biomass is more efficient as a replacement for coal and oil for heating or electricity production, than as a replacement for gasoline/diesel in the

transport sector. More climate benefits are gained when solid biofuels, such as for example wood chips from forestry or woody energy crops, are used for electricity and heat production, replacing coal, oil or natural gases than if they are used as liquid fuels, replacing gasoline or diesel⁴⁵(see Figure 4.5). The reasons for this lie primarily in the energy losses attained when biomass is converted into liquid or gasified fuels.

In the short-term perspective it is both more climate- and cost-efficient to use solid biofuels as a replacement for coal, oil and natural gases in the production of electricity- and heat than as a replacement for fossil vehicle fuels. This can be seen reflected in the Swedish utilization of biomass in which 85% goes to process heating for the industry and district heating, 10% goes to power production and the remaining 5% to the transport sector. However, in a longer perspective several arguments speak for the development of biofuels for use in the transport sector.

In recent years it has become apparent that the supply of crude oil-based vehicle fuels is limited compared to demand (as well as crude oil for other purposes) and that gasoline/diesel has begun to be produced from “non-conventional” fossil sources such as tarsand and coal gasified with similar conversion losses as in biomass gasification. Assuming instead that biofuels replace coal-based vehicle fuels, this evens out the differences between replacing transport fuel or heat/electricity by biomass, see Figure 4.5.

⁴⁵ This is even seen economically, where costs for reducing CO₂ emissions are reduced.

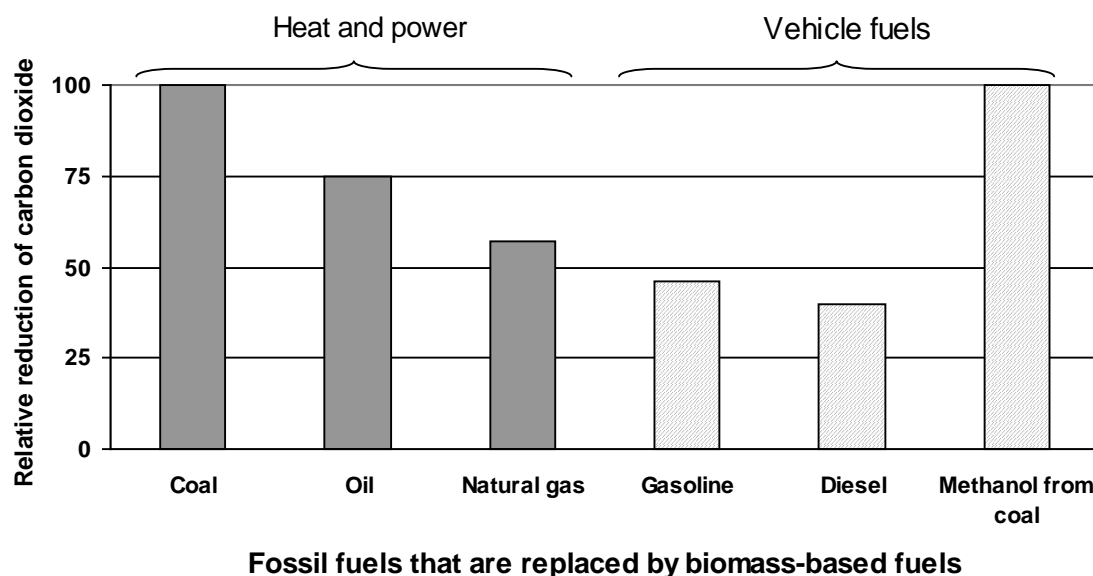


Figure 4.5. The relative reduction of CO₂ when biofuels replace fossil fuels for electricity/heat production or as vehicle fuels. The biomass consists of woody biomass, either in the form of wood chips for electricity and heat or in the form of methanol via thermal gasification (Börjesson 2007).

In studying ambitious climate goals for an entire society one must apply a broad systems perspective, even including a number of different technical/economic climate efficient solutions. One example is in the future energy consumption in the private housing sectors and emission of CO₂ gases, reducible through bioenergy but also through improved energy efficiency, sun heat, heat pumps with renewable electricity etc. How the “ideal” climate and cost efficient distribution of our biomass resources can be shaped in the future (2050 and forward) with a strict climate policy, is something that has been studied by a number of research groups with different models and hence different results. The results from Azar et al. (2003) are that no biomass should be used in the transport sector, while Dielen et al. (2002) reaches the opposite result⁴⁶. Åkerman et al. (2007) use 5 different scenarios to demonstrate how bioenergy should comprise between 0-40% of the transport sector’s future energy consumption. The variations in the results are explained foremost by the different assumptions made on technological development in transport, private housing and the electricity sector. In the electricity sector it is above all the possibility of future sun-based hydrogen-driven vehicles that affects the conclusions.

⁴⁶ See Grahn (2006) for a detailed discussion on the difference between these two studies.

The scenarios above are simplified, presupposing “simple” fuel producing plants producing only fuels. In the future, however, fuel-producing plants utilizing lignocellulose in, for example, the production of ethanol, methanol, DME and methane, are expected to be built as energy combinations, or bio-refineries, generating biofuels as well as electricity and heat and even chemicals. In this way the total efficiency of the plant can remain high and hence also increase the climate benefits from biofuels. The factor most often limiting an extension and the adaptation of energy combinations is the market potential for the heat production. One important requirement is therefore the existence of a local demand for heat, such as municipal heating networks, process industries, drying plants for pellets etc. On a national level it is therefore the total market potential for heat which is decisive for the extent energy combination plants and bio-refineries will be built⁴⁷. The difference in cost and climate efficiency between utilizing biomass for heat, electricity, transport fuel and possibly platform chemicals is made considerably more difficult to assess for energy combinations and bio-refining plants since the profitability of the various products can vary over time and region.

⁴⁷See e.g. Ericsson and Börjesson (2008).

Conclusions

- To ensure that biofuels from crops lead to substantial climate benefits it is required that: 1) fuel plants run on renewable energy, not fossil fuels, 2) cultivation is avoided on “carbon rich” soils, for example, peat soil with permanent pasture etc., 3) possible by-products should be utilized effectively in order to maximize their (indirect) energy and climate benefits and 4) nitrous oxide emissions are minimized through effective fertilization strategies and through the use of nitrogen fertilizers coming from factories with nitrous oxide gas cleaning.
- Second generation fuels based on forest raw material lead to substantial climate benefits. Double climate benefits can be gained when waste products, for example manure, are used in biogas production, due to the reduction of the methane emissions from conventional handling.
- If increased biofuel production leads to cultivation of new farmland with high carbon content, the climate benefits from the use of biofuels could be lost. Climate benefits, on the other hand, can be enhanced if cultivation takes place on marginal lands with low carbon content. The binding of carbon dioxide in soils and vegetation eventually diminish, while the climate benefit of replacing fossil fuels with biofuels goes on continually.
- It is very doubtful to charge biofuels with long-term indirect effects on land use as “displacement effects” by assuming that increased biofuel production always leads to cultivation of new farmland. Possible displacement effects also apply to increased food and feed production. Nevertheless, “sustainable fuels” require a planning for “sustainable land-use”.
- Electricity use in the transport sector, in the form of small electric cars or plug-in hybrids, leads to a substantial reduction in emissions of greenhouse gasses when renewable electricity is used.
- Depending on the calculations used, the environmental benefits from electricity can vary substantially. However, in a coherent climate policy strong reasons advocate the use of electricity in the transport sector as an excellent solution for the future, since it is a CO₂-free energy carrier and its production has very good potentials to become carbon dioxide-efficient.
- In the future, biofuels will, to a large extent, be produced in combination with electricity and heat; the extent of the combinations is decided by the heating sink available (locally and nationally). Today’s debate regarding whether biomass should be used for electricity or heat production is therefore partly irrelevant.

5. How are other emissions being affected?

5.1 Regulated and unregulated emissions

Hydrocarbons (HCs), carbon monoxide (CO), nitrogen oxides (NO_x) and particles are all emissions which affect our health. The level of emissions is decided by (i) fuel quality, (ii) engine technology, and (iii) technologies for exhaust emission control. In general, the differences in emissions between biofuels and conventional fuels are small. Gaseous fuels such as hydrogen, methane and DME are considered to have the lowest emissions of hydrocarbons, carbon monoxide and particles, followed by ethanol and methanol and lastly gasoline. NO_x emissions are similar for all fuels and to the greatest extent decided by the specific engine technology and the implementation of advanced systems to control exhaust emission. Emissions of particulate matter come foremost from diesel and biodiesel such as RME, the latter having slightly lower emissions according to some studies. Also here, the application of advanced emission control technologies such as particle filters is more decisive for the emission level.

A general disadvantage of alcohols, such as ethanol and methanol, is the higher levels of volatile organic compounds (VOCs) in a cold start compared to gasoline. Among these we find formaldehyde, a gas hazardous to health⁴⁸. Cold weather increases the level of emissions in a cold start and this received the attention of the Swedish media some years ago. This is normally handled by preheating and/or direct fuel injection systems. For low blended fuels (e.g with 5 to 10% ethanol in gasoline) this is not considered a problem.

It is important, however, not to exaggerate differences between biofuels and gasoline concerning emissions hazardous to health. The levels of emissions from vehicles are today mostly decided by regulations and the exhaust gas aftertreatment systems available. With current technology, all fuels require some form of control systems for exhaust gas emission in order to meet regulations on emission, even ethanol, methanol and biomethane. There is potential for reducing today's exhaust levels both for fossil fuels and biofuels.

A warning can, however, be maintained regarding small and ultra-fine particles. An increased use of diesel engines, or higher compression in otto-engines is assumed to release higher levels of ultra-

⁴⁸ A cold start means that the engine has yet to reach regular working temperature.

fine particles (PM_{2,5})⁴⁹. It is only recently that the EU has acknowledged particles of this size as a real health hazard. Equipment for measuring and filters to catch particles of this size are under development. The only future fuels which differ considerably from conventional fuels are hydrogen in fuel cells and electricity, both having a potential zero emission from the vehicle.

5.2 Fuel handling

Both ethanol and methanol combust more easily than gasoline and diesel, but they vaporize more slowly, which gives low concentrations of combustible vapours. In the case of accidents ethanol and methanol are therefore considered less dangerous than gasoline and diesel. Methanol, gasoline and diesel are all poisonous to consume, as also ethanol albeit at a lower level. One advantage concerning ethanol and methanol is that they are both biodegradable, which means that possible leaks, on land or water, will be broken down by microorganisms. RME can safely be handled, and is less dangerous for humans and animals alike than fossil fuels. Hydrogen is safe when released into the air, but when it is stored in a tank there is a risk of explosions. However, this is seen to be a manageable risk⁵⁰.

⁴⁹ Today particle emissions are regulated in the unit mg/km. All particles are measured by weight up till 10 micrometer (PM₁₀). PM_{2.5} concerns particles up to 2.5 micrometers. A reduction in all emissions up till PM₁₀ can still entail an increase in particles such as PM_{2.5} and PM₁, which are today considered much more dangerous to the health. In a coming requirement for emissions within the EU ("Euro 6") a discussion not only to measure particles by mg/km but even the number of particles per km driven.

⁵⁰ See for example SPI (2007)

Conclusions

- Normally, gaseous fuels emit lower quantities of regulated substances compared to conventional diesel and gasoline, as do also, to a certain extent, liquid biofuels. This distinction, however, should not be exaggerated since emission levels today are decided by regulations based on available engine technologies and exhaust emission control technologies.
- Future plug-in hybrids, electric cars and fuel cell vehicles are the only ones that can have “zero-emission” on the street. However, these emissions are being shifted “upwards” in the system to the power station or hydrogen production plant. Nevertheless, emissions are usually easier and cheaper to purify in a centralized, large plant than in a vehicle.
- For certain new fuels (for example hydrogen) there are security issues concerned with the handling, but these seem controllable.
- Biofuels have an advantage in the case of leakage into soil or water, since these fuels are biodegradable, in contrast to fossil fuels.

6. Are today's systems leading towards better biofuel systems?

Today there is a great variety of biofuel production systems. Even starting with the same feedstock and ending with the same product (e.g. ethanol) costs and climate gains can vary substantially. Generally speaking, development is always driven towards more efficient systems, a better use of raw materials and energy input in a market exposed to competition. With the right incentives (taxes, certifications, regulations etc.) the development can be accelerated. One example is the development towards poly-generation, where for instance ethanol is produced jointly with biomethane, electricity, process heat or animal feed.

6.1 1st and 2nd generation biofuels

It is an often heard assertion that investment in 1st generation grain-based biofuels will pave the way for 2nd generation biofuels. Even the name itself “1st generation” implies that it will be followed in a natural way by the 2nd generation, based on lignocellulose.

Technically speaking some arguments do support this. However, the production systems for 1st generation biofuels (harvest, transport, refining etc.) normally have only little in common with biofuel systems based on lignocelluloses but there are some co-ordination advantages if waste products from cereals (hay, maize tops etc.) are used as base materials for the production of 2nd generation biofuels. In the US, investments are being made for the building of 2nd generation biofuel plants in direct connection with “traditional” maize ethanol plants in order to utilize the maize waste directly. Another potential co-ordination advantage between starch- and cellulose-based ethanol, is the increasing use of starch in development projects for 2nd generation biofuels. This is done to ease the breakdown of the cellulose into decomposable sugar. It is therefore most likely that future cellulose-based ethanol plants will use a certain amount of grain or other starch-rich raw materials. Synergy effects are also ensured in the production of biogas, when different raw materials and substrates are mixed.

In the field of vehicle and fuel technology the access to 1st generation ethanol and biodiesel such as RME has forced fuel specifications to be drawn up, both for low and high blended ethanol and for biodiesel in the form of FAME (Fatty Acid Methyl Esther, a generic term for the most common types of biodiesel, e.g. RME). This obviously facilitates the introduction of 2nd generation ethanol⁵¹ but could be seen to create a “lock in” effect for 2nd generation *methanol*. The vehicle- and fuel

⁵¹ 2nd generation biodiesel, called Fisher-Tropsch diesel, is assumed to be fully compatible with today's diesel.

technological barriers for these biofuels should, however, not be overstated. As mentioned earlier, it is relatively simple to fit fuel specifications as well as engines with a purification system for the alcohol fuels and biodiesel such as RME.

The foremost argument for today's ethanol and RME to be working as a "bridging technology"⁵² is that they gather a critical mass of interested actors and users, which can give the impetus needed for the development towards 2nd generation biofuels. The notion of "bridging technologies" does, however, not only concern the technological systems. Another, more important aspect is the network of engaged actors (businesses, regulators, NGOs, academia) that can encourage development within the energy- and transport sectors, using their knowledge and experience of the market.⁵³ The development of 2nd generation biofuels needs separate, dedicated support in order to develop, but obviously an already existing network of actors, in an already existing market, ready to invest and take strategic decisions, will facilitate this development. Most major actors involved in 1st generation biofuels in Sweden today, are also involved in the development of 2nd generation biofuels.

6.2 Development of 2nd generation biofuels

The long-term potential for bioenergy within the transport sector is dependent on 2nd generation biofuels to be developed concurrently with more efficient vehicles and electric vehicles. The development and diffusion of a new technology on the market is a complex process, difficult to predict or control in detail. Lead times between research, demonstration and market diffusion are long, often more than 20 years, and sometimes as long as 40 years. In order to accelerate this development, state intervention is needed, but there is always a risk of betting on the "wrong" technology. Research indicates that technologies which are flexible and hence better suited to withstand changed conditions (be it changing policy priorities or technological development) have the biggest chance of success in the long run⁵⁴.

The risk of homing in on the "wrong" technology (called "lock-in") concerns established technologies on the market. During the development phase competing alternatives support rather than exclude one another. For 2nd generation fuels and efficient vehicles there are three different

⁵² Sandén and Jonasson (2005)

⁵³ Ibid; Nilsson et al (2005)

⁵⁴ Not only technically flexible but also "politically" flexible, meaning that support can be gained for many different reasons, see for example Åhman 2006, Nilsson et al 2005

platforms of technology, the electrical (the hybrid track) the biochemical (the hydrolysis track) and the thermo chemical (the gasification track). These platforms require development irrespectively of which fuel or vehicles will be available in the future. A great deal of the basic research and market development within these platforms is already outside of the bioenergy- and transport sector. Enzymatic hydrolysis and associated technology is being developed by the biochemical industry with future biorefining plants as the aim, in order to optimally utilize biomass as a raw material in the production of the platform chemicals (base chemicals for other products). Another example is power electronics and batteries which are being developed in particular for the growing market for home electronics. Technology for gasification, above all on large-scale production, is primarily driven by the ambition of a more efficient utilization of coal resources in China and the US .

The risks of expensive investments “wasted” are thus very small. In Sweden there are strong research- and development environments both in connection with to the gasification track and the hydrolysis track. We have, for example, working trial- and demonstration plants for gasification in Piteå, and for hydrolysis in Örnsköldsvik.

Conclusions

- Today’s production and use of ethanol, RME and biogas brings advantages, rather than upsetting the development of new and efficient biofuels.
- In order to implement a long-term assimilation of the great potential of biofuels in the transport sector, better systems than those of today are needed. This development requires extensive investments on (i) gasification technologies, (ii) enzymatic hydrolysis and (iii) efficient electric drive-systems.
- Today’s as future production systems will consist of bio-refineries, where also platform chemicals will be produced, as, for example, ethylene or ethanol for the chemical industry.

7. Can renewable fuels be economically sustainable?

Today, biofuels require state subsidies in order to compete economically with gasoline and diesel. In 2006 the average price in Sweden for gasoline and diesel was approximately 3.9 and 5 SEK./liter (excluding taxes), respectively.⁵⁵ This reflects the situation when the average price per barrel of crude oil was \$65. This is a considerable increase in price, considering the 2 to 3.5 SEK/liter which was the average price (excluding taxes) for both gasoline and diesel between 1995 to 2005. In 2006 the price of Swedish produced grain ethanol was 7 to 8⁵⁶ SEK/liter and RME was 6.5 to 7.5 SEK/liter⁵⁷. Biogas is today sold at approximately 6 to 7 SEK/liter but production costs vary greatly. Today only one biofuel is competitive without tax exemption, and this is Brazilian sugar cane ethanol, which is being produced at a price of 2- to 3 SEK/liter⁵⁸.

Last year's rise in price of crude oil has increased the price of gasoline and diesel, and this year the price rose to even more than 5 SEK/liter⁵⁹. Even grain- and oil seed prices have doubled in recent years, for during this year to be reduced somewhat. Reliable and updated data for production costs of, for example, ethanol from wheat and maize or biodiesel are difficult to come by. The prices cited above are those up till 2006, which means, immediately before the abrupt price increase on grain.

Today, energy taxation on gasoline is circa 2.95 SEK/liter and for diesel around 1.23 SEK/liter. To this should be added the 2.3-2.9 SEK/liter CO₂ tax on all fossil fuels (since Jan. 1. 2008). Biofuels are exempt from the CO₂ tax since they are considered CO₂ neutral, and are, until 2012, also exempt from the energy tax. In total, gasoline and diesel have a tax disadvantage of 6.6 SEK/liter compared to biofuels. The tax exemption on biofuel has been a powerful incentive to date to develop the market. However, the exemption from the energy tax is only temporary. The long-term economic incentive will be the exemption from the CO₂ tax (currently 2.6 SEK/liter for the transport sector). With current production costs, not even the CO₂ tax is sufficient to allow biofuels to become competitive, with the exception of Brazilian sugar cane ethanol.

⁵⁵ SPI 2008

⁵⁶ Agricultural Department, 2006. Biofuel are here in general compared with gasoline equivalents or diesel equivalents, which means that the amount of biofuels needed to obtain the same energy from one liter of gasoline/diesel. One liter of ethanol is the energy equivalent of 0.67 liter of gasoline, and one liter of biodiesel is the equivalent of 0.92 liter of diesel.

⁵⁷ Agricultural Department, 2006, given that there was a market for the by-products (glycerin and rape cake) for 1.5-2.5 SEK/liter.

⁵⁸ Agricultural Department, 2006, SOU 2007-36, Boisen 2008

⁵⁹ SPI 2008

7.1 The long-term oil prices

The price for crude oil over the long-term is difficult to judge but the IEA estimated in 2007 that it could be between \$60-70/barrel till the year 2030⁶⁰ with a significant risk of sudden price increases given the precarious balance between increase in demand and supply. Only months after this estimate was made the price rose suddenly from \$70/barrel to \$140/barrel but is currently falling again (circa \$60-80/barrel). A long-term price range between \$50-70/barrel can be assumed given the production costs involved in extracting “non-conventional” oil resources such as tarsand⁶¹ which is not subject to the same physical limitations as current oil reserves.

7.2 The long-term biofuel costs

The price of feed stock is the dominating factor for the final price of the production of ethanol, averaging between 58-65% of the final price⁶², and for RME, circa 90%.⁶³. What speeds the development towards 2nd generation biofuels is among other things that these are able to use much cheaper base raw materials, such as lignocellulose, than those currently used (wheat, maize and rapeseed). A further important factor is that this development will increase the climate gains and limit the competition between food and fuel. The price of lignocellulose is today dependent on whether it is produced from waste products or energy crops. Below is shown, as an example, a prognosis for the development of feed stock prices within the EU for the coming years. The uncertainty regarding the price development is significant, dependent on competition as well as technological advances in, among other areas, cultivation, harvest etc. However, table 7.1 can give an indication of the significant price variations between different types of feed stock.

Table 7.1. *Estimated feed stock prices within the EU till the year 2012*

Biomass cost at a crude oil price of 50 euro/barrel	Euro/GJ
Wheat	6.7
Rapeseed	10.4
Wood raw material from forestry	2.9
Wood raw material from dedicated cultivation	4.5

Source: Concawe et al 2007

⁶⁰ IEA 2007_a

⁶¹ Brandt and Farrel 2007

⁶² IEA 2004; Kojima and Johnson 2005

⁶³ Agricultural department 2006

Another factor which will make it possible to reduce production costs, is that so-called “learning effects” arise. Learning effects refer to the reduction of production costs by accumulated production, as an effect of small, continuous improvements and streamlining in the entire production chain.

Learning effects have been measured for a number of energy technologies and are normally between 5-20%, implying that production costs are reduced by between 5-20% for every doubling of production.⁶⁴ A relevant example of a “learning effect” is shown below in figure 7.1, demonstrating the price development of Brazilian sugar cane ethanol in the years between 1980 and 2005.

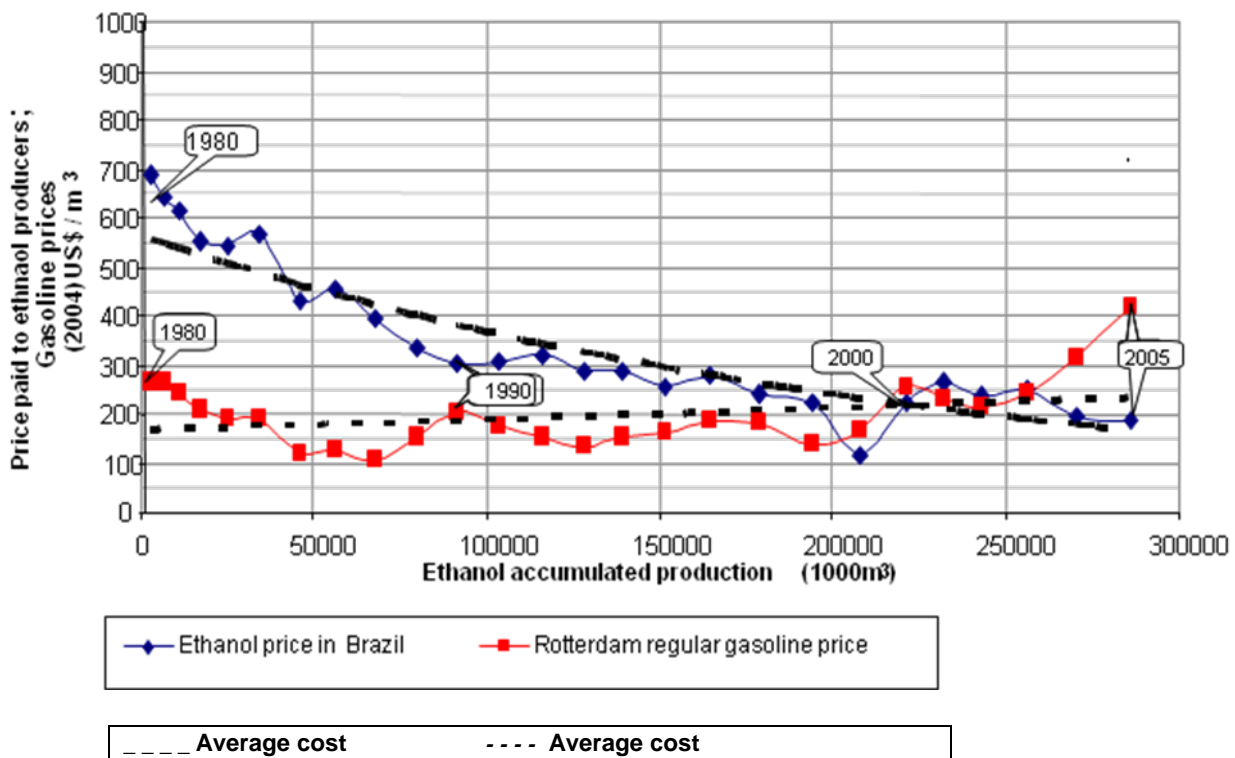


Figure 7.1 Cost development for Brazilian ethanol and for gasoline (Rotterdam). Source: Goldemberg J., (personal communication)

⁶⁴ See for example Neij (2008)

7.3 How far can the price of biofuels fall?

Several models have been constructed in order to estimate the possible future costs involved in the production of 2nd generation biofuels. In table 7.2 below is shown a compilation of different estimates for 2nd generation biofuels compared to gasoline/diesel. The estimates in table 7.2 are for *possible* future costs, assuming production on a large scale, as well as learning effects and technological advances. The costs are divided between production costs and distribution costs since these vary greatly between gaseous- and liquid fuels.

Table 7.2 Estimated potential production costs for 2nd generation fuels, with production on a large scale and including technological development.

Fuel	Production costs (SEK/l gasoline eq.)	Distribution costs (SEK/l gasoline eq.)	Total
Gasoline/diesel	2.8 – 3.5	0.9-1	3.7–4.5
Ethanol (wood)	3 – 6	1	4 – 7
Biomethane (wood)	3	1 – 2	4 – 5
Methanol (wood)	2.7 – 3.5	~1,1	3.8- 4.6
DME (wood)	2.7 – 3.5	1.5-2	4.2 – 5.5
Synthetic diesel (wood)	3.3 – 5.3	0.9-1	3.2 – 6.3

Sources: Based on Hamelinck and Faaij (2006), IEA (2004), SGC (2008). Distribution costs from Ecotrafic (2002), IEA (1999) and Boisen (2008). The variation indicates different assumptions regarding technological development and different biomass prices (0.5 SEK/l. gasoline or 0.75 SEK/l. gasoline). Gasoline/diesel costs correspond to a crude oil price of \$50- 65/barrel.

As seen in table 7.2, biofuels are estimated to have future possibilities of becoming competitive with their fossil alternatives, at a cost level of today's average, excluding economic incentives. However, in order to realize these optimistic estimates much technological development is required, as well as investments in production in order to gain experience and a continued development of the biomass market for lignocellulose. When it comes to specific energy crops such as Salix, production costs are assumed to decrease considerably in the future through different scale advantages and learning effects, if the area of cultivation in Sweden is increased from the current circa 15,000 hectares to between 50,000-100,000 hectares.⁶⁵ Unfortunately the increase in grain prices implies that the farmer will require a higher land compensation to crops than grain, which again entails an increase in production costs for, among others, woody energy crops.⁶⁶

⁶⁵ Rosenqvist H., Börjesson P., Neij L., Berndes G. (2005).

⁶⁶ Ericsson, K., Rosenqvist, H. and Nilsson, L.J. 2008

Production costs for 1st generation biofuels are also deemed reducible in the future through the streamlining of processes and the development of bioenergy combinations. Another important factor is the price development of the by-products of, for example, ethanol and RME production (distiller's waste and rapeseed flour). If the world market price of feedstock increases (for example soy flour) this also increases the market for feedstock by-products, which in part can compensate the higher prices of cereals and oil seeds.

In both a short and a medium time perspective, the costs for 2nd generation biofuels are considerably higher than gasoline and diesel and 1st generation biofuels. A long-term tax distinction, corresponding to today's Swedish CO₂ tax of 2.6 SEK/liter (incl. vat) will indeed further biofuels in general, but is not sufficient to generate risk investments and focused research needed to facilitate the further development of 2nd generation biofuels. Apart from specific support for research and demonstration, 2nd generation biofuels require at least the same type of support that 1st generation biofuels receive in Sweden today, i.e., a temporary tax exemption from energy taxation as well, in order to penetrate the market. Increasing oil prices can also favor 2nd generation biofuels, if the countries with large non-conventional oil resources choose not to exploit these, possibly for environmental reasons.

Conclusions

- The ability of biofuels to compete with fossil fuels, will for the future above all be decided by environmental taxes such as CO₂ taxes.
- With increased competition for raw materials, the biofuel industry will align itself towards the use of cheaper raw materials such as waste products from forestry and agriculture as well as from households, producing the 2nd generation biofuels and biogas.
- The development of production techniques for 2nd generation fuels requires a substantial development in technology and the market in order to gradually generate learning effects and thereby decrease production expenditures. Higher prices of feedstock will also entail risks associated with expanded and intensified land use

8. Are biofuels a threat to biological diversity and access to water?

8.1 Biological diversity

One potential environmental conflict often debated in connection with increased biofuel production, is the risk that this will lead to a diminished biological diversity. The defining point in this issue is the type of land used to grow raw material, for example, existing farmland and forested areas already in production, or new farmland with high natural values. Several environmental institutions have raised the alarm for this happening in Southeast Asia where rain forest is being cut down to make room for palm plantations used in the production of biodiesel. Greenpeace opposes the introduction of palm oil biodiesel (Eco 20) in Sweden, claiming that production leads to losses of biological diversity and no climate benefits due to deforestation and drainage of tropical peat lands⁶⁷. If an increased production of sugar cane ethanol in Brazil leads to indirect effects such as deforestation in the Amazon region, this is also a threat to biological diversity.

The cutting of natural forests of high biological value has been a general problem, so far primarily in connection with food and feed production as well as with the extraction, often illegally, of valuable wood. As an example of this, approximately 100,000 tons of palm oil from Malaysia are imported to Sweden every year to be used for food, cosmetics etc. In energy terms this equals roughly 3 % of the current diesel consumption in Sweden. Land areas with high biological diversity should be protected regardless of what is being produced. Sustainability criteria and certification schemes in the areas of wood production, food and feed production and biofuel production, both existing and those under development, almost always include measures and requirements to protect biodiversity. Furthermore, efforts against illegal deforestation in relevant countries should be supported.

There are also situations in which the production of biofuels can lead to positive local environmental effects. One example is the planting of jathropa, a drought-resistant bush, on dry marginal lands, for instance in southeast Asia and Africa, or the growing of switchgrass, a similarly drought resistant energy grass, on semi-dry areas in the western parts of the US and northern China. Even palm oil biodiesel could be sustainably produced in the future if the raw material is grown on

⁶⁷ Greenpeace, 2008

degraded farmland not in use today and the by-products are used efficiently.⁶⁸ The impact of future production on biodiversity levels is indirectly connected with the quantity of biofuel produced, in other words, how much land will be required. An analysis of the European Environmental Agency⁶⁹ shows that the supply of bioenergy can increase to 15-20% of current energy consumption in compliance with strict environmental requirements. A substantial part of the bioenergy potential consist of different waste- and by-products, which normally have a far smaller impacts on biodiversity than land use changes for the cultivation of energy raw materials.

In regard to Swedish conditions and the growing of energy crops on farmland, there are only a few and relatively old studies analyzing the effects on biodiversity of different energy crops.⁷⁰ Existing analyses are primarily concerned with wood energy crops and show that, for instance, *Salix* contributes to biological diversity when planted on farmlands under intensive cultivation. However, if the cultivation takes place on land with high natural values, for example on old pasture and grazing land etc, biological diversity is negatively affected. In the same way, biodiversity is menaced if valuable forest biotopes are harvested for raw materials for 2nd generation biofuels. However, within the forestry industry environmental certification systems (FSC and PFEC) have been developed to protect biodiversity in forests. These certification systems apply regardless of how the forest raw materials are used.

A new product which could be used as raw material for biofuels is tree stumps. So far in Sweden, no harvesting of stumps is allowed on a large scale since, among others, the Swedish Forest Agency has required an assessment of the environmental impact of this kind of harvesting. There are certain risks involved in large-scale harvesting of stumps on traditional forest land. In certain areas, for example areas already lacking natural dead wood, this could have negative consequences on the level of biological diversity. In forest plantations (for example of broad-leaf trees and spruce) on former farmland stump harvesting is deemed to imply only marginal impacts on biological diversity.

In summary, it can be said that knowledge on possible impacts on biodiversity of biofuels is limited, but as long as no land of high biodiversity is employed the effects are estimated to be relatively marginal. Table 8.1 shows a summary of the possible environmental consequences of an increased production of energy crops for biofuels on farmland in Sweden.

⁶⁸ IFEU, 2007

⁶⁹ EEA, 2006

⁷⁰ Börjesson, 2007

Table 8.1. Possible effects on biological diversity in the case of an increased production of energy crops for biofuel production in Sweden.

Production system	Effects on biological diversity
Energy forest & energy grass replace annual crops in intensive agriculture	+
Energy forest replace extensive pasture & “green” fallow land in forest regions	–
Energy forest & energy grass replace extensive pasture & “green” fallow land in regions under intensive agriculture	+
Energy forest & energy grass are grown on low yielding farmland with high natural value	– – –
Grain crops & oil seed plants replace annual crops	0
Grain crops & oil seed plants replace extensive pasture & “green” fallow land in forest regions	+
Grain crops & oil seed plants are grown on low yielding farmland with high natural value	– – – –

Plus (+) indicates positive effects, minus (–) negative effects and nil (0) no change. Based on Börjesson (2007).

In connection with the Oil Commission (2006), professor Urban Emanuelsson (superintendent for the “Center for Biological Diversity”) was given the task to describe a strategy for increasing the production of bioenergy in Sweden, a strategy which should include minimizing the risk of losing biological diversity. The analysis resulted in the following four main conclusions: 1) farmland use should, if possible, be planned in order to identify areas which are adequate for efficient biofuel production as well as suitable for the sustenance of biological diversity, 2) current food and wood production need constant adaptation in order to preserve the biological diversity, leaving increased space for bioenergy production, 3) existing agricultural systems for bioenergy should, if possible, be developed with the aim to support biological diversity (for example modified production systems for fast growing broad-leaf trees), and 4) new agricultural systems for bioenergy, which generate biological diversity (e.g. areas similar to wetlands), are needed. All of these important issues require a number of new measures and policy instruments.

Today’s production of fossil fuels, to a certain extent, also has implications on biological diversity, directly through oil spills at sea and on land, coal mining which generates toxic waste etc, as well as through air pollution from combustion. In the future, we might see an increased use of “non conventional” fossil fuels, such as tarsand (or oil sand) and oil shale, which give rise to greater biological consequences due to the processes involved in mining. Some deposits of tarsand are extracted in open-cast mines which claim huge areas. The ones in Canada which have attracted

much attention, supply tarsand cover an area larger than England and are mostly situated in the boreal forested belt in Alberta and consist partly of peat land⁷¹. Many of these wood- and wet land areas are considered important for biological diversity (and as a binder of carbon). Large scale mining of tarsand is thought to lead to great negative ecological consequences. The mining operation also leads to vast quantities of water pollution which affect biological diversity in lakes and streams.

8.2 Water access

The increased production of biofuels has stimulated a debate regarding future access to freshwater. A number of international reports have been published, all with the message that a large scale production of biofuels, based on crops requiring large amounts of water, will accelerate problems concerning water shortages in exposed regions such as parts of India, China and Africa. Approximately 70% of global water consumption goes to agriculture (20% to industry and 10% to households). Currently, only 2% of agricultural irrigation is for biofuel crops.⁷² 20% of global arable land is thought to be irrigated, while 80% is supplied by rainfall. The use of irrigation is, however, expected to grow in the future for economic reasons as well as increased needs due to climate changes.

If farmland used for biofuel production increases threefold globally by 2030, it is estimated that 4% of all irrigation will be used for these crops. There are, however, considerable regional differences. These depend on rainfall, which crops are being grown where, and which areas that will experience the greatest expansion of biofuel production. An estimate is that approximately 30% of all irrigation in southern Africa by 2030 will be for sugar cane crops in ethanol production. The equivalent for American maize crops is expected to be approximately 20%. In countries such as China, India, Brazil and Indonesia irrigation for biofuel production is assumed to reach 5-10% of the total amount by 2030.⁷³

Of currently grown biofuel crops, sugar cane is expected to need the most irrigation in the future, followed by maize.⁷⁴ The remaining crops are judged to be largely self-sufficient. The cultivation of sugar beet requires only half the water for sugar cane for an equivalent ethanol production. This is

⁷¹ WWF, 2008

⁷² Faurés, 2008

⁷³ Faurés, 2008

⁷⁴ Ibid

why plant breeding companies are trying to develop a new type of “energy beet” to replace sugar cane which can be cultivated in Southeast Asia and Africa where water resources are limited. There are certain crops which can be cultivated in semi-dry areas without irrigation, for example, jathropa, switchgrass etc. Irrigation also entails a reduced energy balance for biofuels. One exception is when nutrition-rich waste water (e.g. sewage water) is purified by being used as irrigation for energy crops, than when a conventional purification technique is used.⁷⁵

Conclusions

- Possible effects on biological diversity depend mainly on which type of land are being used. If existing arable land is utilized the effects are often marginal, or even positive, while they can be substantial and negative if new land with high natural value is being cultivated.
- Cultivation of new land with high biodiversity is, however, a general problem which includes food, feed and wood production. This requires new and general measures and policy instruments, among these certification systems including all land use in order to prevent the loss of biological diversity.
- Influence on regional water access and water consumption must be monitored when biofuels are based on crops which are irrigated (above all sugar cane and maize) since irrigation is resource-demanding and therefore not always sustainable.
- An increased biofuel production may affect the need for irrigation, depending on which crops are cultivated, in which region the cultivation takes place, and the amount of rain fall there. This shows that the “right” crop should be cultivated in the “right” region, in order to avoid water shortage in vulnerable regions.

⁷⁵ Berndes and Börjesson, 2003

9. Have biofuels caused increased food prices?

The price of food has increased markedly in the past two years (Figure 9.1), something that has led to criticism of the use of food crops and farmland for the production of biofuels since this may have contributed to the price increases. The price increases, above all those on the staple commodities, have been a hard blow for many poor people, the urban poor and other net consumers of food products. For the poor in the countryside, on the other hand, the price increases provide an opportunity for higher incomes, at least in the longer term (see chapter 10). Firstly, the price increases benefit net producing farmers, but later they could also benefit the landless farmhands via higher wages. In the short term, however, the price increases have increased the number of poor people around the world who are in urgent need of supporting measures against hunger and malnourishment.

Recent price increases have broken the trend of almost 30 years of falling prices (in real terms) ⁷⁶. Between 2005 and the spring of 2008, prices of cereals such as wheat, rice and maize doubled, or even tripled (Figure 9.1). The prices reached their highest levels in the spring of 2008. Since then, prices have decreased but are expected to stabilize at a level higher than at the beginning of the 21st century. ⁷⁷ Sharp increases in food prices are, however, not a new event. In connection with the oil crises in 1973 and 1979, food prices increased drastically, after which they fell again. According to the UN Food and Agricultural Organization (FAO), the recent price increases are caused by a number of interacting factors, above all i) increased food demand, ii) increased production of biofuels, iii) increasing oil prices, iv) falling cereal stocks, v) drought, vi) speculation and vii) trade and agricultural policy. ⁷⁸ It is very difficult to quantify the different factors that have contributed to the development. Both quantitative and qualitative analyses have been made ⁷⁹, but the results vary significantly depending on choice of time period, geographic area, method of analysis and the crops selected. Our assessment is that the increased production of biofuels is one of several contributing factors to the price increases and that its contribution has been relatively limited so far. Regardless of what impact the production of biofuels has had on recent price development, it is probable that

⁷⁶ In this paragraph, *prices* refer mainly to international prices. These are then transferred into domestic prices, these being the prices for the consumer. International prices in general effect the prices in developing countries more than in the industrial countries.. FAO, 2008_a

⁷⁷ OECD/FAO 2008

⁷⁸ Ibid

⁷⁹ See among others IFPRI (2008), Mitchell (2008) and DG Agriculture (2008). In Wiggins et al. (2008), the effect of biofuel production on food prices in the future, is analyzed.

climate policies will strengthen the link between the agricultural and energy sectors (including biofuels) (see Chapter 10).

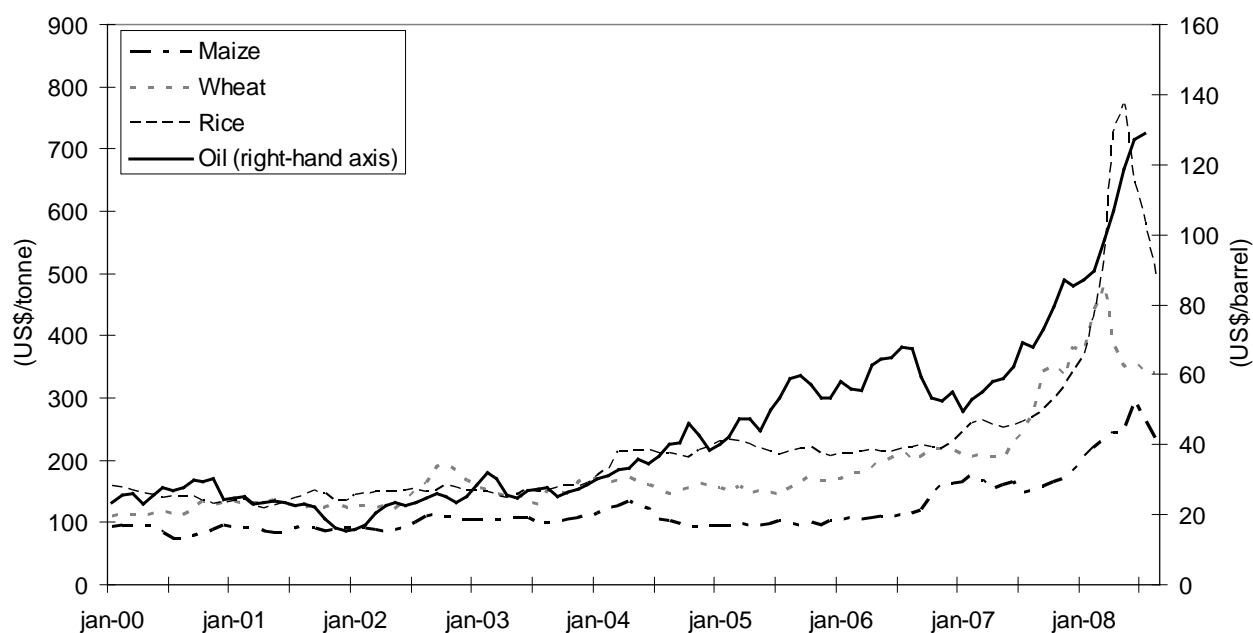


Figure 9.1. The nominal price development (US\$) for wheat, maize, rice and crude oil, during the period 2000 until August 2008 (July 2008 for crude oil) (EIA, 2008; FAO, 2008_b). It should be noted that the actual price is lower in many countries since the dollar has decreased in value against many other currencies.

9.1 Increased production of biofuels

The production of biofuels has increased considerably in recent years (but from a generally very low level) and is hence estimated to be a contributing factor to the price increases of cereal and oil crops. The price effect occurs through competition for crop material or changes in the farmers' choice of crop (competition for land). For a crop such as rice there is, however, no connection with the production of biofuels, since rice is neither used in biofuel production, nor competing for the same land (on a longer term there could be a certain indirect effect due to changed consumption patterns). Between 2000 and 2007 ethanol production increased 3 times and biodiesel production increased 11 times.⁸⁰ Above all it is the production of biodiesel from oil crops and ethanol from cereal crops (to 95% maize) that is thought to have caused the price increases, while the production

⁸⁰ OECD/FAO, 2008

of sugar cane ethanol is assumed to have had a smaller effect⁸¹. According to the latest assessment, 4.4% of cereal production and 8.6% of vegetable oil production were used as feedstock in the production of biofuels.⁸²

In spite of the considerable increase in production, the area of land used for biofuel production is still modest. For 2004 the cultivation area for biomass feedstock was estimated to be 14 million hectares⁸³, which corresponds to about 1% of the total arable land. According to our assessment, this area has now increased to approximately 22 million hectares, which corresponds to 1.5% of the arable land (Table 9.1). This approximation includes only the US, the EU and Brazil, which account for 92% of ethanol production, and 79% of biodiesel production.⁸⁴

Table 9.1 Agricultural land used for the cultivation of biomass feedstock for the production of biofuels. The data for 2004 are based on IEA (2006) those for 2007 are our assessments.

Region	2004	2007
North America	8.4	14.6 ¹
EU	2.6	4.0 ²
Latin America	2.7	3.6 ³
Total	13.8	22.2

¹Includes only the US where about 25% of the maize production, corresponding to 9.2 Mha, is utilized for the production of ethanol and 20% of the production of soy beans, corresponding to 5.0 Mha, is utilized for the production of biodiesel (USDA, 2008).

²The European Commission (2008)

³Includes only Brazil, where circa 50% of sugar cane production, corresponding to 3.1 Mha, is utilized for production of ethanol. The production of biodiesel, mainly from soy beans is estimated to use circa 0.5 Mha.

9.2 Increased food demands

One fundamental cause for the price increases of recent years is the steady increase in the demand for food is, not least meat and dairy products. This development is driven partly by population increase⁸⁵ and partly by high economic growth in large economies such as China and India. Higher incomes in low-income countries, in combination with urbanization, have led to changing

⁸¹ Mitchell, 2008

⁸² OECD/FAO, 2008;FAO, 2008c

⁸³ IEA, 2006

⁸⁴ OECD, 2008

⁸⁵ The yearly population increase was in average raised to 1.23% during the period 1990-2007.

consumption patterns towards a diet with more meat and dairy products. Between 1980 and 2002 the meat consumption per capita doubled in the developing countries, but even so, remains only half of that in the industrialized countries.⁸⁶ The increased production of animal fodder has in turn entailed increased production of fodder crops such as cereals and soy protein. Today, approximately 1/3 of all cereal production and 1/3 of all arable land are used for fodder production.⁸⁸

9.3 Increasing oil prices, falling cereal stocks, speculation and drought

Increasing oil prices have contributed to the price increases of food by increasing the costs of diesel and fertilizers used in the agricultural sector, as well as increasing the costs connected with distribution and freight.

Yet other causes for the price increases are the decline in cereal stocks and increased speculation on the markets in agricultural products. For several years in the 2000s, the consumption of cereals has exceeded production, which has led to falling cereal stocks (Figure 9.2). The main reasons for the increased utilization of the cereal stocks are agricultural reforms and increased liberalization of agricultural markets. The utilization of the cereal stocks has in turn delayed the price signals for increased demand to the production sector. Falling cereal stocks have also increased the market sensitivity to rapid changes in demand and supply, something which partly explains the larger price effects at the time of the production slump in 2006-2007 compared to that in 2000-2003. The latest production slump was caused by among other things, drought in Australia and Eastern Europe. Assuming normal weather conditions, the global production of cereals (especially wheat) this year (2008) will surpass that in former years since the area under cereal crops expanded in 2007-2008.⁸⁷

⁸⁶ Steinfeld, 2006

⁸⁷ FAO, 2008d

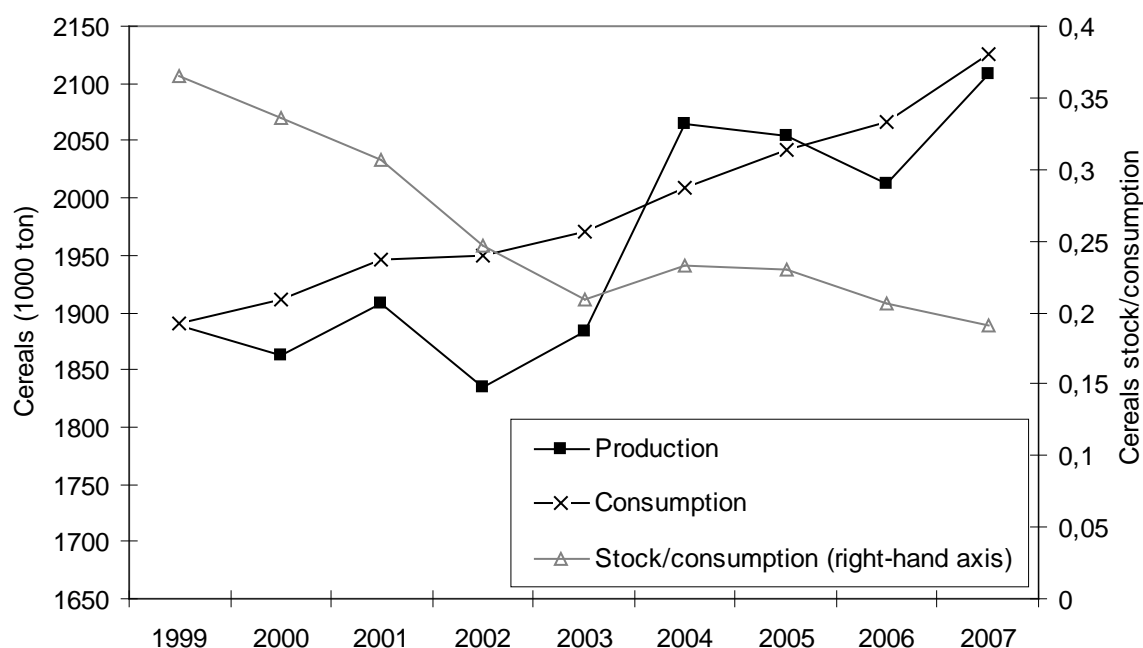


Figure 9.2. The world's production and consumption of cereals (left-hand axis) and the quota between cereals stocks and consumption (right-hand axis) for the period 1999-2007 (FAO, 2004, 2006, 2008c).

9.4. Trade and agricultural policy

The price increases of recent years should also be seen as the outcome of decades of substantial national agricultural subsidies, export subsidies and trade barriers (e.g. tariffs) primarily in the EU, the US and Japan. These trade and agricultural policies have limited the international trade in agricultural products and exerted downward pressure on world market prices. Sharp criticism has been directed at the different types of export subsidies, not least those in the EU. The export subsidies have led to domestic surpluses of food products being dumped on the world market, at very low prices, something which has hampered the agricultural development in many developing countries and contributed to their import dependency. Following pressure from the World Trade Organization (WTO), the EU has decreased the use of export subsidies in the past ten years, and hence gradually lowered the pressure on world market prices. Since 2001, WTO negotiations were taken up regarding, among other issues, trade in agricultural products in the Doha-round. The aim

of these negotiations is to increase liberalization within the agricultural sector, something that is likely to benefit agricultural development in the developing countries.⁸⁸

During the recent price increases a reversed development within trade policy has emerged. In order to limit the price increases in domestic markets, a number of countries, e.g. India, Vietnam and Ukraine, have introduced temporary export restrictions. These restrictions have most probably reinforced the price increases on the world markets, not least on rice.

Conclusions

- Recent years' price increases of food products have been caused by a number of interacting factors, among which increased biofuel production has had a certain, albeit limited effect.
- So far the production of biomass feedstock for biofuels account for only about 1.5% of the world's arable land. Approximately 4.4% of the global production of cereal is used for biofuel production.
- Other factors that have contributed to the price increases are: i) increased demand for food, not least meat and dairy products, ii) increasing oil prices, which have increased cultivation and freight costs , iii) falling cereal stocks, iv) drought, v) trade and agricultural policy and vi) speculation on the markets in agricultural products

⁸⁸ World Bank, 2007

10. Is there enough land for food and fuel?

With an increased focus on climate change issues and commitments to reduce CO₂ emissions substantially, the value of biomass feedstock increases in relation to fossil feedstocks in the production of fuels. The earth's surface and area of productive land is a limited resource, something which implies an increased competition for land when the production of biomass feedstock increases. Today, approximately 10% of the earth's surface, or 1400 million hectares (Mha), is utilized as arable land, and 25% or 3440 Mha is utilized as pasture land. In addition, approximately 135 Mha is utilized for the growing of permanent crops (fruit trees, vines etc.). The global forest area amounts to 3960 Mha. In Sweden the arable land amounts to 2.9 Mha. In order to replace all fossil fuels in the transport sector (84 EJ) with biofuels, 400-800 Mha would be required for the cultivation of biomass feedstock (given a yield of 100-200 GJ/ha, see Figure 3.1) The example illustrates that considerable production of biofuels is possible, but also that this would require large areas of productive land. Therefore, as mentioned earlier in the report, biofuels should be seen only as part of the solution to reduce the environmental impact of the transport sector.

The land used in the production of fossil fuels is relatively small, i.e. the energy production per hectare is considerably larger for mining/extraction of fossil feedstocks than for the cultivation of biomass feedstock. The land use connected to fossil feedstocks is, however, often environmentally problematic, in particular for mining of non-conventional fossil feedstocks such as tarsand, and in coal mining. These ventures entail large, often irreversible, interference with the natural environment.

The discussion in this chapter focuses on the competition for land between the food and energy sectors. However, in reality the competition includes more sectors. For example, agricultural land is also used for cultivation of fiber crops for the production of textiles and paper, and in the future, yet more agricultural land may be used for the cultivation of biomass feedstock for the chemical industry. Apart from food and feedstock production, large areas of agricultural land are claimed for infrastructure, industrial areas, housing and recreational areas.

10.1 A stronger connection between the energy and agricultural sectors in the future

In a climate-constrained world, with high costs for CO₂ emissions, there will be a stronger link between the energy and agricultural sectors. Several modeling studies⁸⁹ indicate that high CO₂ prices, creating a high demand for biomass feedstock, leads to increased prices on land as well as increased expenses for food production. Historically the energy and agricultural sectors have been connected through energy prices that influence the costs of fossil-based inputs in agricultural production. When agricultural crops become competitive on the energy market the link between the energy and agricultural sectors is strengthened by the fact that the energy sector emerges as an alternative market, parallel to the food sector. Hence competition appears between the food and energy sectors for agricultural factors of production, primarily agricultural land and water. This chapter will focus on agricultural land as a limited resource, although locally or regionally the availability of water may often be the limiting factor (see earlier chapter).

At the farm level, the competition for land is demonstrated by the fact that economically rational farmers allocate their land to the most profitable crop or activity, which thus sets the price of land. Consequently, if the willingness to pay for biomass feedstock increases, the cultivation of energy crops becomes more profitable. In order for food crops to remain an interesting alternative, the price of these has to increase. In line with this, the recent price increases on cereals and oil crops have also led to increased prices on land.

10.2 Land requirements for food and fodder production

Over the years a number of scenarios describing the future land requirements for food and fodder production have been produced. In a recently published report, The Gallagher Review (RFA, 2008), the land requirements for food and fodder production are estimated to increase by 200-500 Mha by 2020. Some other studies, however, show that even an opposite development could be realistic. For example, Waggoner and Ausubel (2000) estimate that 200 Mha of arable land could be released from cultivation in the next 50 years. Decisive factors for the results arrived at by the different studies are the assumptions on *population development*, *diet* and *productivity*. Especially the two last factors vary in the studies, while most studies assume the UN forecasts on population development. According to this forecast, the population will continue to grow in the coming

⁸⁹ Among others, Johansson and Azar (2007), Ignaciuk et al. (2004) and Azar and Berndes (2000)

decades, but at a declining pace. The global population is expected to increase from 6.7 billion (2007) to 9.2 billion in (2050).⁹⁰

In recent decades, the production of different crops as well as meat has increased significantly in step with the increase in population and prosperity. The production increases have mainly been achieved through higher productivity (higher crop yields per hectare and a higher meat-to-fodder ratio) and to a smaller extent through increased land use. Typically, cereal yields have increased by approximately 2% per year, while the area of arable land has increased only by 0.2%. The expansion of arable land has taken place in the developing countries, while the area of arable land has even decreased somewhat in the industrial countries. The yield increases vary greatly between regions and have primarily been achieved through the use of refined (breeding) crop material, fertilizers and irrigation.

It is evident that the large regional differences in the development of yield levels can not only be explained by climatic conditions (temperature, precipitation etc.), but also depend on socio-economic factors. For that reason it should be possible to increase the yields in particularly economically weak areas where the agricultural sector is often underdeveloped. The best example is southern Africa (Africa south of the Sahara) where the yields have remained almost unchanged since 1960.⁹¹ By the use of developed production methods, better access to fertilizers, adapted and improved crop material, investments in irrigation systems etc, yields could be greatly improved in this region, but also in more advanced regions. For example, the yields in several Eastern European countries are unjustifiably low compared to those in Western Europe and thus indicate a great potential for yield increases. The potential for improvement should be especially large for dedicated energy crops, since these have been involved in breeding only recently. In the longer term there are hopes that biotechnology will provide even greater and faster production increases.

The size of yield increases that can be attained in the future by crop breeding and agricultural developments is uncertain. It is clear, however, that the recent price increases can contribute to future yield since they improve the profitability of investments aiming to increase productivity. The importance of agricultural development in poverty reduction schemes, especially in Africa, has also been emphasized by the UN and other international organizations. Obviously, such an intensification must be done in a sustainable way, and be adapted to local conditions. In several

⁹⁰ UN, 2008

⁹¹ World Bank, 2007

areas of the world, the intensification of agriculture has entailed environmental problems such as eutrophication of watercourses and salinization of arable land. The use of environmental problems has given rise to an opposite trend, ecological farming, which may lower future yield increases. Ecological farming without chemicals such as fertilizers and pesticides entails lower yields (up to 40% for cereals), thus increasing the requirements of land compared to conventional farming. In the EU a target for 20% of arable land to be farmed ecologically by 2020 has been set.

Another important factor of uncertainty to future yields, not least in many developing countries, is the climate. The effects of climate change on agriculture are expected to vary greatly between regions, depending on the adaptability of agriculture as regards, for instance, the choice of crops.⁹² Climate models set up by the IPCC show that an increase in temperature will have a negative impact on yields in the southern hemisphere, not least southern Africa, while agriculture in the northern hemisphere may benefit. There are, however, great uncertainties in the models, which make it difficult to draw clear and concise conclusions on regional impacts. For further information regarding possible climate effects on future agriculture and forestry, we refer to the IPCC report.⁹³

Diet is also of major importance for the area of land required to feed one person. The land requirements for a diet rich in meat are usually 2-3 times that for a vegetarian, nutritiously correct diet.⁹⁴ The land use requirements are particularly large for beef production. Today, approximately 1/3 of the world's arable land and around 78% of the total agricultural land (arable, permanent crop and pasture land) is used for meat and dairy production⁹⁵. People's diet is strongly connected to their income, but is also dependent on cultural factors. Higher incomes for low-income earners often lead to increased consumption of meat- and dairy products. Therefore it is also probable that increased wealth in the world will lead to increased consumption of meat and dairy products.

Yet another important aspect on land requirements for food production is the efficiency in the production and distribution chain, from harvest in the field to the plate. According to a rough estimation only 50% of edible produce on the field reaches the plate⁹⁶. There are, of course, substantial differences between different food products, and where in the chain the losses occur

⁹² IPCC, 2007

⁹³ IPCC, 2007

⁹⁴ Wolf et al, 2003

⁹⁵ Steinfeld 2006

⁹⁶ Lundqvist et al, 2008

varies between countries. In developing countries the largest losses are usually at the beginning of the chain while they are towards the end in the industrial countries.

10.3 Idle land and residues

There are ample opportunities for producing substantial amounts of biofuels without being in conflict with food production or environmental values. One way of avoiding such conflicts is to use residues of biomass as feedstock. Several assessments show that it is possible to increase the utilization of residues for energy purposes substantially. In the IEA's (2007) compilation of biomass assessments, the potential supply of residues from agriculture and forestry amounts to 45-220 EJ/year. The majority of studies, however, still estimate the cultivation of energy crops to be the largest production potential for biomass feedstock in Europe⁹⁷, as well as globally.

There is a good possibility of increasing the total production capacity by utilization of marginal land and fallow land. The productivity on this kind of land is, however, usually substantially lower than that on currently used arable land. Furthermore, it is very difficult to estimate the total area of marginal land and fallow fields. A study from IIASA indicates considerable areas of cultivable (non-forested) land, in particular in southern Africa and South America, but that the opportunities for expansion are relatively limited in the rest of the world⁹⁸. A rough estimate indicates that agriculture could expand by 800-1200 Mha while at the same time safeguarding forest land and land with high biodiversity.⁹⁹ This assessment should, however, be interpreted with great caution.

In assessments of the area of idle land and discussions on land competition, it is often implied that energy crops should be grown only on idle land in order to reserve currently used agricultural land for food production. This is a very theoretical approach since such crop distribution can only be attained through extensive regulations. Often, however, dedicated energy crops make a better choice of crop on marginal land than many food crops. Marginal land is often of poorer quality, and sometimes degraded, which makes perennial crops more suitable than annual crops. The cultivation of perennial crops on this land may in fact decrease erosion, improve soil quality and increase the carbon content of the soil.

In the EU and the US, farmers have for a long time been encouraged to set aside land, as fallow land, in order to reduce domestic overproduction of food. The fallow land in the EU increased in

⁹⁷ Ericsson and Nilsson 2006; Berndes, 2003

⁹⁸ Fisher et al, 2002

⁹⁹ RFA 2008

2006 to 10.8 Mha, which corresponds to 11% of the arable land.¹⁰⁰ The amount of fallow land is somewhat smaller today (2008) due to improved profitability (higher prices of food) as well as the removal in late 2007 of the obligatory setting aside of land. Apart from this, there is estimated to be 23 Mha of unutilized arable land in Russia, the Ukraine and Kazakhstan which had been laid fallow due to reduced profitability associated with the collapse of the Soviet Union. 11-13 Mha of this area is estimated to be suitable for cultivation.¹⁰¹

Whether marginal land and fallow land will be taken into production depends on profitability. The recent price increase of food crops may, in this respect, contribute to the utilization of these lands. The price increases, however, also increase the risk of agricultural production expanding into forest land or other types of land of high environmental value. In order to avoid agricultural production on such land, strong environmental protection laws are required, as well as the enforcement of such laws. Such laws are required regardless of the development of biofuels.

¹⁰⁰ Eurostat, 2008

¹⁰¹ European Bank for reconstruction and development and FOA, 2008

Conclusions

- There are ample possibilities for producing considerable amounts of biomass feedstock while at the same time securing food supply and avoiding agricultural expansion into ecologically sensitive areas. This can be achieved, for instance, by utilizing residues from agriculture and forestry and utilizing fallow land and marginal land.
- The production increases in agriculture in recent years have been achieved mainly by yield increases and to a smaller extent by increased land use. The area of arable land has even decreased somewhat in several countries.
- Price increases on food products improve the profitability of investments aiming to increase the productivity within the agricultural sector, not least in economically weak regions, which leads to increased production without the need for increasing the crop area.
- Population development, diet and productivity are decisive factors for future land requirements for the production of food.
- Climate change may also have substantial effects on future yields, but there are great uncertainties regarding the effects on a regional level.
- When agricultural crops become competitive on the energy market, the connection between the energy and agricultural sectors is strengthened since the energy sector becomes an alternative market, together with the food sector.

11. Threat or opportunity for developing countries?

Biofuels can be seen as yet another curse for developing countries.¹⁰² Increased demand for biofuels contributes to higher food prices, even if it is not clear to what extent. For many poor people, who spend half or more of their income on food, even small price increases will entail less food, and less nutritious food, to eat. But biofuels can also be seen as a blessing which, if handled correctly, can offer a way out of poverty.¹⁰³ The most important underlying cause for hunger and malnutrition is poverty. Rural and agricultural development is perhaps the most important strategy for fighting poverty.¹⁰⁴ This requires, among other things, fair prices and access to markets for all types of agricultural products, including biofuels. Below, we discuss different views on these issues as well as how they can be handled.

11.1 The effects of increased food prices

With the debate on biofuels, globalization issues have entered our everyday life and landed right on our dinner tables. It is becoming ever more apparent, how our choices of fuel (gasoline or ethanol) and food (beef, chicken or pea soup), along with much other consumption, have an impact on climate change, world market prices of cereals and the use of farmland in other parts of the world. The list of products which claim farmland is long, but demand for meat products and biofuels are some of the main driving forces behind the rising prices of food (see chapter 8). The question of whether increased consumption of biofuels leads to increased hunger and poverty could just as easily be a question of whether increased consumption of meat, or dairy products leads to increased hunger and poverty.

It is apparent that the short-term effects of increased food prices lead to worsened conditions for the poorest people. The so-called tortilla crisis in Mexico is a very manifest example of this. The increase in demand for maize for ethanol production in the US led to more than doubled prices of maize in 2006 and 2007, which was followed by violent protests from the poor population in Mexico City. Nevertheless, the largest percentage of the world's poor lives in the countryside where many farmers stand to gain by the price increases, while the poor without land could be the losers. Calculations show that the percentage of people under the poverty line increases by half or even up

¹⁰² Oxfam, 2008

¹⁰³ Cooperation without borders, 2008

¹⁰⁴ World Bank, 2008

to an entire percent already at a food price increase of 10 %.¹⁰⁵ Other calculations indicate very limited effects on the welfare in poor countries caused by the demand for biofuels and higher food prices.¹⁰⁶

The effects of elevated food prices do vary greatly, in part depending on the group of people or countries in question, in part whether the effects are for the short term, or for a longer term which allows certain adaptations to be made in the agricultural sector. Elevated food prices hit the urban poor harder than the poor in the countryside, and the poor buyers of food more than the poor producers of food. Among the developing countries in the world, there are today several net importers of food. Many of these countries, for example in southern Africa, would not need to import food if the production potential were utilized by the development of the agricultural sector. Other countries, especially in northern Africa will presumably remain net importers due to their geographical location and poor climatic conditions for agriculture. The winners in a situation with expanding biofuel production and elevated food prices are therefore to be found mainly in South America and in the southern parts of Africa, where there are great potentials for increased production.

One question is what constitutes “fair” prices on food. The agricultural sector has, over 30 years, till 2005, been pressed by ever lower food prices and other agricultural products (see Figure 11.1). An important factor has been the technical development and the intensification of production, which led to increased supply. Since demand did not increase correspondingly, the prices fell. The downward trend was strengthened by the agricultural policy led by the EU and the US. As an example could be mentioned that the US and EU have sold their surplus with export subsidies, which has put pressure on world market prices while the prices on the protected domestic markets have been held up. Development aid, including the part going to agricultural and rural development, has been halved since the mid 1980s. This, in conjunction with low world market prices, has led to a reduction in investments in agriculture. An expanding market for biofuels and higher prices can lead to new investments followed by higher agricultural yields and hence, better living conditions in rural areas. This would, in turn, lead to diminished poverty among the three-quarters of the world’s poor – 880 million people –who live in rural areas. A large part of the value added is created in the processing

¹⁰⁵ Ivanic M., and Martin W., 2008

¹⁰⁶ Wiggins et al, 2008

and upgrading of the products. The establishment of a new industry, for local processing of the raw material, can create new jobs.

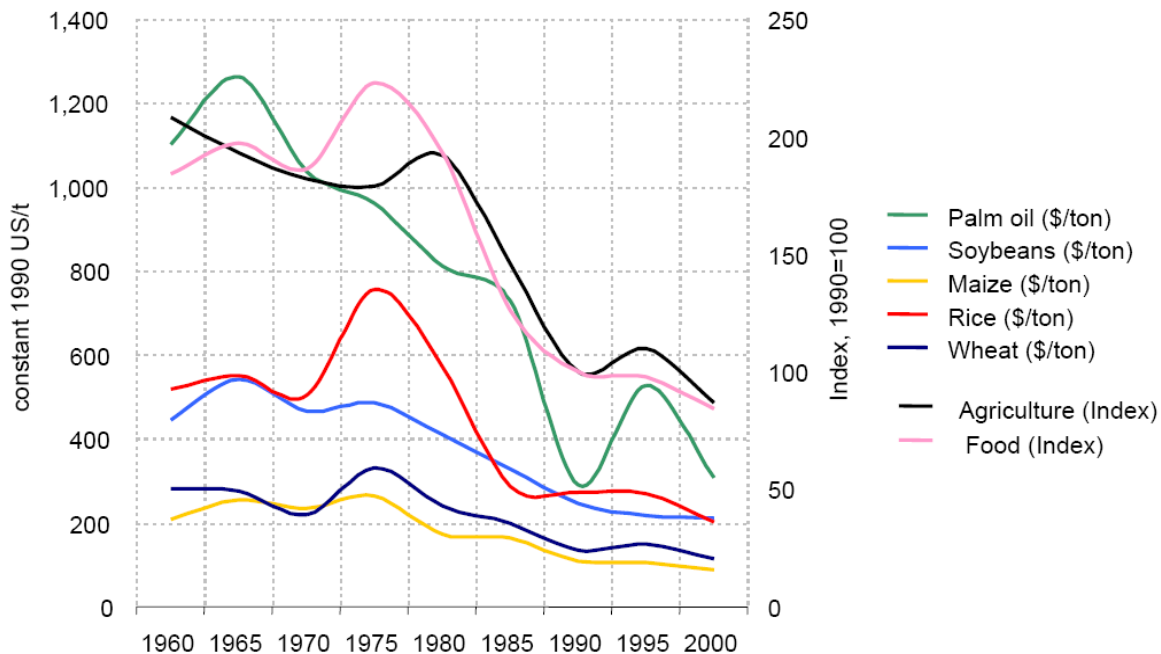


Figure 11.1 The price development for certain food crops 1960-2000 (source: J. Schmidhuber, FAO)

11.2 The effects of current policy

The overwhelming majority of farmers in the developing countries are small holders, 85% of whom have farms smaller than 2 hectares.¹⁰⁷ The question is how these farmers can take advantage of the growing biofuels production. The production of certain biofuels, such as ethanol from sugar cane, is on a large scale. To join large investments in ethanol factories, with small scale production of sugar cane, entails many demands on infrastructure, fair contract agreements, distribution of land rights, financing solutions, logistics, etc. In Brazil, small farmers have entered the market for sugar cane ethanol through the establishment of farmers' cooperatives. Even without access to the market for biofuels, small farmers can be advantaged by higher prices of other agricultural products.

Biofuels and bioenergy do not concern only large-scale production for export to the world market. They also concern small-scale production of fuels such as biodiesel and biogas for local markets

¹⁰⁷ World Bank, 2008

and for utilization in other than the transport sector. Here, the aim is to support a sustainable development for energy with other technical solutions, sometimes based on other energy crops. Even ethanol can be produced on a small scale and utilized locally, for example as fuel for cooking. These kinds of solutions are an important part of many countries' strategies for rural development, the energy system, and reduced dependence on imported oil. High prices of oil, diesel and gasoline constitute a huge problem which aggravates the deficits in the trade balance of many poor countries, as in the case of Mozambique (see paragraph 11.3).

One objection can be made against the comparison of meat consumption and biofuels as causes of price increases for staple goods, since demand for biofuels, to a greater extent, is created through different policy measures. These measures are motivated with arguments concerning both climate- and energy security.¹⁰⁸ An important question then arises; should legitimate aims in these policy areas be recalled due to unwanted effects originating from higher food prices. Or should socio-economic policy, income distribution and support for economic development be seen as more adequate measures to reach varying development goals. Maybe this is a rhetorical question since oil prices already at \$25-30 per barrel make ethanol production profitable in many countries. With oil prices of \$100-150 per barrel many more countries will necessarily develop an alternative to oil, regardless of what we choose here in Sweden or in Europe. In this perspective we should maintain our engagement in the development of biofuels and try to contribute to an environmentally and socially sustainable development.

Many of the questions regarding biofuels and possible problems or opportunities for the developing countries are debated without the participation of these said countries. One exception is a report from the organization Kooperation utan gränser (Cooperation without borders).¹⁰⁹ Here, the message conveyed from several African sources is that biofuels are seen as a possibility to escape from poverty, with the prerequisite that measures to implement sustainable methods of production, both ecologically and socially, are needed. Basically, increased food prices are seen as something positive and great potentials are perceived for increased production by the introduction of improved cultivation methods as well as increased areas under cultivation. The importance of policy and regulations which can help small farmers is emphasized. Thereby, these farmers can take part in the technological development and the profits the development of the market could entail.

¹⁰⁸ Di Lucia L. and Nilsson L.J., 2007

¹⁰⁹ Kooperation utan gränser, 2008

The developing countries have comparative advantages for the production of biofuels as well as for the production of many other food crops. By virtue of its warmer climate, Brazil and other countries produce ethanol with a considerably better energy output and at lower costs than Europe. In many instances these countries have not been able to take advantage of this due to regulations and customs protecting the market in the rich part of the world. Higher food prices should make it easier to reduce subsidies and the border protection for the agricultural sector in the western world. In spite of this, hindrances for the trade of biofuels persist, through import customs on ethanol and the subsidy systems implemented in the US and Europe.

In summary, there are both possibilities and risks involved concerning the increase in demand for biofuels. Even if it is uncertain how food prices will be influenced in the long term, after modernization and adaptations have been made in the agricultural sector, many factors point towards higher prices in the future. This is the situation after three decades of decreasing prices. Elevated prices do have distributional effects which are worrying, but which can not be blamed only on biofuels. Even in the absence of a demand for biofuels there are substantial problems regarding poverty and malnutrition which should motivate measures to help the neediest. These could range from free school food to an extension of the social security system. Any positive development does, however, imply high demands on policy to lead us in the right direction, both in the west and the developing countries. A new development cooperation policy is needed which to a larger degree is focused on agriculture and rural development. New trade- and energy policies are also needed, in order not to undermine these possibilities with the protectionist approach of the developed part of the world. The developing countries need to establish their own policies in order to promote the domestic development of their agricultural sector.

11.3 Case – study Mozambique

In February 2008, Maputo, the capital of Mozambique, one of the poorest countries in the world, experienced violent riots. The uproars, which later spread to other major cities, were caused by the sharp price increases on bread, rice, gasoline and not least the ticket price of local minibuses (the *chapas*). These events shed light on two vital issues for Mozambique: food and oil supply. Mozambique imports all the fuel needed by a relatively small, but rapidly growing, transport sector. Private citizens and the country's trade balance have been hit hard by a doubling of gasoline and oil prices.

In an attempt to follow the success of the Brazilian ethanol program, which was started in the 1970's to reduce oil imports and develop the agricultural sector, the government of Mozambique set

up a commission on biofuels in 2005. The strategy proposed is to establish mandatory use of biofuels in the country, of 10% ethanol in gasoline and 5% biodiesel in diesel. This would rely exclusively on national production and would contribute to job creation and development of rural areas. Rural development has been a top priority for the national strategy for poverty eradication in consideration of the fact that 80% of the population works in agriculture and more than 50% still lives under the line of absolute poverty. Agricultural land is abundant in Mozambique. Out of 36 Mha of arable land only a small part (5 Mha) is currently under cultivation. However, this does not even cover the national food demand due to very low productivity and a generally poorly developed agricultural sector.

The government in Mozambique has taken up the challenge to design a biofuels program that will mitigate the potentially negative impacts of higher food prices for the urban poor and avoid harm to the natural environment. While contributing to rural job creation and generating private income, the government plans to improve the country's trade balance. This will help offset the impacts of higher food and fuels prices, which rest to a great extent beyond government control.

Conclusions

- There are both opportunities and risks for developing countries in the increased demand for biofuels.
- The effects of high food prices are very different depending on which group of people is considered, for example poor urban population or poor farmers in rural areas, in which country, net-importer or net-exporter of food, and also whether a short or a long term perspective is considered, before or after adaptation in the agricultural sector has taken place.
- High food prices have worrying distribution effects, but this is a general problem. Famine and malnutrition are not due to a lack of food in the world, but to poverty.
- Biofuels have put globalization issues on the map, but there is a great variety of products which demand soil for cultivation, implying that these questions are equally relevant for all types of consumption.
- With new markets for biofuels and higher prices of agricultural products the options for poverty reduction increase through new ventures within agriculture and rural development in many countries, especially in southern Africa and South America.
- In order to achieve a positive development, a policy with strict requirements leading in the right direction is needed both for the west and the developing countries.

12. Is today's policy with its policy instruments leading us in the right direction?

The surge in biofuels consumption raises a set of questions regarding its environmental and social effects. It is important to analyze what rules and policies now govern the development and critically evaluate the options and current initiatives.

Only a few years ago biofuels were seen as the solution for a range of problems connected to energy supply, environment and development. Today this is widely questioned. It is broadly recognized that sustainability criteria need to be developed and applied in order to ensure a development which is environmentally as well as socially and economically sustainable. In order to attain this it is vital, among other things, to be able to distinguish and trace different production chains.

12.1 Strategies for sustainable fuels

A fundamental question in the debate is whether it is possible to guarantee sustainable production of biofuels in all aspects, and if so, how it can be done. One problem is that sustainable fuels do not differ in their chemical or physical properties from unsustainable biofuels. A system is needed to ensure sustainability, but how can this be attained in practice? Sustainability requirements introduced through public or private initiatives can be voluntary or mandatory in nature, and require differing degrees of stakeholders' participation

Business voluntary commitment is a business strategy that can be compared to advertising. Following an internal control, or control by a third party, information on the product is released to public and private actors alike. This works as long as the benefits are seen to outweigh the costs.¹¹⁰ Reporting on sustainability aspects can be a company's own initiative, or a demand from society.¹¹¹ Reporting, however, does not put demands on the production of biofuels, it only guarantees that information is available to consumers and officials.

¹¹⁰ Greenergy is a fuel distributor that since 2008 provides information about each consignment of biofuels it supplies to the UK market (www.greenergy.com).

¹¹¹ The national governments in the UK and in the Netherlands have worked to introduce a reporting obligation on fuel suppliers.

Both private and public actors alike are mostly interested in certification schemes for biofuels.¹¹² A certification is a written assurance that a certain product possesses predefined standards. The standard can be formulated by various actors, but the certification itself is always carried out by an independent party. An important part of the certification process is how to verify compliance with the agreed standards.

The most credible and reliable, but expensive option is physical segregation of the products all the way from production to final destination. Other systems offer economic and logistic advantages because they allow the blending of certified and uncertified biofuels during transportation. Another possibility is to completely separate the physical trade in the fuels from the trade in sustainability certificates. The choice of a verification system has impacts on costs and cost distribution, as well as on the accessibility and credibility of the certification.

12.2 Current initiatives for sustainable biofuels

Considerable work has already gone into the development of systems to ensure sustainable production of biofuels. This has been done partly by governments, but also by NGOs and public – private partnerships. Such initiatives include multilateral, regional, bilateral negotiations and unilateral actions.

The EU policy for sustainable biofuels is currently being drafted. In the proposal for the “Directive for renewable energy sources” there is a set of standards on biofuels that must be met in order to account for the attainment of the 10% consumption target established by the Directive.

- a minimum reduction by 35% of greenhouse gas emission
- no conversion of wetlands or continuously forested areas
- no raw material from undisturbed forests, highly biodiverse grassland or nature protection areas.

The EU scheme is important for various reasons. Firstly, compliance will be mandatory in all member countries so that only certified biofuels will receive government support. Secondly,

¹¹² An EU wide certification scheme is currently negotiated by member states and EU institutions. Private certification initiatives are led by non profit organizations - ‘roundtables’, and also private companies such as Sekab in Sweden (www.sekab.com).

national authorities are not allowed to apply different or stricter requirements. Finally, the use of other sustainability schemes will be promoted through an accreditation process managed at EU level.

Currently, the proposal is being discussed by the European Parliament and the Council of EU ministers. The importance of the issue is recognized and highly prioritized, yet the position of the Parliament is towards a lowering of the 10% target, which is the target for 2020 presented by the European Commission. The Council seems to support the 10% target on the condition that all biofuels comply with the requirement of a 35% GHG emission savings by 2015, and a 50% emission reduction by 2017. Although the Directive's proposal could go through many changes before being adopted, questions have been raised regarding the incapacity to handle impacts on land-use changes, food prices and food security, as well as social issues.

The development of the EU framework is running in parallel with the work being carried out by a number of proactive EU governments in the Netherlands, Great Britain and Germany. Principles, criteria and standards for biofuels and biomass have been formulated and are now being integrated into different national policy instruments and support systems. Despite a great deal of effort to develop comprehensive schemes to ensure environmental, social and economic sustainability, the results of these initiatives so far are simple reporting requirements. These reporting requirements are often criticized for focusing on specific aspects, not ensuring minimum levels of sustainability, and not rewarding performance improvements.

Businesses, trade-unions, environmental organizations, traders, distributors and farmers are involved in the development of voluntary certification schemes. The Round Table for Sustainable Palm Oil (RSPO), and the Better Sugar Cane Initiative are examples of such cooperation. Apart from RSPO which is now entering the trial phase, none of these voluntary certification projects has been fully implemented. Hence, it is too soon to assess their practical viability. These initiatives have been recognized for covering a wide variety of environmental and social aspects, but they also have been criticized for limited participation of weak actors and for low credibility, as well as for the absence of systems to calculate GHG emissions. The Round Table for Sustainable Biofuels (RSB) may constitute an exception due to its broad participation and high credibility.

The number of business-led initiatives is also increasing, and range from voluntary commitments (i.e., Greenergy) to specifically created certification schemes (i.e., Sekab). As previously discussed, the credibility and effectiveness of these systems are often questioned, despite the broad range of sustainability aspects included. Voluntary commitments are often the least credible and effective

means to guarantee sustainability. Certification appears to be a suitable first step even if many questions remain. In particular, limited participation of weak actors among the local population in the shaping of standards affects certification's credibility negatively.

Several international organizations such as the OECD, FAO, the IMF, the World Bank, the IEA have taken an active role in the debate. Some of these organizations have become increasingly critical of biofuels. FAO stresses concerns on food security in poor countries and the OECD points to the negative effects of intensified agricultural practices. On the other hand, the World Bank sees opportunities for rural development and poverty reduction in developing countries.

The position of NGOs has also shifted towards a more critical stance. Just two years ago biofuels were seen by many as something very positive. Today, several are outspokenly critical with the argument that the risks are unacceptably high and that a meaningful assurance scheme for sustainability is impossible. Some NGOs have required a moratorium on the support of biofuels.¹¹³ Others again, such as WWF, Birdlife and WCU are less critical and see biofuels at least partly positive if environmental and social aspects are respected. The Swedish NGO Kooperation utan gränser goes further in stressing how biofuel production creates important opportunities for farming and rural development in poor countries.

12.3 Important remaining questions

There are important issues still to be solved for the definition of a certification system for biofuels. Some of the more important ones are discussed below.

Costs and accessibility

Costs and their distribution affect how the benefits are distributed among the actors in the value chain. High certification costs could imply that only large producers gain access to the scheme. In order for biofuels to successfully contribute to the development and poverty reduction of rural areas, also smallholders should be able to participate. Current certification schemes must pay more attention to this. Possible ways to further this include certification of farmers organized in cooperatives, or a reduction of the legal requirements for small farmers.

¹¹³ The moratorium call can be viewed <http://www.econexus.info/biofuels.html>.

International trade rules

Trade restrictions, including certification or other forms of discrimination between products, can be in breach of current international trade agreements. Discussions on the compatibility of certifications with WTO rules are focused on the nature of the certifications. Voluntary schemes are in general allowed since any advantage or disadvantage is the result of the free choice of consumers. Mandatory systems which discriminate between like products (in this case sustainable and non-sustainable fuels would probably be considered 'like products') can be seen as unjustified trade barriers. However, WTO rules allow discrimination for political goals such as environmental protection. It is therefore believed that a system made of objectively measurable standards and aiming at the protection of the environment or biodiversity could be justified. Requirements regarding social development, and non competition with food production, however, are probably not admissible under current WTO rules. All attempts to implement worker rights, eradicate child labor and promote other social aspects have been met with harsh opposition. Nevertheless, one has to ask whether free trade should outweigh issues like the right to food and social wellbeing.

Displacement

Increased use of biofuels is expected to lead to changes in land use. There is growing concern for the effects this will have on, among other things, biological diversity, carbon stocks, food production, and soil and water quality. Potentially large impacts could arise from the interaction of food, fodder, fuel and fiber markets. Biofuels could impact on food production, which in turn could push fodder fields into rain forest areas, for example. These types of indirect effects are difficult to quantify and control by a certification system focusing on a single product such as biofuels. Ideally, sustainability criteria should be applied to all types of production, including production of fossil fuels. Nevertheless, certification schemes are not an effective tool to monitor and control effects on land use.

Fairness

The active participation of consumers in the west and producers in developing countries is often claimed to be a prerequisite for the development of schemes for sustainable production. The application of this principle is challenging and lacking, not least in the area of biofuels. Current initiatives are largely Euro-centric and do not actively encourage cooperation by developing countries. Worldwide, farmers operate in a variety of circumstances, with regard to climate, soil

conditions, infrastructure and financial situations. In spite of this, the standard and certification schemes currently being discussed aim at global implementation. One could argue that by establishing sustainability schemes, industrial countries are creating a premium market for biofuels and for this reason they should have the right to introduce specific demands on such fuels. This, however, should not stop us from asking whether unilateral action is the best way to promote sustainable development. Problems regarding certification and sustainability criteria can easily arise in developing countries, not least in Africa where most countries lack stable institutions, with the consequence that complicated rules and regulations constitute unfair treatment of these countries.

In conclusion, certification is judged to be the most suitable instrument for the development of sustainable biofuel systems. Certification systems can substantially contribute to the sector's sustainability, environmental performance and credibility, but certification also has flaws and cannot guarantee that all sustainability criteria are met. Nevertheless, further development and implementation of certification systems is an important tool to that end. In order to acquire credibility, certification has to be verified by a third, independent party, have mandatory application, be applied equally to foreign and domestic sources and be geared to involve small actors, if rural development and poverty reduction are important objectives.

Finally, two types of problem remain in connection with mandatory certification systems, (i) practical (enforcement and international trade rules), and (ii) effectiveness (indirect effect and displacements). The challenge lies in the development of mechanisms to promote biofuels that do not imply negative land use changes, and which include social safeguards at the national level to guarantee that vulnerable people are not further disadvantaged by increasing food and energy prices. Work is in progress and suggestions include monitoring efforts in cooperation with local authorities to avoid unwanted displacement effects, and supporting local initiatives for the development of land use plans. At the national level, legislation and above all enforcement is needed especially concerning worker rights and child labor. At the international level, bilateral and multilateral agreements between producing and importing countries are both advisable and necessary tools to improve cooperation, enforcement, and thus reduce unfair trade practices.

Conclusions

- Sustainability concerns dominate the current debate on transport biofuels. Decisive for the continued expansion of the sector is how it can fulfil these demands.
- Certification, an important tool currently being developed by many actors at different levels, above all from a Eurocentric perspective, cannot guarantee respect of all sustainability criteria.
- Limitations and problems with certification include over and above the handling of social and labor issues also indirect land-use changes. Apart from this, many developing countries lack stable institutions, which implies that complicated regulations constitute unfair treatment of these countries.
- Certification schemes therefore need to be complemented by bilateral and multilateral international agreements and by other tools which strengthen national legislation and local enforcement.
- Today we have the opportunity to introduce sustainability criteria for biofuels at a global level. Even without these sustainability criteria the production of biofuels will increase, above all in developing countries, with the inherent risk of the development of less sustainable systems.

13. What are the conclusions and the recommendations?

The term “sustainability” entails a variety of different aspects (criteria) in its widest definition, which makes it difficult to come to a general conclusion as to whether vehicle fuel systems are sustainable or not. In order to describe sustainability of a vehicle fuel system, the system is required to be defined from a number of different aspects and factors. When it comes to criteria such as energy balance and area efficiency, it is possible to judge these, while for other criteria such as indirect effects on biodiversity and land competition it is considerably more difficult – the result is here dependent on the total production volume (the scale) but also on the pace of growth. In other words, one cannot decide whether biofuels are sustainable or not without taking into consideration both the *scale* and the *pace of growth*.

In Table 13.1 the different fuel systems are compared from a sustainability point of view in a matrix form based on the conclusions drawn in the separate chapters of this report. The matrix is not complete, but it shows the most important aspects and how vehicle fuel systems can be compared in a systematic way. Furthermore it describes how certification can help in fulfilling the various sustainability criteria. In the matrix a relative comparison between renewable fuel systems (including electricity) in relation to gasoline and diesel is made. For certain criteria this reference is not relevant, in which case Swedish grain-based ethanol is used as reference instead.

Regarding the *energy balance* for biofuels, this is normally highest for electric vehicles and the 2nd generation biofuels, followed by ethanol from sugar cane and biogas from waste products. Today’s Swedish production of ethanol from wheat and RME from rapeseed has also a good energy balance thanks to the by-products being used in an efficient way as protein feed, replacing soy protein feed imported from Brazil. The *area efficiency*, expressed as biofuel output (gross) per hectare of arable land, is a relevant criterion when existing farmland is used for biofuel production. However, area efficiency is less relevant for 2nd generation fuels and biogas based on waste products from forestry and agriculture, and when marginal land, not previously cultivated, is utilised for biomass production. The area efficiency is highest for electric vehicles using energy forest-based electricity produced in combined heat and power plants, followed by ethanol from sugar cane, the 2nd generation biofuels based on gasification of energy forest, and biogas from high yielding crops. Thereafter comes ethanol and at last RME. The area efficiency is in these cases only including the output of biofuels, and not by-products. Both energy balance and area efficiency can be included in certification schemes, but this requires a precise description of the actual biofuel systems to make sure that relevant calculation methods are used.

Tabell 13.1. Comparison of different vehicle fuel systems with regard to a number of sustainability criteria.

Criteria (Refer. system)	Vehicle fuel system							Does certification help?
	Ethanol – grain	Ethanol – sugar cane	Biodiesel – oil seed crops	Biogas	Ethanol – ligno- cellulose	Biofuel – gasification –lignocell.	Electric vehicles	
Energy balance (grain.ethanol =0)	0 optimal use of by-prod.	+	0 optimal use of by-prod.	+	+ energy combination	++	+++ effective electr.-prod.	Yes (but precise system description required, e.g. how by-prod are utilized)
	- other cases	0 irrigation required	- other cases	0 / + crops				
Area eff. (grain.ethanol =0)	0	+	- rapeseed	0 / + crops	0 / + energy forest	+	++ bio heat power	Yes (when crops on productive farmland and woodland is utilized)
			+	Area efficiency is not relevant when waste prod. from farming and forestry is utilized & marginal land is cultivated				
Climate benefit (Gasoline / diesel =0)	+	++	+	+++	++	++	++	Yes (but precise system description required, from cultivation to tank) No - not for indirect effects via displacement effects leading to change in land use
	optimal use of by-prod.		optimal use of by-prod.	manure	energy combination	++	bio heat power	
	0 coal used in prod. fact.		0 high emissions of nitrous oxide	++ Waste prod.	+++ cultivation on marginal land	+++ cultivation on marginal land	0/- fossil electricity	
	- cultivation on carbon- rich land		- cultivation on carbon rich land	+				
&Air pollution. - vehicles (Gasol./die=0)	+	+	0/+	++	+	+ / ++ (gaseous)	+++	Yes
Biolog. diversity water (Grain.ethanol = 0)	0	0	0	+	+	+	0 existing land use	Yes - direct effects No - indirect effects via displacement
		- irrigation			0/- forest raw mat.	0/- forest raw mat.		
Need of tech. development (Gasol./die=0)	-	0 / -	-	--	---	---	--	Not relevant
Need of Financ. support (Gasol./die =0)	- today	0 today	- today	- today	-- today	-- today	-- today	Not relevant
	0 10-20 years	+	0 10-20 years	0 / + 10-20 years	+	+	+	
Economic effects dev. countries (Gasol./ die =0)	- / 0 / +	0 / +	- / 0	+	0 / +	0 / +	0	Yes, partly
Social effects dev. countries (Gasol./die = 0)	These are controlled by national legislation and compliance							No (conflicts with among other things int. trade rules)

Nil (0) indicates no/marginal effects compared to reference (see lefthand column), plus (+) positive effect and minus (-) negative effects. The more positive/negative effect, the more (+) or (-), respectively (up to +++ respective ---).

There are great *climate benefits* to be won from vehicles using biomass-based electricity, 2nd generation fuels as well as sugar cane ethanol (compared to gasoline and diesel). In particular, substantial climate benefits are gained from vehicles using biogas from waste products such as manure and from 2nd generation fuels produced from forest raw material grown on marginal land with low carbon content. Grain ethanol and RME also have climate benefits due to the climate-efficient use of their by-products, such as protein feed replacing imported soy protein, which leads to substantial indirect climate gains. In these cases the production volume impacts on the climate gains since the protein feed market will eventually be sated, but the domestic production of ethanol and RME can continue to increase many times over before this will happen. In future, new solutions can then be developed for grain ethanol and RME production, for example in combination with biogas production, with good greenhouse gas performance. If the cultivation of grain and oil seed plants takes place on land rich in carbon, for instance peat land, which is currently being used for pasture, the climate benefits from ethanol and RME are lost, due to the carbon emissions from the tilled land. The same goes for electric cars using coal-based electricity.

All these aspects regarding climate benefits can be included and conditioned in the certification scheme, but an inherent flexibility is also needed in the certification systems which allows for the variations in different systems. In this way the certification system can become a motive for the continued development and improvement of the biofuels system, from a climate point-of-view. If however, certification systems become too general and imprecise and do not allow for local and regional variations, in the worst case scenario, this could bolster today's partly good biofuels system in Europe and other places in the world and counteract an improvement of these systems. An important aspect also in need of being highlighted is how the biogenic emission of nitrous oxide from cultivated land should be taken into consideration in a certification system, since there are great uncertainties regarding these emissions.

As discussed above, it is considered possible to include direct effects on land use in a certification system. On the other hand, is it very difficult, if not impossible, to include indirect effects on land use which lead to changes of the carbon flow via displacement effects. An indirect land use change, for example, cultivation of new farmland, can arise from all sorts of cultivation (food and feed production etc.), these effects must be handled with other measures and tools, for example, national plans and programs for sustainable land use as well as the compliance with these rules and regulations. The same goes for indirect effects on biological diversity by way of displacement effects. Indirect effects on land use can be seen as intimately connected with future production volumes of food, feed, forest raw material, biofuels etc.

It should be possible to include direct effects on *biological diversity* and the use of *water resources* from biofuel production in a certification system. The increased cultivation of perennial crops for the production of, for example, biogas or 2nd generation biofuels, can have a certain positive effect on the biological diversity in the agriculture landscape, when these replace annual energy crops. Use of biomass residues from forestry is judged to have a marginal effect on biological diversity when this is done by appropriate methods (including recirculation of wood ash). A degree of uncertainty exists regarding the harvesting of tree stumps in certain forest environments. This requires further study. Today, biofuels are being produced almost without artificial irrigation, but an increase in production of especially sugar cane ethanol in southern Africa could lead to an increase in the use of water resources. This could in its turn lead to negative effects on the sustainability of these biofuel systems, which a certification system and other policy instruments, nationally adapted, should be able to manage.

The transition from fossil vehicle fuels to biofuels and electricity is presumed to lead to diminished emissions of *air pollution* from vehicles (on the street). These local environmental gains will arise first and foremost from the use of electric vehicles, followed by gaseous fuel vehicles and vehicles running on alcohol fuels. This aspect can be included in the certification system. Regarding the need of *technical development* for various fuel systems, these are prevalent for the 2nd generation fuels, followed by electric vehicles and biogas. In these areas, investment in the technical development is a prerequisite. There is also a potential for development of grain-based ethanol and RME production, while the need for technical development of sugar cane-based ethanol is judged to be slighter. This aspect is not relevant in a certification system.

A significant need of technical development also requires a significant need of *financial support* in order to go from pilot projects on a trial scale, to commercial scale with competitive prices. Today, only sugar cane ethanol is competitive with gasoline and diesel without subsidies or carbon dioxide taxation. When production of 2nd generation fuels becomes reality on a commercial and large scale, these biofuels are expected to become, together with the developed systems for electric vehicles, biogas from waste products as well as sugar cane ethanol, the most competitive compared with fossil vehicle fuels. In the case of increased prices of fossil vehicle fuels, due to higher oil prices and/or high CO₂ fees, even 1st generation biofuels can become competitive due to a general reduction of production costs through the on-going development of the entire system, from cultivation to end product. The competitiveness here largely depends on the development of the entire agricultural sector. These aspects are not relevant for inclusion in a certification.

Regarding the *economic effects on developing countries* of increased biofuel production, these can vary from negative to positive, depending on a variety of factors, such as whether countries are net importers or net exporters of food, whether the countries are highly dependent on imported oil, whether the poor on the land or in the city are being considered, etc. The risk of negative effects is judged to be highest for biofuels based on agricultural crops such as grain and oil seed plants and in short-term perspectives, while fuels based on different kinds of waste products from forestry and agriculture are seen as implying fewer risks. Quite the contrary, the utilization of waste products, together with an increased cultivation on available fields not used due to too low profitability, involves marginal risks and potentially great gains. There is also a great potential for development in the agricultural sector in many developing countries, which can lead to a significant production increase on existing farmland and which again entail less competition between food and energy production. These increases can come about thanks to a rise in demands on biofuels and foods etc. which again leads to an improved profitability for many farmers. In these cases, the adequate pace of growth is of major importance for the agricultural sector, in order to make possible corresponding development. Simultaneously, the development of parallel frameworks and regulations can ensure that increase in revenue will go to local farmers and farm hands and ensure rural development. To a certain extent it will be possible to include these aspects in certification schemes, but they will need to be supplemented by other tools and political measures. International trade rules (WTO- rules) do allow for a certain implementation of measurable standards with the aim of protecting the environment and climate.

An important criterium for sustainable vehicle fuel production, and all production, in above all developing countries, are *social aspects* such as workers' rights, child labor etc. These are, however, difficult or even impossible aspects to include in certification schemes today. In part current WTO rules make requirements for social developments unfeasible, in part, these problem needs solution through other measures and at national levels, with precise legislation and tools, as well as through improved control of the compliance with these. A way to facilitate this development is through bilateral and multilateral agreements and contracts.

To sum up, we consider the biofuels used in Sweden today (domestically produced and imported) to be sustainable, based on the production volume currently used. An increase in production and use of these 1st generation biofuels will also facilitate the development of 2nd generation fuels, which are often even more effective and can be produced in even greater volumes. How large the volumes are that can be produced "sustainably" depends in large part on general societal factors, such as legislation, agricultural development, trade policy etc. which influence social and economic criteria

for sustainability. The growth rate also influences whether fuels are developed to be sustainable or not, since there is a risk that a growth rate that is too fast can lead to a certain sub-optimization and hence the use of less sustainable systems. On the other hand, an adjusted growth rate could lead to increased potential for sustainable vehicle fuels by rendering more effective agricultural production on existing farmland (which will diminish the risk of land competition), develop more effective biofuel production combinations and ensure that synergy between today's technology and that of the future (1st and 2nd generation fuels) are being handled in an effective way. In other words, the society in general (infrastructure, research and development, structural transformation of the agriculture, rural development, legislation etc.) has to manage to develop at the same rate, since renewable fuels affect so many different sectors.

Whether today's investments on biofuels will be seen as an expensive dead end or as an important step towards a sustainable transport system depends on how we choose to go on with these investments. We have the opportunity to make the most of the will to invest, and the knowledge which exists today and steer the development towards yet more effective biofuels, also sustainable at increased production volumes. The use of proposed sustainability criteria is an important part of this. For the society in general it is important to use policy instruments properly so that we can continue our course towards this development. For the car industry and fuels distributors, the proposed sustainability criteria can give a hint as to where the development is going and which requirements can become obligatory in the future.

To close ones eyes to the recent years' criticism and push the development of fuels fast forward without any sustainability requirements will lead to unacceptable consequences and insufficient support, both from important actors and from the general public. A moratorium implemented for biofuels is an equally poor alternative. Taking the wind out of the growing biofuels industry will not advantage the development of 2nd generation biofuels or boost the confidence between politicians and investors. Instead we should focus on the potential interplay and the ability to complement each other, which exist between the different technical platforms, for current and future biofuels systems.

To sum up, these are our recommendations regarding choice of vehicle fuels based on the current sustainability criteria discussed in this report:

- High priority should be given to the development of fuel-efficient cars, in this field electrical hybrid technology and electric cars will grow in importance.
- Any long-term strategy for biofuels should include investments on technology for both thermal gasification and biological methods of transformation for lignocellulose, since these are complementing as much as competing technologies and increase the flexibility as well as decrease the risk of conflicts (land-use etc.).
- Today's biofuels in Sweden are sustainable at the present production volume and promote the further development of new vehicle fuel systems, but we need precise demands for the energy and climate efficiency in the entire fuel chain (from cultivation to tank) for the case of increased production volumes.
- Biogas from waste products has great environmental advantages and can expand with little risk of conflict. Furthermore, today it is well suited for regional vehicle fleets, pending further development of the infrastructure.
- Certifications (correctly framed) are important and necessary tools on the way towards more sustainable vehicle fuels and increased production volumes, but these systems should not be overrated as they can never contain all sustainability criteria.
- Socio-economic aspects such as working conditions, rural development etc. must in the first place be solved by general measures such as national laws, distribution policy, programs and plans, all of which ought to be supported by international agreements and development cooperation at various levels.
- Irrespective of the development in Sweden or the EU, global production of biofuels will increase, not least in the developing countries. It is therefore important to deal well with the opportunity we have today to participate in the development and implementation of sustainability criteria.
- Renewable fuels can, with the correct framing and guidance for adequate pace of growth and production volumes, lead to a positive as well as sustainable development in both industrial and developing countries.

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