INTERNATIONAL ENERGY AGENCY
AGENCE INTERNATIONALE DE L'ENERGIE

FROM 1st- TO 2nd-GENERATION BIOFUEL TECHNOLOGIES

An overview of current industry and RD&D activities

EXTENDED EXECUTIVE SUMMARY

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INTERNATIONAL ENERGY AGENCY

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- To promote rational energy policies in a global context through co-operative relations with non-member countries, industry and international organisations.
- To operate a permanent information system on the international oil market.
- To improve the world's energy supply and demand structure by developing alternative energy sources and increasing the efficiency of energy use.
- To promote international collaboration on energy technology.
- To assist in the integration of environmental and energy policies.

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The OECD member countries are: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Republic of Korea, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom and United States. The European Commission takes part in the work of the OECD.

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Extended Executive Summary

It is increasingly understood that 1st-generation biofuels (produced primarily from food crops such as grains, sugar beet and oil seeds) are limited in their ability to achieve targets for oil-product substitution, climate change mitigation, and economic growth. Their sustainable production is under review, as is the possibility of creating undue competition for land and water used for food and fibre production. A possible exception that appears to meet many of the acceptable criteria is ethanol produced from sugar cane.

The cumulative impacts of these concerns have increased the interest in developing biofuels produced from non-food biomass. Feedstocks from ligno-cellulosic materials include cereal straw, bagasse, forest residues, and purpose-grown energy crops such as vegetative grasses and short rotation forests. These "2nd-generation biofuels" could avoid many of the concerns facing 1st-generation biofuels and potentially offer greater cost reduction potential in the longer term.

This report looks at the technical challenges facing 2nd-generation biofuels, evaluates their costs and examines related current policies to support their development and deployment. The potential for production of more advanced biofuels is also discussed. Although significant progress continues to be made to overcome the technical and economic challenges, 2nd-generation biofuels still face major constraints to their commercial deployment. Policy recommendations are given as to how these constraints might best be overcome in the future.

The key messages arising from the study are as follows.

- Technical barriers remain for 2nd-generation biofuel production.
- Production costs are uncertain and vary with the feedstock available, but are currently thought to be around USD 0.80 – 1.00/litre of gasoline equivalent.
- There is no clear candidate for "best technology pathway" between the competing biochemical and thermo-chemical routes. The development and monitoring of several large-scale demonstration projects is essential to provide accurate comparative data.
- Even at high oil prices, 2nd-generation biofuels will probably not become fully commercial nor enter the market for several years to come without significant additional government support.
- Considerably more investment in research, development, demonstration and deployment (RDD&D) is needed to ensure that future production of the various biomass feedstocks can be undertaken sustainably and that the preferred conversion technologies, including those more advanced but only at the R&D stage, are identified and proven to be viable.
- Once proven, there will be a steady transition from 1st- to 2nd-generation biofuels (with the exception of sugarcane ethanol that will continue to be produced sustainably in several countries).

A) First Generation Biofuels

Current status

The production of 1st-generation biofuels - such as sugarcane ethanol in Brazil, corn ethanol in US, oilseed rape biodiesel in Germany, and palm oil biodiesel in Malaysia - is characterised by mature commercial markets and well understood technologies. The global demand for liquid biofuels more than tripled between 2000 and 2007. Future targets and investment plans suggest strong growth will continue in the near future.

The main drivers behind the policies in OECD countries that have encouraged this growth are:

- energy supply security;
- support for agricultural industries and rural communities;
- reduction of oil imports, and
- the potential for greenhouse gas (GHG) mitigation.

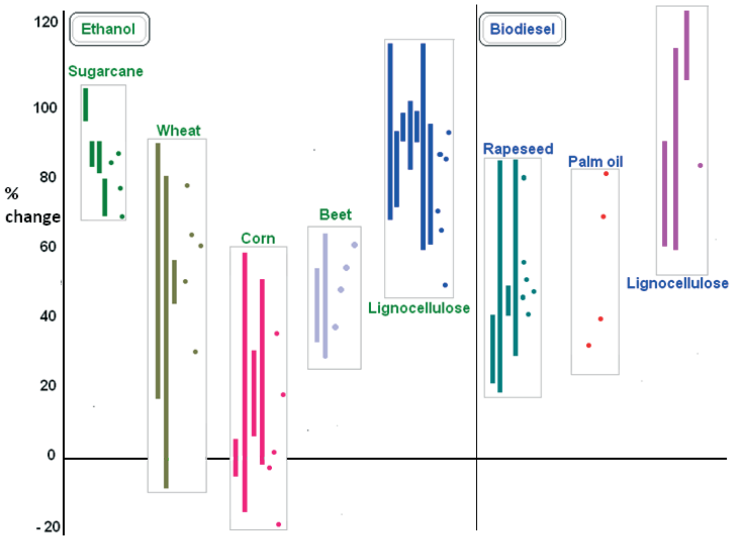
Recent fluctuating oil prices and future supply constraints have emphasised the need for non-petroleum alternatives. Several non-OECD countries have developed their own biofuel industries to produce fuels for local use, as well as for export, in order to aid their economic development. Many others are considering replicating this model. Driven by supportive policy actions of national governments, biofuels now account for over 1.5% of global transport fuels (around 34 Mtoe in 2007).

Constraints and concerns

While most analyses continue to indicate that 1st-generation biofuels show a net benefit in terms of GHG emissions reduction and energy balance, they also have several drawbacks. Current concerns for many, but not all, of the 1st-generation biofuels are that they:

- contribute to higher food prices due to competition with food crops;
- are an expensive option for energy security taking into account total production costs excluding government grants and subsidies;
- provide only limited GHG reduction benefits (with the exception of sugarcane ethanol, Fig. 1) and at relatively high costs in terms of $ /tonne of carbon dioxide ($ /t CO_2) avoided;
- do not meet their claimed environmental benefits because the biomass feedstock may not always be produced sustainably;
- are accelerating deforestation (with other potentially indirect land use effects also to be accounted for);
- potentially have a negative impact on biodiversity; and
- compete for scarce water resources in some regions.

Figure 1. Well-to-wheel emission changes for a range of 1st- and 2nd-generation biofuels (excluding land use change) compared with gasoline or mineral diesel.



Source: OECD, 2008 based on IEA and UNEP analysis of 60 published life-cycle analysis studies giving either ranges (shown by the bars) or specific data (shown by the dots).

Additional uncertainty has also recently been raised about GHG savings if indirect land use change is taken into account. Certification of biofuels and their feedstocks is being examined, and could help to ensure biofuels production meets sustainability criteria, although some uncertainty over indirect land-use impacts is likely to remain. Additional concerns over the impact of biofuels on biodiversity and scarce water resources in some countries also need further evaluation.

Most authorities agree that selected 1st-generation biofuels have contributed to the recent increases in world prices for food and animal feeds. However, much uncertainty exists in this regard and estimates of the biofuels contribution in the literature range from 15-25% of the total price increase (with a few at virtually zero or up to 75%). Regardless of the culpability, competition with food crops will remain an issue so long as 1st-generation biofuels produced from food crops dominate total biofuel production.

Production and use of some biofuels can be an expensive option for reducing GHG emissions and improving energy security. Estimates in the literature for GHG mitigation from biodiesel and corn ethanol vary depending on the country and pathway, but mostly exceed USD 250 /t CO_2 avoided. Given the relatively limited scope for cost reductions and growing global demand for food, little improvement in these mitigation costs can be expected in the short term.

B) Second Generation Biofuels

Many of the problems associated with 1st-generation biofuels can be addressed by the production of biofuels manufactured from agricultural and forest residues and from non-food crop feedstocks. Where the ligno-cellulosic feedstock is to be produced from specialist energy crops grown on arable land, several concerns remain over competing land use, although energy yields (in terms of GJ/ha) are likely to be higher than if crops grown for 1st-generation biofuels (and co-products) are produced on the same land. In addition poorer quality land could possibly be utilised.

These 2nd-generation biofuels are relatively immature so they should have good potential for cost reductions and increased production efficiency levels as more experience is gained. Depending partly on future oil prices, they are therefore likely to become a part of the solution to the challenge of shifting the transport sector towards more sustainable energy sources at some stage in the medium-term. However, major technical and economic hurdles are still to be faced before they can be widely deployed.

To address these issues, significant investment in RD&D funding by both public and private sources is occurring. In addition, there has been significant investment in pilot and demonstration facilities, but more is likely to be required in the near future if rapid commercial deployment of these technologies is to be supported.

Given the current investments being made to gain improvements in technology, some expectations have arisen that, in the near future, these biofuels will reach full commercialisation. This would allow much greater volumes to be produced at the same time as avoiding many of the drawbacks of 1st-generation biofuels. However, from this IEA analysis, it is expected that, at least in the near to medium-term, the biofuel industry will grow only at a steady rate and encompass both 1st- and 2nd-generation technologies that meet agreed environmental, sustainability and economic policy goals.

Production of 1st-generation biofuels, particularly sugarcane ethanol, will continue to improve and therefore they will play a continuing role in future biofuel demand. The transition to an integrated 1st- and 2nd generation biofuel landscape is therefore most likely to encompass the next one to two decades, as the infrastructure and experiences gained from deploying and using 1st-generation biofuels is transferred to support and guide 2nd-generation biofuel development. Once 2nd-generation biofuel technologies are fully commercialised, it is likely they will be favoured over many 1st-generation alternatives by policies designed to reward national objectives such as environmental performance or security of supply. In the mid- to long-term, this may translate into lower levels of investment into 1st-generation production plants.

Ligno-cellulosic feedstocks

Low-cost crop and forest residues, wood process wastes, and the organic fraction of municipal solid wastes can all be used as ligno-cellulosic feedstocks. Where these materials are available, it should be possible to produce biofuels with virtually no additional land requirements or impacts on food and fibre crop production. However in many regions these residue and waste feedstocks may have limited supplies, so the growing of vegetative grasses or short rotation forest crops will be necessary as supplements. Where potential energy crops can be grown on marginal and degraded land, these would not compete directly with growing food and fibre crops which require better quality arable land.

Relatively high annual energy yields from dedicated energy crops, in terms of GJ/ha/yr, can be achieved from these crops compared with many of the traditional food crops currently grown for 1st-generation biofuels. Also their yields could increase significantly over time since breeding research (including genetic modification) is at an early phase compared with the breeding of varieties of food crops. New varieties of energy crops may lead to increased yields, reduced water demand, and lower dependency on agri-chemical inputs. In some regions where low intensity farming is currently practised, improved management of existing crops grown on arable land could result in higher yields per hectare. This would enable energy crops to also be grown without the need for increased deforestation or reduction in food and fibre supplies.

Supply chain issues

Harvesting, treating, transporting, storing, and delivering large volumes of biomass feedstock, at a desired quality, all-year-round, to a biofuel processing plant requires careful logisitical analysis prior to plant investment and construction. Supplies need to be contracted and guaranteed by the growers in advance for a prolonged period in order to reduce the project investment risks. The aims should be to minimise production, harvest and transport costs and thereby ensure the economic viability of the project. This issue is often inadequately taken into account when 2nd-generation opportunities are considered. Supply logistics will become more important as development accelerates and competition for biomass feedstocks arises. Reducing feedstock delivery and storage costs should be a goal since feedstock costs are an important component of total biofuel costs.

Conversion routes

The production of biofuels from ligno-cellulosic feedstocks can be achieved through two very different processing routes. They are:

- biochemical – in which enzymes and other micro-organisms are used to convert cellulose and hemicellulose components of the feedstocks to sugars prior to their fermentation to produce ethanol;
- thermo-chemical – where pyrolysis/gasification technologies produce a synthesis gas ($CO + H_2$) from which a wide range of long carbon chain biofuels, such as synthetic diesel or aviation fuel, can be reformed.

These are not the only 2nd generation biofuels pathways, and several variations and alternatives are under evaluation in research laboratories and pilot-plants. They can produce biofuel products either similar to those produced from the two main routes or several other types including dimethyl ether, methanol, or synthetic natural gas. However, at this stage these alternatives do not represent the main thrust of RD&D investment.

Following substantial government grants recently made to help reduce the commercial and financial risks from unproven technology and fluctuating oil prices, both the biochemical enzyme hydrolysis process and the thermo-chemical biomass-to-liquid (BTL) process have reached the demonstration stage. Several plants in US and Europe are either operating, planned or under construction. A number of large multi-national companies and financial investors are closely involved in the various projects and considerable public and private investments have been made in recent years. As more of these demonstration plants come on-line over the next 2-3 years they will be closely monitored. Significant data on the performance of different conversion routes will then become available, allowing governments to be better informed when making strategic policy decisions for 2nd-generation development and deployment.

Based on the announced plans of companies developing 2nd-generation biofuel facilities, the first fully commercial-scale operations could possibly be seen as early as 2012. However, the successful demonstration of a conversion technology will be required first in order to meet this target. Therefore given the complexity of the technical and economic challenges involved, it could be argued that in reality, the first commercial plants are unlikely to be widely deployed before 2015 or 2020. Therefore to what degree 2nd-generation biofuels can significantly contribute by 2030 to meeting the global transport fuel demand remains debatable.

Preferred technology route

There is currently no clear commercial or technical advantage between the biochemical and thermo-chemical pathways, even after many years of RD&D and the development of near-commercial demonstrations. Both sets of technologies remain unproven at the fully commercial scale, are under continual development and evaluation, and have significant technical and environmental barriers yet to be overcome.

For the biochemical route, much remains to be done in terms of improving feedstock characteristics; reducing the costs by perfecting pretreatment; improving the efficacity of enzymes and lowering their production costs; and improving overall process integration. The potential advantage of the biochemical route is that cost reductions have proved reasonably successful to date, so it could possibly provide cheaper biofuels than via the thermo-chemical route.

Conversely, as a broad generalisation, there are less technical hurdles to the thermo-chemical route since much of the technology is already proven. One problem concerns securing a large enough quantity of feedstock for a reasonable delivered cost at the plant gate in order to meet the large commercial-scale required to become economic (Table 1). Also perfecting the gasification of biomass reliably and at reasonable cost has yet to be achieved, although good progress is being made. An additional drawback is that there is perhaps less opportunity for cost reductions (excluding several untested novel approaches under evaluation).

Table 1. Typical scale of operation for various 2nd-generation biofuel plants using energy crop-based ligno-cellulosic feedstocks.

Type of plant	Plant capacity ranges, and assumed annual hours of operation.	Biomass fuel required. (oven dry tonnes / year)	Truck vehicle movements for delivery to the plant.	Land area required to produce the biomass. (% of total land within a given radius).
Small pilot	15 000-25 000 l/yr 2000 hr	40-60	3 - 5 / yr	1 - 3% within 1 km radius
Demonstration	40000-500 000 l/yr 3000 hr	100-1200	10 - 140 / yr	5 - 10% within 2 km radius
Pre-commercial	1-4 Ml/yr 4000 hr	2000-10 000	25 - 100 / month	1 - 3% within 10km radius
Commercial	25-50 Ml/yr 5000 hr	60,000-120,000	10 - 20 / day	5 - 10% within 20 km radius
Large commercial	150-250 Ml/yr 7000 hr	350,000-600,000	100 - 200 / day and night	1-2% within 100km radius

Note: The land area requirement would be reduced where crop and forest residue feedstocks are available.

One key difference between the biochemical and thermo-chemical routes is that the lignin component is a residue of the enzymatic hydrolysis process and hence can be used for heat and power generation. In the BTL process it is converted into synthesis gas along with the cellulose and hemicellulose biomass components. Both processes can potentially convert 1 dry tonne of biomass (~20GJ/t) to around 6.5 GJ/t of energy carrier in the form of biofuels giving an overall biomass to biofuel conversion efficiency of around 35%. Although this efficiency appears relatively low, overall efficiencies of the process can be improved when surplus heat, power and co-product generation are included in the total system. Improving efficiency is vital to the extent that it reduces the final product cost and improves environmental performance, but it should not be a goal in itself.

Although both routes have similar potential yields in energy terms, different yields, in terms of litres per tonne of feedstock, occur in practice. Major variations between the various processes under development, together with variations between biofuel yields from different feedstocks, gives a complex picture with wide ranges quoted in the literature. Typically enzyme hydrolysis could be expected to produce up to 300 l ethanol / dry tonne of biomass whereas the BTL route could yield up to 200 l of synthetic diesel per tonne (Table 2). The similar overall yield in energy terms (around 6.5 GJ/t biofuels at the top of the range), is because synthetic diesel has a higher energy density by volume than ethanol.

Table 2. Indicative biofuel yield ranges per dry tonne of feedstock from biochemical and thermo-chemical process routes.

	Biofuel yield (litres/ dry t)		Energy content (MJ/l)	Energy yields (GJ/t)	
Process	**Low**	**High**	**Low heat value**	**Low**	**High**
Biochemical Enzymatic hydrolysis ethanol	110	300	21.1	2.3	6.3
Thermo-chemical Syngas-to-Fischer Tropsch diesel	75	200	34.4	2.6	6.9
Syngas-to- ethanol	120	160	21.1	2.5	3.4

A second major difference is that biochemical routes produce ethanol whereas the thermo-chemical routes can also be used to produce a range of longer-chain hydrocarbons from the synthesis gas. These include biofuels better suited for aviation and marine purposes. Only time will tell which conversion route will be preferred, but whereas there may be alternative drives becoming available for light vehicles in future (including hybrids, electric plug-ins and fuel cells), such alternatives for aeroplanes, boats and heavy trucks are less likely and liquid fuels will continue to dominate.

Production costs

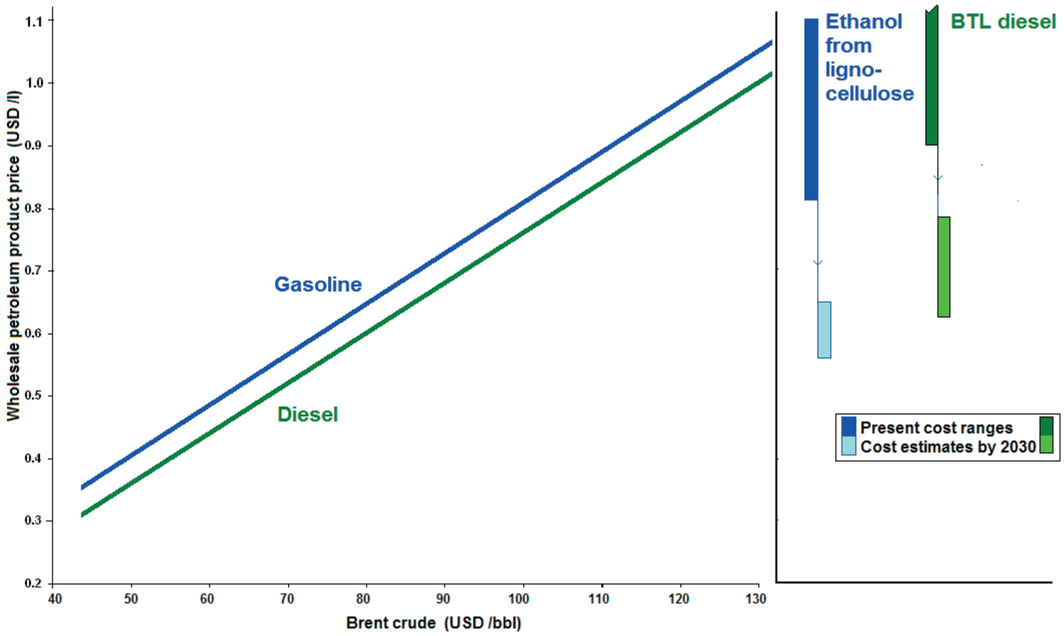
The full biofuel production costs associated with both pathways remain uncertain and are treated with a high degree of commercial propriety. Comparisons between the biochemical and thermo-chemical routes have proven to be very contentious within the industry, with the lack of any real published cost data being a major issue for the industry.

The commercial-scale production costs of 2nd-generation biofuels have been estimated by the IEA to be in the range of USD 0.80 – 1.00/litre of gasoline equivalent (lge) for ethanol and at least USD 1/litre of diesel equivalent for synthetic diesel (Table 3). This range broadly relates to gasoline or diesel wholesale prices (measured in USD /lge) when the crude oil price is between USD 100-130 /bbl (Fig. 2). The present widely fluctuating oil and gas prices therefore make investment in 2nd-generation biofuels at current production costs a high risk venture, particularly when other alternatives to conventional oil such as new heavy oil, tar sands, gas-to-liquids and coal-to-liquids can compete with oil when around USD 65/bbl taking into account infrastructural requirements, environmental best practices and an acceptable return on capital but excluding any future penalty imposed for higher CO_2 emissions per kilometre travelled when calculated on a life cycle basis.

Table 3. IEA 2nd-generation biofuel cost assumptions for 2010, 2030 and 2050

Lignocellulosic conversion technology	Assumptions	Production cost- By 2010 USD /lge	By 2030 USD /lge	By 2050 USD /lge
Bio-chemical ethanol	Optimistic	0.80	0.55	0.55
	Pessimistic	0.90	0.65	0.60
BTL diesel	Optimistic	1.00	0.60	0.55
	Pessimistic	1.20	0.70	0.65

Figure 2. Production cost ranges for 2nd-generation biofuels in 2006 (USD / litre gasoline equivalent) compared with wholesale petroleum fuel prices correlated with the crude oil price over a 16 month period, and 2030 projections assuming significant investment in RDD&D.



Source: Based on IEA World Energy Outlook, 2006, section on biofuels.

The main reasons for the major discrepancies between various published cost predictions relate to varying assumptions for feedstock costs and future timing of the commercial availability of both the feedstock supply chain and conversion technologies. Given that 2nd-generation biofuels are still at the pre-commercial stage, widespread deployment is expected to lead to the improvement of technologies, reduced costs from plant construction and operation experience, and other "learning by doing" effects. The potential for cost reductions is likely to be greater for ethanol produced via the biochemical route than for liquid fuels produced by the thermo-chemical route, because much of the technology for BTL plants (based on Fischer-Tropsch conversion) is mature and the process mainly involves linking several proven components together. So there is limited scope for further cost reductions. However if commercialisation succeeds in the 2012-2015 time frame and rapid deployment occurs world-wide beyond 2020, then costs could decline to between USD 0.55 and 0.60/lge for both ethanol and synthetic diesel by 2030. Ethanol would then be competitive at around USD 70/bbl (2008 dollars) and synthetic diesel and aviation fuel at around USD 80/bbl. By 2050, costs might be further reduced for biofuels to become competitive below USD 70/bbl. `

Successful development - technology and knowledge challenges

Success in the commercial development and deployment of 2nd-generation biofuel technologies will require significant progress in a number of areas if the technological and cost barriers they currently face are to be overcome. Areas that need attention are outlined below.

Improved understanding of feedstocks, reduction in feedstock costs and development of energy crops

- A better understanding of currently available feedstocks, their geographic distribution and costs is required. Experience in the production of various dedicated feedstocks (e.g. switchgrass, miscanthus, poplar, eucalyptus and willow) in different regions should be undertaken to understand their yields, characteristics and costs.
- The ideal characteristics of specific feedstocks to maximise their conversion efficiencies to liquid biofuels need to be identified, as well as the potential for improving feedstocks over time. Rates of improvement could then be maximised through R&D investment.
- On a micro-scale, the implementation of energy crop production needs to be assessed to ascertain the area within a given collection radius sufficient to supply a commercial-scale plant. Although in some regions there may be enough agricultural and forest residues available to support several processing plants, it is likely that large-scale production will require dedicated energy crops either as a supplement or in some regions as the sole feedstock. The optimal size of production facility, after trading off economies of scale against using local, reliable and cost-effective feedstock supplies, should be identified for a variety of situations.

Technology improvements for the biochemical route, in terms of feedstock pre-treatment, enzymes and efficiency improvement and cost reduction

- Feedstock pre-treatment technologies are inefficient and costly. Improvements in physical, chemical and combinations of these pre-treatments need to be achieved to maximise the efficacy of pre-treatment in opening up the cellular structure of the feedstock for subsequent hydrolysis. Dilute and concentrated acid processes are both close to commercialisation, although steam explosion is considered as state-of-the-art.
- New and/or improved enzymes are being developed. The effective hydrolysis of the interconnected matrix of cellulose, hemicellulose and lignin requires a number of cellulases, those most commonly used being produced by wood-rot fungi such as *Trichoderma*, *Penicillum*, and *Aspergillus*. However, their production costs remain high. The presence of product inhibitors also needs to be minimised. Recycling of enzymes is potentially one avenue to help reduce costs. Whether separate or simultaneous saccharification and fermentation processes represent the least cost route for different feedstocks is yet to be determined.
- A key goal for the commercialisation of ligno-cellulosic ethanol is that all sugars (C5 pentoses and C6 hexoses) released during the pre-treatment and hydrolysis steps are fermented into ethanol. Currently, there are no known natural organisms that have the ability to convert both C5 and C6 sugars at high yields, although major progress has been made in engineering micro-organisms for the co-fermentation of pentose and glucose sugars. The conversion of glucose to ethanol during fermentation of the enzymatic hydrolysate is not difficult provided there is an absence of inhibitory substances such as furfural, hydroxyl methyl furfural, or natural wood-derived inhibitors such as resin acids.
- The need to understand and manipulate process tolerance to ethanol and sugar concentrations and resistance to potential inhibitors generated in pre-saccharification treatments, remains a scientific goal. Solutions to these issues will also need to accommodate the variability within biomass feedstocks. While pentose fermentation has been achieved on ideal substrates (such as laboratory

preparations of sugars designed to imitate a perfectly-pretreated feedstock), significant work remains to apply this to actual ligno-cellulosic feedstocks.

- Due to the large number of individual processes in the overall conversion of ligno-cellulosic biomass into bioethanol, there remains considerable potential for process integration. This could have benefits in terms of lower capital and operating costs, as well as ensuring the optimum production of valuable co-products. Given that development is still at the pre-commercial stage, it may take some time to arrive at the most efficient process pathways and systems.

Technology improvements for the thermo-chemical route, in terms of feedstock pre-treatment, gasification and efficiency improvement and cost reductions

- BTL faces the challenge of developing a gasification process for the biomass at commercial-scale to produce synthesis gas to the exacting standards required for a range of biofuel synthesis technologies such as Fischer-Tropsch (FT). In spite of many years of research and commercial endeavours and recent progress, cost effective and reliable methods of large-scale biomass gasification remain elusive. The goal should be to develop reliable technologies that have high availability and produce clean gas that does not poison the FT catalysts, or that can be cleaned up to meet these standards without significant additional cost. Given the constraints on scalability and the level of impurities in the desired syngas, pressurised, oxygen-blown, direct entrained flow gasifiers appear to be the most suitable concept for BTL.
- Improving the efficiency and lowering the costs of the biofuel synthesis process are important RD&D goals, although improvements are likely to be incremental given the relatively mature nature of the technologies. Developing catalysts that are less susceptible to impurities and have longer lifetimes would help reduce costs.

Co-products and process integration

- The production of valuable co-products during the production of 2nd-generation biofuels offers the potential to increase the overall revenue from the process. Optimisation of the conversion process to maximise the value of co-products produced (heat, electricity, various chemicals etc.) needs to be pursued for different feedstocks and conversion pathways. The flexibility to vary co-product output shares is likely to be a useful hedge against price risk for these co-products.
- Market assessments of the biofuels and co-products associated with biofuel production need to take into account all the disbenefits, costs and co-benefits, including rural development, employment, energy security, carbon sequestration etc. if a fair assessment of their deployment is to be made.

C) Implications for Policies

Promotion of 2nd-generation biofuels can help provide solutions to multiple issues including energy security and diversification, rural economic development, GHG mitigation and help reduce other environmental impacts (at least relative to those from the use of other transport fuels). Policies designed to support the promotion of 2nd-generation biofuels must be carefully developed if they are to avoid unwanted consequences and potentially delay commercialisation.

One related view is that the relatively high cost of support currently offered for many 1st-generation biofuels is an impediment to the development of 2nd-generation biofuels, as the goals of some current policies that support the industry (with grants and subsidies for example) are not always in alignment with policies that foster innovation. Another view is that 2nd-generation biofuels will eventually benefit from the present support for 1st-generation biofuels. With well designed support policies for both, the fledgling industry for 2nd generation will grow alongside that of 1st-generation using the infrastructure already developed and thereby reducing overall costs. This report leans more towards the latter position that advances in technology will enable 2nd-generation biofuels to build on the infrastructure and markets established by 1st-generation biofuels to provide a cheaper and more sustainable alternative. This assumes that future policy support will be carefully designed in order to foster the transition from 1st- to 2nd-generation and take into account the specificities of 1st- and 2nd- generation biofuels, the production of sustainable feedstocks, and other related policy goals being considered. Other views also exist and only time will tell which view will eventuate.

Policies to support 1st- or 2nd-generation biofuels should be part of a comprehensive strategy to reduce CO_2 emissions.

- A first step that would help produce a more level playing field for biofuels is to ensure that there is a carbon price or other CO_2 reduction incentives in place. Taking into account the environmental impacts of CO_2 emissions from liquid fuels derived from fossil fuels would mean biofuels could compete on a more equal footing. This is also important to ensure that bioenergy feedstocks are put to their highest value use, due to competition for the limited biomass resource for heat, power, bio-material applications etc. In addition, the harmonisation of policies across sectors - including energy, transport, health, climate change, local pollution, trade etc. – is necessary to avoid policies working at cross purposes.

- However, the levelling of the playing field for biofuels is in itself unlikely to be enough to ensure the commercialisation of 2nd-generation biofuels in a timely manner. In addition to systems placing a value on CO_2 savings, an integrated package of policy measures will be needed to ensure commercialisation, including continued support for R&D; addressing the financial risks of developing demonstration plants; and providing for the deployment of 2nd-generation biofuels. This integrated policy approach, while not entirely removing financial risk for developers, will provide the certainty they need to invest with confidence in an emerging sector.

Enhanced RD&D Investment in 2nd-generation biofuels

- Continued investment in RD&D is essential if 2nd-generation biofuels are to be brought to market in the near future. This includes evaluating sustainable biomass production, improving energy crop yields, reducing supply chain costs, as well as improving the conversion processes via further basic RD&D and demonstration. This ultimately will lead to deployment of commercial scale facilities. The goals of public and private RD&D investments related to biofuel trade, use and production should include:
  - producing cost effective 2nd-generation biofuels;
  - enabling sustainability lessons learned from 1st-generation biofuels to be used for 2nd-generation;
  - increasing conversion technology performance;
  - evaluating the costs and benefits of increasing soil carbon content and minimising loss of soil carbon via land use change; and
  - increasing crop productivity and improvement of ecosystem health through management techniques, improved mechanisation, water management, precision farming to avoid wasting fertilisers and agro-chemicals, and plant breeding and selection.
- A broad, collaborative approach should be taken in order to complement the various RD&D efforts in different countries; to reduce the risk to investors; and to create a positive environment for the participation of financial institutions. Continued analysis of co-benefits including energy security, GHG mitigation, potential local advantages particularly for rural communities and sustainable development, and the value of co-products, should be undertaken. International collaboration on assessing the benefits and impacts of 2nd-generation biofuels trade, their use and production, and sustainability monitoring should be continued. Agreement on sustainability principles and criteria that include effective, mutually agreed and attainable systems via means such as certification, and that are consistent with World Trade Organization (WTO) rules, would be a significant step forward.

Accelerating the demonstration of commercial-scale 2nd generation biofuels

- Before commercial production can begin, multi-million dollar government grants are currently required to encourage the private sector to take the risk of developing a commercial scale processing plant, even when high oil prices make biofuels a more competitive option. This risk sharing between the public and private sector will be essential to accelerate deployment of 2nd-generation biofuels.
- Funding for demonstration and deployment around 2nd-generation biofuels is needed from both the public and private sectors. Developing links between industry, universities, research organisations and governments, has already been shown to be a successful approach in some instances. Present support to provide risk sharing for demonstration projects does not match the ambitious plans for 2nd-generation biofuels of some governments, although there are some exceptions. Additional support policies need to be urgently put in place. Funding to support demonstration and pre-commercial testing of 2nd-generation biofuels technologies should be encouraged in order to reduce the risk to investors. Support for the necessary infrastructure and demonstration plants could be delivered through mechanisms similar to the US "*Program for Construction of Demonstration Technologies*", funded by the US Department of Energy.
- Where feasible, funding for 2nd-generation biofuels and/or bio-refinery demonstration plants should be harmonised with national and regional renewable energy programmes which incorporate biomass production and utilisation. Links with other synergistic policies should be made where feasible in order to maximise support for development of infrastructure. Integration and better coordination of policy frameworks requires coordinating national and international action among key sectors involved in the development and use of biofuels.

Deployment policies for 2^{nd}-generation biofuels

- Deployment policies generally fall into two categories: blending targets (which can be mandatory or voluntary) and tax credits. Mandatory targets give certainty over outcomes, but not over the potential costs, while it is the inverse for tax credits. What pathways individual countries choose will depend critically on their policy goals and the risks they perceive.
- Deployment policies are essential if rapid scale-up of the industry is required to reduce costs through learning-by-doing. Otherwise deployment and cost reductions are likely to be slow since initial commercial deployment focuses on niche opportunities where costs and risks are low.
- Continued support for development of 2^{nd}-generation biofuels by governments is essential, but it should not necessarily be at the expense of reducing current programmes designed to support 1^{st}-generation developments. To obtain a smooth transition from 1^{st}- to 2^{nd}-generation over time where this is deemed desirable (for reasons of cost savings, supply security or greenhouse gas mitigation for example), the two classes of biofuels should be considered in a complementary but distinct fashion, possibly requiring different policies due to their distinct levels of maturity.

Environmental performance and certification schemes

- Continued progress needs to be made in addressing and characterising the environmental performance of biofuels. Approaches to standardisation and assessment methods need to be agreed, as well as harmonising potential sustainable biomass certification methods. These will need to cover the production of the biomass feedstock and potential impacts from land-use change. Policies designed to utilise these measures could work as a fixed arrangement between national governments and industrial producers, or could be designed to work as a market-based tool by linking to regional and international emission trading schemes such as the one in place between member states of the EU.
- It is considered that 2^{nd}-generation technologies to produce liquid transport biofuels will not become commercially competitive with oil products in the near future unless the oil price remains well over USD 100 / bbl. Therefore a long-term view should be taken but without delaying the necessary investment needed to bring these biofuels closer to market. International co-operation is paramount, although the constraints of intellectual property rights for commercial investments must be recognised. Collaboration through international organisations such as the Global Bioenergy Partnership should be enhanced with both public and private organisations playing active roles to develop and sustain the 2^{nd}-generation biofuels industry for the long term.

D) Conclusions

The production of 1st-generation biofuels, mainly from traditional food crops, has increased rapidly over the past few years in response to concerns about energy supply security, rising oil prices and climate change. Due to an improved understanding of total greenhouse gas (GHG) emissions as a result of detailed life cycle analyses, and related direct and indirect land use change issues, their perceived environmental benefits have more recently been brought into question.

It has become evident that some "good" 1st-generation biofuels such as sugarcane ethanol, have GHG emission avoidance potential; are produced sustainably; can be cost effective without government support mechanisms; provide useful and valuable co-products; and, if carefully managed with due regard given to sustainable land use, can support the drive for sustainable development in many developing countries.

Other "less good" 1st-generation biofuels, such as vegetable oil-based biodiesel, are being criticised with regard to their relatively low GHG emissions avoidance; unsustainable production relating to deforestation, water use, and land management; competition for food crop feedstocks pushing up food commodity prices; and the need for generous government support schemes to remain competitive even after the technologies have become mature. As a result a lot of hope has been placed on 2nd-generation biofuels.

Where these rely on crop and forest residues, or high yielding, non-food energy crops grown specifically for feedstocks, they are considered to be produced more sustainably, with better land use opportunities, including potential production on marginal lands.

However full commercialisation of either biochemical or thermo-chemical conversion routes for producing 2nd-generation biofuels appears to remain some years away. This is in spite of several decades of research and development, and more recent investment in several pilot-scale and demonstration plants in US, Europe and elsewhere. Even with generous government subsidies the commercial risks remain high, especially with recent widely fluctuating oil prices and global financial turmoil adding to the investment uncertainty.

There is no doubt that good progress in RD&D has been made during the past decade following increasing public and private investments. Successful outcomes include development of improved micro-organisms and the evaluation of innovative conversion technologies with improved performance and efficiencies. There is also a better understanding by the industry of the overall feedstock supply chain, whether from crop and forest residues or from purpose grown crops, necessary to provide consistent quality feedstock delivered all-year-round to the conversion plant gate. There has also been successful developments relating to the construction of pilot-scale bio-refineries to produce a range of co-products, some being *small-volume, high-value* products, and others, like biofuels, being *high-volume, low-value*.

Overall, unless there is a technical breakthrough in either the biochemical or thermo-chemical routes that will significantly lower the production costs and accelerate investment and deployment, it is expected that successful commercialisation of 2nd-generation biofuels will take another decade or so. During this period, demonstration and industrial-scale 2nd-generation plants will be continually improved in order that the biofuel products become competitive with petroleum fuels as well as with 1st-generation biofuels. Emphasis will need to be given to aviation, marine and heavy vehicle applications which will have limited alternatives. After 2020 or thereabouts, 2nd-generation biofuels could become a much more significant player in a global biofuels market characterised by a balance between 1st- and 2nd-generation technologies.

Policies designed to reward environmental performance and sustainability of biofuels, as well as to encourage provision of a more abundant and geographically extensive feedstock supply, could see 2nd-generation products begin to eclipse 1st-generation alternatives in the medium to longer-term.

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The full 120 page report will be made available on the IEA web site as a free publication download.

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For further information on this report please contact the IEA Renewable Energy Unit of the Directorate of Energy Markets and Security, Ralph.Sims@iea.org

[1] The Implementing Agreement on Bioenergy is an international collaborative agreement set up in 1978 by the IEA to improve international co-operation and information exchange between national bioenergy RD&D programmes. IEA Bioenergy aims to accelerate the use of environmentally sound and cost-competitive bioenergy on a sustainable basis, to provide increased security of supply and a substantial contribution to future energy demands. Currently IEA Bioenergy has 22 Members and is operating on the basis of 13 Tasks covering all aspects of the bioenergy chain, from resource to the supply of energy services to the consumer. More information on IEA Bioenergy can be found on the organisation's homepage www.ieabioenergy.com

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