New biofuel production technologies: overview of these expanding sectors and the challenges facing them

The numerous research programmes looking at new-generation biofuels that were initiated over the last ten years are now starting to bear fruit. Although no plants are producing and marketing biofuels yet, the large-scale, industrial feasibility of second-generation biofuel production at competitive cost may be demonstrated in the short-term. As far as third-generation biofuels derived from algal biomass are concerned, there is a great deal of R&D interest in the sector, but the technology is still only in its infancy.

In France, biofuels are currently incorporated at a rate of nearly 7% into all petrol and diesel fuels used in road transport, and it is hoping, along with all EU Member States, to see this share rise to around 10% by 2020.

The so-called first-generation biofuels which are currently being marketed are derived from conventional agricultural resources (sugar beet/cereals/sugarcane for ethanol, rape/sunflower/soya/palm for biodiesel), and should start to reach the limits of their development potential in the years ahead. New possibilities are therefore being researched and developed in order to meet the growing need for fossil fuel substitutes. These include:

- second-generation biofuels derived from ligno-cellulosic biomass (wood, straw, farming and forestry waste, dedicated ligno-cellulosic crops),
- biofuels the production methods of which are already mature (vegetable oil methyl ester, hydrogenation of vegetable oils), but which use new oil resources which are not in direct competition with the food industry, such as jatropha and camelina (plants for which oil production have no significant use until now), as well as oils derived from fresh or seawater microalgae – a so-called third-generation resource.

What can we expect from these new technologies? When will we be able to start marketing them? What are the brakes which are preventing them from being developed?

Second-generation biofuels derived from ligno-cellulosic biomass – a summary

Overview of the technologies, their sources and their advantages

The various technologies used to convert ligno-cellulosic biomass into fuel (and which are currently the focus of a number of major research programmes) include those which can produce substitutes for petrol and diesel, as well as kerosene for the aviation industry.

The main petrol substitute is ligno-cellulosic ethanol. This is the same product as the ethanol which is currently being marketed – only the resource and the first processing phases are different (see the Panorama 2008 article "Second-generation pilot biofuels units worldwide"). This is the technology which has so far been the focus of the most amount of research, particularly in the United States. Although it is advantageous to produce ligno-cellulosic ethanol from sugarcane bagasse in Brazil, China is looking into the possibility of producing it from farming waste, while in North America and Europe, different types of resources are being considered, such as crop residues (stems and stalks, etc.), forestry waste and dedicated energy crops (miscanthus, switchgrass, short rotation coppices, etc.).

Other petrol substitutes are also starting to garner interest from manufacturers and universities. These

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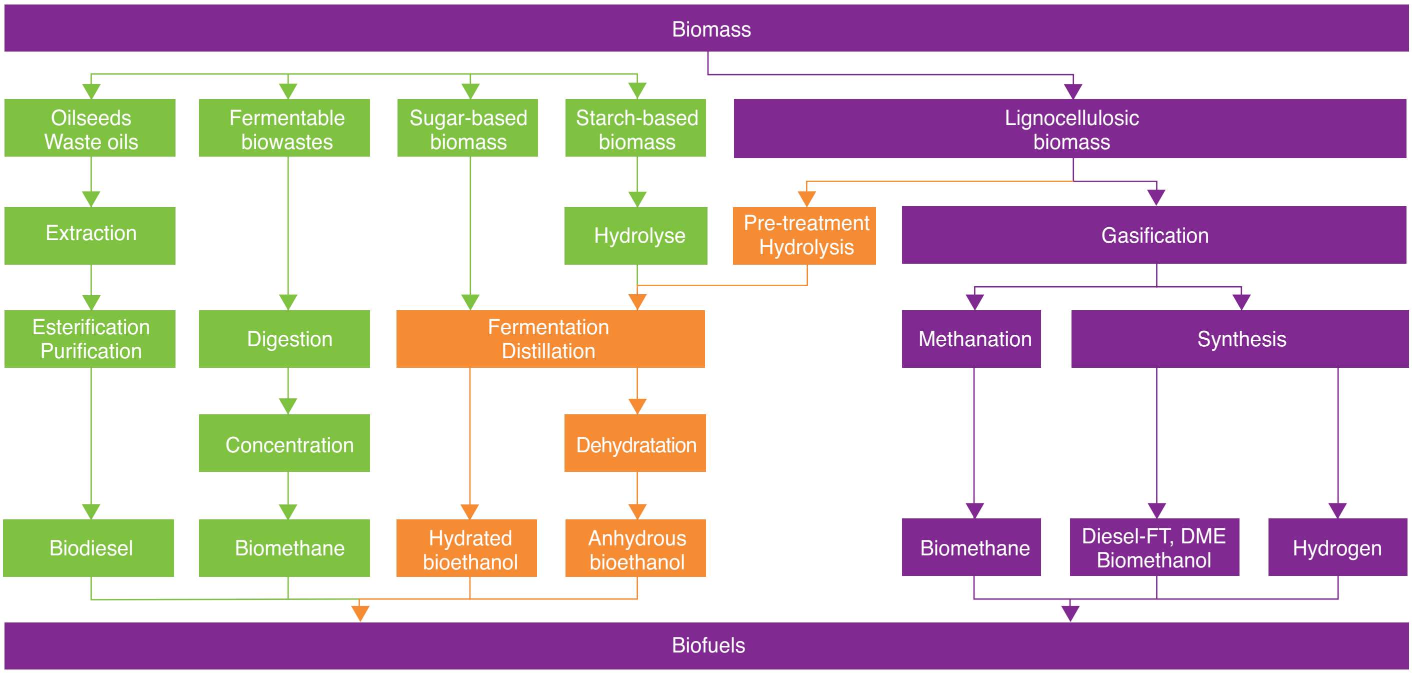
Fig. 1 - Various biofuel production means and sectors, e.g. ligno-cellulosic biomass



Source: www.plateforme-biocarburants.ch

include biomethanol, which can be thermochemically produced from biomass and incorporated into petrol (a share of 10 to 20%), and biobutanol, which is produced by biochemical process with an energy content higher than that of ethanol, and which can be more easily mixed with petrol without the need to adapt car engines (a share of 16% in the United States).

Bioethanol, like products currently used as substitutes for diesel fuel (VOME[1]), is a product the incorporation of which into conventional vehicle fuels is technically limited to around 10% (10 to 15% vol. for ethanol, 7% vol. for biodiesel).

The ligno-cellulosic biofuel which is most commonly considered for diesel vehicles, BtL[2], is a very high quality synthetic diesel which can be mixed in very high proportions into conventional tanks. It is also known as Diesel-FT – as in Fischer-Tropsch synthesis (see the Panorama 2008 article "Second-generation pilot biofuels units worldwide"). This type of process can be used to produce not only synthetic diesel, but also synthetic kerosene for use in aviation.

This technology is seen as an attractive alternative in Europe, where demand for diesel fuel is high and on the increase. But with aviation being integrated into the Kyoto protocol and the growing desire to reduce greenhouse gas emissions in the sector, this means of producing fuel oil from biomass is garnering wider interest.

Various gaseous biofuel production technologies exist for dedicated vehicle fleets. These include biomethane, a fuel which can be produced by fermentation (biogas) or thermochemically (bioSNG[3]) (see the Panorama 2008 article "Second-generation pilot biofuels units worldwide"). There is also BioDME[4], a fuel similar to LPG which is also produced thermochemically from lignocellulosic biomass.

Production aims and development incentives

In Europe

The most recent directive — 2009/28/EC — on the promotion of the use of energy from renewable sources specifies the methods for producing and quantifying products, in order to meet the goal of the share of energy from renewable sources in the transport sector amounting to at least 10% by 2020. In particular, this directive mentions that the contribution of biofuels produced from waste, residue, non-food cellulosic matter and ligno-cellulosic matter is considered to be the equivalent of twice that of other biofuels. It is also worth mentioning that ligno-cellulosic biofuel production technologies are able to coproduce significant quantities of electricity which, once linked up to the grid, can benefit from repurchase rates for electricity from biomass.

(1) VOME: Vegetable Oil Methyl Esters
(2) BtL: Biomass-to-Liquid
(3) BioSNG: Bio Synthetic Natural Gas
(4) BioDME: Bio Dimethyl Ether

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As far as tax exemption schemes for products and other incentives are concerned, it is up to each member state to decide how to implement them. In France, the biofuels that are currently on the market are subject to a tax exemption scheme that is differentiated for each product, including BtL, until 2012; a similar scheme is in place in Germany until 2015. But tax exemption cannot be guaranteed beyond these dates.

As far as research is concerned, within the framework of FP7, in May 2010 the European Commission launched a €35 million finance programme for the production of cellulosic ethanol. This financial aid will cover the period 2010 to 2013. 26 partners, mainly manufacturers, will invest an extra €24 million. This will involve the construction of four major demonstrator projects between now and 2015.

In the United States

In spring 2010, the EPA[5] published a second version of the Renewable Fuel Standard programme (RFS2), initiated by the Energy Independence and Security Act of 2007, to promote the development of renewable fuels in the United States. In accordance with these new regulations, 136 billion litres (Gl) of renewable fuel have to be used to meet transport requirements by 2022.

The United States should soon be able to produce up to 56 Gl of bioethanol from corn starch. It also plans to produce 3.8 Gl of biodiesel. The remaining 76 Gl will need to be from ligno-cellulosic biofuels and other third-generation biofuels. The USDA[6] believes that in order to meet the production targets set by the RFS2, 527 biorefineries with an annual capacity of 150 Ml will need to be built – at a cost of $168 billion.

In order to meet these targets, the EPA, the USDA and the DOE[7] are developing various aid and incentive schemes. The EPA has recently authorised E15 (which contains 15% ethanol and 85% gasoline) to be sold for conventional petrol vehicles built later than 2007. Government finance schemes for manufacturers and research laboratories have been allocated for the installation of pilot projects and demonstrators, and to develop research projects into new biofuel technologies. A total of nearly $850 million has been given by the USDA and the DOE for developing new-generation biofuels, with States also providing their own financial support.

(5) EPA: the US Environmental Protection Agency
(6) USDA: United States Department of Agriculture
(7) DOE: the US Department of Energy

In addition to this aid, companies working on these projects are setting up partnerships with energy and vehicle production groups, as well as groups involved in forestry-related industries, etc. They provide them with access to engineering and marketing expertise, as well as — in some cases — conversion technologies. For major manufacturing groups (BP Biofuels North America, Shell Oil Co., Chevron, Valero, General Motors), these partnerships offer opportunities to vertically integrate or diversify their activities.

Overview of pilot projects and demonstrators

Some 157 second-generation biofuel production projects are currently in operation or in development throughout the world, representing a total capacity of around 6.5 Gl/year. Existing capacity and capacity that is currently in construction only represent slightly more than 15% of this volume. No plant has yet been able to start production on a commercial scale, and many pilot projects and demonstrators have been severely delayed as a result of the effects of the financial crisis. Many projects should, however, come into service in 2011.

Table 1

Second-generation biofuel pilot projects and demonstrators throughout the world

Product	Existing and being built plants		Proposed plants	
	Pilots/ demo	Capacity (Ml/year)	Pilots/ demo	Capacity (Ml/year)
Cellulosic ethanol	53	627.5	64	4,593
Diesel, kerosene (BtL, FT)	13	41.6	13	888
Other*	6	336.5	8	37
Total	72	1,005.6	85	5,518

* Biobutanol, biomethanol, bioDME

Sources: IEATask39, Global Biofuels Centre

The United States has the highest number of projects. But its actual service capacity is relatively low. Most of its installations are low-capacity cellulosic bioethanol demonstrators. There are also a number of synthetic fuel installations (BtL). Around thirty companies are currently active in the second-generation biofuel sector in the United States.

Asia plans to have a second-generation biofuel production capacity of approximately 3 Gl/year. Existing second-generation bioethanol production capacity is currently around 71.8 Ml/year, and is mainly based in Thailand, China and Japan.

In Europe, existing second-generation cellulosic bioethanol production capacity is around 17.4 Ml/year, mainly distributed across three plants in Scandinavia and Spain. Synthetic diesel production capacity accounts for around 55% of overall potential biofuel production capacity in Europe.

Technological breakthroughs and remaining obstacles

One of the key issues which concerns all bioenergy sectors is still whether or not the supply of biomass can be guaranteed in the long-term. Biomass can also be used for heat and electricity generation and is proving increasingly popular (demand for the energy sector should increase from 13.5 to 20 Mtoe between 2006 and 2020 in France). In order to keep pace with the increase in second-generation biofuel options, the ways in which the resources and their flows are used will have to be properly structured. This is already an obstacle for current industrial biomass cogeneration projects to work properly. Many action programmes for improving access to the resource are, however, currently underway (see the Panorama 2010 article "Which biomass resources should be used to obtain a sustainable energy system?").

As far as ligno-cellulosic bioethanol is concerned, three main issues are at play:

- identifying and/or obtaining raw plant matter that has the best carbohydrate concentration,
- developing economically viable grinding, pre-treatment and saccharification processes for releasing the simple sugars that are contained in these carbohydrates. The pre-treatment process that is the most efficient at industrial scale for releasing these sugars from the plant — and that is sufficiently flexible for a variety of biomass resources — then has to be determined. The enzyme production cost for the sugar hydrolysis phase is also a limiting factor. However, recent announcements from enzyme producing companies suggest considerable progress with significant reductions in costs,
- Identifying micro-organisms with a genetic heritage that makes it possible to ferment as much of these sugars as possible. Yeasts are not able to ferment all of the sugars released by cellulosic biomass. Work carried out at pilot units has demonstrated the effectiveness of certain strains on C5-sugars. But the productivity of this fermentation can still be improved.

As far as the integration plans for the process chain are concerned, several options are still being looked into, primarily designed to reduce production costs — which are still high — by coupling certain phases together (hydrolysis and fermentation into one single phase, even combined with enzyme production). Although these solutions are technically feasible, they still result in a significant loss in matter yield. Starting up the demonstrators should make it possible to verify these technological advances on a large scale.

Regarding BtL, a major issue should be highlighted concerning load flexibility. Indeed, being able to optimise the cost of the final product is contingent on the production facilities being large enough: large-scale installations are required, together with large quantities of resources. And these resources therefore need to take different forms and be of various compositions. The biomass pre-treatment phase before gasification is therefore considerably important: it is during this phase that the biomass is converted into an intermediary product of homogenous quality. There are two main pre-treatment techniques: pyrolysis (which produces liquid) and torrefaction (which produces a solid in a similar form as coal). Torrefaction is well-known for its various non-energy-related applications (coffee, purification plant sludge) and for considerably lower production capacities. The operating conditions for this phase still have to be optimised depending on the treatment process – hence the need to study the process within the framework of a demonstrator.

Regarding synthetic gas purification, several technologies are currently being demonstrated on reconstituted gas. Complete installation tests on a real synthetic gas could be used to validate these technologies and select the most appropriate ones on the basis of economic criteria. This process chain integration work could also be used to test methods for increasing global yield (recycling head gases, for example). Indeed, the current mass yield of Diesel-FT is only just above 20%.

Alongside the need to industrialise future high-capacity plants in order to take advantage of economies of scale (around 200,000 t of product/year), these constraints mean that very large quantities of biomass have to be mobilised for a single unit. Co-processing biomass loads and refinery residue could be a solution for gradually removing these obstacles until more suitable biomass supply systems are in place.

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Table 2

A few examples of recent announcements regarding second-generation biofuels

Project/partners	Location	Type of unit Capacity (Ml/year)	Raw material	Start-up
Ligno-cellulosic ethanol				
Poet	Scotland, South Dakota, United States	Pilot 0.76	Corn stover	Production start-up: end of 2008
Abengoa Bioenergy, Biocarburantes Castilla y Leon, Ebro Puleva	Babilafuente, Salamanca, Spain	Demonstrator 5	Barley and wheat straw	Production start-up: end of 2009
DuPont Danisco Cellulosic Ethanol LLC, University of Tennessee/ Genera Energy LLC	Vonore, United States	Demonstrator 0.945	Farming waste, corn stover, switchgrass	Start-up: January 2010
Inbicon	Kalundborg, Denmark	Demonstrator 11.4	Cereal straw	Production start-up: end of 2009
Futurol (R&D): ARD, IFP Energies nouvelles, INRA, Lesaffre	Bazancourt-Pomacle, France	Pilot 0.18	Ligno-cellulosic multiload	Start of construction: 1st quart. 2010 Prototype: 2015
Sinopec, Novozymes, COFCO	China	Demonstrator 11.3	Corn stover	May 2010: construction agreement. Start-up planned for end of 2011
BtL/SNG/DME				
Bioliq: Karlsruhe Institute of Technology, Lurgi	Karlsruhe, Germany	Pilot	Straw, other waste	Start of construction of 3rd installation (synthetic gas phase)
BioTfueL: IFP Energies nouvelles, Sofiprotéol, CEA, Axens, Total, Uhde	Compiègne, refinery, France	Pilot	Ligno-cellulosic biomass and fossil loads	1st phase during 2012
Bure-Saudron: CEA, Air Liquide, Choren Industries GmbH	Bure-Saudron, France	Demonstrator 29.5	Forestry and farming resources	Launch of engineering studies
UPM, Andritz	Strasbourg, France	Commercial 128.2	Wood residue	Project implementation decision in 2010
Choren Industries GmbH	Freiberg, Germany	18	Wood residue, very short rotation coppices	Production start-up in 2010
ClearFuels Tech. Inc, Rentech	Collinwood, Tennessee, United States	Demonstrator	Wood residue	Start-up planned for end of 2011
NSE Biofuels Oy	Varkaus, Finland + set-up study underway at 2 sites	Demonstrator	Wood, forest residue	2009
GAYA: GDF Suez (leader)	France	Pilot	Ligno-cellulosic multiload	
BioDME project: Chemrec, Haldor Topsoe, Volvo, Preem, Total, Delphi, ETC	Pitea, Sweden	Pilot	Ligno-cellulosic biomass	Production start-up: early 2010

Source: IFP Energies nouvelles

Overview of industries which use new oil resources

Given the problems associated with having to use certain crops for both food and energy-related purposes (particularly oleaginous crops such as rape, soya and palm oil), new vegetable oil sources are being looked into for powering first-generation biodiesel production plants. These include plants that produce oil that has not yet been used for food purposes, such as the jatropha curcas, the camelina, as well as various aquatic organisms, such as lipid microalgae.

As far as processes for converting oil into biodiesel are concerned, the technologies for doing this have now

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matured (transesterification for producing VOME, catalytic hydrogenation for producing HVO[8]) and are used at many commercial plants across the world. A number of major new projects are also in development for the construction of HVO plants in Singapore and Rotterdam (800,000 t/year each).

Non-food related terrestrial plants

Fig. 2 - Jatropha curcas

Source: www.jatropha-curcas.be

Fig. 3 - Camelina sativa

Source: http://fr.academic.ru

The jatropha curcas was historically cultivated for the production of soap and candles, as well as for cattle pen barriers on farms. It is a shrub that grows well in subtropical climates, being able to withstand drought and grow in relatively barren soil. The oil stored in its seeds contains a toxic molecule that makes it unfit for consumption in food products. Given these properties, there are many projects underway to grow jatropha in Asia and Africa in order to use the oil for biodiesel production. Various factors have, however, dampened enthusiasm for this crop: financing problems to do with the world economic crisis, people's awareness of the technical difficulties and issues of profitability involved in growing the plant on a large scale. The plant is still a potentially interesting means of mobilising biomass in difficult regions.

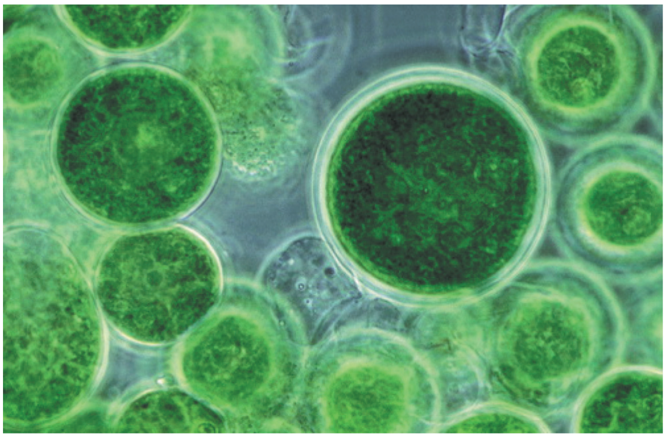
Camelina (or camelina sativa) is a plant that grows in temperate climates, and is from the same family as rape. It is very sturdy, meaning that it is less demanding in terms of inputs than other conventional oil producing crops. This makes it highly suitable for less fertile soils, providing an oil yield which is just below that of rape. A number of research programmes into this crop and techniques for harvesting it are currently underway in several European countries (Italy and Spain in particular), as well as the United States, Canada, China and Brazil.

Several airline companies have already carried out flight tests using fuel containing varying percentages of jatropha and hydrogenated camelina oils.

Lipid microalgae

These are aquatic organisms of which there are several hundred thousand different species. It has been discovered that some of them are able to store lipids inside their cells. These extremely small (a few micrometres) autotrophic organisms are able to use photosynthesis to replicate themselves very rapidly (with simple elements, such as carbon dioxide, water, mineral salts, etc.). Their oil yield can be 10 to 30 times greater than that of terrestrial species (10 to 40 t of oil/ha/year) depending on production conditions.

Fig. 4 - Microscopic view of microalgae



Source: www.devicedaily.com

Apart from their high levels of productivity, microalgae also have the advantage of being able to be grown in a basin or reactor – farming or forestry land is not needed. Also, certain species can even grow away from the light (heterotrophic mode), but require an external source of organic food. Microalgae cultures can potentially be used to produce different forms of energy, depending on the species (ethanol from starch, hydrocarbons, hydrogen, etc.) and depending on the methods used to convert the by-products (biogas by fermenting algal biomass, then heat and electricity production through cogeneration).

(8) HVO: Hydrotreated Vegetable Oil

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R&D obstacles that are hindering the conversion of lipid algae into biofuels

Microalgae are already being grown commercially in order to produce high-value added products for use in beauty care, the food industry, pharmacology, etc. But these are niche production operations, the scales of which have nothing in common with the kinds of volumes required for energy production. The processes currently used for growing and extracting the relevant molecules are not economically viable and require too much energy for large-scale conversion into fuel. Consequently, researchers have to take a second look at the various technologies used across the whole chain.

First of all, more research has to be done into finding out about different microalgae strains and selecting the right ones in order to get the best compromise between productivity, sturdiness, the right physical properties, tolerance against contaminants, etc. The right growing conditions can then be created so that productivity can be optimised. Optimising the design of the reactor in which they are grown and using new harvesting/extraction technologies should bring about a significant reduction in energy consumption. And the suitability of the sources of the inputs (CO_2, water, nutrients) for what the outputs are converted into (oil, residual biomass, other proteins or useful sugars) and of the environment in which the facility is operating, is a major factor in ensuring the viability of this industry.

Financing of research into microalgae

From 1978 to 1996, the Aquatic Species Programme being run at the DOE's National Renewable Energy Laboratory (NREL) was looking into ways of producing biodiesel from microalgae. However, the programme was halted because of low oil prices and the projected high costs of producing fuel from algae.

In 2006, the NREL formed the Biofuels Strategic Initiative, aimed at defining the potential of algae for biofuels production and positioning the NREL in algae-derived biofuel research. It entered into a partnership with Chevron in 2007. Research is now being funded by a collaboration of partners and agencies including Chevron, the DOE, the EPA, the Colorado Center for Biorefining and Biofuels, the Air Force Office of Scientific Research and the NREL.

In June 2010, the DOE announced its intention to invest $24 million in three research groups led by the Universities of Arizona and California, and the Cellana LLC consortium. These consortia are looking at a number of issues, such as how to improve strains, growing methods and fuel quality.

Overview of pilot projects and demonstrators for producing biofuels from algae

More than a hundred companies throughout the world are currently involved in producing biofuels from algae. These include a number of start-ups. Although no commercial structures have started operating yet, some petroleum groups have recently launched a number of large-scale projects (ExxonMobil, Shell, ENI, Chevron).

In the United States, more than thirty companies are experimenting with different methods for cultivating algae and converting it into fuel. Although most of these companies are looking into ways of producing biodiesel from lipid microalgae, some are planning to use it to produce ethanol (Algenol) or biocrude oil (UOP, Sapphire). In Canada, a project was recently launched at the National Research Council's Institute for Marine Biosciences in Halifax.

In Asia, in addition to the pilot project in Karratha in Australia (Cape Cod Algae Biorefinery) and a number of projects in China and Thailand, Japan is also very active in this search for new ways for producing biofuels from algae. The NEDO, The University of Tokyo, the CRIEPI and various manufacturers (power companies) are working in particular on new oil extraction processes. This should result in substantial energy savings compared with conventional methods.

In Europe, many manufacturers and research bodies are looking into these methods. The Shamash project is a collaboration between French manufacturers and research teams. In the United Kingdom, the BioMara project, led by the Scottish Association for Marine Science, aims to demonstrate the feasibility and viability of producing third-generation biofuels from marine biomass.

In other countries, Argentina and Israel in particular, many initiatives are being led by well-known manufacturers.

Development prospects

Although ligno-cellulosic biofuels cannot currently compete with conventional fuels, the number of demonstrator projects is growing, promising significant breakthroughs in terms of the choice of technologies available and reducing costs. Provided governments keep up their promotional initiatives (financial support, requirements to incorporate biofuels into fuel mixes, etc.), we should see them being marketed before 2020, with ethanol leading the way, given the major resources that have been mobilised for its production. In the meantime, large-scale projects to use biomass could power existing facilities using resources that are more sustainable (less competition with the food industry and a lower impact on the environment in particular). More effective use of wood and other agricultural by-products, together with the integration of dedicated ligno-cellulosic crops into farming systems, will supply second-generation facilities.

Finally, looking further ahead, technologies for producing microalgae could serve as a new means of supplying existing industries for converting lipids into fuels.

High-quality renewable fuels can be mixed in large proportions into the tanks of current vehicles, resulting in improved performance (for example, HVO and BtL in fuels used for road transport and aviation). These varied resources and technologies will be used to develop industries that are adapted to different geographical contexts, thus increasing energy independence, encouraging economic development and reducing greenhouse gas emissions associated with transport.

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Final draft submitted in December 2010