PANORAMA 2011

a look at ...

Water and biofuels

Nowadays, water is seen as a major sustainability criterion for bioenergies. Although the biofuels being produced by food crops are subject to the same risks as the farming sector as far as water resources are concerned, future sectors have a significant potential to reduce these risks, and this potential needs to be better understood in order for biofuels as a resource and their related technologies to develop properly.

In 2007, the area in Europe set aside for producing biofuels was less than 3% of the continent's total useful farming surface, and it provided for less than 4% of all road fuels used. The target is for at least 10% of all fuels used for transport purposes to be renewable fuels by 2020, with biofuels playing an important role in road — and even air — transport. Similar development targets have also been announced for the USA, South America and a number of countries in Asia. Industrial production plants are being developed and use is being made of biomass in order to help ensure that these countries meet their targets.

For these bioenergy sectors to develop properly, they need to be sustainable. Various European bodies (as well as bodies in America and Asia) are therefore now talking about implementing various sustainability criteria that will need to be met: thresholds for greenhouse gas emissions, restrictions on changing the ways in which land used for farming and forestry practices is used, etc. And although no particular criterion has yet been established with regard to protecting water as a resource, assessment methods are currently being looked into.

As far as biofuels and bioenergies in general are concerned, the water footprint can be measured at two main levels: the water footprint generated by growing the resource that is used for producing biofuels, and the water footprint of the conversion plant. The levels of potential pressure on the quantity of water, and on its quality will be addressed within the context of this analysis.

Water for producing biomass energy: quantity issues

Water plays a wide variety of roles in the lives of cultivated terrestrial plants. And one of its vital roles is to enable photosynthesis (alongside CO_2) so that they can produce their organic material. Depending on the species in question, the pedoclimatic conditions of a particular environment and the requirements with respect to the expected yield, a crop can be sustained simply by extracting water from the ground... or it can require additional water provided by an external irrigation system at certain times of the year (it should be pointed out that agriculture accounts for 70% of the world's total water use).

The different types of biomass concerned

There are a number of categories of biomass involved in the biofuel sector. These include food type crops for use in first-generation fuels (G1) which are already being sold (wheat and beet ethanol, Vegetable Oil Methyl Ester (VOME), Hydrotreated Vegetable Oil (HVO), as well as ligno-cellulosic biomass for use in second-generation biofuels (G2), which are still in the R&D phase (ligno-cellulosic ethanol, Biomass to Liquid (BtL)). The dedicated ligno-cellulosic crops include annual whole plant crops and high-biomass-yield perennial crops, such as miscanthus, switchgrass, short rotation coppices, etc. (Table 1).

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Water and biofuels

Table 1

Overview of biofuels sectors and main dedicated crops associated with them

Geographical zone	Ethanol G1	Biodiesel G1 (VOME/HVO)	Ethanol G2/ BtL
Europe	Bett, straw crops (wheat, rye)	Rape, sunflower, microalgae*	Whole plant cereals corn), miscanthus*, switchgrass*, short rotation coppices*
North America	Corn	Soya, microalgae*	
South America	Sugarcane, sorghum	Soya, microalgae*	Sugarcane bagasse
Asia	Corn, sugarcane, sorghum	Palm, jatropha*, microalgae*	

*Species in the process of being domesticated, or that is currently little used

Source: IFP Energies nouvelles

A third category of resource, which is currently being investigated, is aquatic biomass and microalgae in particular. This so-called "third-generation" resource is being developed in fresh and seawater — depending on the species — and is grown in a open or closed-cycle reactor. The trend currently is to grow lipid microalgae for use in producing biodiesel or hydrotreated oils (for diesel vehicles or as a substitute for kerosene in aviation).

First-generation industries will be used during the transition period between now and when ligno-cellulosic biofuel technologies can be launched on the market. At the same time, by-product type ligno-cellulosic resources from harvests (straw tops, etc.) and gathered from forests (waste, pruning wood, etc.) are used for other bioenergy industries (heat, electricity) and are also being considered for eventual use in the production of biofuels. As resources that are not specifically cultivated for energy production, there is no extra need for water or other inputs directly associated with them. It should be noted, however, that removing large quantities of straw — that was previously buried in the ground — can, for example, affect the structure of the ground, resulting in changes in its ability to retain water.

Quantities of water used by crops

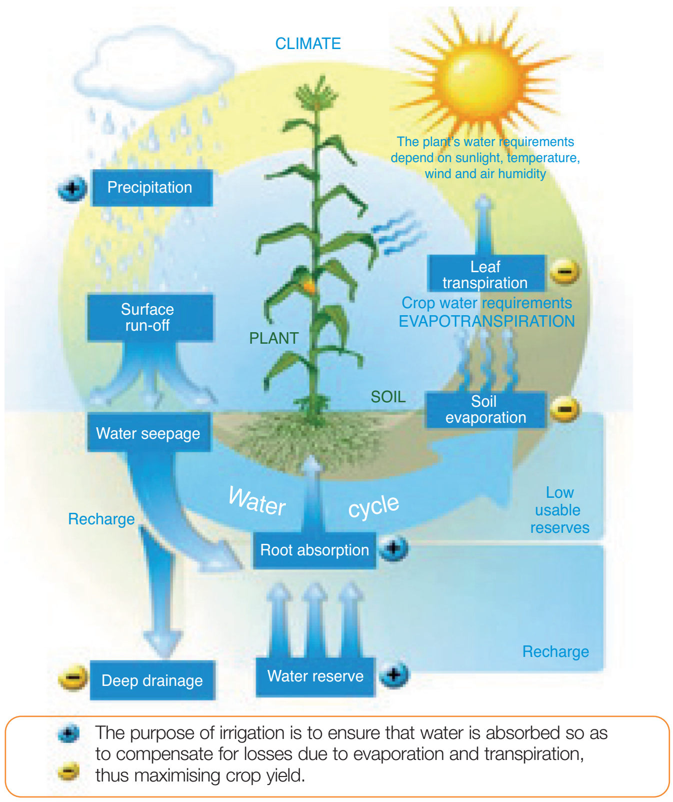
The difficulty with the water footprint is that — unlike greenhouse gases, which can be assessed globally — it has to be measured on a limited scale, since it is very much dependent on the local context. So a given system taking water from the ground can be very problematic in a region where resources are limited and completely unproblematic in a region where resources are abundant.

It is, however, worth taking a look at different crops at the scale of the total area of farmland available, then at issues associated with changes in the ways in which the land is used as a result of dedicated crops, on a regional scale.

Water removed per surface or product unit: dependent on the resources, practices and pedoclimatic conditions

The water that plants take from the ground can be replaced by precipitation, reserves of underground water or rivers, or failing that, by irrigation water (Figure 1). Depending on how large the ground's reserve capacities are and on the type of plant coverage, removing water can subject the resource to greater or fewer constraints.

Fig. 1 – Water cycle at global level



Source: Association of irrigation companies in the Vienne region

So depending on the ground type, the climate and agricultural practices, water requirements for a given crop can vary considerably: growing corn for ethanol production in the USA requires between 7 (Iowa) and 320 l of water (Dakota) for every litre of ethanol produced (GAO, ANL, 2009). Soya is a crop that requires smaller quantities of water, but irrigation is still needed in certain US regions. In France, oleaginous crops, such as rape and sunflowers, are not usually irrigated. Wheat and sugar beet growing in certain regions can be given extra water in particularly dry years. In Asia, growing oil palms does not — at first glance — appear to have any major impact on water resources. But it does have other environmental consequences (on biodiversity in particular). The jatropha, a shrubby plant which is potentially suitable for arid regions with relatively barren soils, is a resource that could be developed without the need for extra water or inputs. But yield is dramatically improved if extra water and inputs are provided.

For ligno-cellulosic crops dedicated to second-generation biofuels, knowledge of different species behave with regard to water is still under development, and agricultural practices are still in the process of being defined. Major research programmes are currently underway to find out more in these areas. From a qualitative perspective, less water evaporates from the ground when perennial crops (miscanthus, switchgrass, etc.) are being cultivated than when the ground is left to lie fallow between crops. These plants also generally appear to be better at withstanding water stress than annual crops: a lack of water in year n will result in a fall in yield in year n. Yield will start to rise again in year n+1, whereas the whole harvest could be lost in the case of annual crops.

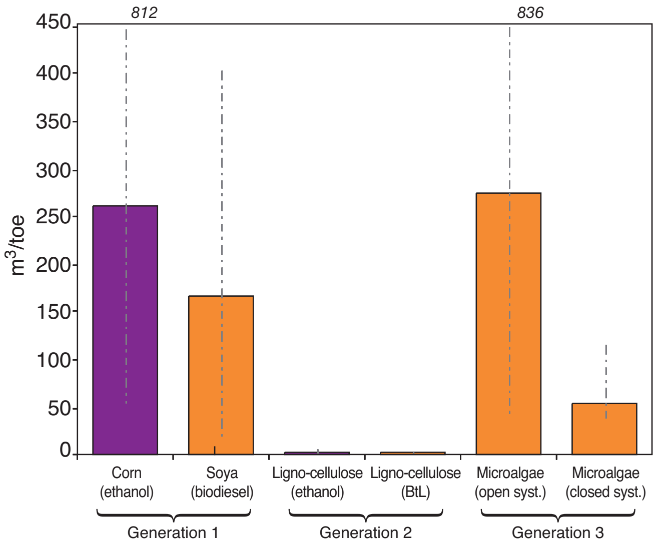
However, when these crops are planted in shallow soil in order to use land that is less productive for energy, it can sometimes be necessary to bring in water from external sources in order to maintain yield and so maintain a minimum revenue for the farmer. Species that are least sensitive to water stress should therefore be chosen for the most vulnerable regions (for example, switchgrass seems better suited to the climate in the southern half France than miscanthus, which is more water-hungry in the summer).

As far as short rotation coppices are concerned, these are also perennial crops which are not harvested every year. This means that the lesser yields of certain years can be made up for it in subsequent years. Short rotation coppice crops (rotated every 7 years) are not irrigated, regardless of where they are located. Nevertheless, certain species — such as the willow, the poplar and the eucalyptus — run the risk of drying out in soils that contain only limited amounts of water. Careful consideration should also be given to where they are planted.

Microalgae have the advantage of growing outside the ground. The various water flows involved can therefore be easily controlled, particularly in closed culture systems. In these reactors, how much water is used is a direct function of the recycling rate to be implemented in the growing medium. In an open system, the amount of water that needs to be supplied so as to compensate the amount which naturally evaporates through the growth basins should also be taken into account. This amount is a direct function of the ambient climate. Nearly 575 litres may be required for every litre of fuel in a basin based in California, whereas no water at all may be required in regions with sufficient levels of precipitation where rainfall alone will be enough to compensate for evaporation (Harto et al., 2010). And for certain species of microalgae in marine environments, water availability is less of an issue.

A number of publications seek to shed light on the water footprint of biofuels on a per pathway basis by life cycles analysis (Wu et al., 2009; Engel et al., 2010; Yan et al., 2010; Harto et al., 2010 etc.). This approach is already used for measuring global warming power via greenhouse gas emissions. Different biofuel production means can therefore be compared using the same set of assumptions and for the same functional unit. The figure shown below (Figure 2) shows a comparison of the different water footprints for growing 5 crops dedicated to biofuel production in the USA.

Fig. 2 – Water consumption for growing different species dedicated to biofuel production (m^3 of water per toe of fuel)



Source: from Harto et al., 2010

In this reference, water is mainly used for irrigation (when it is necessary), producing the other inputs (fertilisers, pesticides, etc.) and — to a lesser extent — building closed-cycle reactors for the microalgae.

Given the significant disparities with regard to different ways of managing the cultures and the dearth of statistical information available on the subject, it is still difficult to provide any quantitative information for ranking the cultures on the basis of how much water they require. But it is possible to highlight the fact that planting certain cultures and decisions about which practices to adopt should be considered on the basis of water availability in the environment — given the potentially large quantities of water required.

On the scale of a production basin: issues to do with changes in the availability of water as a resource with regard to a given situation

Unlike greenhouse gas emissions, which are a global factor impact, issues to do with the availability of water as a resource need to be analysed on the scale of a consumption pool from a given source, such as for example, the hydrographic basin or the various different basins that make it up. Using this regional unit can help highlight the potential effects that changing the purpose that the soil is used for can have on a body of water — which supplies different types of facility both upstream and downstream.

With regard to the growth of the biofuels industries, the area of farmland for dedicated crops needs to grow if national production targets are to be met. On the scale of a regional farm, this could involve:

- changing the intended purpose of an existing crop (for example, sugar beet could be converted into ethanol, instead of processed in a sugar refinery),
- existing crop rotations could be modified by introducing a new dedicated crop into the rotation scheme (for example, peas, for which demand is on the wane, could be replaced by rape for biodiesel),
- areas of land which were not previously cultivated could be used for crop growing (for example, fallow land could be used to grow industrial crops).

All of these various scenarios are indeed implemented and can lead to different results, depending on the choice of dedicated crop and the type of land that is converted. A recent prospective study puts forward a number of different scenarios for how biofuels might be deployed in 2030 at two French hydrographic basins, and measures the amount of pressure on the water recorded between 2006 and 2030 (CLIP Journal no.19[1]). This is directly dependent on various scenarios for how ground use might change, as considered on the scale of the basin. By nature, the pressure on water is greater if a bare soil surface devoid of any activity is replaced by one which hosts a series of annual irrigated summer crops. The effect can, on the other hand, be beneficial if an annual irrigated crop is replaced by a perennial crop which consumes less water.

The study mentioned above highlights the need to diversify rotations at regional level so as to disperse and attenuate any pressure on water as a resource. Globally, the various scenarios for developing crops dedicated to first-generation biofuels involve increasing water use and so worsening the dry-period hydric deficit. But the pressure is far less significant than it would be for a scenario involving ligno-cellulosic crops for second-generation biofuels that would need to be irrigated in order to obtain the highest yield. This type of approach also emphasises the fact that sensible water consumption for agriculture is not necessary critical if the resource is sufficiently available. The hydric deficit for a given crop will be less great in the deep soil of the Seine-Normandy basin than in the soil of the Adour-Garonne basin which contains lower reserves. And a scenario in which ligno-cellulosic crops are planted in such a way as to avoid the need for irrigation (thus accepting a certain reduction in farming productivity), can lead to a dramatic improvement in pressure indicators on water at the scale of the basins' farming areas.

It should also be remembered that it will be possible to produce second-generation biofuels using ligno-cellulosic crops — which will consume far less water —, as well as using farming and forestry by-products for which the effects of their use on water as a resource have not yet been measured. Irrigation is not currently carried out in order to boost straw productivity, and so the amount of water required is not known. This approach could nevertheless be questioned in energy production systems which convert plants in their entirety in different energy production means, for example.

Water for producing biomass energy: quality issues

The main effects of cultivating crops used for biomass energy on the quality of surface and underground water are essentially to do with irresponsible use of fertilisers and plant care products (or pesticides). There is a risk of water being polluted when potentially polluting substances spread on the ground are carried away by drainage water and end up in streams or water tables (Figure 3).

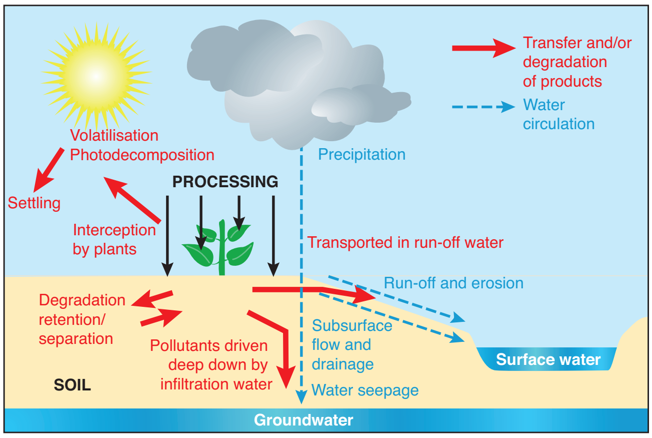
The potential for these products to end up being transferred into water resources is very much a function of the requirements of the plants in question, the practices used to cultivate them and soil/climate conditions. And the risk of pollution from these substances is greater when they remain in the environment in significant quantities over a relatively long period of time. These factors are themselves dependent on the intrinsic properties of the substances used and on how they behave in water.

(1) Impact of the development of biofuels on water in France up to 2030, CLIP Journal no.19 - http://www.iddri.org/Publications/Les-cahiers-du-CLIP/Eau-et-biocarburants-a-l%27horizon-2030

Water and biofuels

Assessing the impact that they have on water often involves developing complex simulation models. A number of reference studies have been carried out into the issues associated with nitrates and pesticides escaping into water bodies for conventional crop systems. They can be used for looking into the effects of first-generation biofuel crops (wheat, corn, rape, etc.), since the ways in which inputs are used are more or less the same regardless of what the crops are used for. For ligno-cellulosic crops, experimental protocols are in the process of being developed to feed into the impact prediction models.

Fig. 3 – The various ways in which pollutants from farming can be transferred



Source: DDAF (Department for Agriculture and Forestry) in the Loiret region

Extra pressures or situations which bring about improvements can be dealt with on the basis of changes in the ways in which the ground being studied is used. An evergreen coverage throughout the year has the effect of limiting drainage, and so reduces the risk of polluting substances flowing out into water resources. With ground on which crops are alternated with periods of bare soil or only limited coverage, on the other hand, the risk of amounts of the substances used escaping is increased.

As far as the risks associated with using fertilisers are concerned, nitrates and phosphates are the main pollutants found in water nowadays. These can — in some cases — cause algae to develop on the water's surface. This can reduce the water's oxygen content, thus disturbing aquatic life.

The extent to which crops can make effective use of fertilisers varies from species to species. In order to reach the yields that are obtained nowadays, cereal, oil-producing and beet crops are nearly always fertilised, irrespective of what their intended use is. Sunflowers and sorghum are hardier species, and so need lower quantities. With regard to perennial species, the amount of fertiliser used depends on the desired levels of productivity and the quality of the soil used. As a general, lower quantities are required than for annual crops.

With regard to plant care products, there are around 520 approved active ingredients which make up nearly 3,000 specialist products used in farming which are commercially available. These plant care products include substances designed to provide protection against pests (insecticides, fungicides, etc.), and products designed to limit the growth of weeds (herbicides). Each commercially available product is approved for a certain number of identified plant species and for a given dose. Dedicated energy crops, such as miscanthus and switchgrass, are less prone to attacks. The use of herbicides during the plantation periods (years 1 and 2) can sometimes be justified in certain cases, but so far, no substance has been approved for these crops yet.

The CLIP Journal mentioned above provides an analysis of common uses of pesticides in the various scenarios in which biofuels will be developed in 2030. It suggests that although a scenario in which crops are developed for producing first-generation biofuels involves increasing the use of pesticides on the land used, the risk of these substances being transferred into underlying water bodies in the basin remains unchanged. Similarly, a scenario in which annual or perennial ligno-cellulosic crops are developed across a significant area of the basin's usable farmland will involve a reduction in the number of substances used and the frequency with which they are applied. But the risk of their being transferred into the water will remain unchanged given the extent of the area used. And a scenario in which mainly perennial ligno-cellulosic crops are grown in the same area will bring about a significant reduction in the risk of polluting substances entering the water as a result of the species in question requiring less water.

Water in biofuel production plants

As is the case with conventional manufacturing plants, the water requirements for biofuel production plants are mainly associated with three uses: water for the processes, water for heat production and water for cooling. The first use involves water being integrated at various stages of the process (dilution, rinsing, etc.). Depending on the situation, it can include different recycling processes, with different levels of processing required. Boiler water is used for producing steam, which has various applications (heat exchangers, turbines, etc.). The third use is required in order to evacuate residual heat from certain processes (see the Panorama article "Water in fuel production"). It should be noted that water consumption can vary depending on how well optimised the processes are and on the extent to which different processes are integrated at the same plant.

Very little water is consumed in open cycle cooling systems. At the very most, a little more water evaporates than it would naturally from a water body. However, they require unit withdrawals the sizes of which are the same as in farming for growing a crop which needs irrigation; but the impact on these resources should be less given that most of the water is returned to its natural original environment with this cooling method. There is, however, a constraint with regard to where these plants can be set up: they need to be near a water body with an average-to-high flow rate, or on the coast. This, together with the constraint associated with harvesting the biomass, should not be ignored. An evaporative closed cycle system involves relatively negligible quantities of water being used. This does away with the location constraint, but the result is higher investment costs.

As far as process water is concerned, the roles that it plays can be quite different. It may be used to dilute the load in order to make it easier to transport or mix (as is the case with ethanol and producing microalgae, for example). Water can also be used directly in chemical reactions (as is the case with Biomass to Liquid and hydrotreated vegetable oils where oxygen is eliminated through the production of water).

Table 2

Unit water withdrawals in biofuel production units (m^3 per toe of fuel).

m^3 of water par toe of fuel	Process		Open cycle cooling	
	min.	max.	min.	max.
Ethanol G1	2	27.5	–	
Ethanol G2	3.9	19.7	325	598
Biodiesel G1 - VOME[1]	–		1	2
Biodiesel G1 bis - HVO[2]	–0.1		45	57
Biodiesel G2 - BtL[3]	–6.1	–3	156	707

(1) VOME: Vegetable Oil Methyl Ester
(2) HVO: Hydrotreated Vegetable Oils
(2) BTL: Biomass to Liquid
Sources: IFP Energies nouvelles, Nexant

Ethanol production is the only technology that consumes significant quantities of water (Table 2). It should also be noted that ethanol production plants are often located in farming production basins that are near supplies of raw materials. These are areas where there may already be stress on water resources as a result of existing farming activities. Biodiesel production plants tend to be near ports and/or near seed-crushing plants so that they can make use of any extra imported raw materials. There are fewer problems associated with having to locate plants near areas where water is readily available.

Conclusion and outlook for developing industries

Although relatively few analyses have been carried out that can be used to assess well-to-wheel stresses on water used in biofuels, it would appear that the main issues are upstream of the industries, at the level of biomass production. From a quantitative perspective, between 50 and 800 m^3 of water is used per toe of fuel, and less than 30 m^3 per toe is required for the conversion processes. From a qualitative perspective, the risks associated with pollutants entering the water are easy to manage and manufacturing plants than in more diffuse farming environments.

At first glance, the pressures on water from first-generation biofuels industries are the same as on food industries which use the same crops, in the current context in which cultivated farmland is used. The levels of pressure on both quantity and quality are greater when the way in which the ground is used changes, and involving the replacement of a perennial coverage or of a crop which requires particularly low quantities of water.

Although second-generation technologies will use by-product type resources (straw, forest waste, etc.), which have a low production cost and little impact on the environment, dedicated ligno-cellulosic crops should be used in supply schemes that can reach 1 Mt/year of biomass. They therefore need to be selected and integrated into current crop farming systems such that pressure — quantitative pressure in particular — on water resources is limited. It should still be pointed out that in certain operational conditions (crops requiring little water together with a fall in acceptable yield), planting perennial ligno-cellulosic crops can potentially improve the state of water resources in certain high-stakes regions (basins supplying drinking water, watercourse banks, etc.). Although there is still agronomic research to be carried out, these initial analyses suggest a high development potential for future biofuel industries which are less harmful to the environment.

As far as third-generation biofuels are concerned, if the expected high yields are to be obtained, microalgae culture systems have to be developed in order to bring about maximum synergy and recycling between the various input (water, CO_2, nutriments, energy) and co-product flows. But such systems would be difficult to implement in regions that are already subject to water stress.

Just as biofuels are required to bring about significant reductions in greenhouse gas emissions compared to their fossil fuel benchmarks, their water footprint should be factored in and could even end up being included in the biomass energy certification process. When it comes to alternative forms of fuel, close attention should be paid to water related issues that strong growth in energy demand would involve for making electric vehicle fleets available (see the Panorama article "Water and electricity").

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