# ISSUE PAPER

BIOENERGY ISSUE PAPER SERIES NO. 2

*Bioenergy and water are inextricably linked. Water is an emerging issue of concern in the area of bioenergy development both in terms of quantity and quality. As a limiting factor, water will undoubtedly affect the level to which bioenergy can contribute to the overall energy mix. Especially in areas with scarce water resources bioenergy production can add on existing water stress and increase environmental and social impacts. Moreover, there are potential impacts that come with increased bioenergy production with regard to water quality. Like any other agricultural and industrial production system, bioenergy production has an impact on water quality. Well chosen feedstocks, sustainable agricultural production and an overall life-cycle analysis are elements to assist in achieving sustainable water use and management in bioenergy production.*

# WATER AND BIOENERGY

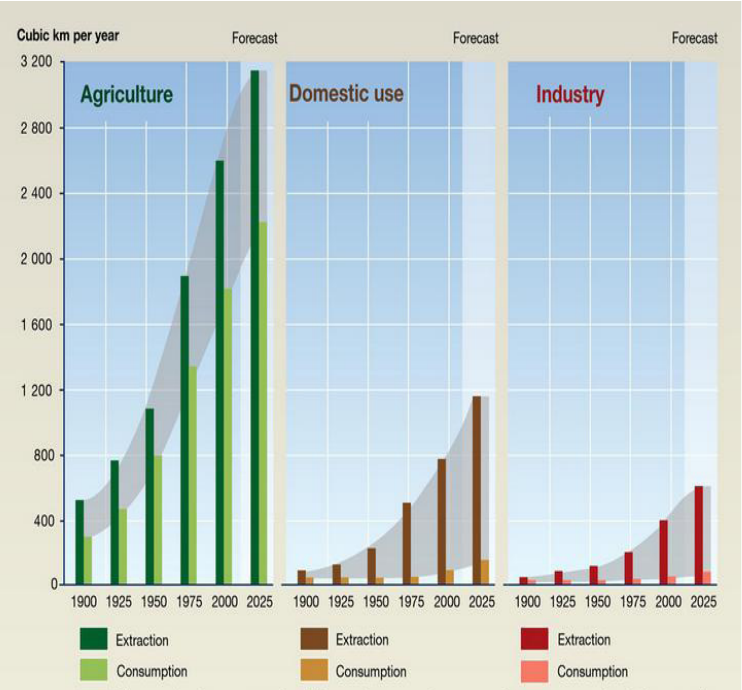
## WATER: THE CURRENT PICTURE AND FUTURE TRENDS

In the most recent United Nations World Water Development Report, researchers purport that global water supplies are experiencing tremendous pressure, with withdrawals nearly tripling in the past fifty years. Of all sectors, agriculture is the biggest user, consuming approximately 70-80% of global freshwater supplies (UN World Water Development Report, 2009) (see Figure 1). The Global Environmental Outlook 4 (GEO-4) estimates that by 2025, 1.8 billion people will live in places with "absolute water scarcity ", with two-thirds in areas experiencing water stress (UNEP, 2009).

However, it is not only the trends in the quantity of water withdrawn that are alarming, but also the quality of the water that is recycled back into natural systems. Nutrient loads in freshwater bodies from agricultural run-off, household waste, and effluents from industry have resulted in eutrophication and even hypoxia in some regions. The predictions paint a startling picture for the future of global water quality as studies predict a 10-20% increase in nitrogen effluents over the next thirty years, and a 50-100% increase in phosphorus by 2050, which may impair freshwater ecosystems beyond their natural resilience (UNEP, 2009; Cordell et al, 2009).

Consequently as the integrity of water systems decline, they are less able to provide fundamental ecosystem services such as the provision of clean water, natural filtration services and providing natural habitat for fisheries, etc. And as the patterns of global water use are changing and new challenges emerge, some of these services will be increasingly threatened or compromised.

Global challenges such as climate change, population growth, change in living standards and an increase in agriculture (esp. dietary standards and an increase in meat consumption in developing countries) and energy demand (not least linked to further industrial development) will impact the Earth's water supplies. Furthermore, the long term effects due to climate change present an enormous challenge for global water resources as the intensity of hydrologic events, and change in precipitation patterns are likely to increase. The prevalence of droughts in countries that are under water stress is of particular concern. As these dynamics are constantly changing, it is



The grey band represents the difference between the amount of water extracted and that actually consumed. Water may be extracted, used, recycled (or returned to rivers or aquifers) and reused several times over. Consumption is final use of water, after which it can no longer be reused. That extractions have increased at a much faster rate is an indication of how much more intensively we can now exploit water. Only a fraction of water extracted is lost through evaporation.

Source: Igor A. Shiklomanov, State Hydrological Institute (SHI, St. Petersburg) and United Nations Educational,Scientific and Cultural Organisation (UNESCO, Paris), 1999.

difficult to determine the exact degree to which they affect water use and water quality. However, it is important to understand their inter-linkages and how sustainable water management and planning can help prevent future water stress and revitalize ecosystem health (See Toolbox at the end).

## BIOENERGY AND WATER

Bioenergy production has an impact on water quantity and quality, both during production and cultivation of feedstocks and conversion of feedstocks to liquid fuels, (bioethanol, biodiesel, straight vegetable oil, biobutanol, etc.) gas, (biogas, bagasse, etc) or electricity (combined heat and power (CHP), cogeneration). The extent of the impact depends on the region, climatic conditions, supply chain models, choice of feedstock, production methods, conversion technologies and end product. In that sense, data and estimates for water use in bioenergy as a whole cannot be aggregated, but must be delineated according to pathways chosen. For instance, water use for biomass combustion in dedicated power and CHP is markedly different than water use for first generation bioethanol, because of different production pathways.

Triggered by bioenergy targets, mandates and related investments, bioenergy demand is growing – and with it the pressure on water. This growth is markedly evident for biofuels produced for transport which are expected to grow 0.8EJ in 2005 to 4.3EJ in 2030 – representing a total of 0.9% of global energy consumption (IEA, 2007). Growth in the modern biomass sector for power generation is projected to increase from a current 1.3% to 3-5% by 2050. Bioelectricity from CHP generation is particularly rising in Europe, with some countries registering a 50-100% capacity increase in the sector (IEA, 2007). Although scenarios predict that there is a considerable amount of biomass for energy available (1100EJ in the most optimistic prediction, 40EJ under pessimistic scenarios), *bioenergy availability is also determined by critical inputs – with water being one of the most critical limiting factors* (Faaji, 2006) .

Currently, an estimated 44km$^3$ or 2% of total water withdrawals for irrigation are for bioenergy crop production (UNESCO, 2009). Implementing current bioenergy standards and targets would require 180 km$^3$ of additional irrigation water, exerting tremendous pressure on water resources and potentially diverting from other uses such as food production, industrial and household use (UNESCO, 2009). As well, when compared to traditional fossil fuels, the water footprint of bioenergy can be 70 – 400 times larger (Box 1).

Therefore, one of the greatest challenges, assuming that bioenergy use will be used in the energy mix, will be how to meet future bioenergy demand without overexploiting or damaging water resources; and how to better manage bioenergy supply chains to reduce the pressure on water use and minimize the impacts on water quality.

### Water use

Water requirements for bioenergy depend on several factors and pathways throughout the life cycle including cultivation, production, processing, mixing, and storage. Additional factors also include the type of feedstock, land management, geographic and climatic conditions, production methods and conversion pathways, leading to various end-products, are just a few variables that affect the total water footprint of a bioenergy product.

**Box 1:**
**Water Footprint**
Total annual volume of fresh water used to produce the goods and services related to consumption. The total water footprint is comprised of three different types of water used – Green water, blue water and grey water. *Green water* refers to water that has been evaporated during crop growth; *Blue water* is the amount of (evaporated) surface and ground water used for irrigation; and *Grey water* refers to water that becomes contaminated during the production process. (Hoekstra & Hung, 2002; Hoekstra & Chapagain, 2008)

A study conducted by the National Academies of Science finds that water usage ranges from 1400 to 20,000 litres of water per every litre of liquid biofuel produced from different feedstocks. An overview of the total water footprint per unit of bioenergy (m$^3$/ gigajoule (GJ) is provided in Table 1, which shows feedstocks that are commonly used for ethanol and biodiesel. For ethanol production, sorghum is the most water intensive feedstock, requiring 419 m$^3$/GJ of water. Whereas sugar beet only has a water foot print of 59 m$^3$/GJ . However, the results show that, as a whole, biodiesel feedstocks are more water consuming than ethanol feedstocks (excluding palm oil).

**Table 1: Total Weighted Global Average Water Footprint**

| Crop | Total WF | Blue WF | Green WF | Total Water |
|---|---|---|---|---|
| Ethanol (m3 per GJ ethanol) | | | | |
| Sugar Beet | 59 | 35 | 24 | 1388 |
| Potato | 103 | 46 | 56 | 2399 |
| Sugar Cane | 108 | 58 | 49 | 2516 |
| Maize | 110 | 43 | 67 | 2570 |
| Cassava | 125 | 18 | 107 | 2926 |
| Barley | 159 | 89 | 70 | 3727 |
| Rye | 171 | 79 | 92 | 3990 |
| Paddy Rice | 191 | 70 | 121 | 4476 |
| Wheat | 211 | 123 | 89 | 4946 |
| Sorghum | 419 | 182 | 238 | 9812 |
| Biodiesel (m3 per GJ biodiesel) | | | | |
| Soybean | 394 | 217 | 177 | 13,676 |
| Rapeseed | 409 | 245 | 165 | 14,201 |
| Jatropha | 574 | 335 | 239 | 19,924 |

Proceedings of the National Academies of Science, 2009

*Pathways of bioenergy production matter.* Research suggests that the most efficient form of modern bioenergy, in regards to water use, is utilizing biomass for electricity production rather than converting feedstocks into a biofuel, as the cultivation process makes up a majority of the total water footprint of the end product. In this regard, bioenergy pathways that do not require the cultivation and irrigation of feedstocks, but instead maximize waste or residues are more likely to have a lower water footprint. Straight vegetable oil (SVO) if not produced from intensive agriculture, for example, has a lower water footprint than biodiesel because of lower water cultivation inputs and reduced processing.

Even though bioenergy pathways vary in terms of their level of water use and efficiency, it is still difficult to determine exactly which ones are more water efficient as so far, only few life-cycle assessment (LCA) studies on bioenergy cover water – a lacuna that needs to be addressed by including water quality and quantity as important impact categories. For comprehensive bioenergy considerations, full LCA studies must account for total water use throughout the full product life cycle.

***Water use impacts.*** The depletion or diversion of local water sources can cause environmental, social and economic impacts. On the environmental side, the depletion of natural water bodies can affect the biodiversity of local ecosystems, as it can change and impact natural species composition and reduce variability in flora. It can also affect species richness, particularly in freshwater ecosystems, reducing biodiversity.

On the social side, deteriorating water sources can also affect social development and right to water. As access to water is one of the Millennium Development Goals (MDGs), it is imperative that water sources are protected for vulnerable and marginalized communities. However, if certain bioenergy feedstocks and production processes require water that withdraws beyond water table replenishment levels, then this has the potential to divert water resources from local communities. Unsustainable water use can also pose economic development problems.

Water stressed areas can experience economic impacts if there is a limitation on water that can be used for goods and resources. For example, groundwater depletion has been linked to a reduction in GDP for some economies, including a 2.1% reduction in Jordan and 1.3% reduction in Egypt (World Bank, 2007). Competition for water resources can have implications on other sectors as well. Since a significant amount of water is used for the agricultural sector, in some cases bioenergy can present a competing demand diverting water resources, leading to reduced food production and in extreme cases food security concerns. Other competing uses such as domestic use and industrial use might be affected as well.

Even though water use for bioenergy production can have some potential impacts if managed unsustainably, it can also create opportunities if managed correctly. In developing countries, water needs for bioenergy can bring investment in efficient water infrastructure, boosting development goals. As well, certain bioenergy feedstocks can help regulate local water cycles and groundwater replenishment levels, especially in arid and semi-arid environments. Bioenergy can also serve as a tool for the provision of water as it can help fuel equipment like irrigation and water pumps in a substitute for traditional fossil fuels.

These impacts demonstrate that water use and water requirements for optimal yields of bioenergy feedstocks need to be considered in planning and implementation. However, although there is some research on the *water usage* of various bioenergy feedstocks, most of the research focuses on aggregate water figures, accounting for water use in the irrigation and cultivation processes on regional or national levels only. As well, there is still a sizable gap for research that includes water throughout a full product life-cycle comparing different bioenergy pathways, and including processes such as the processing, conversion, storage, and blending phases for biofuels (GAO, 2009). For example, research on consumptive water use in biorefineries is limited. All of these gaps have to be addressed for sustainable water management and use in bioenergy production and planning

## Water quality

Bioenergy production can also lead to water quality problems, both on a project-level and on a regional level due to cumulative effects. At the project level, run-off from fertilized fields can increase nutrient loads (particularly in nitrogen and phosphorous) in local water bodies and further downstream. Most of the actions that lead to worsening water quality occur during the bioenergy crop production phase, but also if managed unsustainably, conversion processes, and to a lesser extent transportation and storage, may impose risks to clean water quality.

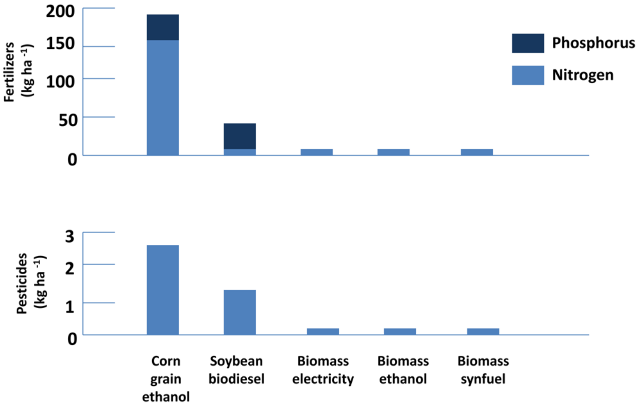
Often times monitoring site level impacts from agricultural inputs is difficult, leading to information gaps on a macro-level about the total amount of fertilizers used in bioenergy production. Application of agrochemicals varies among different bioenergy feedstocks, agricultural management practices and pathways. The National Research Council finds that of potential feedstocks, corn ethanol has the greatest application rates of fertilizers and pesticides per unit of energy gained, and biomass feedstocks for electricity production result in the lowest agrochemical application (Figure 2). Although problems such as nutrient loading come from an accumulation of different non-point sources, it is difficult to determine how responsible bioenergy production is for these environmental problems. However, what is evident is that bioenergy production schemes that use heavy fertilizer application will continue to aggravate the problem. Even the utilization of degraded land for bioenergy production can negatively affect water resources, if more agrochemical inputs are required to produce and optimize yields on those lands.

Although agricultural practices represent the bulk of water quality problems from bioenergy production, leakage from the storage and distribution of biofuels can also raise additional water quality concerns. Leaks can originate from incompatible tank systems, when biofuel blends are higher than what the existing infrastructure is built for. If unmanaged, leakage of ethanol or biodiesel into groundwater systems can present risks to local ecosystems and human health (Government Accountability Office, 2009). As well, externalities from biorefineries can also impair local water resources. For example, if left unregulated, glycerine and methanol, two main byproducts of biodiesel production, can end up untreated in waste streams, depleting the oxygen content of water bodies very fast. More research is needed on the impacts of water quality from biorefineries, particularly the impacts these externalities have on local water systems.

***Water Quality Impacts.*** These water quality impacts from bioenergy affect all tiers of sustainable development. Environmentally, worsening water quality has the potential to reduce ecosystem health and biodiversity. Accumulated on a regional- level, nutrient loading in surface water bodies can cause larger environmental problems such as eutrophication, hypoxia and even 'dead zones' in some cases, impairing the diversity of water ecosystems and reducing ecosystem services. Currently there are an estimated 400 dead zones worldwide, covering a total area of about 245,000$km^3$ (Diaz & Rosenberg, 2008). An excessive amount of nutrient loading in freshwater ecosystems can also lead to increased algal blooms and cause the reproduction of cynobacteria. Also known as blue-green algae, cynobacteria can lead to environmental implications, as well as health impacts as the toxins from the algae can bioaccumulate in fish, causing acute health impacts when digested.

The socio-economic impacts of reduced water quality are also overwhelming. Poor water quality can cause nitrate contamination in drinking water, worsening human health, and limiting access to clean water. It can also reduce the amount of species variability, particularly for fish, to which many communities depend on for livelihood activities.

**Figure 2: Comparison of fertilizer and pesticide application**



National Research Council, 2009

Economically, as water quality decreases so do basic ecosystem services that are provided by clean water and clean water bodies. Some of these are water systems and basins that serve as sources of filtration and purification, and the provision of fish nurseries (UNEP, 2009). A study completed by Dodds et al., 2009, found that the economic costs of eutrophication in the U.S. alone accounted for an annual loss in an estimated USD2.2 billion.

Similar to research on the water use of bioenergy, there is a lack of research on water quality issues originating from the bioenergy process. Within the small pool of research on water quality impacts from bioenergy, there are even fewer studies conducted on water quality concerns on different parts of the product life cycle. For example, more research is needed on the externalities from biorefineries, as little information exists. In addition, water quality impacts from the production of advanced bioenergy feedstocks also remain questionable. Information on the contaminants and wastewater from algae cultivation and fertilizer needs (and subsequent impacts) for cellulosic feedstocks need to be analyzed (See Box 2).

## MITIGATION OPTIONS

However great the research needs are, they should not detract from using existing mitigation options that can be used to reduce the overall impacts on water. These mitigation options serve to reduce additional pressures on a vital natural resource. On a project level, selecting practices and fostering certain mechanisms can considerably reduce these impacts to the environment, and prevent socio-economic problems. On a macro-level encouraging these changes in a systematic way, is also pertinent in reducing impacts.

### Reducing water use

#### *Feedstock suitability*

To buffer the need for additional water withdrawals from local aquifers, bioenergy feedstocks should be chosen with respect to geo-climatic conditions (this includes conditions such as local water availability and rainfall). Feedstocks that require less water should be considered, even though their use might result in a reduction of yields; this particularly applies to areas under existing or future water stress (adaptation). Breeding low input native plant varieties that do not have environmental impacts is one option to reduce feedstock water requirements. Along these lines, water management plans should include an assessment of local water availability taking into consideration water needs for local communities, and the replenishment rate of water systems affected by production. Management tools such as Integrated Water Resource Management (IWRM) can provide guidance on suitable feedstocks which can reduce overall environmental and social risks (Box 3).

Box 3: IWRM

The Global Water Partnership (GWP) defines IWRM as “a process which promotes the coordinated development and management of water, land and related resources in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital eco-systems”. The GWP tool on IWRM can be found at: http://www.gwptoolbox.org/

#### *Efficiency in water use in cultivation*

As the cultivation process of bioenergy production constitutes a majority of water use through the product life-cycle, feedstocks should optimize water efficiently during this stage. Increasing water availability through rain water harvesting for irrigation, implementing sub surface drip irrigation, and utilizing reclaimed water (instead of potable water) are approaches that have proven to be successful in Israel, Australia and Tunisia (UNEP, 2009). These two techniques can also be effective for corn and cellulosic ethanol feedstocks (The National Research Council, 2009).

#### *Improving technology*

New technological advances in industrial facilities have been shown to reduce the water required during the distillation and cooling process in conversion in first generation biofuels. Overall water withdrawls are decreasing as water recycling and rated metered use is being introduced in the overall production process. Modifying and upgrading for new infrastructure that is water efficient can reduce overall water use in the total life-cycle of a product.

***Box 2: Advanced biofuels and water:*** Although there is not a lot of research available on advanced biofuels (i.e. second and third generation biofuels), studies suggest that advanced biofuels, such as cellulosic ethanol, might have the potential to reduce overall water needs compared to first generation biofuel feedstocks, but the research on actual savings is far from conclusive. Cellulosic ethanol from some high yielding grass varieties and perennials (such as miscanthus and switchgrass) seem to perform well under lower water requirements; although the pre-treatment process, as it can potentially utilize a high amount of water, can affect the total water footprint. Water use estimates range from 1.9 to 5.9 gallons of water per gallon of cellulosic ethanol produced, compared to 785 gallons to produce 1 gallon of corn-based ethanol (GAO, 2009). Information about algae is even scarcer as it is not yet at commercial production. However, there is the potential that algae production for fuel will demand a considerable amount of water since water is required in vast amounts during the cultivation process (in closed systems or ponds) and in the oil extraction process. More information is needed on the water requirements of these advanced biofuels.

### Reducing water quality impacts

#### *Sustainable agricultural practices*

Selecting nitrogen fixing crops in multi-cropping systems (such as using legumes) is an example of an agricultural management practice that can potentially reduce the need for fertilizers. Promising technologies such as spectral radiometers and technologies using precision agriculture tools can also limit overall agrochemical use, as these tools apply nutrients at a variable rate on a project site (this can also be relevant to localized irrigation application, to reduce overall water use). On a policy level, government programs that provide assistance (financially or technically) on how to implement nutrient management to improve water quality could be effective.

#### *Foster market and regulatory mechanisms*

As impacts such as eutrophication are often times ubiquitous, fostering mechanisms that can reduce practices that decrease agrochemical use can be one form of mitigation. Certification, as a market incentive, is one mechanism that can do so, as many certification systems require that fertilizer and pesticide use be kept to a minimum and auditing processes go through on-site monitoring and evaluation. Some certification systems, such as the Roundtable on Sustainable Biofuels outline that the use of buffer zones, for example, can encourage ecosystem resilience to absorb possible water pollution from bioenergy projects.

Another mechanism that has been proposed is supporting regionally based nutrient trading systems which would function like other exchanges and platforms, such as carbon exchanges. As well, on the regulatory side, the integration of a ‘polluter – pays’ scheme, or compulsory tax for the amount of agrochemicals production sites could be effective in some cases.

In conclusion, the emerging issues that we face in the allocation of this precious resource will be a principal development challenge in the short and medium term; and the potential impacts deriving from unsustainable bioenergy production will only aggravate the pressures of global water use and water quality. Complex as the issue is, water use and water quality have been largely overlooked within the current bioenergy debate. In order for decision makers to create sound and scientifically appropriate policy decisions on bioenergy, research on the water requirements and potential impacts of different bioenergy pathways needs to be reinforced. The options and avenues presented here can serve as guidelines for decision makers to secure the integrity of water resources for the environment and human development.

***Other useful tools:***

**a) DPSIR**: The DPSIR framework (Driving Forces Pressures-State-Impacts-Responses) is an analytical framework used to assess and manage environmental problems. The framework considers the driving forces such as socio-economic and cultural forces that drive human activities, which aggrevate pressures and stresses on the environment.

*Website:* http://maps.grida.no/go/graphic/dpsir_framework_for_state_of_environment_reporting

**b) IWRM for Climate Change:** A training manual that has been developed to increase understading of climate change impacts and the interaction with water management.

*Website*: http://www.cap-net.org/node/1628

## AVENUES FOR SUSTAINABLE BIOFUEL PRODUCTION

## LOOKING AHEAD:

- Match bioenergy feedstocks with locally available water resources, favoring feedstocks that require a lower amount of irrigation and agrochemical inputs.

- Employ sustainable agricultural practices and technologies to minimize site based water use and nutrient application and foster mechanisms that encourage their adaptation.

- Conduct life-cycle analyses in total water use and quality in different bioenergy pathways, with specific regard to advanced bioenergy feedstocks.

- Foster market mechanisms that encourage sustainable water use and reduce potentially harmful effluents with regard to regional needs and contexts.

For more information on the Bioenergy Issue Paper Series, please contact Punjanit Leagnavar at: punjanit.leagnavar@unep.org, or visit our website at http://www.unep.fr.

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