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BIOFUELS: FUTURE BENEFITS AND RISKS

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Abstract: Biomass continues to be investigated as an alternative resource to resolve the demanding consumption of petroleum-based gasoline and diesel fuel. In addition, biomass can be used to provide bio-oil, biogas, and hydrogen as well as electricity. The growing demand for alternative energy sources has contributed to increased biofuel production, but the effects on biodiversity of land-use change to biofuel crops remain unclear. As a result and in order to minimize impacts of biofuel crops on biodiversity, management practices that reduce chemical inputs, increase heterogeneity within fields, and delay harvests within wildlife areas are recommended. There is also the need to address the growing challenge of climate change by closer scrutiny of biofuels to assess whether they can be produced, traded and used sustainably. Criticism of biofuels has centered on the perceived negative impacts on the environment through deforestation, spread of monocultures, loss of biodiversity and possible higher GHG emissions under uncontrolled land-use change. The potential of biofuels to contribute to a shift into more sustainable energy systems has been contested, and scientists had to move away from emotional preferences and question the claimed environmental superiority of biofuels.
Keywords: Biomass, biofuel, hydrogen

INTRODUCTION

The term biofuel is referred to as liquid or gaseous fuels that can be used to supplement the demand for petroleum-based liquid fuels. Furthermore, biomass offers a sustainable source of liquid and gaseous fuels with the further promise of a reduction in the amount of greenhouse gas emissions as well as playing a role as a co-feedstock in the refinery of the future (Figure 1) (Reijnders, 2006; Speight, 2008, 2011a, 2011b, 2011c). Furthermore, the widespread availability opportunities of biomass resources may also allow the petroleum-importing counties to enjoy a measure of self-sufficiency in energy production (2011b).

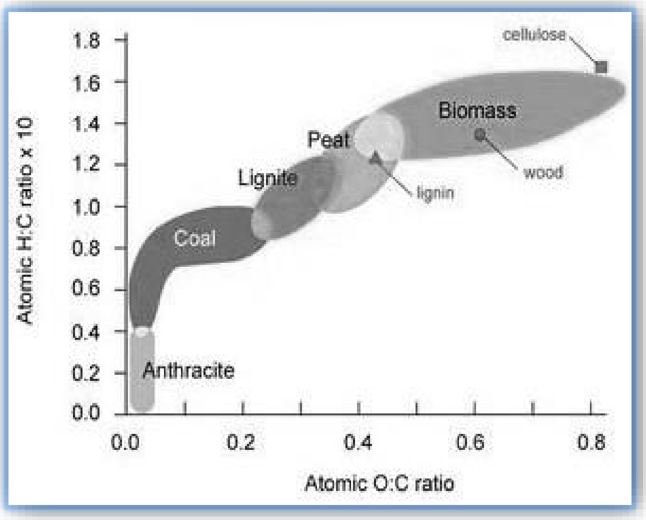

Figure 1: Van Krevelen Diagram showing the Relationship of Biomass and other Fuel Sources.

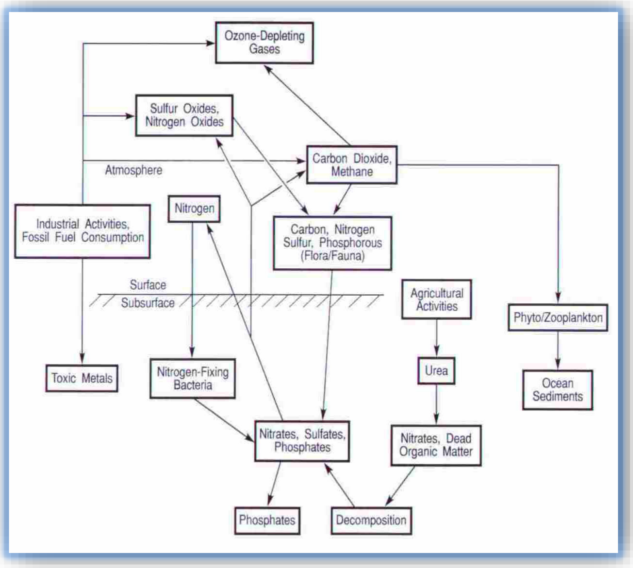

Figure 2: The Industrial Cycle Initiated by the Use of Fossil Fuels.

Biofuels, unlike fossil fuels which give rise to a compex industrial cycle (Figure 2) are a renewable energy source and the raw material (biomass) is are grown all over the world and include: (1) corn and soybeans, mainly in the United States, (2) palm oil in South East Asia, (3) rapeseed mainly in Europe, (4) sugar cane in Brazil, and (5) jatropha in India. In addition, food waste such as cooking oil can also be used as a feedstock to produce biofuels as can waste products such as straw, timber, cattle manure, and sewage (Gabrielle, et al., 2014). Furthermore, biofuels have (correctly or incorrectly) been recognized hailed as the answer to two major issues: (1) moving away from the heavy reliance on petroleum and (2) climate change. However, *biofuels may not be the panacea they have been made out to be and are worthy of a thorough analysis of the benefits and risks of using and producing such fuels.*

BIOFUELS

There is no doubt that the supply of crude oil is finite and the flow of petroleum to refineries will eventually become unsustainable as supply/demand issues are erode by the depletion of the resource. However, the precipice will not appear suddenly and out-of-the-blue (as many observers seem to think). With adequate pre-planning and consideration of the resource availability in terms of real numbers, the peak-oil-production situation can be mitigated by the exploitation of more technically challenging fossil resources and the introduction of technologies for fuels and chemicals production from biomass. Consequently, in addition to the variety of potential energy-production technologies (Speight 2008), there is a renewed interest in the utilization of plant-based matter as a raw material feedstock for energy and chemicals production (Speight, 2008, 2011b). Plants accumulate carbon from the atmosphere via photosynthesis and the widespread utilization of these materials as basic inputs into the generation of power, fuels and chemicals is a viable route to reduce greenhouse gas emissions.

While the use of biomass may not be the ultimate source of energy, the production of fuels and chemicals from renewable plant-based feedstocks utilizing state-of-the-art conversion technologies presents an opportunity to fend off any potential energy crises which arise from the depletion of petroleum resources. However, bioprocessing routes have a number of compelling advantages over conventional petrochemicals production but in the last two decades rapid progress in biotechnology has facilitated the commercial development of plant-based processes with the emergence of the biorefinery concept (Figure 3), which is analogous to conventional petroleum refineries and petrochemical complexes that have evolved over many years to maximize process synergies, energy integration and feedstock utilization (Speight, 2008, 2011).

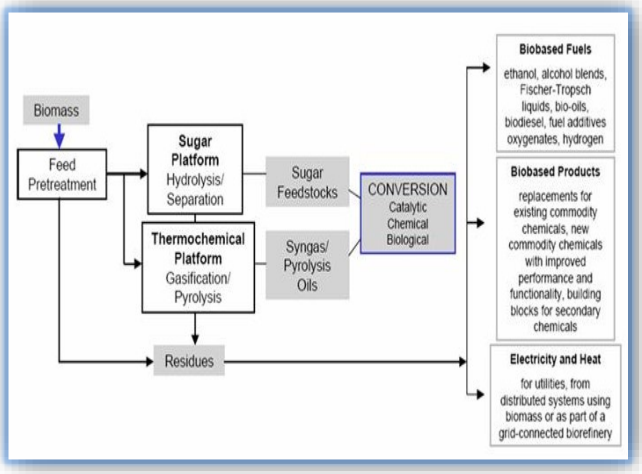

Figure 3: Fuels from Biomass using the Sugar (Biochemical) Platform and the Thermochemical Platform (Source: Office of the Biomass Program-Multiyear Plan 2004 and Beyond, Nov. 2003).

Plants offer a unique and diverse feedstock for energy and chemicals production. For example, biomass can be gasified to produce synthesis gas, which is a basic source of hydrocarbon fuels and chemical feedstock as well as a source of hydrogen for a future hydrogen economy (Table1, Figure 4) (Chadeesingh, 2011; Speight, 2013a, 2013b, 2014). In addition, the specific components of plants such as carbohydrates, vegetable oils, plant fiber and complex organic molecules known as primary and secondary metabolites can be utilized to produce a range of valuable monomers, chemical intermediates, pharmaceuticals and materials. Furthermore, a simple, cheap, and common method of obtaining energy from biomass is direct combustion. The heat of combustion can be used, through the use of a steam turbine, to produce electricity (Speight, 2013b).

Table 1: Fischer-Tropsch Reactions.

Reaction:	Reaction enthalpy: $\Delta H_{300\,K}$ [kJ/mol]
$CO + 2H_2 \rightarrow -CH_2- + H_2O$	- 165.0
$2\,CO + H_2 \rightarrow -CH_2- + CO_2$	-204.7
$CO + H_2O \rightarrow H_2 + CO_2$	-39.8
$3CO + H_2 \rightarrow -CH_2- + 2CO_2$	-244.5
$CO_2 + 3\,H_2 \rightarrow -CH_2- + 2H_2O$	-125.2

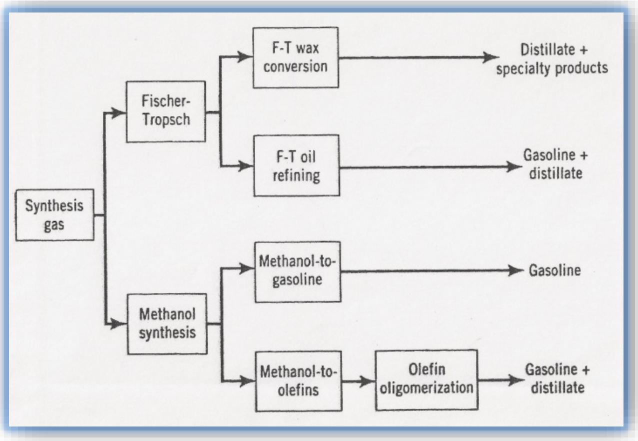

Figure 4: Routes for the Production of Fuels from Synthesis Gas.

Thus, almost all crops, whether grown for food, animal feed, fiber or any other purpose, result in some form of organic residues after their primary use has been fulfilled. These organic residues, as well as animal wastes (excrement) can be used for energy production through direct combustion or biochemical conversion. Current worldwide production of crop residues is very large; but an increased scale of use for fuel may have significant environmental impacts, the most serious being those of lost soil fertility and soil erosion.

BENEFITS

Biofuels have the potential to be a sustainable, low carbon fuel source and at a time when the depletion of petroleum reserves becomes obvious biofuels could be crucial factors in world energy production. Thus, with effective management and global compliance (Nasterlack et al., 2014), the biofuels industry could help to reduce the greenhouse gas emissions from transport, alongside increased fuel efficiency and *public transport improvements. However, whether or not biofuels can replace all of the crude oil that is currently used for energy and chemicals, it may not be possible to grow sufficient biomass without serious consequences for the environment and people. It has to be recognized that biofuels may only be part of the answer to provide energy after petroleum production has peaked and there will be limits to the amount of biofuel feedstocks that can be grown due to conflict with current land uses – growing food, forests, and human habitation. Food prices could increase significantly as crops once destined for food are sold for fuel instead.*

Indeed, various national governments are insisting (even legislating) that petroleum refining companies start to use some biofuels in the fuel they sell. There is widespread support for an alternative to traditional fossil fuels. However, the possible negative impacts of a huge growth in biofuels are beginning to be realized.

In theory, biofuels are carbon neutral insofar as the carbon released (as carbon dioxide) when they are burned was taken from the atmosphere by the plants as they grew. However, the energy needed to transport and refine crops usually comes from fossil fuels and the chemical fertilizers and pesticides used in growing the crops require energy and cause nitrous oxide to be released. Potential climate benefits can be lost or limited this way. In addition, agricultural chemicals can make their way into water supplies, contaminating drinking water and killing aquatic life. The availability of water can also be affected if supplies are diverted to irrigate crops leading to the risk of drought in some areas.

As an example, one of the biofuels with the most contentious issues is palm oil – demand for palm oil from both the food and biofuel industries has led to massive expansion of oil palm tree plantations. This, in turn, requires clearing land for use as these plantations and the land cleared is often is often rainforest. Thus, natural habitats are lost and the biodiversity of the Earth, including many endangered flora and fauna will be threatened and eventually lost. The destruction of ecosystems such as rainforests has indirect impacts on people as well. The forests are responsible for regulating water flow and protecting soils; many people also depend on them for food and medicines. Destroying ecosystems can even lead to outbreaks of disease. These effects are felt most by the poor who are more dependent on the natural environment.

The implosion of new fuels, in this case biofuels, will have implications across many business sectors and in a time when interest in being green is high, the race to secure safe, sustainable stocks of biofuels is already in place. In fact, with a focus on the environment and worries about crude oil reserves becoming depleted, governments across the world are understandably getting involved to encourage the growth of the biofuels industry.

In 2007, EU leaders agreed on an integrated climate and energy policy which includes 'a 10% binding minimum target to be achieved by all Member States for the share of biofuels in overall EU transport petrol and diesel consumption by 2020. At first glance, many would see this as a step forward. However, if not implemented sustainably, it could actually set us back. In the UK, the government claims that the Renewable Transport Fuel Obligation (RTFO) will deliver substantial carbon savings but this assumes that biofuels will (pound for pound) emit less than half the carbon (dioxide) of fossil fuels and this is often not the case at the moment. Until there is a move to a system where only biofuels from sustainable sources are eligible for RTFO certificates, there will be no positive carbon balance. In the US, the strategy is to cut petroleum consumption by 20% by 2017, which is to be achieved (in part) by replacing approximately 15% of the gasoline used in vehicles with renewable fuels or biofuels. This will require the production of biofuels to increase five-fold to meet projected demand. However, biofuels do present the opportunity of a more environmentally friendly alternative to crude oil, but there is a risk of doing more harm than good if sustainability is not made a priority. If managed properly, biofuels could form part of the solution in the fight against climate change.

RISK ASSESSMENT

The quality and composition of a biofuel depends on the source of the biomass/feedstock as well as the types of processing and conversion techniques utilized in its manufacture (Ramroop Singh, 2011). The feedstock composition ultimately decides the yield from the chemical or biochemical conversion processes, which in turn, affects the production economics. There are many plant varieties which are used as biofuel sources - the geography, weather conditions, soil composition and legislation of a location normally dictates what types are grown specifically for biofuel production.

Furthermore, the risks that arise from the production of the raw starting materials for biofuels production can cause serious problems – for example the destruction of rainforests while in some places people may be forced from their land. Furthermore, greenhouse gas savings of some biofuels may even be just as bad as crude oil!

Agricultural feedstocks are critical for decreasing petroleum dependence through sustainable biofuels production. Continued rapid improvements in both biofuel resources and processes are needed if agricultural biofeedstock crops are to significantly address concerns about the depletion of fossil fuel reserves, energy security and greenhouse gas emissions as contributors to climate change (Antizar-Ladislao and Turrion-Gomez, 2008). The current first generation biofeedstock crops represent modification and the use of food-based grains for biofuel production. These will be largely supplanted by second generation crops representing specialized industrial oilseed crops and the utilization of lignocellulosic crops and crop residues (Gressel, 2008). Unless, and until, third generation technologies using algae and bacteria become a reality, plant-based agriculture – with the attendant tradeoffs regarding land use alternatives and the balance of needs for food, feed and fuel production – will remain the leading opportunity for biofuel production.

Briefly, risk in any area is the joint probability of exposure and the consequence of exposure, the conventional risk assessment process describes exposure and its consequence (an adverse effect or harm) in four steps: hazard identification, dose-response, exposure characterization and risk characterization (EPA, 1998). Risk is assessed through a science-based process that integrates with risk management to facilitate informed decision-making.

The long-term success in developing sustainable bioenergy resources is frequently tied to perennial herbaceous and woody plants such as switchgrass (Panicum virgatum) and poplar (Populus) for ethanol production or jatropha (Jatropha curcas) for biodiesel production (Speight, 2011c). The targeted attributes for an ideal bioenergy crop vary, depending on whether the objective is a dedicated biofeedstock crop or a food and fuel crop. Nevertheless, in those cases where range and forest plants are targeted as dedicated biofeedstock crops there will be a need for domestication in order to improve agronomic performance, uniformity, quality and productivity. These crops will also need to undergo compositional modifications, for instance to better affect the conversion of lignin, cellulose and other cell wall polysaccharides to ethanol or to improve yield and quality of the bio-oils.

Food versus fuel is the dilemma regarding the risk of diverting farmland or crops for liquid biofuels production in detriment of the food supply on a global scale (Speight, 2008; 2011c). There is disagreement about (1) the cause, (2) the impact is, (3) the overall significance of such an issue, and (4) the resolution. Biofuel production has increased in recent years and some foodstock commodities such as corn, sugar cane, and vegetable oil can be used either as food, feed or to make biofuels. For example, vegetable oils have become more attractive recently because of its environmental benefits and the fact that it is made from renewable resources (Demirbaş, 2008). Vegetable oils are a renewable and potentially inexhaustible source of energy with energy content close to diesel fuel. On the other hand, extensive use of vegetable oils may cause other significant problems such as food shortages in many countries (Demirbaş, 2007).

The need to address the growing challenge of climate change has led to closer scrutiny of biofuels to assess whether they can be produced, traded and used sustainably. Criticism of biofuels centered on the perceived negative impacts on the environment through deforestation, spread of monocultures, loss of biodiversity and possible higher GHG emissions under uncontrolled land-use change. Moreover, the food crisis of 2007-08 and the ensuing surge of commodity prices heightened the debate over food versus fuel and the possible consequences of biofuel production on food security. The potential of biofuels to contribute to a shift into more sustainable energy systems became contested, and scientists had to move away from emotional preferences and question the environmental superiority of biofuels.

Biofuel certification schemes, despite their multiplicity, are dominated by a singular form of governance – namely voluntary, private industry-led initiatives targeting sustainability assurances with input from non-industry stakeholders. These schemes are driven as much by market access and trade considerations as by the need to provide sustainability assurances. This may explain why the first schemes and initiatives have focused on those feedstocks and biofuels most involved in south-to-north trade (soybeans, sugarcane and oil palm). This dual role of biofuel certification schemes also explains the tendency to target selected sustainability criteria and not others and hence the absence of a full integration of the three core dimensions (economic, environmental and social) into a coherent framework or strategy.

Rethinking sustainability also requires incorporating full environmental costs in economic cost-benefit assessments and fostering business models that can reconcile sustainability with economic growth and integrate inclusive-development with food security. Also required are policies, regulations and incentives that broaden the biofuel development options to include small-scale locally harnessed renewable energy technologies and systems.

Finally, biofuel sustainability will need to be integrated into major trends that focus on sustainability and climate-smart agriculture in line with the triple objectives of enhanced productivity, strengthened food security and climate change adaptation and mitigation.

CONCLUSIONS

The growing demand for alternative energy sources has contributed to increased biofuel production, but the effects on biodiversity of land-use change to biofuel crops remain unclear (Robertson and Doran, 2013; Dauber and Bolte, 2014). To minimize impacts of biofuel crops on biodiversity, management practices that reduce chemical inputs, increase heterogeneity within fields, and delay harvests until breeding seasons have ceased are recommended.

From the perspective of sustainability, biofuels offer not only advantages but also risks (Table 2) .

Table 2. Advantages and risks

Advantages	Risks
Contribute to increased energy security Help reduce GHG emissions Improve air quality in cities Spur growth in rural areas	Negative impacts on biodiversity Replace of natural forest with biofuel crops Influence water availability Influence water quality Adversely influence GHG emissions due to indirect land-use change

Indeed, balancing the economic benefits with environmental and social impacts is a delicate act. Even when biofuels meet environmental and social sustainability criteria, they need to first pass the economic sustainability (or viability) test. This means ensuring efficiency of production (through high yields and intensive management) and long run profitability, access to productive resources (e.g. land, labor, technology), and reliable output markets. The challenge is to achieve these goals while ensuring economic viability and minimizing potential negative social and/or environmental impacts.

Many of the initiatives on biofuel sustainability at the country or supranational levels come from industrialized economies where biofuel growth has been most dynamic and where there is large scope for bioenergy demand and huge energy substitution possibilities. Sustainability initiatives coming from Europe or North America largely mirror the industrial economies' priorities for biofuels (e.g. energy security supply, protection of agriculture, and increasingly climate-change mitigation).

Finally, the need to address the growing challenge of climate change has led to closer scrutiny of biofuels to assess whether they can be produced, traded and used sustainably. Criticism of biofuels has centered on the perceived negative impacts on the environment through deforestation, spread of monocultures, loss of biodiversity and possible higher GHG emissions under uncontrolled land-use change. The potential of biofuels to contribute to a shift into more sustainable energy systems has been contested, and scientists had to move away from emotional preferences and question the environmental superiority of biofuels.

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