CONSULTATIVE GROUP ON INTERNATIONAL AGRICULTURAL RESEARCH

Biofuels Research in the CGIAR

A Perspective from the Science Council

A CGIAR Science Council Policy Statement on Biofuels Production

Science Council Secretariat

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There are serious concerns about the greenhouse gas (GHG) emissions, energy and nutrient and water use efficiency of large-scale, first generation bio-energy feedstocks currently in use. A major question is whether biofuels obtained from these feedstocks are effective in combating climate change and what impact they will have on soil and water resources. Another fundamental issue relates to the magnitude and nature of their impact on food prices and ultimately on the livelihoods of the poor. A possible solution to overcome the current potentially large negative effects of large-scale biofuel production is developing second and third generation conversion techniques from agricultural residues and wastes and step up the scientific research efforts to achieve sustainable biofuel production practices. Until such sustainable techniques are available governments should scale back their support for and promotion of biofuels. Multipurpose feedstocks should be investigated making use of the bio-refinery concept (bio-based economy). At the same time, the further development of non-commercial, small scale production of first-generation biofuels in rural settings, e.g., biodiesel for rural household electricity supply in developing countries, should be explored in terms of promoting rural development to reduce dependence on imports of fossil fuels.

[1] This 'position paper' was motivated by a request from the FAO Assistant Director General (Natural Resource Management and Environment Department) for a policy statement from the SC on the challenges related to the global community's renewed interest in and attention to biofuels, what the likely implications of this development are for the poor and the environment, and what role the CGIAR is expected to play. This note has benefited from a paper on biofuels by Ken Cassman presented to the SC 8 Meeting at FAO in Rome and subsequent discussions at the SC 9 Meeting in Nairobi, but draws on a number of other sources as well, listed in the References.

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Summary

Government policies, motivated by concerns about energy security, high oil prices, greenhouse gas (GHG) emissions and various vested interests, are driving the latest expansion in the global biofuels industry. This is most evident in Brazil, the USA and the EU, but increasingly, developing countries are moving in a similar direction – creating new markets for biofuels by adopting policies, mandates and targets aimed at stimulating domestic biofuels production.

Developed and developing countries should be guided by sound policies that serve the long term best interest of its peoples, in particular, ensuring that biofuels development strategies are not conflicting with food security and environmental sustainability goals. As biofuels production will draw on the same resources that agriculture, livestock, forestry, fisheries and water sectors now depend, the CGIAR and other international agencies should provide R&D guidance and define the appropriate steps for governments to take.

In response to policies being adopted or about to be adopted, the CGIAR must (i) draw attention to the critical issues surrounding biofuels, food security and the environment, highlighting the likely consequences (positive and negative) likely to emerge from different biofuels policies and, (ii) target research that addresses the new challenges emerging from biofuels expansion, such as the need for ecological intensification of dominant crop and livestock based systems, keeping a tight focus on food security and environmental health goals consistent with the CGIAR mandate. Many of the CGIAR centres have already initiated technology oriented biofuels related research, e.g., on sweet sorghum, *jatropha*, cassava, etc., but questions remain about the priority of this work and what trade-offs are implicit, particularly if they support ill-advised government policies for expanding domestic biofuels production without having undertaken the required economic, social and environmental analyses.

The Science Council of the CGIAR is proposing a system-wide strategy to address the biofuels challenge as it relates to food security and the environment. It recognizes opportunities associated with this development, but also identifies risks. From the perspective of the CGIAR, it is essential to define a response (strategy) to the global biofuel boom that is "people-centered", i.e., one that offers opportunities for commodity producers but does not compromise the food security of poor producers and consumers and pays adequate attention to the full set of environmental risks. This brief note constitutes a first step in developing a coherent and unified strategy.

The **potential** benefits from biofuels are primarily four-fold:

- increasing energy availability and security

- reducing GHG emissions
- increasing biofuel & food crop producers' incomes
- increasing employment and rural economic development in rural areas.

But there are also serious doubts about the energy, GHG, and nutrient balances and water use of bioenergy feedstocks currently in use, and the potential adverse impacts on food security and the environment.

The search for alternative energy sources has intensified in the past few years, driven primarily by high petroleum prices and increasing concerns about energy security in the face of larger increases in energy demand over the next several decades. Many are looking to biofuels as at least a partial solution. As such, an increasing share of major crops like maize, sugarcane, oil palm and rapeseed, in addition to some new crops like *jatropha*, is now being diverted to biofuel production. This has the potential to reduce dependence on oil imports at the national level and to create readily available supplies of energy at the local level. But how efficient are biofuels as a substitute for fossil fuels, and how much land will be required to generate a significant share of transport fuel needs?

The land requirement alone is excessive when one considers conversion of starchy grains or sugar crops to bioethanol or oilseeds to biodiesel. Even if the entire USA maize crop were diverted into biofuel production, leaving no maize for the food and feed market, it would only displace around 10% of the nation's gasoline consumption. At the global scale, large parts of the world's wheat, rice, maize or wood output would need to be diverted to meet just a small share of global transportation fuel needs. With the exception of Brazil, biofuels currently in use generate comparatively little substitution effect for fossil fuels and are not economically competitive. Biofuels are currently heavily dependent on government support and protection for continued development in both developed and developing countries, via sales and excise tax exemptions, loan guarantees and high import tariffs. Even higher oil prices will have the effect of increasing biofuel production costs while simultaneously making fossil fuel alternatives such as tar sands and coal-to-liquids increasingly competitive.

Second generation technologies and bio-refinery concepts offer better prospects in the long run in support of a rational biofuels policy. The EU policy on biofuels looks increasingly to second generation technologies and other forms of renewable energy to achieve its targets and recognizes the role of second generation technologies in helping to meet the mandatory 10% biofuel component in vehicle fuel by 2020. The recent Royal Society report considers that biofuel production from ligno-cellulose holds significant potential, given the amount of energy in biomass and the extent of biomass that is available globally. Major research efforts are now underway globally to develop and optimize technologies for producing biofuels from these ligno-cellulose feedstocks and many processing facilities are now in operation or planning throughout the world. Second generation biofuels extracted from micro-algae and other microbial sources and ligno-cellulosic biomass present a better option for addressing both food and energy security and environmental concerns than large scale plantation of bio-fuel crops like *jatropha* and *pongamia*.

Second and third generation biofuel crops that can be produced with little water or fertilizer on dry or easily erodable soils, and that actually improve degraded soils, may have superior benefits to even the best sugarcane ethanol. However, the widely held assumption that marginal, abandoned and degraded lands can and will be used for massive production of biofuels are too optimistic—from a technical, economic and social perspective.

As a renewable energy source, biofuels are a potential low-carbon energy source, but whether they offer carbon savings and thus are effective in combating climate change depends on the type of feedstock, production process, changes in land use, and conversion into a usable fuel. Earlier estimates of GHG reductions from Brazil sugarcane-based bioethanol (90%), ethanol from cellulosic feedstock (70 - 90%), ethanol from sugar beets and soybean-based biodiesel (40 - 50%), and ethanol from maize (25 - 75%) fail to capture a key element in the life cycle analysis – the direct and indirect changes in land use. Some methods of producing biofuels actually increase global warming due to land conversion and the release of huge amounts of carbon that otherwise would remain in plants and soil.

Two studies published recently in *Science* raise serious questions about the GHG-reducing effects of biofuels. The studies found that when direct and indirect land use changes are taken into account, e.g., conversion of forests, peatlands, savannas and grasslands to new cropland to replace the grain diverted to biofuels, then biofuels create a huge ‘carbon debt’, that will take decades or even centuries to repay. Biofuel policies need to focus on biofuels that do not trigger significant land use changes and rely excessively on fossil fuel derived inputs, but instead rely on waste products and crop residues and take into account fossil fuel derived inputs. Obligatory blending and government subsidies of biofuels production creates a strong incentive to produce biofuels in any possible way, whereas the techniques to achieve this large scale production in a sustainable way are not yet available.

As the current generation of biofuels, which is derived from food crops, is intensive in land, water, energy, and chemical inputs, there are a number of other adverse consequences that may result from a major policy initiative towards expanding biofuel production in developing countries, including:

- Increased demand for water flows to agriculture to sustain bioenergy production & processing;

- Reduction in water quality from increased fertilizer rates and pesticide use with currently available technologies and greater soil erosion from maize and other row crops;
- Expansion of cropping to marginal land resulting in a significant increase in erosion, ecosystem degradation and loss of biodiversity;
- Expansion of cropping into fragile and strategic ecosystems like rain forests, wetlands, grassland savannahs with its negative impacts on GHG, biodiversity, aquifer recharge and soil erosion;
- Increased levels of nitrous oxides released into the atmosphere from fertilizer use—the single most important GHG output in the biofuels process.

The introduction and enforcement of appropriate technologies, regulations, standards and certification schemes can help to mitigate the potentially large environmental footprint of biofuels production, but these will be slow to materialize where policy environments are weak and often difficult to enforce.

Positive impacts will accrue to those directly involved in the production and processing of biofuels, through higher feedstock (commodity) prices and higher volumes of marketable produce. As such, rising commodity prices could benefit many millions of crop farmers in both developed and developing countries, to the extent that developing country farmers have access to markets and are therefore able to respond to higher prices. However, for the millions of small-scale producers who are net purchasers of food and the many millions of urban poor in developing countries who spend more than half of their income on food, rising global food prices constitutes a serious threat to their food security. Numbers and magnitudes of those likely to be adversely affected must be considered.

Critics, therefore, emphasize the evident trade-offs between food (calories) and fuel (energy) as the global biofuels economy expands, although similar tradeoffs, e.g., between food and feed for livestock, have long existed. Those most vulnerable to the rising food prices, i.e., those living in countries that suffer food deficits, typically live in countries that rely on imported petroleum. For them, the biofuels boom is likely to exacerbate world hunger. Empirical studies suggest that caloric consumption among the world's poor declines by 0.05% for every 1.0% increase in the price of all major food staples. Others argue that biofuels production need not lead to increased food insecurity and could even present a win-win situation for developing countries by creating rural jobs, increasing incomes and thereby improving food security.

The biofuels-food security nexus merits closer consideration. A rise in the world price of commodities – whether related to biofuel production or not – does provide an opportunity for farmers around the world who have been discouraged by artificially low global commodity prices to once again start producing for domestic and regional markets. Higher global feed prices will also exert pressure on integrated industries, e.g., poultry and pork, to shift feed formulation towards locally available feedstocks (such as cassava), thus possibly favoring smallholder production and local agricultural development. For those small producers with access to markets, these are positive effects derived from biofuels development, but they must be weighed against the negatives ones likely to affect millions of others who are net purchasers of food or who cannot participate in the market.

A potentially positive consideration relates to employment and overall rural economic effects due to biofuels. Increasing crop prices in addition to raising producers' incomes translate into higher land values, and thereby draw capital into rural areas, creating jobs in the rural economy. A dynamic biofuels industry has the potential to revitalize rural development and implies new roads and other infrastructure projects. Drawing on the Brazilian experience, biofuel production may offer scope for labor intensification. This revitalization, however, depends on good elasticity of supply, which in turn depends on many factors, including producers' access to commodity output and input supply markets. Higher prices, therefore, can revitalize agriculture, but only in those rural areas which have reasonably good road and market infrastructure, and where price transmission is possible.

As the CGIAR has a mandated, global responsibility for helping to reduce poverty and protect the environment through its research and research related activities, it is incumbent upon it to bring critically missing knowledge, practices or policies to bear on issues such as biofuels that directly or indirectly affect food security and agricultural sustainability in developing countries. A key area where the CGIAR could usefully contribute is in policy-related research, in particular, in developing analytical frameworks and appropriate methods and tools to assess the potential impacts of biofuels production on food security and environmental sustainability in global, regional, national and local contexts. Modeling work being undertaken by IFPRI (MIRAGE) and FAO (Bioenergy & Food Security and Bioenergy Impact Assessment projects) are appropriate steps forward in trying to understand and assess benefits and risks of biofuels in a systematic way. Such results will be useful to donors and policymakers in making investment decisions about biofuels production, and also provide guidance to NARS and CGIAR scientists in addressing both food and biofuels production goals.

A second key area relates to sustainable intensification of traditional and new food crop systems. If government policies continue to promote biofuels as currently used, i.e., targeting large-scale first generation technologies, then major food security and environmental challenges loom ahead. Indeed, drawing on the limited land, water and nutrient resources to produce a significant portion of a country's energy demands, in addition to the food, feed and fiber demands of a growing and wealthier global population will exert enormous pressures on a resource base that is already struggling to cope. World food demand is expected to double by 2050. Population increases and broad-based economic growth in developing countries, coupled with increasing demand for using foodcrops as biofuel feedstocks, will keep many food commodity prices above historical averages reversing an otherwise long-term declining trend in the real price of food. Only by continuing to raise agricultural productivity will the adverse consequences of this development be averted. A much higher priority, therefore, will have to be given to accelerating growth in sustainable productivity of the major food crop systems. Research on sustainable natural resource management, i.e., ecological intensification, should therefore constitute a much larger component of the CGIAR portfolio than previously. This is one area where the CGIAR could appropriately respond to the biofuels challenge.

The CGIAR should consider carefully before engaging in genetic improvement and characterization of crops for biofuel use, paying particular attention to issues such as: (a) trade-offs in terms of other (foregone) research opportunities; (b) ultimate impact of the research/development on the poor (vs. non-poor); (c) lternative suppliers; (d) restrictions imposed through the International Treaty on Plant Genetic Resources for Food and Agriculture; and, (e) long-term value of the research investment (assuming it take 10-15 years to develop a variety) if second generation biofuels would be competitive after about 10 years. Productivity improvements should focus on food staples and high value crops where markets are well established and where environmental effects are better understood.

Introduction

Government policies, motivated by concerns about energy security, high oil prices, greenhouse gas (GHG) emissions and various vested interests, are driving the latest expansion in the global biofuels industry. This is most evident in Brazil, the USA and the EU, but increasingly, developing countries are moving in a similar direction – creating new markets for biofuels by adopting policies, mandates and targets aimed at stimulating domestic biofuels production. To enable biofuels to compete with gasoline and diesel, governments are providing support through consumption (fuel tax incentives) and production (tax incentives, loan guarantees and direct subsidy payments) incentives and through mandatory consumption requirements. Domestic producers in the EU and USA also receive additional support through high import tariffs.

Developed and developing countries should be guided by sound policies that serve the long term best interest of its peoples, in particular, ensuring that biofuels development strategies are not conflicting with food security and environmental sustainability goals. As biofuels production will draw on the same resources that agriculture, livestock, forestry, fisheries and water sectors now depend, the CGIAR and other international agencies should provide R&D program advice to governments to guide rational biofuels strategies and policies.

In response to policies being adopted or about to be adopted, the CGIAR must (i) draw attention to the critical issues surrounding biofuels, food security and the environment, highlighting the likely consequences (positive and negative) likely to emerge from different biofuels policies and, (ii) target research that addresses the new challenges emerging from biofuels expansion, such as the need for ecological intensification of dominant crop and livestock based systems, keeping a tight focus on food security and environmental health goals consistent with the CGIAR mandate.

Many of the CGIAR centers have already initiated technology oriented biofuels related research, e.g., on sweet sorghum, maize, *jatropha*, cassava, etc., but questions remain about the priority of this work and what trade-offs are implicit, particularly if they support ill-advised government policies for expanding domestic biofuels production without having undertaken the required economic, social and environmental analyses.

The Science Council of the CGIAR is proposing a policy statement about biofuels (see Box above) and a system-wide strategy to address the biofuels challenge as it relates to food security and the environment. It recognizes opportunities associated with this development, but also identifies risks. From the perspective of the CGIAR, it is essential to define a response (strategy) to the global biofuel boom that is "people-centered", i.e., one that offers opportunities for commodity producers but does not compromise the food security of poor producers and consumers and pays adequate attention to the full set of environmental risks. This brief note constitutes a first step in developing a coherent and unified strategy.

The Rationale for Biofuels Expansion – Opportunities and Risks

The search for alternative energy sources has intensified in the past few years, driven primarily by high petroleum prices (due to increasing consumption of fossils fuels and diminishing oil reserves) and increasing concerns about energy security and, to some extent, global climate change. Governments from the more developed countries have charted a new policy to promote biofuels, hence creating a new market for them. Nations are investing heavily to increase their energy security and reduce their fossil-fuel imports, carbon emissions and pollution, especially in the face of large increases in demand for energy over the next several decades. Based on current consumption, expected population and broad based economic growth, the world's energy demand is forecast to increase by 57 percent by 2030 when more than half of this total demand will be from non-OECD countries (**1**).

Many are looking to renewable energy and in particular biofuels as at least a partial solution. As such, an increasing share of major crops like maize, sugarcane, oil palm and rapeseed, in addition to some new crops like *jatropha*, is now being diverted to biofuel production, and the trend is expected to continue. While this is most evident in the industrialized world, and has been the case with sugarcane in Brazil for more than three decades, developing countries too are making significant investments in and establishing mandates for biofuel production and consumption. China, for example, with its booming economy and rapidly expanding energy consumption is expected to diversify its energy supplies beyond the use of coal and oil, for both economic and environmental reasons.

FAO emphasizes the critical role bio-energy systems throughout the world could play in helping reduce GHG emissions, contributing to energy security for fossil fuel-importing countries, generating new income opportunities in rural areas, and improving energy access for the poor, with positive implications for the environment and poverty reduction (**2**). But it recognizes that rapid shifts to bio-energy and the related conversion of land and other productive resources from food to bio-fuels could reduce food availability and inflate food prices, and contribute to depletion of natural resources -- water and soil fertility -- when done in a non-sustainable manner. Higher commodity prices motivate farmers to expand production into fragile ecosystems such as rainforests, wetlands and grassland savannah. In short, bio-energy offers both opportunities and risks for food security and the environment.

Box 1. Useful definitions of biofuel-related terms

Biofuels can be broadly defined as solids, liquids, or gas fuels consisting of, or derived from, plant biomass. Its use here is primarily with respect to a liquid transportation fuel (bioethanol or biodiesel)

First generation biofuels are made from sugar, starch and vegetable oils and thus refer to those feedstocks within the food cycle, e.g., maize grain, palm oil, rapeseed, etc. using conventional technology.

Second generation biofuels or 'cellulosic biofuels' refer to those feedstocks produced utilizing non-food biomass like crop residues, forest and wood chippings or wild grasses relying on bioconversion techniques such as enzymatic breakdown of ligno-celluolose to make ethanol.

Third generation biofuels are made from energy and biomass crops that have been designed in such a way that their very structure or properties conform to the requirements of a particular bioconversion process. The bioconversion agents (bacteria, micro-organisms) are bio-engineered in such a way that the bioconversion process becomes more efficient, e.g., for woody crops, the lignin structure may be altered so that it breaks down 'on command' and releases the sugars needed, much easier.

Biorefinery integrates a variety of conversion processes to produce multiple product streams such as motor fuels, heat, electricity, and chemicals from biomass consisting of carbohydrates, lignin, proteins and fats. The useable energy in biomass depends on the efficiency with which it can be converted, and this depends on the technology that is used. Moreira (2006) estimates that new, highly efficient combined ethanol and electricity plants in Brazil operating on sugarcane and cellulose can operate with an efficiency of 31% for ethanol production and 23% for electricity (a net conversion efficiency of 54%). Ideally, such a biorefinery approach that takes advantage of the various components in biomass and maximises the value derived from it, should be applied widely. The biorefinery concept is important for improving the economics of advanced bio-energy technologies and is likely to expand in the future.

Some seriously question whether this 'integrated agricultural approach' to meeting the diverse goals of food security, energy supply and GHG emission control can be achieved in a safe and sustainable manner. Drawing on limited land, water and nutrient resources to produce, in addition to the food, feed and fiber demands of a growing and wealthier global population, a significant portion of any country's energy demands, will exert even heavier pressures on a resource base that in many cases, is already struggling to cope. A report commissioned on behalf of the OECD concluded that the potential of the current technologies of choice — ethanol and biodiesel — to deliver a major contribution to the energy demands of the transport sector without compromising food prices and the environment is very limited indeed (**3**).

The bioenergy sector is heavily influenced by policies related to agriculture, environment, energy and trade. These policies play a large role in the financial attractiveness of biofuel production and trade. Domestic production is supported through border protection, production subsidies and mandated regulations for usage. Production subsidies are running into the billions of dollars per year (over $7 billion in United States alone) and the leading OECD countries producing ethanol apply import tariffs that add at least 25% to the cost of imports (**3**).

Even in Brazil, sustained government support through direct subsidies was required until recently to develop a competitive industry, despite uniquely favorable sugarcane-growing conditions, a well-developed infrastructure and a high level of synergy between sugar and ethanol production. Border protection has meant that current trade is only about 10% of the world's biofuel consumption, an inefficient outcome since biofuels produced in tropical regions from sugarcane and vegetable oils have a considerable cost advantage over those derived from agricultural crops in temperate zones (**3**). This was highlighted in the UNDP Human Development Report 2007-08 which emphasizes the important role international trade in biofuels could have for climate change mitigation (**4**). For example, although sugar-based ethanol is more efficient in cutting carbon emissions and Brazil is more efficient than the EU or USA in producing ethanol, currently imports of Brazilian ethanol are restricted by high import tariffs. Still, there are legitimate concerns about opening up biofuels to free trade without safeguards in place to ensure they are produced in a sustainable manner. Otherwise, imports risk 'exporting' environmental problems to countries supplying the fuels (**5**).

Given that oil prices are likely to remain high and with the strong public support and tax incentives that biofuels enjoy in both developed and developing countries, the increasing trend in the use of biofuels will continue for some time. But who is likely to benefit most, and least, is a critically important question. Nations that earn or preserve foreign exchange by substituting domestically produced bioenergy for imported fossils fuels are obvious gainers – provided it can be done in a cost effective and sustainable manner. But within those countries there will be clear tradeoffs between urban and rural households and between producers and consumers. First developments suggest benefits accrue for large-scale actors in the biofuel production system chain, while the prospects for small-scale activities may be disappointing leading to skewed economic developments (**6**). It is not yet clear if this is the general case. The Brazilian experience with biofuels for example has tended to be broadly inclusive, with benefits accruing to millions of laborers (**7**).

Global Developments

Global agriculture is undergoing a ‘biofuel revolution’, as rising prices for petroleum and other forms of energy coupled with generous government subsidies make food crop conversion to biofuels a profitable proposition for producers and processors of biofuel crops. Governments in over 40 countries are encouraging the use of biofuels to reduce oil consumption. Public and private investments worldwide in biofuels rose from $5 billion in 1995 to $38 billion in 2005, and are expected to reach $100 billion by 2010 as world demand for biofuels is projected to expand nearly 20% annually to 92 million tons by 2011, from 38 million tons in 2006 (**8**).

Brazil and the USA are the leading producers of bioethanol accounting for over 90 percent of world supply. Brazil, the most competitive producer, has the longest history of ethanol production, dating back to the 1930s. About half of its sugarcane is used to produce ethanol. It is already the world’s leader in biofuels production and has tremendous capacity to further increase its ethanol production from sugarcane and biodiesel from soybean and perhaps oil palm. Annual ethanol production is projected to reach some 44 billion liters by 2016 (from 21 billion today) and the government has set various mandates for biodiesel use (**9**).

The amount of maize being used to make ethanol in the USA has tripled since 2000 and last year accounted for about 17% of total maize production. This resulted in five billion gallons of ethanol, replacing just over 2% of total gasoline consumption. Supported by generous government subsidies in production and border protection, the industry is gearing up for expansion. Ethanol production is now mandated to reach some 36 billion gallons by 2022, equivalent to roughly 15-20 percent of total gasoline consumption by volume (**1**). More than 40% of the maize crop would be required to meet this target, and would result in major reductions in US maize exports and domestic feeding stock. This effect is already being felt. Ethanol demand in the USA will bring 2007 inventories of maize down to their lowest levels since 1995, a drought year.

Biofuels’ targets and policies in Europe mainly concern biodiesel, which makes up 80 percent of the EU's combined use of biofuels. The EU has a non-binding target of moving to 5.75 percent of its transport fuel consumption from biofuels by 2010, but last year European leaders agreed on a legally binding objective to meet 20 percent of their energy needs and 10 percent of their transport fuel needs with renewables by 2020, and 25 percent by 2030 (**10**). Biodiesel is expected to play a major role in trying to reach this goal. European biodiesel is at present mainly produced from rapeseed - although the goal is to achieve diversity of supply using domestic agricultural waste for second generation biofuels together with biodiesel imports. At present, biofuel production in the EU is heavily subsidized in the form of high import tariffs, production subsidies and fuel tax preferences.

Developing countries too have established national biofuel policies with mandates for ethanol and biodiesel use. Indonesia and Malaysia have rapidly expanded production of biodiesel from oil palm and are gearing up in an effort to meet an increasing share of their transport needs from biofuels and to contribute to helping the EU meet its renewable energy needs. The Philippines and Thailand have introduced aggressive policies for biofuels and have already begun production. Biofuel programs in Mozambique and several Central American countries are reviewing the prospects of exploiting ethanol from sugarcane (**11**). Nigeria and DR-Congo also have potential for biodiesel, and South Africa hopes biofuels will contribute up to 75 percent of its energy needs by 2013 (**12**), a target unlikely to be achieved but it reflects a serious effort to move forward.

Governments in increasingly industrialized countries such as China and India are developing comprehensive plans for rapidly expanding their domestic ethanol and biodiesel production capacity with programs, targets, regulations and tax incentives. India is giving particular attention to large scale production of *jatropha*, already grown on an estimated 500,000 ha, and *pongamia* on millions of hectares of 'unused lands' (**13**). Pilot production and processing projects are planned and a major program for promotion of biodiesel has been finalized (**14**). India has set a target for biofuels to meet 5% of all oil requirements by 2010 and 20% by 2017. China already produces some 7.5% of its primary energy needs from renewable sources, mainly from hydropower, but it also includes some 2 million ha of *jatropha* for biofuels (**13**). It is likely achieve and may even exceed its target to obtain 15 percent of its energy from renewables by 2020 and as much as 30 percent of the nation's energy by 2050 (**15**).[2] Annual production capacity of liquid biofuels is expected to reach 11 million tons by 2020. New targets include utilization of hundreds of millions of tons of crop residues, forestry wastes and livestock wastes into energy and developing millions of low quality land into energy crops (**14**). In China, as in other developing countries, the driving forces for developing bio-fuels include petroleum shortage, developing the rural economy and, increasingly, environmental (air pollution) concerns (**16**).

[2] China is expected to invest over $10 billion in new renewables capacity in 2007, second only to Germany worldwide (**15**). It is developing solar, wind and biomass projects so rapidly that some experts say it could soon become a world leader in renewable energy. Even so, forecasts show these sources will amount to less than 4 percent of the energy supply by 2020. Hydropower, however, accounts for 6 % of the power supply and has major growth potential.

While it is true that biofuels are currently heavily dependent on government support for continued development in both developed and developing countries, given lingering concerns about rising oil prices and climate change effects, public support for and private investment in biofuels is unlikely to shift soon. An analysis done by FAO concludes that demand for bioenergy is now significant enough to change the traditional paradigm for global agriculture, a paradigm characterized for decades by robust supply growth, slowing demand growth and falling real prices for commodities (**17**). A critical question, therefore, is what are likely to be the economic and environmental impacts of developed and developing countries' efforts to achieve their bioenergy production targets and what could the CGIAR and its partners do to mitigate undesirable effects and maximize beneficial ones?

The potential benefits from biofuels are primarily four-fold:

- increasing energy availability and security
- reducing GHG emissions
- increasing biofuel & food crop producers' incomes
- increasing employment and rural economic development in rural areas.

But there are also serious doubts about the energy, GHG, and nutrient balances and water use of bioenergy feedstocks currently in use, and the potential adverse impacts on food security and the environment. These are discussed in turn.

Energy, Environment, Income and Rural Development Effects: Benefits and Risks

Increasing energy availability and security With an increasing share of major food crops being diverted for biofuel production to help reduce dependence on oil imports at the national level and to create readily available supplies of energy at the local level, an obvious question to ask is 'how efficient are biofuels as a substitute for fossil fuels and how much land will be required to generate a significant share of transport fuel needs?'

Using starch to produce biofuels is, from an energy balance point of view, inefficient[3]. The land requirement alone is excessive when one considers conversion of starchy grains or sugar crops to bioethanol or oilseeds to biodiesel. If the entire maize crop in the USA were diverted into biofuel production, leaving no maize for the food and feed market, it would only displace around 10% of the nation's gasoline consumption, and this assuming complete efficiency in the conversion of maize grain to ethanol (**18**). At the global scale, large parts of the world's wheat, rice, corn or wood output would need to be diverted to meet just a very small share of global

[3] Along a similar vein, it may be argued that converting cereal grains to livestock products is an energy inefficient way of producing food for humans.

transportation fuel needs[4]. With the exception of Brazil, biofuels currently in use generate comparatively little substitution effect for fossil fuels and are not economically competitive. As noted, biofuels are currently heavily dependent on government support and protection for continued development in both developed and developing countries, via sales and excise tax exemptions, loan guarantees and high import tariffs.

A recent report commissioned on behalf of the OECD concludes that the scope for biofuels from agriculture to make a substantive contribution to energy supply is limited from a technical (land availability), economic and environmental point of view (**3**). The authors emphasise that higher oil prices will have the effect of increasing biofuel production costs while simultaneously making fossil fuel alternatives such as tar sands and coal-to-liquids increasingly competitive.

A potential solution to this, one being examined and invested in very seriously in the EU, the USA and other countries, is producing ethanol from cellulose in major crop and other plants, including native grasses like switchgrass or buffalo grass, miscanthus and even algae. These ‘second generation’ biofuels have the potential to produce biomass rapidly and provide thousands of liters of biofuel per hectare, thus allowing the scale required to significantly contribute to transport fuel[5]. The energy balance[6] for cellulosic ethanol ranges from 2 to 36 compared to maize grain based ethanol at ~ 1.3 depending on the production method (**20**). Currently, cellulosic processes are much more expensive to operate than maize-based ethanol and thus major research breakthroughs are still required to make them economically competitive. Nevertheless, second generation technologies and bio-refinery concepts offer better prospects in the long run in support of a rational biofuels policy.

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[4] Doornbosch and Steenblik (2007), using data from Fisher et al. (2000), estimate that 0.44 Gha of unused land (vs. 1.5 Gha currently in use for agriculture) is the technical upper limit for dedicating to biofuels in 2050, sufficient to generate at a maximum 23% of world foreseen demand for liquid fuels in the baseline scenario. Thompson (2007) suggests that there is at most only 12% more arable land available globally (that isn’t presently forested or subject to erosion or desertification). Pardey et al. (2007), however, suggest that there remains significant scope to expand agricultural areas, citing Bruinsma (2003) estimates of only 34% of the potential agricultural area in the developing world currently cultivated and only 44% of the potential agricultural land in the developed world presently cultivated.

[5] A USA government study estimates that new biotechnologies to transform cellulosic material such as maize stalks, sugarcane bagasse, wheat and rice straw, and switch grass could yield almost 265 billion liters of ethanol a year, produced on ‘other land’, without impacting food production. (**19**)

[6] Energy balance refers to the energy output to energy input ratio, i.e., a ratio of 1.3 means one unit of energy is required to produce 1.3 units of energy, for a net gain of only 0.3 units of energy.

The EU policy on biofuels looks increasingly to second generation technologies and other forms of renewable energy to achieve its targets (**21, 22**), and recognizes the role of second generation technologies in helping to meet the mandatory 10% biofuel component in vehicle fuel by 2020. The January 2008 Royal Society report considers that biofuel production from ligno-cellulose holds significant potential, given the amount of energy in biomass and the extent of biomass that is available globally, particularly in residues, co-products and waste from many different sectors such as agriculture, forestry, paper and pulp and food processing (**5**). Major research efforts are now underway globally to develop and optimize technologies for producing biofuels from these ligno-cellulosic feedstocks and many processing facilities are now in operation or planning throughout the world. Experts at a biofuels conference held in Delhi recently agreed that second generation bio-fuels extracted from micro-algae and other microbial sources, ligno-cellulosic biomass, rice straw and bio-ethers can be a better option for addressing both food and energy security and environmental concerns than large scale plantation of bio-fuel crops like *jatropha* and *pongamia* (**23**). Still, algae grown in the desert or feedstocks produced on lands that generate little carbon may keep GHG emissions low, but its ability to produce biofuel feedstocks abundantly on unproductive lands remains questionable (**24**).

Second and third generation biofuel crops that can be produced with little water or fertilizer on dry or easily erodable soils, and that actually improve degraded soils, may have superior benefits to even the best sugarcane ethanol. However, the widely held assumption that marginal, abandoned and degraded lands can and will be used for massive production of biofuels using, for example, *jatropha* or *pongamia* or even wild grasses, are too optimistic—from a technical, economic and social perspective—and have thus far not been validated by scientific or empirical evidence.

Whatever feedstock is used for the production of bio-fuels—either from first or second generation technologies—any biomass source will put a claim on land (directly or indirectly) and other limited resources, and this has implications for food production and food security. In fact, extensive use of crop residues by second generation technologies would also pose a threat to the sustainability of many cropland resources and, in some cases, reduce feed available for livestock.

Reducing GHG emissions and other environmental effects. As a renewable energy source, biofuels are a potential low-carbon energy source, but whether they offer carbon savings and thus are effective in combating climate change depends on the type of feedstock (raw material), production process, changes in land use, and conversion into a usable fuel. The largest GHG reductions (90%) can be derived from Brazil sugarcane-based bioethanol (**25**), followed by ethanol from cellulosic feedstock (70 to 90%). Ethanol from sugar beets and biodiesel are next (40% to 50%), followed by soybean-based biodiesel. Ethanol from starchy grains yields about a 12% reduction (**26**), although more recent analysis for maized-based ethanol systems in the USA shows GHG reduction between 25 and 75% (**27**). However, this and the other analyses above largely fail to capture a key element in the life cycle analysis – the direct and indirect changes in land use. Some methods of producing biofuels actually increase global warming due to land conversion and the release of huge amounts of carbon that otherwise would remain stored in plants and soil.

Two studies published recently in *Science* raise serious questions about the GHG-reducing effects of biofuels (**24, 28**). By examining the emissions effects from the natural land that is being converted to cropland globally to support biofuels development, the authors find that when direct and indirect land use changes are taken into account, e.g., conversion of forests, peatlands, savannas and grasslands to new cropland to replace the grain diverted to biofuels, then biofuels create a huge 'carbon debt', that will take decades or even centuries to repay. For example, maize-based ethanol, instead of producing a small positive savings, nearly doubles GHG emissions over 30 years and increases GHG emissions for 167 years. Cropland absorbs far less carbon than rainforests or even scrubland that it replaces. Even biofuels from switchgrass – a 2nd generation technology – if grown on US maize lands, increase emissions by more than 50%. If reducing GHG emissions is one of the objectives, policies need to focus on biofuels that do not trigger significant land use changes and rely excessively on fossil fuel derived inputs, but instead rely on waste products and crop residues and take into account fossil fuel derived inputs. In fact, biofuels policies should be based on carbon reduction goals and not on the fulfilment of renewable mandates. Obligatory blending and govt subsidies of biofuels production creates a strong incentive to produce biofuels in any possible way, whereas the techniques to achieve this large scale production in a sustainable way are not yet available.

As the current generation of biofuels, which is derived from food crops, is intensive in land, water, energy and chemical inputs (**29, 30**), there are a number of other adverse consequences that may result from a major policy initiative towards expanding biofuel production in developing countries (**31**):

- Increased demand for water to agriculture to sustain bioenergy production & processing (**32**);
- Reduction in water quality from increased fertilizer rates and pesticide use with currently available technologies and greater soil erosion from maize and other row crops (**30**);
- Expansion of cropping to marginal land resulting in a significant increase in erosion, ecosystem degradation and loss of biodiversity;
- Expansion of cropping into fragile and strategic ecosystems like rain forests, wetlands, grassland savannahs with its negative impacts on GHG, biodiversity, aquifer recharge and soil erosion.

- Increased levels of nitrous oxides released into the atmosphere from fertilizer use—the single most important GHG output in the biofuels process. A recent study (**33**) shows emissions of N_2O from fertilizer use to grow energy crops were heavily underestimated previously[7].

The introduction and enforcement of appropriate technologies, regulations, standards and certification schemes can help to mitigate the potentially large environmental footprint of biofuels production, but these will be slow to materialize where policy environments are weak and often difficult to enforce.

In short, conventional agricultural feedstocks have serious environmental shortcomings and risks. Second generation ligno-cellulosic technologies have considerably more potential for avoiding many of the GHG emission and other environmental shortfalls and perform better in terms of energy efficiency.

Increasing biofuel & food crop producers' incomes via higher commodity prices. Increasing demand for maize, sugar and oilseeds to produce biofuels has strained commodity supplies and pushed commodity prices higher—particularly maize (Figure 1). The enormous volumes of maize required by the ethanol industry in the USA have resulted in maize prices doubling since last year and they are now the highest in more than a decade. Although reduced stocks, droughts in major wheat-growing regions, floods in China and higher oil prices and, in particular, increasing food demand in rapidly growing developing economies (China and India) are also contributing to higher global commodity prices, the increasing use of starch grains, sugarcanes and oilseeds for biofuel production is exerting mounting pressure on commodity prices. As world maize prices rise, so too do those of wheat and rice, both because of consumer substitution among grains and because of competition for land[8]. The growing use of cereals, sugar, oilseeds and vegetable oils to satisfy the needs of a rapidly increasing biofuels industry is believed to be one of the major contributing factors to food prices having risen by 45% over the past nine months, according to the UN FAO Director General, as farmland has been diverted from food to fuel crops. The Prime Minister of India recently expressed deep concern over the rising commodity and food prices both at the global and country level,

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[7] Crutzen et al (2007) found that microbes in the soil turn 3-5 percent of the nitrate in the fertiliser into nitrous oxide, as opposed to 1 percent as previously thought. They calculated that emissions of nitrous oxide, some 300 times more potent a greenhouse gas than carbon dioxide, from growing rapeseed crops actually caused up to 1.7 times more global warming than the 'offset' effect caused by burning a supposedly 'carbon-neutral' fuel.

[8] The limit to feedstock and hence food price increases depends on the price of fossil fuels. For a good discussion of direct and indirect transmission of energy prices to agriculture and differential price impacts across agricultural markets see **17**.

alleging that biofuel programs are at least partly responsible for this phenomenon (**34**). Food prices are likely to remain high over the medium to long term. According to the OECD-FAO Agricultural Outlook 2007-2016 report, food prices rising by 20% to 50% by 2016 (**9**).

The livestock and poultry industries are also affected by rising feed prices, which ultimately will translate into higher livestock and poultry prices. Indeed, because agricultural prices in most countries are driven by market forces (within parameters shaped by domestic policies), adjustments to higher feed grain prices brought about by increased ethanol production will take place around the world.

Positive impacts will therefore accrue to those directly involved in the production and processing of biofuels, through higher feedstock (commodity) prices and higher volumes of marketable produce. As such, rising commodity prices could benefit many millions of crop farmers in both developed and developing countries, to the extent that developing country farmers have access to markets and are therefore able to respond to higher prices. However, for the millions of small-scale producers who are net purchasers of food and the many millions of urban poor in developing countries who spend more than half of their income on food, rising global food prices constitutes a serious threat to their food security. Numbers and magnitudes of those likely to be adversely affected must be considered.

Critics, therefore, emphasize the obvious trade-offs between food (calories) and fuel (energy) as the global biofuels economy expands (**35**), although similar tradeoffs, e.g., between food and feed for livestock, have long existed. Those most vulnerable to the rising food prices, i.e., those living in countries that suffer food deficits, typically live in countries that rely on imported petroleum. For them, the biofuels boom is likely to exacerbate world hunger. Empirical studies suggest that caloric consumption among the world's poor declines by 0.05% for every 1.0% increase in the price of all major food staples (**35**). Others argue that biofuels production need not lead to increased food insecurity and could even present a win-win situation for developing countries by creating rural jobs, increasing incomes and thereby improving food security (**36**).

The biofuels-food security nexus merits closer consideration. A rise in the world price of commodities – whether related to biofuel production or not – does provide an opportunity for farmers around the world who have been discouraged by artificially low global commodity prices to once again start producing for domestic and regional markets. Higher global feed prices will also exert pressure on integrated industries, e.g., poultry and pork, to shift feed formulation towards locally available feedstocks (such as cassava), thus possibly favouring smallholder production and local agricultural development. For those small producers with access to markets, these are positive effects derived from biofuels development, but they must be weighed against the negatives ones likely to affect the millions of others who are net purchasers of food or who cannot participate in the market.

Rising petroleum prices exert their influence not only on food prices but on virtually all other products. It is important to consider the impact that rising oil prices would have on the poor urban and rural populations without the substitution effects of biofuels. Although biofuels do not and will not have a major effect on the price of oil, at least in the near term, locally produced biofuels will have a marginal impact and cause oil prices at the local level to rise more slowly than they otherwise would have. Thus, the appropriate counterfactual to consider is how would the poor fare in the face of rising petroleum prices without any mitigating effects of biofuel substitutions. This, of course, must be balanced against the other positive and negative distributional economic and environmental effects from biofuels.

Increasing employment and rural economic development in rural areas

A potentially positive consideration relates to employment and overall rural economic effects due to biofuels. Increasing crop prices in addition to raising producers' incomes translate into higher land values, and thereby draw capital into rural areas, creating jobs and new income opportunities in the rural economy (**37**). A dynamic biofuels industry has the potential to revitalize rural development and implies new roads and other infrastructure projects. Drawing on the Brazilian experience, biofuel production offers good scope for labour intensification (**36**). In 1997 the ethanol sector in Brazil employed about 1 million people—35 percent of these jobs were temporary harvesting jobs employing many poor migrant laborers, but 65 percent were permanent. The number of jobs in manufacturing and other sectors created indirectly by the ethanol sector was estimated at 300,000 and many of these jobs are unskilled, offering an opportunity for increased income to poor rural people. Small farmers are not left out: some 60,000 small farmers produce about 30 percent of the sugarcane in Brazil. Rural revitalization through biofuels, however, depends on good elasticity of supply, which in turn depends on many factors, including producers' access to commodity output and input supply markets. Higher prices, therefore, can revitalise agriculture, but only in those rural areas which have reasonably good road and market infrastructure, i.e., where price transmission is possible.

Within developing countries, there are still trade-offs and distributional effects that must be considered, between rural and urban, and between well endowed and poorly endowed groups. Whether a reasonable share of the benefits from biofuels development can accrue to small-scale actors in the biofuel production system chain is still a question. The Brazilian experience with development of the biofuels sector has tended to be broadly inclusive according to IFPRI (**7**). Hundreds of rural communities in Mali have biodiesel generators powered by oil from *jatropha* to meet their energy needs and the government is promoting this biofuel feedstock, traditionally used as a hedge or medicinal plant, to provide electricity to 12,000 villages throughout the country (**12**).

Implications for Developing Countries

For many developing countries, pursuing their bioenergy production targets will require major increases in maize, sugarcane, rapeseed and other biofuel crop productivity. Germplasm improvement could play some role but improved management of water, soil and human resources will need to contribute in a major way as food-crop biofuel systems expand (**31**). Raising crop yields, however, will not be sufficient and in some areas expansion of crop area, e.g., palm in Malaysia, jatropha, sugarcane and sweet sorghum in India, sweet sorghum in Philippines and sugarcane in Mozambique (as well as sugarcane and soybean in Brazil and maize in USA), will be necessary to increase the supply of biofuels if those targets are to be met. These strategies do not take into account the potential that lies in the technical efficiency developments in second-generation biofuel technologies, e.g., ligno-cellulosic feedstock such as grasses, wood, crop and forest residues and municipal wastes, which, although costly at present, are developing rapidly. Although large-scale deployment of cellulosic ethanol production plants may not occur for another 10 years and may not replace food-crop ethanol systems altogether, the CGIAR's research agenda should also consider the needs and opportunities that will arise through second generation biofuel technologies.

It is apparent that major threats to agricultural sustainability will result from straining current resources too far in order to meet domestic food and biofuel production objectives, and biofuel production will increase demand for agricultural land at the expense of natural ecosystems. Pursuing biofuel production in water-deficient countries, for example, will put pressure on an already stretched resource and, hence, this 'green energy' could become a major threat to water sustainability. Parts of China and India have already breached the limits of sustainable water use, even without the added strain of trying to grow significant quantities of biofuels. Research has shown that it is not environmentally sustainable to grow sugarcane to produce the bioethanol needed to meet even a small share of India's petrol demand (**38**). Other, less water-intensive, alternatives for feedstock are required. While it is true that intensifying agriculture and increasing yields in the 'best lands' probably offers the best scope for meeting these challenges, intensive agricultural systems will also require more inputs – water, nutrients and pest control – which must be used more efficiently than presently so that losses from them do not degrade and pollute downstream ecosystems (**39**).

Sustainability-related issues such as these seem to fall within the remit of the CGIAR. Indeed, the current trends in biofuels production and the inherent risks associated with them – both in terms of food security and environmental sustainability – require that the CGIAR Centers consider how best to address these issues in the context of its other research priorities. Research to raise crop productivity sustainably and to understand the impact of agro-energy production on food production, water and the environment needs to be pursued in earnest. The next section describes the current activity underway in the CGIAR in relation to biofuels research.

Research-based policy guidance also seems an appropriate area of activity for the CGIAR. A range of biofuels related topics bear on world food markets and global food security, such as the misguided policies – subsidies and protection measures – of developed countries. Subsidies on biofuel crops act as an implicit tax on staple foods, on which the poor depend the most (**40**).

Current Biofuel-related Activities in the CGIAR and Partners[9]

CGIAR Centers have taken some important initiatives in joint activities on biofuels in recent years, including consultation meetings with stakeholders in New Delhi, India in Nov. 2006, a side event during AGM06 in Washington DC, and facilitating and hosting APAARI Expert Consultation on biofuels at Los Baños in August 2007. A Challenge Program concept note was also put forward in 2007 but was not endorsed by the SC[10].

Recognizing the global urgency of the issue and its high relevance on the CGIAR mission, and the need to complement and synergize Centers' expertise and gain critical mass and visibility, Alliance Centers initiated a joint platform on the bioenergy issue during the 2007 AGM in Beijing. Catalyzed by ICRISAT, CIMMYT and IFPRI, nine Centers have so far joined the Alliance Bioenergy Platform (ABP) that now includes CIAT, CIFOR, ICARDA, ICRAF, IRRI and IWMI. The ABP issued a brief statement of its purpose and focus—that much of the controversy swirling around the issue is based on lack of research knowledge, a gap which the CGIAR is well-suited to fill. The ABP is expanding CGIAR partnerships by organizing a high-profile Symposium at the 2008 American Society of Agronomy meeting on these priority issues. Some of the activities being undertaken in the area of bio-fuels research by specific CGIAR Centers are summarized below.

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[9] Contribution of this section from the Alliance Deputy Executive-Science is gratefully acknowledged.

[10] The concept note for a Challenge Program submitted by the Alliance Executive: *"Biofuels: Growing Energy to Generate Income and Protect the Environment"* describes the Centers' collective research proposal on biofuels emphasizing its role as an alternative, renewable energy source, including its impacts on food security, poverty alleviation, and sustainable management of crop and natural resources.

In collaboration with the CLAYUCA network and CORPOICA and with financial support from Colombia, ***CIAT*** has developed cassava-sorghum rotation systems (with ICRISAT) an innovative, decentralized approach for processing bioethanol from cassava that facilitates the participation and capture of value-addition by small farmers. The pre-processing facility can be easily built using low-cost materials in rural communities. The approach is complemented by the use of modern technologies for the stages of hydrolysis/fermentation (cool enzymes). The recent discoveries at CIAT of amylose-free and/or small-granule cassava mutants could increase system efficiency and environmental benefits considerably. CIAT is considering four main focal points as possible research priorities in its upcoming new Strategic Plan 2010-2020: (1) bioenergy crops and management options; (2) sustainable and competitive technologies for bioethanol processing and management of residues; (3) environmental, economic, and social impact; and (4) capacity building and knowledge sharing.

CIFOR six work packages for bioenergy in the following areas: (1) social and environmental impacts of bioenergy development; (2) potential of forest-based bioenergy for climate change mitigation; (3) legal and institutional frameworks and market-based mechanisms to promote sustainable and equitable forest-based bioenergy production; (4) analysis of opportunities for forest-based bioenergy production that benefits local people in developing countries; (5) potential impacts of bioenergy on forests and local livelihoods; and (6) policy-science dialogue to promote sustainable and equitable forest-based bioenergy.

CIMMYT is conducting an ex-ante impact assessment and prioritization of investments in biofuel or specialty maize. CIMMYT has not engaged in biofuel breeding so far for either maize or wheat.

ICRISAT's key achievements from on biofuels research include: development of higher-yielding multiple-purpose sweet sorghums yielding grain, fodder and bioethanol at prices competitive with sugarcane; building public-private partnerships for development impacts on a pilot scale; and cultivation of *pongamia* and *jatropha* biodiesel crops by women's and tribal groups. The current focus continues to build on these initiatives and includes two others: integrating leguminous fuelwood trees into dryland cropping systems that reduce the drudgery of fuelwood collection while improving the soil; and, socio-economic impact analysis of the biofuels systems described above.

ICRAF's ongoing and planned activities include: (i) bio-energy production and conversion engineering research: high grade charcoal with improved kilns, gasification (dendrothermal energy), electricity from non- edible oil and non-feedable oil cake, bio -diesel from *jatropha*, *pongamia*, *serpendus*, *mahua*, *moringa* and *Dacryodis idulis*, waste derived energy through pyrolysis, life cycle analysis; (ii) genetic and agronomic improvement research: biodiesel crop genotypes with high biomass, nut and oil yields and related adaptive traits; (3) socio economic and policy research: impacts on food production, income, livelihood opportunities and environment; village-based community-managed rural units, land resources that are non-competing with food production, climate change mitigation and payments, policy synthesis in the global context.

IFPRI's work to-date on biofuels research includes issues analyses and modeling exercises simulating the interaction between crop demand for biofuel feedstock and the demand and production of crops for both food and feed, to see how scenarios for projected growth in biofuel production could affect food availability, prices, and consumption. Current biofuels related work continues to examine these relationships and looks at how global food supply and demand trends intersect with biofuels production, evaluating the price impacts on food markets and the implied impacts on food security and poverty. Issues related to land markets, growth in other sectors and the availability of land and water resources are also examined. IFPRI hopes to develop a typology of food systems that are more robust to these influences and map the impact pathways and patterns of socio-economic vulnerability associated with these.

ILRI, working closely with ICRISAT, has found that sweet sorghum bagasse (waste residue after juice is extracted from stalks) is an excellent feedstock that can be further enhanced for nutritional quality, high income and transportability through feed-block technology. ILRI's current focus is to mitigate shortage of livestock feed as a result of competing demands from such as biofuels.

IRRI's bioenergy research is focused on the use of crop residues only as residues (straw and husk) are often a disposal problem and could instead become a valuable energy resource. The use of rice residues in existing small- to medium-scale thermal conversion, residue availability and supply chains for bioenergy, sustainable crop residue management, rice-based cropping systems for bioenergy, breeding for ideal thermal conversion traits, and socio-economic analyses are underway.

Achievements thus far include: paddy drier fueled by rice husks being up-scaled in Vietnam; first tests for rice straw and husks as fuel in gasification reactors successfully completed; long-term trials showed that irrigated rice is probably the only cropping system where most residues can be removed without negative consequences for soil organic matter content; GIS-based systems for the evaluation of residue supplies from rice developed and applied in Thailand and Philippines; brittle straw rice germplasm developed and straw characteristics characterized; recycling of biochar (by-product from thermal combustion of rice residues) can contribute to carbon sequestration and reduction of methane emission from irrigated rice.

IWMI research has shown that pursuing biofuel production in water-deficient countries could put pressure on an already stretched resources and 'green energy' will become a major threat to water resources. On average, the biomass needed to produce one liter of biofuel evaporates between 1000 and 4000 liters of water, depending on the type of feedstock and conversion techniques used. In more arid countries, irrigation must make up the shortfall. IWMI's current focus relates to: (1) assessing water requirements of major biofuels crops in India and China; (2) assessing water requirements of second generation biofuels as compared to maize and sugarcane based ethanol; and (3) impact of biofuel production on basin water use under different biofuel scenarios.

Beyond the CGIAR, national, regional and other international research organizations are actively developing programs of research for biofuels and are strongly interested in collaboration with the CGIAR. Brazil considers its bioethanol industry to have been farsighted and a major success. Indeed, EMBRAPA has had a long history in biofuels research – recent breakthroughs include a new sugary cassava clone with sugar content above the best available sugarcane cultivars grown in Brazil, offering the potential for a new biofuel worldwide (**14**). Since 2004 biomass-based energy has been a part of the long and medium term national programs for science & technology in China. India has also set bioethanol use targets. NARIs in India have been conducting research on new biofuel crops such as *Jatropha* and are actively expanding its cultivation. This particular crop is of special interest since it grows on unutilized "wasteland" areas and under limited moisture conditions and does not compete in the marketplace with food oilseed crops. GFAR and APAARI convened an international workshop in November 2006 to review and catalyze the process of agricultural research partnerships in the field of biofuels and followed-up with an expert consultation meeting in August 2007 involving CIMMYT, IRRI and ICRISAT. In August 2007, ACIAR held its Crawford Fund conference which focused entirely on biofuels and its implications for global food security "Biofuels, Energy and Agriculture: Powering Towards or Away From Food Security?" What is apparent is that developed and developing country governments alike are firmly determined to meet their bioenergy targets by establishing mandates, investing resources and providing support through policies and scientific research.

The question is not whether research on biofuels merits consideration by the CGIAR, but what role the CGIAR should play and what specific areas of research are most relevant here.

SC View: Relevant Biofuels-related Topics for CGIAR research

As the CGIAR has a global responsibility for helping to reduce poverty and protecting the environment through its research and research related activities, it is incumbent upon it to bring missing knowledge, practices or policies to bear on issues such as biofuels that directly or indirectly affect food security and agricultural sustainability in developing countries. Higher commodity prices worldwide brought on by the biofuels boom are likely to induce a number of both desirable and less desirable changes on the agricultural landscape of many developing countries, of which the CGIAR must not only be aware but anticipate and direct research towards the most beneficial and equitable outcome. Basic research on biofuels, e.g., improving fermentation efficiency or experimentation with cellulosic enzymatic processes, is clearly better left to upstream academic organizations and the private sector.

The CGIAR should consider carefully before engaging in genetic improvement /characterization of crops for biofuel use, paying particular attention to issues such as: (a) trade-offs in terms of other (foregone) research opportunities; (b) ultimate impact of the research/development on the poor (vs. non-poor); (c) alternative suppliers; (d) restrictions imposed through the International Treaty on Plant Genetic Resources for Food and Agriculture—where the germplasm held in trust by FAO may only be used for food and agriculture and not for any other industrial (e.g., energy) purpose; and, (e) long-term value of the research investment (assuming it take 10-15 years to develop a variety) if second generation biofuels would be competitive after about 10 years. Productivity improvements should focus on food staples and high value crops where markets are well established and where environmental effects are better understood. In addition to increasing nutrient and water use efficiency in these systems, new novel ways are needed to make significant gains in yield potential and break through current yield barriers thus allowing more food to be produced on the reduced land and water resources. This could involve more "blue sky" basic research on areas such as the transfer of C4 photosynthesis to C3 food systems or more efficient rubisco systems to improve the basic process of photosynthesis or in other areas such as apomixis to more easily capture the heterosis effects on yield.

The CGIAR could still provide a critical interface between upstream research and problem-driven demands for research and development of biofuels in specific contexts where food security and poverty alleviation concerns are paramount. The CGIAR could also serve as a conduit of new knowledge and technology in this respect, in particular, in searching for mechanisms to ensure that smallholder farmers can benefit from the potentially lucrative biofuels market without significant increasing their vulnerability. The CGIAR must at the same time keep a focus on generating international public goods.

What are the key biofuels-related research topics on which the CGIAR should focus its attention? The SC considers there are two major themes of relevance with respect to biofuels and its development. These relate to: (i) policy research, which includes outlook and trend and scenario analyses and simulations; and, (ii) sustainable natural resource management research, including ecological intensification.

Theme 1: Policy research. *Understanding the implications of global, national and local biofuel industry developments on poor producers and consumers and the likely impacts on the agro-ecologies; designing institutional arrangements, policies and investment strategies that help mitigate adverse food security and environmental outcomes and promote positive ones.*

The impacts of the significant investments to-date in bioenergy are already being felt globally as demand for energy directly competes with demand for food. The resulting rise in crop prices worldwide – some of which is clearly linked to this phenomenon – is having and will continue to have major effects on production and consumption decisions worldwide, signaling major threats to both food security and the environment, particularly amongst vulnerable households. Well-targeted policies and appropriate technologies for biofuels, i.e., designed within the context of environmental and economic aspects of the complete life cycle, represent an opportunity for improving the livelihoods of millions of rural poor and for contributing to a cleaner and sustainable environment. Investments in biofuels in both developed and developing countries are expected to increase substantially over the next two decades. Understanding the long-term opportunities and risks and tradeoffs related to the use of food crops as feedstocks in bioethanol and biodiesel in the context of the expected distributional impacts across countries, farming systems, producers and consumers is critical to harnessing its potential to help achieve the MDGs. Identifying the critical sets of conditions under which large constituencies of poor and food insecure people could benefit from these and second generation biofuel opportunities constitutes a major research challenge that the CGIAR could well embrace.[11]

IFPRI and *CIMMYT* have already initiated efforts in this respect with their *ex-ante* impact assessments and priority setting activities, but it is critical that the momentum is stepped up and given a System-wide thrust, including

[11] To take the example of sorghum, a food staple in India: As this is crop considered to have good potential for bioethanol, the relevant question to ask (and empirically estimate) is 'what % of the poor rely on this crop as a primary staple and would be adversely affected by increasing sorghum prices' vs. 'what is the potential for this crop to contribute to income growth for x number of (poor) sorghum producers when grown as a biofuel'?

partnering with key advanced research institutes with specialized expertise in poverty, livelihoods and modeling issues, and more in-depth knowledge of private sector developments in biofuels. Developing analytical frameworks to understand and assess the potential impacts and risks of biofuel production on the food security in various contexts is particularly relevant here. Modeling work being undertaken by IFPRI (MIRAGE) and FAO (Bioenergy & Food Security and Bioenergy Impact Assessment projects) are appropriate steps forward in this direction. Results of such exercises should prove useful to donors and policymakers in making investment decisions about biofuels production. It will also provide guidance to NARS and CGIAR scientists in project design addressing both food and biofuels production goals. Given that biofuels are already in the market, it is essential that policies that promote biofuels development also address the full environmental, economic and social impacts.

Within this broad area, priority activities of the CGIAR might include:

- Scenario development and projections for targeting favorable environments for producing biofuels and identifying areas where risk to loss of biodiversity is low.
- Information and advice for effective implementation of coherent bioenergy policies and strategies with a multi-sectoral perspective (agriculture, trade, environment and energy) in the context of food security and environmental safeguards, especially in relation to trade.
- Assessing the available stock of knowledge in biofuels and creating a forum for exchange of information between center scientists and NARS (possibly, the CGIAR could consider a role for itself in synthesizing and disseminating key information and helping develop local institutions to support biofuels development, or alternatively, letting FAO play that role).
- Integrating in specific national and regional contexts, the key factors likely to influence successful implementation of a biofuels development policy to achieve desirable economic, social and environmental impacts at least-cost, e.g., shifting from policies that rely on fix targets for biofuels replacement to incentives for investing in biofuel systems that deliver low GHG emissions and wider environmental, economic and social (pro-poor) benefits.
- Developing appropriate methods of analysis for agricultural <u>and</u> policy research, since there will inevitably be trade-offs between winners and losers. It is essential to understand the potential markets and actors who will benefit most from this new economic sector and to assess the opportunities for developing societies at large. The evidence to-date suggests biodiesel systems are more pro-poor (fewer economies of scale) than bioethanol ones.
- Policies and incentive structures that direct expansion of biofuel crop area to areas with adequate soil quality to support intensified agriculture in a sustainable fashion, and avoid expansion of biofuels to marginal land and repositories of unique wildlife and biodiversity.

Theme 2. Sustainable natural resource management research. *Research on sustainable agricultural practices in traditional and new cropping systems, particularly emphasizing 'ecological intensification' to address new challenges in sustainably managing landscapes, watersheds and farming systems arising from biofuels.*

If government policies continue to promote biofuels as currently used, i.e., targeting large scale first generation technologies, then major food security and environmental challenges loom ahead. Indeed, drawing on the limited land, water and nutrient resources to produce a significant portion of a country's energy demands, in addition to the food, feed and fiber demands of a growing and wealthier global population will exert enormous pressures on a resource base that is already struggling to cope. World food demand is expected to double by 2050 (**41**). Population increases and broad-based economic growth in developing countries, coupled with increasing demand for using foodcrops as biofuel feedstocks, will keep many food commodity prices above historical averages reversing an otherwise long-term declining trend in the real price of food (**17**). Only by continuing to raise agricultural productivity will the adverse consequences of this development be averted. A much higher priority, therefore, will have to be given to accelerating growth in sustainable productivity of the major food crop systems. Research on sustainable natural resource management, i.e., ecological intensification, should therefore constitute a much larger component of the CGIAR portfolio than previously.

Several key factors taken together lead to a clear mandate for more research on ways to intensify production in an ecologically sustainable manner. First, the amount of uncultivated land left that is suitable for expansion of intensive cereal production in a cost effective manner is quite limited (**41**). At the same time, the global rate of increase in cereal yields is falling below the rate of increase in expected demand – when trends in the population of rapidly growing developing countries and new demands from biofuels development are considered. Also, it must be acknowledged that many current crop and soil management practices are having negative impacts on water quality, GHG emissions, and biodiversity, and in some systems, they are causing a reduction in soil quality, e.g., loss of organic matter, nutrient depletion, salinization and acidification (**30, 31**). Taken together, these facts, alongside the growing demand for foodcrops as biofuel feedstocks, translate into a compelling case for more research aimed at developing high-yield crop production systems that also protect the soil and environmental quality and conserve natural resources. This calls for a serious commitment to research and development that not only use cultivars with higher genetic yield potential but have other critical characteristics such as increased fertilizer and water uptake efficiency, improved soil quality (nutrient stocks, soil organic matter) and greater reliance on integrated pest management.

To meet these challenges implies a research agenda that focuses on the following priorities:

- Sustainable intensification of major food crop systems, accelerating yield gains while protecting soil and water quality.
- Multi-purpose crops development and identifying promising perennial species systems of cultivation that combine food, feed, fiber and biofuel traits for small-holder use.
- Quantitative estimates of the input requirements, viz., land, water and nutrients and, of potential energy savings and reduction of CO_2 emissions to ensure ecological sustainability of biomass production for bio-energy. For a realistic estimate of the production potential of biomass for bio-energy in relation to the growing food and feed demand, a balanced analysis that accounts for production factors and their interactions, is required (**6**).
- Research and development of alternative, high energy output / low energy input systems as alternatives to the existing (maize/sugarcane based) ones, including the development and testing of less water demanding-biofuels than current alternatives such as sugarcane.
- Assess the adverse consequences that could result from a major policy shift toward first generation biofuel production prompting potential for and need for research on: (a) reduction in water quality from increased fertilizer rates with currently available technologies; (b) expansion of cropping to marginal land resulting in a significant increase in erosion and ecosystem degradation; and (c) expansion of cropping into rain forests, wetlands, grassland savannahs.
- Development and use of frameworks, methodologies (e.g., life cycle analyses) and key indicators of efficient and sustainable food/biofuel production systems, against which specific food-energy systems could be evaluated over time and policies developed based on internationally agreed methods of assessing sustainability.

A third area of potential relevance to the CGIAR relates to research on the further development of non-commercial, small scale production of first-generation biofuels in rural settings, e.g., biodiesel for rural household electricity supply in developing countries, in an effort to promote rural development and reduce dependence on imports of fossil fuels. But this is an area where many others are active, particularly NGOs, and it would be important to spell out clearly the CGIAR's special role.

An area of potential relevance to the CGIAR is genetic enhancement of existing food crops with high potential for biofuel production, e.g., identification, development and testing of sweet sorghum, cassava, maize, etc. for single purpose or dual purpose biofuel use. The concern is that this type of work would stretch the CGIAR beyond its comparative advantage and, more importantly, draw it away from its food security imperative. Perhaps a stronger argument can be made for more narrowly focusing on new characterization of germplasm for biofuel attributes and measuring their biological trade-offs with other desirable food production related traits. This would apply mainly to CGIAR mandate crops, i.e., crops traditionally grown for human consumption.

Keeping the CGIAR Focus on Food Security and Environmental Sustainability

Looking into the future, interest in biofuels is likely to accelerate against a backdrop of factors like energy security, increasing oil prices (with rising demand for energy globally and particularly from rapidly growing developing countries' economies) and continued environmental pressures for cleaner and greener energies in the face of global warming. The current demand for biofuels has increased prices of major commodities and raised serious concerns about "food versus fuel" tradeoffs. Impacts from the biofuel expansion that have relevance to the CGIAR include supply and demand concerns – scaling up production but ensuring wide participation, reduced affordability and access to food supplies by the lower income populations and concerns over environmental and sustainability factors. The "food vs. fuel" debate will continue at least until second generation biofuels such as lingo-cellulosic ethanols can provide longer term sustainable fuel options. This is not expected in the near term as cost effective second generation biofuels are still at least 10 years down the road and bio-refineries and bio-based economies are even further afield. Even then, relying on conversion of biomass to provide 'significant' amounts of energy may not be realistic in the long run. Other forms of renewable energy, e.g., solar energy, probably have the most potential in that respect.

Even with the emergence of cellulosic ethanol, food-crop ethanol systems will continue to exert pressure on the global food supply – especially in a world where the most populous developing countries enjoy rapid rates of economic growth. This suggests a high priority be placed on ensuring not only continued but accelerated growth in productivity for the major food crops. Under this scenario, a stronger research commitment to accelerate the rate of gain in crops yields while protecting the environment is essential. Research on the process of sustainable management of food production systems (ecological intensification) will have to constitute a much larger component of the CGIAR portfolio than previously, which implies greater relative emphasis on SP 4A, 4C and 4D, i.e., on resource productivity and sustainability, than currently, in addition to more effort in SP 2A and 2B, i.e., advancing crop improvement. Given little or no appreciable increase in resources, the question then arises, what will the CGIAR do less of? This requires considerably more discussion and debate.

Some critical questions remain which bear directly on how widespread the positive benefits of biofuels are likely to be in developing countries. These relate especially to the new market opportunities and whether small scale producers and small scale enterprises in the chain are likely to be competitive. To what extent will the market be driven by large scale entrepreneurs? The latter would lead to industrial forms of agro-business that may not give the desired level of society-wide economic developments. Research under Themes 1 and 2 above should look at special measures needed to facilitate the participation of small scale actors to benefit from biofuels expansion, for example, how to make small scale biofuel production and processing of *jatropha* or cassava viable.

Biofuels have the potential to play an important role in poverty reduction – via raising biofuel and food crop producers' incomes, employment effects, wider growth multipliers and energy price effects, in addition to providing positive environmental benefits. But there are risks and potential adverse effects on the poor and the environment. The distributional effects of biofuel expansion are crucial – between producers and consumers and between food/feed/energy deficit and surplus countries. It is fundamentally important for the CGIAR to be engaged in addressing and, through its research, influencing developments related to biofuels expansion, such that opportunities for the poor are not lost and risks to them are minimized. Although the impacts of biofuels on poverty can only be assessed on a case by case basis at the country level, there are some overriding generic issues and questions that are of an IPG nature.

Research should be able to identify patterns of appropriate feedstocks, production systems, processing and marketing opportunities, and government roles that will maximise the positive and minimize the negative impacts that biofuel production could have on rural and urban poor. Also, to avoid excessive rises in food costs and a large expansion of crop area into marginal areas and fragile and/or strategic ecosystems, research should target: (i) achieving yields in farmers' fields near the yield potential ceiling without negative impacts on environmental quality, (ii) raising the yield potential of the major food crops and (iii) continuing to improve stress tolerance. Without new technologies to improve productivity, higher commodity prices will exert their full negative impact on the poor and probably exceed the sum income gains by small farm households. Research is also needed to develop the tools and methodologies for undertaking complete life cycle assessments for analyzing the environmental, economic and social impacts from different biofuel feedstocks.

In conclusion, the SC suggests a focus on two broad areas of research for the CGIAR to effectively address the biofuel-related challenges: (i) policy related research to assess the potential impacts of biofuels production on food security and environmental sustainability in global, regional, national and local contexts; and (ii) natural resource management research, including sustainable productivity improvement for traditional and new food crop systems and, in some selected cases, for small holder biofuel production systems.

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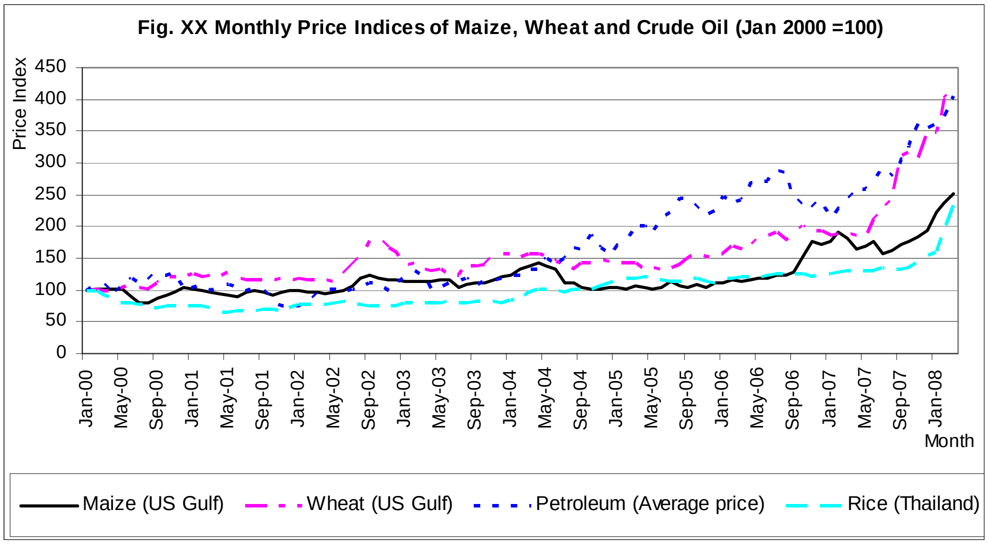

Fig. XX Monthly Price Indices of Maize, Wheat and Crude Oil (Jan 2000 =100)
Price Index
450
400
350
300
250
200
150
100
50
0
Jan-00
May-00
Sep-00
Jan-01
May-01
Sep-01
Jan-02
May-02
Sep-02
Jan-03
May-03
Sep-03
Jan-04
May-04
Sep-04
Jan-05
May-05
Sep-05
Jan-06
May-06
Sep-06
Jan-07
May-07
Sep-07
Jan-08
Month
Maize (US Gulf)
Wheat (US Gulf)
Petroleum (Average price)
Rice (Thailand)

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