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Les Levidow, Helena Paul:
Land-use, Bioenergy and Agro-biotechnology

Externe Expertise für das WBGU-Hauptgutachten
"Welt im Wandel: Zukunftsfähige Bioenergie und nachhaltige Landnutzung"

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'Land use, Bioenergy and Agro-biotechnology'

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1 Introduction: Framing questions about GM bioenergy crops

Regarding the prospects of agbiotech for bioenergy production, the WBGU has posed these main questions:

> To what extent could biotechnology influence global sustainable plant production?
> To what extent could biotechnology (in particular the use of GMOs for food and non-food production) decrease the potential of land-use competition by increasing yields?
> What is the range of expected yield improvements that can be found in existing assessments?
> On the other hand: What may be the risks? Could biotech possibly even increase the potential for competition between different land uses, i.e. due to crowding out effects or biosafety concerns?

This Introduction briefly surveys controversial issues around GM bioenergy crops, ways of framing those questions, assumptions bearing upon possible answers, and key terminology in this report.

1.1 What sustainability?

As official reasons for promoting biofuels, governments seek to reduce carbon emissions, to enhance energy security and to produce energy in more sustainable ways. Such reasons are given for EU targets. However, crops that can be used for bioenergy have already been generating societal conflicts over land use and sustainability, especially degradation of natural resources. Doubts have also been raised about savings in carbon emissions, highly dependent upon the context and modes of bioenergy production.

In this context, GM crops have been promoted as a future means for eventually avoiding such conflicts, especially by increasing yields. Such hopes help to justify current government policy, so that economic incentives stimulate the development of novel GM crops for bioenergy. 'After all, it's difficult to oppose a technology that's helping to save the planet', says the journal *Nature Biotechnology* (Editorial, 2006).

Like many recent innovations, bioenergy has been promoted as a means to link economic growth with 'sustainable development'. This key term has ambiguous and contentious meanings. As an extreme example, let us consider its recent promotion by the CEO of BP France:

> Sustainable development is first and foremost about producing more energy, more oil, more gas, and maybe more coal and nuclear fuel, as well as more renewable energy, of course. At the same time, we need to make sure that this production is not achieved at the expense of the environment (de Fabiani, 2001).

In that vein, bioenergy crops are being promoted as a renewable form of energy which can respond to a greatly expanding market. Here 'sustainable production' denotes new links between agriculture and energy:

> In general, the production of biofuels could provide an opportunity to diversify agricultural activity, reduce dependence on fossil fuels (mainly oil) and contribute to economic growth in a sustainable manner….
> By actively embracing the global trend towards biofuels and by ensuring their sustainable production, the EU can exploit and export its experience and knowledge, while engaging in research to ensure that we remain in the vanguard of technical developments (CEC, 2006a: 5, 6).

According to proponents of GM bioenergy crops, these innovations can avoid competition for land use and sustainability problems, especially through higher yields. For example:

> Europabio considers that the unsustainable use of land for the production of biofuels can be avoided if efforts are concentrated on raising the yields of existing agricultural land instead of widespread deforestation. Besides relying on good agricultural practice, including proper application of crop protection products and fertilizers, one way of increasing the yield per hectare is to use new breeding and modern biotechnology techniques (EuropaBio, 2007: 7).

In this account of sustainable crop production, agrichemicals and GM crops provide complementary ways to increase yield, while also avoiding harm to forests – a special focus for environmental protection.

On those grounds, industry advocates government measures to expand current bioenergy crops, as necessary incentives for investment in R&D towards better ones:

> EuropaBio strongly believes that biofuels, and in particular second generation biofuels (such as bioethanol or biodiesel from ligno-cellulosic biomass or biodiesel from biomass gasification) has the potential to become an attractive replacement for fossil transportation fuels for both environmental and economic (depending on the oil price) reasons, and due to its potential of creating jobs in rural areas.
> To reach the 10% biofuels target, the EU urgently needs to draw up a comprehensive and coherent framework comprising all relevant policy areas. This will require a realistic roadmap to implement the different policies.
> We also need to encourage investments in second generation technologies, and a Europe-wide coherent research project with funding from the European Commission as well as from the different Member States (EuropaBio, 2007: 5).

Although any significant yield increase remains hypothetical, GM techniques are widely proposed as a means to achieve this. Proponents hope that such modifications could include the following: to produce more components for bioenergy (e.g., more carbohydrates and oils), to increase production per hectare, to increase the harvest (the ratio of grain mass to total above-ground biomass), to use more of the plant or tree for more purposes, or to facilitate the metabolic breakdown of plant components. Research also aims to extend the range of crops to marginal lands, as well as to inhospitable areas where conventional crops were not previously cultivated because the climate was too hot, too dry, too cold, saline or acid.

The search for many kinds of higher yield complements the ‘biorefinery’. This concept has multiple meanings – an agri-industrial model of renewable raw materials, an infrastructure for processing them into diverse products, and integration of agriculture with the oil industry. According to a promotional account:

> … the integrated diversified biorefinery – an integrated cluster of industries, using a variety of different technologies to produce chemicals, materials, biofuels and power from biomass raw materials agriculture – will be a key element in the future. And although the current renewable feedstocks are typically wood, starch and sugar, in future more complex by-products such as straw and even agricultural residues and households waste could be converted into a wide range of end products, including biofuels (EuropaBio, 2007: 6).

The ‘biorefinery’ infrastructure provides greater flexibility for transforming various biomass sources into diverse products – e.g. animal feed, biofuels and other industrial products – while also integrating their production (see Section 2 below). Through the ‘biorefinery’, the pursuit of bioenergy from agriculture brings together the major agri-industrial interests (e.g. seed, fertilizer, pesticide, commodities and biotechnology) with the energy sector, including the oil, power and automotive industries. For greatly expanding biomass production, the agri-industrial biorefinery promotes intensive monocultural systems, in turn dependent upon inputs such as agrichemicals and water.

An international conference on the biorefinery brought together diverse industries with a common aim to integrate biomass sources and products:

> Participants included members of the forestry, automotive, pulp and paper, petroleum, chemicals, agriculture, financial, and research communities….
> It was noted by DOE and EU that both the U.S. and EU have a common goal: Agriculture in the 21st century will become the oil wells of the future – providing fuels, chemicals and products for a global community (BioMat Net, 2006).

‘Oil well’ provides an appropriate metaphor: plant material becomes an interchangeable raw material for extraction and processing into standard commodities for a global market – euphemistically called a ‘community’. This metaphor well expresses the agri-industrial biorefinery, with its commercial assumptions about the environment and society.

That agri-industrial model contrasts with an alternative German ‘green’ perspective. This sees GM crops and intensive monoculture as dual threats:

> One thing is clear: the maximisation and intensification of land use at the expense of nature and the environment are not sustainable and would lead to massive acceptance problems... The cultivation of genetically modified plants is associated with incalculable risks and completely superfluous in view of the economic, ecologically compatible alternatives that are available (Alliance 90/The Greens, 2006: 11).

As an alternative to GM crops and intensive monoculture for bioenergy, they advocate regenerative raw materials from agri-ecological cultivation methods:

> The coupled production of, for example, an oil seed for energetic use with peas for use as animal fodder (mixed crop cultivation) offers economic and ecological perspectives, allowing regenerative raw materials to be produced as well as forage and cash crops. On account of their higher biodiversity, mixed cultivation systems compete better against weeds than monoculture systems. This is of particular significance for systems with limited input of resources, such as ecological farming (Alliance 90/The Greens, 2006: 11).

That alternative model corresponds to a different 'biorefinery' concept than the agri-industrial one:

> At the moment, we are squandering the immense potential of raw materials that can be used efficiently through new procedures, in biorefineries for instance. Biorefineries are capable of using biotechnological processes to exploit all kinds of biomass, such as green waste, and transforming them into a wide range of products. Our industrial raw material base must be converted step by step from oil to regenerative raw materials... The use of regenerative raw materials will allow the establishment of closed cycles and therefore the development of sustainable forms of economic activity. The thermal recovery of products that have been produced on the basis of regenerative raw materials is climate-neutral, since only as much CO_2 is released in this process as was absorbed from the atmosphere when the plants were growing... (ibid: 5).

In its view, then, sustainability depends upon minimal energy usage in producing the biomass for bioenergy. It advocates 'decentralised production (for example, in biorefineries or agricultural distilleries)' including the recycling of mown grass from nature conservation sites (ibid: 9).

Less-intensive alternatives are likewise promoted by an international NGO network. Its report raises doubts about GM bioenergy crops on several grounds, as follows: Technical improvements for bioenergy usage through GM techniques remain speculative. At the same time, optimistic expectations provide a pretext to justify government targets for expanding biofuel consumption. This will aggravate social, economic and environmental harm from intensive monocultural practices, especially in the global South, argue NGO campaigners (Econexus et al., 2007).

For evaluating the prospects of GM crops as bioenergy sources, the global South should be a prime focus. It would provide most bioenergy sources consumed in Europe, especially under current policies for biofuel targets. As DG Trade Commissioner Peter Mandelson has clearly stated:

> Europe should be open to accepting that we will import a large part of our biofuel resources… We should certainly not contemplate favouring EU production of biofuels with a weak carbon performance if we can import cheaper, cleaner, biofuels. Resource nationalism doesn't serve us particularly well in other areas of energy policy - biofuels are no different (quoted in Euractiv, 2007).

Therefore, in the context of EU policy, any evaluation of GM crops should focus on prospects for massively expanding bioenergy crops in the global South, along with moves to liberalise imports.

'Sustainability criteria' have been proposed as a means to minimise environmental harm from such imports. This report will not consider such proposals, for several reasons: For the main questions posed earlier, meaningful answers must refer to the causes of agri-environmental unsustainability and land-use competition – whether or how these causes could be addressed by GM crops. Current proposals for sustainability criteria are being fiercely debated, with great political uncertainty about their scope and reliable enforcement (CEO, 2007a). For all those reasons, meaningful answers to the main questions above cannot depend upon the outcome of such policy debates.

1.2 Normative and causal assumptions

The brief sketch above indicates divergent perspectives on potential roles and effects of GM bioenergy crops. What are their prospects for avoiding sustainability problems and competition for land use? Any meaningful answers involve normative and causal assumptions about those key terms.

‘Sustainable crop production’ has divergent normative meanings: For agri-industrial intensive monoculture systems, sustainability means smaller input-output ratios of resource usage – e.g. by increasing the efficiency of externally obtained inputs, by recycling waste biomass into further production, etc. – in order to produce standard commodities for a global market. For many small-scale farmers, by contrast, sustainability means reliance on locally available inputs, bio-diverse seeds and intercropping methods; these provide means to sustain genetic resources, water supplies and soil fertility into the future.

Thus different accounts of sustainable agri-production are in conflict, as regards their aims and methods. This report favours the latter account, which links cultivation methods, agri-environmental resource conservation, and ecological support systems; these provide a basis for food security, local livelihoods and community solidarity. At the same time, the report will analyse divergent accounts implicit in arguments about GM crops as a solution.

In addition to normative assumptions, causal assumptions also underlie perspectives on higher-yielding GM crops as a solution. If they really can avoid competition for land use and unsustainable agri-environmental practices, then those problems must be caused by low yield, inefficient conversion into energy, narrow geographical range, etc. If higher yield offers a solution, then this likewise assumes that a finite production is needed for a particular geospatial unit, such that more production can alleviate competition among diverse uses.

Logically necessary for GM crops to provide a solution, those assumptions can be made explicit as hypotheses. By contrast, other hypotheses attribute the above problems to intensive monocultural practices, linked with global political-economic pressures. These different hypotheses can be tested for their validity, by drawing upon recent global experiences of land-use and sustainability problems. These issues are summarised in the Conclusion, especially in Table 1 there.

Answering the main questions above, then, involves wider issues than the eventual capacity of novel GM crops to increase yields. Rigorous answers depend upon normative and causal assumptions, in particular:

- What are the various meanings of ‘sustainable’ crop production? sustainable for whom? for what purposes?
- Given various criteria for sustainability, in what ways do they complement or contradict each other?
- What causes sustainability problems, variously defined?
- Given the competition for land between food versus other uses, especially in the global South, what drives the competition?
- How do those problems relate to crop yields and prospective increases?
- How could higher-yield GM crops avoid sustainability problems and competition for land use – or, alternatively, aggravate those problems?

These questions will be discussed in general and in specific contexts, as a basis for the conclusions.

1.3 ‘Generation’ terminology

Before proceeding to the analysis, it is necessary to clarify key terms, which could otherwise cause confusion. Bioenergy and biofuels are produced from biomass, which can come from any vegetable matter, such as plant or tree material. Biofuels are generally defined as biomass-to-liquid fuels, while bioenergy has a broader scope. Therefore this report generally uses the term bioenergy, which includes all fuels produced from vegetable biomass. As an exception, we often use the term ‘biofuels’ when citing statements by governments and industry, both of which are currently promoting liquid biofuels more than other forms of bioenergy. The report focuses on crops (including some trees) grown for purposes including bioenergy, because these products are the main target of genetic modification techniques for land use.

‘Generation’ terminology for new products has great confusion and inconsistency. Until recently, ‘second generation GM crops’ meant special quality characteristics for consumers, though few have materialised. Now the same term has a new meaning – GM characteristics especially for bioenergy uses. Yet R&D on stress tolerance has a longer history and so could more justifiably be called 'second generation'.

'Biofuel generation' terminology is also problematic. Now we are being promised second, third, fourth and general 'next generation' biofuels; these terms lack clear definitions and consistent meanings. 'Second/third' generation implies that such crops will be feasibly created in the near future, yet this remains speculative. Some novel GM crops may facilitate use for animal feed as well as for energy purposes, so these would be more appropriately called 'energy-feed' crops.

In the trade literature, bioenergy crops are sometimes foreseen in terms of two stages:

- 'first generation' of currently available crops (such as maize, canola, and soya), for producing bioenergy from the grain, seeds, fruits and roots; and
- 'next generation' (e.g., second, third, fourth, etc.), including so-called ligno-cellulosic fuels to be produced from all other parts of the plant.

The term 'next generation' combines great differences in aims and technical feasibility. Nevertheless the first/next distinction is preferable to more specific categories (second, third, etc.) – which would be even more deceptive.

For all those reasons, this report uses the following terminology:

GM crops

- First generation: herbicide tolerance and insect-tolerance, including multiple stacked genes of those types.
- Second generation: tolerance to stress (e.g., drought, salt, extreme temperature) and thus a broader geographical range.
- Third generation: changes in growth regulation which could increase biomass yield; or changes to facilitate energy extraction from the whole plant, from wood and from agricultural and forestry waste.

Bioenergy crops

- First generation: mostly standard crops, some also used to produce animal feed. Some are poisonous (e.g., castor oil or jatropha), so they are not used also as food plants. In all cases, the seed is used as the bioenergy source.
- Next generation: corresponding to second-generation and third-generation GM crops as above.

2 Agbiotech R&D and future promises for bioenergy

Proponents of biofuels call for strong incentives for the so-called first generation, despite societal disadvantages, in order to stimulate further generations which may be more benign. For GM crops commercialised until now, agbiotech companies have used GM techniques mainly to add genes which facilitate different agronomic practices, e.g. herbicide tolerance and pesticide expression. Such genetic changes have been comparatively simple.

Now R&D has more ambitious aims. According to Europabio (2007), R&D on GM crops for bioenergy aims to:

- Increase biomass yield per hectare while reducing the needs for production inputs.
- Improve crop quality to provide more carbohydrates or higher oil content and thus more bioenergy.
- Grow energy crops in areas with marginal conditions.
- Develop micro-organisms and enzymes to convert cellulose and hemicelluloses to sugars, which can then be fermented into biofuel.
- Convert agricultural waste into bioenergy.

Although not mentioned in the above document, novel traits may also be stacked alongside familiar agronomic traits, i.e. GM herbicide-tolerant traits, which facilitate low-till or no-till cultivation techniques.

Through new, complex applications of genetic modification, R&D now tries to overcome various limits on crop production. As a general aim, R&D seeks to increase crop yield for multiple uses – to produce food, feed and fuel from the same harvested material. Industry intends to stack the same crop with GM traits for production of feed, food and fuel, thus gaining synergies across usages of the same biomass. In that sense, these efforts have a plausible prospect of some increase in yield, though any quantitative estimate lacks a clear basis in evidence.

Moreover, R&D also aims to convert whole plants into fuel, not just their fruits or seeds, as well as agricultural and forestry waste. There are efforts to break down basic plant components (cellulose, hemi-cellulose, and lignin), so that plants can be more easily converted to fuel. Such aims face 'recalcitrant substances' and biological barriers to be overcome, according to the US Department of Energy (US DOE, 2007a). The technical obstacles may prove very difficult to tackle in a cost-effective way in the near future. According to many practitioners and proponents, no significant success can be expected for at least 5-10 years. Consequently, any prospect for higher-energy yield remains entirely speculative; any quantitative estimates would be groundless, even deceptive.

Despite the difficulties, the R&D efforts should be addressed, for several reasons:

- Some may eventually succeed in technical and commercial terms.
- R&D priorities complement wider agri-industrial changes which have potentially significant consequences for land use and sustainable production.
- Hopes or promises for benign consequences have become a factor in policy debates on biofuel targets, so the prospects warrant careful scrutiny.

In surveying the various R&D efforts, this section notes their implicit meanings or assumptions about sustainability – to be taken up in later sections. To avoid confusion, our report uses a relatively simple terminology for different generations of bioenergy crops (as explained in Section 1.3).

2.1 First-generation bioenergy crops

Early R&D investment in agbiotech focused on crops (soya, maize, cottonseed, oilseed rape) that could be used mainly for feed purposes. A similar agenda is being extended by novel GM crops, especially for integrating feed with bioenergy uses, so that the same harvest could be more effectively used for both.

2.1.1 Stacking agronomic genes

Bioenergy production already makes widespread use of GM crops with agronomic traits, mainly herbicide tolerance and/or Bt insecticide expression. These are preferred for industrial-scale production. Biotech companies will continue to use and stack current GM traits in their key crops – which can be readily used for food, feed and/or fuel purposes.

As a general problem, insect pests or weeds may develop resistance to agronomic traits and have already done so in some cases. The herbicide tolerant crop itself may become a 'volunteer' weed under crop rotation, requiring the application of other herbicides (e.g. 2,4-D and dicamba) to remove it. Current GM crops are used in monoculture systems that can generate a rapid development of pest and weed resistance. Such resistance jeopardises the efficacy of the Bt crop, as well as the naturally occurring Bt toxin in microbes as an alternative to chemical pesticides, especially in organic agriculture. Within R&D agendas, such resistance problems are addressed by alternative genes for the same purpose and/or chemicals to accompany them.

For example, Monsanto and Dow Chemical have announced 'a cross-licensing agreement aimed at launching SmartStax™, the industry's first-ever eight-gene stacked combination in corn'.

> Under the agreement, the companies will create a novel seed offering that combines eight different herbicide tolerance and insect-protection genes into top-performing hybrids for the most complete control ever available. The product will include the companies' respective above- and below-ground insect protection systems, including Dow AgroSciences' Herculex® I and Herculex RW technologies; Monsanto's YieldGard VT Rootworm/RR2™ and YieldGard VT PRO™ technologies; and the two established weed control systems, Roundup Ready® and Liberty Link® (DowAgro, 2007)

At the same time the companies announced that they would seek to lighten regulatory requirements of the ‘single-trait refuge programmes’. Refuges are nearby areas, cultivated with conventional crops, which were established to slow down any development of resistant insects. This safeguard is now threatened by deregulatory lobbying, arguing that stacked traits reduce the need for refuges.

In 2007 Monsanto also announced that it was developing a soybean tolerant to dicamba, a growth regulator herbicide. This work is stimulated partly by emergence of glyphosate-resistant weeds, and partly by herbicides (normally used on corn) causing distortions in soya leaves. With a GM dicamba-tolerant soybean, farmers could use dicamba to eliminate volunteers tolerant to other herbicides. Monsanto also seeks to provide a wider range of herbicide tolerance in their feed and fuel products. Dow Chemicals are also working on tolerance to a growth regulator, the herbicide 2,4-D (Purdue Extension 2007). These traits presume widespread use of herbicides, including aerial sprays, whose consequences have not been adequately assessed.

Those agronomic traits will be likely stacked alongside any novel traits that materialise for bioenergy purposes. Their prospects to increase yield depend upon many factors, especially the normal needs of intensive monocultural systems for machinery, fertilisers and water supplies. Regardless of whether stacked genes help to increase yield for bioenergy uses, their prospects for sustainability can be evaluated by analogy to current GM crops in monoculture systems (see Section 3).

2.1.2 Integrating feed and fuels

Until now a major use for GM crops has been animal feed. With some crops (e.g. canola, rapeseed, soya), it is used in the form of the ‘cake’ residue from extracting the oil. Maize is mainly fed in the form of milled grain or gluten. Thus feed can be a by-product of bioenergy production. In the case of ethanol from maize, it is convenient to feed the by-product (distiller’s grain) to cattle in nearby feedlots, without any need to dry out and transport the feed. At the same time the slurry can be used to produce energy to drive the plants. Maize already is being processed in the US to produce ethanol, with the residue used as animal feed.

That integrated industrial system appears an attractive way to supply growing markets, especially in the global South. Rising consumer demand for meat and poultry requires a massive amount of animal feed. In addition to long-established markets in the developed economies, such markets are rapidly expanding elsewhere, especially in China and India. A few companies are cooperating to control the production, processing and movement of feed commodities around the world. With the same agricultural biomass, they now have an opportunity to exploit the potential for bioenergy as well as feed use. However, such feed-energy integration can stimulate the extension of intensive monocultures across wider geographical areas. This system complements the economies of scale, standardised products and the infrastructure that the same companies already control.

Consequently, much initial research for GM bioenergy crops has sought to integrate the production of bioenergy with animal feed. R&D centres on maize, soya and oilseed rape, though also sugar beet and sugar cane. Some examples:

- High-starch & lysine corn

In 2008 Monsanto aims to commercialise ‘Mavera’, a GM maize variety (Monsanto, 2006: 10). It has high starch content for ethanol production and high lysine for animal feed. Renessen, a collaboration between Cargill and Monsanto, is building installations to treat the residue of maize after ethanol production and turn it into animal feed (Kaskey, 2006). Such installations will need to be close to the animal feeding centres, so that the residue need not be dried out for transporting.

- Alpha-amylase corn

Syngenta has developed a variety of GM maize that incorporates a bacterial enzyme to simplify crop processing for ethanol. The bacterial-derived enzyme is a heat-tolerant, thermo-stable alpha-amylase which catalyses the breakdown of starch into smaller molecules, mostly sugars, thus facilitating the fermentation process. By producing the alpha-amylase in the maize grain, the variety replaces the external addition of microbes or microbially produced enzyme.

The GM variety was designed to produce the enzyme only in the kernel (with storage in the endoplasmic reticulum), yet alpha-amylase has also been detected in root, leaf and other plant tissue, especially during early development. The enzyme turns starch into sugars, a widely utilized food source for insects. So the GM variety holds the risk of attracting pests at several stages – early stages of growth, seed transport, or grain storage.

At present the maize is intended for cultivation and biofuel processing outside the EU. Syngenta expects some quantities to become inadvertently mixed with other maize varieties. To avoid difficulties later, its application for EU authorisation seeks full approval for feed and food uses of the GM material:

> Event 3272 maize is intended to be cultivated outside the EU. The grain will be locally used in the dry-grind fuel ethanol process. The grain is not intended either to be used in other processing applications (e.g. wet milling and dry milling processes) or to be exported as a commodity crop. However, it cannot be excluded that extremely low levels of the grain originally intended to be used in the dry-grind fuel ethanol industry could finally enter international trade routes (Syngenta, 2006: 4).

Regardless of whether the EU grants full approval, contamination could cause commercial difficulties for feed or food supplies in Europe. (See also Section 4.3 on this problem.)

2.2 Next-generation bioenergy crops

While the R&D efforts above seem feasible in technical terms, other efforts specifically for bioenergy purposes remain more speculative. All the latter prospects will be called ‘next-generation’, to avoid any assumptions about their relative feasibility (see Section 1.3).

2.2.1 Growth regulation

Some companies propose to engineer plants to produce more biomass by altering the plant’s own systems for growth regulation. According to proponents, the modification could be targeted at particular parts of the plant, depending on whether the priority is larger seeds, fruits or roots.

As an example of such investment, Targeted Growth, Inc. (TGI) is a company seeking to increase the yield of plants, especially as material for biofuels. It is currently working with canola, maize and soya. In 2005 the company made a licensing agreement with Monsanto regarding use of its technology – which it calls the Yield Enhancement Gene. Investors include companies interested in bioenergy crops, especially for biodiesel. TGI has research partners in the US and Canada.

TGI uses a variety of techniques. According to the company’s CEO,

> Targeted Growth is the “friendly version” of genetic modification because the company modifies a gene that already exists in the plants, and isn’t introducing any foreign DNA. The company is also aggressively working on a way to make these high-yield seeds without genetic modification (quoted in Kho, 2007).

In February 2007 TGI acquired a patent on a technique to postpone the cessation of cell division, so as (for example) to increase the size of plant seeds. Its patent application emphasises the previous difficulties of such aims:

> Conventional plant breeding has been the principle driving force for increased crop yields over the past 75 years... More recently, transgenic crops have become available that for example has resistance to insect pests and herbicides. However, these transgenic crops do come with a yield penalty... To date, no known transgenic crop is commercially available that has an increase in seed size or an increase in crop yield (WIPO, 2007).

In that context, the application claims novelty:

> There is a need in the art for improved methods of modifying characteristics of certain commercially valuable crops, including for example, but not limitation, increasing crop yields, increasing seed size,

> increasing the rate of germination, increasing root mass, and the like. The present invention as described herein meets these and other needs (ibid).

In order to achieve these diverse aims, TGI is applying GM techniques to intervene in the processes that 'regulate the transitions between different phases of the cell cycle'.

If a yield increase is achievable, can it be maintained in isolation and over time? Plant cell division is a finely-tuned process, normally dependent the tissues and developmental stage of the plant, as well as its wider environment. The plant uses processes involved in cell division to help it to respond to adverse conditions, e.g. insect attack. Interfering with the regulation and processes of cell division is also to interfere with the plant's own ability to adapt to environmental changes. If a crop is modified to produce larger seeds but lacks the capacity to maintain this large energy expenditure, then it could become more vulnerable to biotic and abiotic stresses as well as to diseases and pathogens.

If GM crops are expected to increase yield, in order to facilitate greater production of feed and fuel, then this assumes or implies that the total energy within the crop can be increased. However, a redesign can only redistribute the energy from one function of a crop to another, within its inherent metabolic limits. In efforts to alter these functions, GM techniques may jeopardise traits important for plant health and other functions, without reliably increasing yield. It sounds simple and desirable, but technical intervention to regulate cell division for higher yield remains only hypothetical – and potentially harmful, at least to the crop.

The prospect of eventual success has been equated with an improvement in environmental sustainability as well as yield. TGI's CEO speculates on such prospects:

> "If we want to help reduce stress on the competition between food vs. fuel, the best mid-term solution is just to make more of it [crops]," he said. "If you increase yields by 20%, you reduce the pesticides, herbicides, and fertilizers by 20 percent – which is very good for the environment – and you also relieve some of the pressure on food vs. fuel" (Kho, 2007).

The above claim – that increasing yield by 20% will decrease inputs by 20% – is attractive but simplistic and deceptive. Green Revolution high-yield varieties (HYVs) reduced the height of the wheat (dwarfism), so enabling the plant to redistribute energy to seed production, but such HYVs still require more inputs. Moreover, a company such as Monsanto can be expected to stack a 'Yield Enhancement Gene' with tolerance to broad-spectrum herbicides; this trait will consume some of the energy available within the crop.

By late 2007 TGI was making specific claims for yield increases: 'Targeted Growth has demonstrated annual yield increases of 20% or more in crops optimized for the biofuel market.' Such efforts were initially directed at Arabidopdis: 'Increased activity in cell cycle regulation was originally shown to increase the seed size in Arabidopsis by 80% to 100%.' This initial success was translated into commercial crops such as canola and soybeans, according to the company:

> By incorporating knowledge of plant genetics and trait selection through genetic markers, Targeted Growth is able to improve plant varieties more rapidly than through traditional methods. While traditional methods generate annual yield increases of approximately 1%, Targeted Growth has consistently demonstrated yield increases of 20 – 40% (TGI, 2007a, section on Modern Breeding Techniques).

The company gives no details about the basis or conditions for yield increases. Likewise no details are available for similar claims from Mendel Biotechnology. (Our efforts to contact them about progress have been unsuccessful.) So their claims should be seen as speculative.

2.2.2 Structural changes to plants, especially trees

Lignin and cellulose are two vital groups of substances present in the cell walls of plants. Some R&D seeks to change their characteristics for easier breakdown into raw materials required by industry.

Lignin is a complex chemical compound cross-linking with other cell wall components especially hemi-cellulose. Together they give mechanical strength to the cell wall and thus to the whole plant. Lignin is particularly abundant in trees, enabling them to grow tall or spread wide. It has other essential functions too. As lignin is hydrophobic, it keeps water in – and out; it is crucial for conducting water through the stems or branches of plants. Its forms have evolved over millions of years in response to the pressures on each plant species within various ecosystems. Lignin has great mechanical strength and cannot be broken down by animal enzymes, so it has also evolved as a major plant defence against pathogens, parasites and pests or any organisms that try to eat them or invade their internal environments. Lignin is the plant substance that decomposes the most slowly, as it is digestible only by some bacteria and fungi; it is crucial for building up humus in the soil and thus for its fertility.

Cellulose is the main substance of interest for conversion into fuel, while lignin is regarded as an obstacle to the extraction and use of cellulose. GM techniques are thus being used in efforts to alter, remove, reduce or break down the lignin. To succeed fully, this research will need to achieve those aims – but without making novel plants more vulnerable to predators, competitors or invaders. If successful, then this change would facilitate conversion of the cellulose into fuels.

Specially designed crops for easier breakdown of cell walls are being pursued through multidisciplinary research teams. According to a European R&D consortium, 'This larger-scale research effort was considered essential to achieve the foundation for designing *in planta* strategies to engineer bespoke [custom-made] cell walls optimised for integrated biorefinery systems'. This aim exemplifies the search for genetic changes in crops which would be available in large quantities 'with the potential to produce both chemicals and biofuels in an integrated biorefinery' (EPOBIO, 2006: 34, 10)

Funded by the US Department of Energy, Purdue University is working to develop a poplar hybrid with altered or reduced lignin, so as to access the cellulose more easily for conversion into fuels, hence reducing the cost and energy used. The research also seeks to make the trees sterile (unable to reproduce), in response to fears that the traits would spread to wild trees and that GM trees would spread to and harm forest ecosystems (Purdue University, 2006). According to some researchers, this tree could be grown on millions of acres of so-called 'abandoned, neglected and unused land' in the US.

If GM trees or plants have 'customised' or reduced lignin, then they could become more vulnerable to disease and pests. Although not mentioned in information about the project, the Purdue poplars would likely be planted in monocultures, for which it would be logical to stack the trees with GM traits for herbicide tolerance and insecticide expression. If planted in genetically uniform monocultures, they would become even more vulnerable to pests and diseases.

Trees are an obvious choice for GM bioenergy research. As compared to annual field crops, trees require lower maintenance and fewer inputs, thus promising a double advantage for the industry. They also contain more carbohydrates, the raw material for agrofuels. At the same time, trees have characteristics – complex interactions with ecosystems, long life cycles, and wide dissemination of fruit and pollen – which would allow GM trees to cause more negative effects than those of GM annual field crops. Little is known about the impacts of releasing GM trees, especially on natural forest ecosystems.

Sometimes called 'synthetic biology', research using GM techniques attempts to design custom-built organisms to process biomass. If successful, then such efforts could help to accelerate the utilisation of so-called agricultural and forestry waste for bioenergy. It could also provide an additional incentive for extensive plantations of cellulosic bioenergy feedstock, possibly in conjunction with the paper industry. Although this is a long term aim, optimistic expectations could influence land-use decisions in the next few years.

Waste biomass?

Easier breakdown of plant material and of energy-rich molecules would facilitate conversion of organic matter into bioenergy. Such organic matter could include waste from agri-industrial processes. It is often claimed that there is a vast reservoir of waste plant matter that could be converted into energy, thus avoiding competition with food production. However, 'waste' is a deceptive term, implying or assuming that such biomass (stalks, stems, wood, etc) has no other importance or is even an environmental liability.

On the contrary, organic residues normally replenish soil nutrients and fertility. If such residues are intensively removed for conversion into bioenergy, then farmers would need to increase the use of nitrate fertilisers, leading to greater emissions of nitrous oxide (a powerful greenhouse gas), together with nitrate overloading in water supplies. For example, nitrate run-off has killed an entire section of the Gulf of Mexico (Shapley, 2007). The production of nitrogen is itself a highly energy-intensive process, so undermining any savings in carbon emissions (or energy independence) from extra energy sources.

The removal of plant material is also likely to accelerate topsoil losses, thus causing further decline in soil carbon, soil quality and nutrients in the soil. The UK already has seen reductions in mineral levels of vegetables between 1946 and 1991 (Paul and Steinbrecher, 2003: 11). Many species depend on 'waste' wood in forests. 'It is estimated that 20- 25% of all woodland species depend on so-called 'forestry waste' being left in woodlands – including 1500 types of fungi and 1350 types of beetles in Germany alone, as well as many other species of insects, lichens, birds, and mammals' (Econexus et al., 2007: 15).

If organic material is removed on industrial scales for bioenergy uses, then this would likewise cause serious impacts on soil, biodiversity and water. It would be very difficult to regulate such activity so as to remove only amounts not needed by the ecosystem, given the nature of industrial processes and mechanical power now available.

2.2.3 Stress tolerance

Since the 1980s there have been promises of novel crops tolerant to various stresses, e.g. drought, salt, acid or heat. These are sometimes called third-generation GM crops. According to FAO Director-General Jacques Diouf,

> … most genetically modified (GM) crops being cultivated today were developed to be herbicide tolerant and resistant to pests. Development of GM crops with traits valuable for poor farmers, especially within the context of climate change – such as resistance to drought, extreme temperatures, soil acidity and salinity – is not yet a reality (FAO, 2007).

Such traits have been promised for many years, especially to improve the public profile of agbiotech. But they remain a low priority for commercial R&D and technically difficult to achieve. Stress tolerance involves numerous genes in interaction. According to Osama El-Tayeb, Professor Emeritus of Industrial Biotechnology at Cairo University:

> … transgenicity for drought tolerance and other environmental stresses (or, for that matter, biological nitrogen fixation) are too complex to be attainable in the foreseeable future, taking into consideration our extremely limited knowledge of biological systems and how genetic/metabolic functions operate (El-Tayeb 2007).

According to scientists at UC Davis, recent research has identified a gene that controls the amount of atmospheric ozone entering a plant's leaves. This provides a potential basis to regulate the opening and closing of stomatal pores. Such control could help develop drought resistance in plants, because moisture loss is reduced when pores are closed. However, such plants take up less carbon dioxide than had been expected and do not photosynthesise optimally (McDonald, 2008). This disadvantage indicates the complexity of altering metabolic and regulatory processes in plants.

This complexity has been recognised for a long time. For example, Ethiopian varieties of sorghum can survive drought, thanks to what is called the 'Stay Green' gene. According to a leading

Australian researcher on such crops, 'If you look at human genetics, then some traits like eye colour can be determined by a single gene, whereas a trait like Stay Green is a complex trait, so there is more than one gene involved and each of those genes may have more than one function' (ABC, 2004).

Indeed, numerous interacting genes are involved. Science may have identified some relevant genes and particular functions of those genes – but not how they interact, nor other roles played by these genes. Current scientific knowledge does not understand the complexity of traits for stress tolerance, nor their role in other metabolic pathways.

If the stress tolerance of a plant is truly enhanced, then this entails particular risks such as invasiveness. Arborgen is using GM techniques to enhance cold tolerance in a variety of eucalyptus, in order to extend its geographical range. Success could be problematic. Many members of eucalyptus family are invasive, so extending the range will increase the potential for invasiveness. Furthermore, it is impossible to predict how a plant may alter its response if enabled to flourish outside its usual range.

Non-GM techniques for stress tolerance

Flood tolerance in a rice variety has been achieved by an international team without GM techniques. The trait for flood tolerance was identified through gene mapping. Then, using marker assisted breeding, it was bred into a widely-used Asian cultivar, which survived a submergence period of 14 days (UC Davis, 2006; Xu et al., 2006).

As a more modest way to design a plant for bioenergy production, a *Brassica* variety has been bred for better adaptation to marginal land which otherwise would not be cultivated. Targeted Growth International was originally promoting GM techniques for increased yield but now places more emphasis on this project.

> Targeted Growth, Inc. (TGI), a renewable energy bioscience company, and Green Earth Fuels, a vertically integrated renewable biodiesel energy company [announced] the formation of a joint venture called Sustainable Oils, Inc… TGI has been perfecting camelina for the past three years in greenhouse and field trials. Specifically, it has used non-transgenic molecular-assisted breeding programs to create a crop that is well suited to Montana's climate and soil and that produces high quality biodiesel. "We have created a better feedstock for biodiesel," said Tom Todaro, CEO of Targeted Growth. "Camelina can be rotated with current Montana crops, it grows in land with lower agricultural value, and it doesn't significantly increase the use of fertilizer or irrigation water. We think this will be a model for the development and use of other biofuel-specific crops."… Headquartered in Houston, Texas, Green Earth Fuels is a national leader in the production and distribution of environmentally sound biodiesel with a vertically integrated business model representing end-to-end fuel production. "This deal allows us access to a high quality feedstock at an extraordinarily competitive price," said Green Earth Fuels CEO Greg Bafalis (TGI, 2007b).

If camelina is cultivated along the above lines, then perhaps it could provide a more sustainable way to produce bioenergy. Like jatropha, it may grow in poor, dry soil, but will it grow better in more fertile soil or with more water? If greater fertilizer use or irrigation significantly increases yields, then this would provide a commercial incentive for farmers to use such inputs on camelina. Questions still must be answered about its performance on 'land of lower agricultural value', cultivation with less water, its potential invasiveness, etc.

Beyond those two examples of stress tolerance, alternatives to GM techniques have potential to identify traits for more benign forms of breeding, for contexts other than intensive monocultural systems. As in the rice variety above, marker-assisted breeding (MAB) can identify active genes linked with a desirable trait, by checking that offspring have it. However, the desired trait can result from interactions, so the technique can be deceptive.

2.3 Assumptions about higher yield: basis and consequences

As surveyed above, R&D efforts seek higher yield by various methods: larger seeds, tubers, roots or other constituents of plants, easier conversion to fuel, more flexible use as feed, fuel and/or other industrial materials, even from the same harvest. An overall aim is productive efficiency for a more competitive, flexible production of standard commodities for global markets.

Understood in those terms, success would depend upon many assumptions, for example,

- that metabolic energy can be redistributed to specific functions within a crop or perhaps increased overall, without weakening its protective responses to biotic and abiotic stresses;
- that cell walls (and vital molecular components of plants) can be altered in ways which facilitate breakdown for industrial purposes, but without increasing vulnerability to predators, diseases and pathogens;
- that crop 'limitations' can be overcome by the addition of a single gene construct , without taking into account the interactive, unpredictable nature of agricultural ecology.

For the above R&D efforts to result in a more sustainable crop production for bioenergy, success depends on further assumptions:

- that agronomic genes can be stacked in ways which reduce losses from weeds or insect pests, while avoiding a further treadmill that needs more genetic and/or chemical solutions;
- that genetically uniform, standard GM crops can enhance efficient production – without jeopardising a plant's capacities for defence, adaptation or response;
- that genetic modification can increase yield without needing additional inputs such as agrichemicals.

Those ambitious expectations for bioenergy depend upon GM crops as means to address inherent problems of intensive monoculture. If higher-yield GM crops are developed to overcome agri-environmental unsustainability and land-use competition, moreover, then success depends on these further assumptions:

- that those problems are caused mainly by inadequate crops or low yield.
- that crop production serves finite needs within a given geospatial unit, such that greater yield or production reduces competition among different uses (food, feed, fuel, etc.).

Such assumptions can be tested by reference to recent experiences of similar problems, as discussed in the next section.

3 Causes of unsustainable production and land-use competition

Crop production for various uses – food, feed, edible oils and more recently bioenergy –has already generated conflicts over land use and agri-environmental sustainability. These problems arise mainly from industrial monocultures. Such systems have generally degraded environmental resources and marginalised local food needs, in order to supply distant markets with cash crops. This section takes up examples from the Green Revolution and GM crops.

3.1 Hybrid high-response varieties

In many parts of the global South, the Green Revolution was made possible by so-called 'high-yielding varieties' (HYVs), which were really 'high-response varieties'. Designed for intensive monoculture cultivation methods, their higher yields depended upon agrochemicals, irrigation, mechanisation and/or other purchased inputs. While celebrating higher yields, a report acknowledges the dependence on such inputs: 'Between 1970 and 1990, fertiliser use in developing countries shot up by 360%, while pesticide use increased by 7-8% per year', i.e. a cumulative, compounded increase. Land under irrigation increased by one-third (FAO, 1996).

Together these inputs substantially increased grain yields, mainly wheat and rice. The increase has been celebrated as greater efficiency in the common good. But this account measures only a single commodity, while ignoring previous sources of agri-environmental sustainability and food security – which are not valued by the commodity system.

Higher grain yield from dwarf varieties meant less straw, formerly used as animal feed, especially in India. Previously farmers had used intercropping – e.g. sorghum and wheat with pulses -– whose combination helped to renew soil fertility, while providing other nutrients. Those local benefits were lost in the switch to HYVs. Moreover, land use shifted away from cultivating oilseeds and pulses, which had been a vital protein source. Eventually India had a shortage of oilseeds and pulses, which had to be obtained through imports (Shiva, 1991).

HYVs also undermined previous forms of agri-environmental and economic sustainability. Through monoculture farming, intensive agrichemical usage undermined soil fertility and water quality, so that yields became increasingly dependent upon those inputs and less reliable over time. Large land areas have not maintained yields or have even become useless for agriculture. Water tables have fallen. New pests and diseases have undermined yields, making production dependent upon more or different pesticides (Paul and Steinbrecher, 2003: 8-10).

HYVs favoured those farmers who could obtain loans for the purchased inputs. Financial dependency and market competition drove many into debt, even out of business, leading some to commit suicide. Landless peasants became wage-labourers for the successful industrial farmers or migrated to cities (Shiva, 1991).

Meanwhile monocultural systems lost thousands of locally adapted varieties which had been developed by farmers for maximum genetic diversity. This traditional germplasm had bred in resistance to new pests, while also allowing co-evolution of the crop with the ecosystem and its various environmental stresses. This biodiversity protection was now destroyed.

In sum, the Green Revolution generated a socio-political conflict between maximising production of a single commodity versus serving multiple agri-food needs of local populations. Short-term higher yields ran into conflict with longer-term agri-environmental sustainability. These conflicts were driven by intensive monocultural systems, linked with agri-input supply companies.

3.2 Soya monocultures in Latin America

Most GM crops have transgenes designed to control pests and weeds in monocultures, mainly through tolerance to broad-spectrum herbicides and/or insect tolerance. GM varieties of staple crops – important also for bioenergy production – are grown on a massive scale, notably in North and South America. The consequences provide instructive analogies for GM crops as bioenergy sources, especially regarding the causes of conflicts over land use and sustainability. As a case study, this section looks at herbicide-tolerant soya in South America.

The GM herbicide tolerant (HT) crop, Roundup Ready soya, is designed for the application of the broad-spectrum herbicide glyphosate. This crop has been crucial in expanding GM soya monocultures in Argentina since 1996 to cover more than 15 million hectares today. It is planted using mainly no-till systems, in which the soil is not turned. Instead, herbicide is applied to remove weeds and 'volunteer' crops from previous rotations, leaving the HT crop able to grow free of weed competition. The use of HT crops enables aerial spraying of herbicide. Huge areas are cultivated by vast direct-drilling machines which apply fertilizer, seed and pesticide in a single trip. This upscales and simplifies the farming process, often reducing the farmer's need for labour. On their own criteria these systems have had some success in providing mass production, at least in the short term.

Although a minority of large producers have benefited from the soya boom, general prosperity in Argentina has not increased and in some regions has been reduced. Negative impacts have been serious from the standpoint of rural communities, local food production, biodiversity, livelihoods, and land ownership. The following story is drawn from several sources (Altieri and Pengue, 2006; Benbrook, 2005; EcoNexus/GRR, 2005; Valente, 2005).

Many farmers have been forced to leave the land for expanding urban slums as land prices and debts have risen. It has become very difficult for them to sustain livelihoods from farming, as they are caught between high input costs and low prices for commodities. Powerful interests have used threats and violence to drive people off their land.

Mixed farming in Argentina once produced a wide range of staple food products and provided incomes for rural communities. Mechanisation and monoculture have greatly reduced the number of jobs. Milk and other foodstuffs now have to be imported into a country which used to produce ten times its own food needs. Hunger and malnutrition have been reported from some regions. Diverse nutritious food production has been marginalised by soya; attempts to replace meat with soya among the urban poor have caused health problems. Argentine soybeans reportedly contain less protein and amino acids than soybeans from the US, China and Brazil (Karr-Lilienthal et al., 2004).

Communities surrounded by GM soya monocultures suffer serious harm from the aerial spraying of herbicides. They, their children, their animals and crops, are made ill (from skin, respiratory, digestive ailments and cancers); some even die from the spraying. There is generally no advance warning and no escape. They lose their own crops and local biodiversity. Protests have been met with violence.

Forests have been seriously damaged in Argentina. For example, the Chaco Forest had previously survived a century of smallholder presence, but large areas had been completely removed for GM soya by 2003. This loss has provoked reductions in rainfall, more flooding, local climate change and losses of unique biodiversity. Diseases such as leishmaniasis have increased in some areas of intense deforestation.

At first the spread of GM soya in Argentina seemed to be a great success, at least in its own terms. More recently, problems have been emerging in the monocultures themselves. The application of huge amounts of a single herbicide is a perfect way to induce the development of herbicide tolerance in weeds. This had already been researched and recorded by 2002 for about twelve common weeds in Argentina. As a result of such tolerance, additional herbicides such as atrazine and paraquat are being used to clear the weeds after the harvest.

In addition, monocultures are known for their vulnerability to disease attacks. Since 2001 *Phakopsora pachyrhyzi* or Asian rust has been active in Argentina. Fusarium fungus has also become a threat, meaning that farmers have to apply fungicides as well, requiring different equipment and methods. This requirement removes some advantages of GM crops in simplifying the farming process. As these problems show, ‘Excessive reliance on a single agricultural technology, like RR soybeans, sets the stage for pest and environmental problems that can erode system performance and profitability’ (Benbrook, 2005).

Soil quality and water resources have also been adversely impacted. After more than a decade of intensive production, often without rotation, soil nutrients need to be replaced and soil structure has been damaged, especially by compaction. Glyphosate has adverse impacts on earthworms. Yields are not increasing. Any further growth in production will take place at the expense of forests, soil quality and communities that depend on these resources. Fertiliser usage generates N_2O emissions, which may counter any benefit from bioenergy replacing fossil fuels (Crutzen et al., 2007).

In the form of RR soya in Argentina, then, GM crops have undermined sustainable crop production (EcoNexus/GRR, 2005). Diverse, productive farming systems have been reduced to monocultures, adversely affecting biodiversity, human health, rural welfare, etc. Doubts are now being cast on the quality of the crop itself.

What caused the sustainability problems and land-use competition through Argentina’s expansion of GM soya? A key driver was intensive monoculture for producing animal feed as a bulk commodity for global markets. This in turn had a political-economic driver. In 1989-99 the Menem government undertook a privatization campaign that tripled Argentina's enormous national debt. In parallel it subsidised investment in facilities for grain transport from agri-industrial areas to ports, as well as for container shipping. Under this government, Monsanto was granted the licence to commercialise RR soya. Most soya production there is exported to earn foreign currency in order to service the national debt, especially under political pressure from creditors.

The Argentina disaster has similarities with Paraguay. Farmers there face even more serious violence and expulsions brought by monocultures, in turn facilitated by GM soya (Palau et al. 2007; Rulli, 2007; Semino, 2006).

Brazil also has had an enormous increase in soya production, mainly for global export. Land and grain use there has shifted from food to animal feed and bioenergy, stimulated by higher market prices. A major plantation has imposed super-exploitation of labour: Brazilian officials rescued 41 workers from 'slave-like' conditions (Carroll and Phillips, 2008). Effects on deforestation are indirect but traceable:

> Soya producers buy up land already cleared by cattle ranchers, who then acquire cheaper land deeper in the Amazon jungle, replacing virgin forest with vast pastures. The rocketing of soya prices – 72% in the past year – has been widely blamed for the accelerating clearances (ibid).

Rainforest destruction has increased in Brazil, despite government claims to the contrary (Phillips, 2008). Thus socially exploitative, environmentally unsustainable practices are driven by monocultural systems serving global markets which raise the soya price. Complementing these drivers, government policies promote commodity exports, without effective means to control the high price or its domestic consequences.

3.3 Causes of those conflicts

In the cases above, agri-environmental unsustainability and land use competition were not caused by low yield or inefficient inputs. Indeed, the prospect of greater productivity, combined with political-economic interests, created incentives and pressures for extending intensive monoculture systems. Centrally important in Argentina was the linkage between GM seeds and herbicide; their combination stimulated investment, land theft, more intensive cultivation practices and longer-distance trade. In the Green Revolution, high-response varieties initially increased yields, which eventually reached limits due to agri-environmental problems. Higher yields remained dependent upon intensive inputs for monocultural practices, which undermined soil fertility. Although production of a specific crop was increased, millions of farmers lost their livelihoods and local communities lost their food security.

GM crops have extended that commercial logic of intensive practices for global markets. For example, GM herbicide-tolerant soya in Argentina facilitated changes in land use towards intensive large-scale monocultures, in order to supply global markets for animal feed in particular. More generally in the global South, GM crops have shifted land use towards non-food uses, e.g. animal feed (soya and maize) and fabrics (cotton).

GM techniques also facilitated a shift towards monocultural production through more uniform seeds. Greater uniformity is sought by farmers as a means to increase productivity, as well as by processors to simplify industrial processes. These seeds have facilitated large-scale mechanised farming, with herbicide and chemical fertilisers. After initial success, pest problems began to emerge, as insect or weed ecology responds to changes in crops and agronomic practices. The system generates more pest problems needing solutions, thus adding a technological treadmill to other agri-environmental problems. Many farmers have had greater difficulty in maintaining yields, even their livelihoods. Moreover, changes in land use have led to dispossession of many farmers, e.g. through economic pressures, environmental damage and/or violence. The shift towards monocultures has undermined sustainable agriculture, soil fertility, food production, biodiversity and rural communities.

In sum, what explains the competition for land use and sustainability problems? As the above cases indicate, these problems have been caused by various political-economic drivers, in particular:

companies' search for more profitable products and distant markets; governments' search for export markets, foreign currency and foreign investment; a greater global demand for animal feed, integration of food and feed, shifts from food to feed production, international trade promoting global movements of bulk commodities, and intensive monocultures -- facilitated by standard uniform seeds, e.g. hybrid and/or GM.

Inadequate yield was not a cause. On the contrary, the prospect of higher yields has provided an incentive for agri-industrial systems and global market integration, in turn driving increases in local prices and production for export. Next let us compare those systemic causes with the drivers of bioenergy crops.

4 Conflicts extended through GM bioenergy crops

GM bioenergy crops are driven by economic-political forces similar to those which have already caused agri-environmental sustainability problems and land-use competition, as this section shows. Most acute in the global South, these problems result mainly from industrial monocultural systems, using just a few crop varieties and producing standard commodities for global markets. Most GM crops are designed for such systems; both are mainly driven by private interests which increasingly converge.

The prevalent R&D has several related aims – increasing yield, integrating energy with feed production, using agricultural 'waste', broadening the geographical range, etc. If technically successful, such crops would provide greater incentives for shifts towards agri-industrial monocropping, thus aggravating the political-economic pressures which crowd out food production in favour of animal feed as well as bioenergy.

Regardless of whether a crop is bred by conventional, GM techniques or marker-assisted breeding, a design for intensive monoculture and global market integration will generate similar problems. The recent competition between food versus feed production, moreover, is now being aggravated by extra competition for fuel purposes. Even if GM crops can increase yields, the current pressures on land use will continue through market incentives and greater global demand.

As a scientific report has argued,

> even as cropland declined in Europe in recent years, changing technology and economics led cropland to expand into forest and grassland in Latin America. Higher prices triggered by biofuels will accelerate forest and grassland conversion there even if surplus croplands exist elsewhere. Most problematically, even with large increases in yields, cropland must probably consume hundreds of millions more hectares of grassland and forest to feed a rising world population and meat consumption, and biofuels will only add to the demand for land (Searchinger et al., 2007: 3).

4.1 Globalisation of biofuel crops

Greater industrial integration and commodity flows are globalising bioenergy production. Until recently, it was promoted for mainly national uses, sometimes even protected from foreign competition or consumption. However, bioenergy has been undergoing a shift towards deterritorialising relations between production and consumption. An emerging 'global integrated biofuel network' (GIBN) is characterised by greater transboundary flows, weaker influence by states, a homogenisation of products and processes, and an integration with analogous networks of fossil fuels (Mol, 2007: 302-3). This means horizontal integration of various fuel sources and products, symbolised by the emerging agri-industrial biorefinery.

Embryonic small-scale, local biofuel networks are undergoing pressures for integration into national biofuel regions and then international commodity flows, as exemplified initially by Brazil. In both developed and developing countries, local bioenergy production systems are being undermined. 'Local marginal farmers become increasingly dependent on powerful global players in the GIBN' (Mol, 2007: 307).

> These national biofuel regions result in large-scale monocropping biofuel production and the increasingly centralised, homogenised production and refining of these crops, while local biofuel regions are losing their relevance. Secondly, there is a clear tendency towards the development of a GIBN in which production, trade investment, consumption, control and governance lies beyond the control of nation–states (ibid: 305-6; also Worldwatch Institute 2006b).

Such systems damage local environmental resources; they degrade soil and water (through large-scale, high-input, monocropping farming), while undermining food availability and affordability for place-based local populations. Under pressure from civil society, the GIBN may incorporate some efforts to address climate change, e.g. by monitoring bioenergy for savings in carbon emissions. However, it is much more difficult to envision means to mitigate new social vulnerabilities, given the structural change in power relations between global traders, developing countries and small-scale farmers (ibid: 309-10). Even if governments would like to limit harm to resources and livelihoods, they have less capacity to exercise effective control over what happens.

Those globalisation processes undermine optimistic assumptions about GM crops avoiding the problems of current biofuel crops. Contrary to the assumptions listed earlier (section 2.4):

- Sustainability problems and land-use competition arise from the drive towards intensive monoculture, linked with high prices for global commodities (especially feed and oil) – rather than from low yield.
- Bioenergy crop expansion responds to global market demands, which can expand indefinitely and readily consume any extra production or yield, especially given the integration of feed and fuel industries – regardless of local food needs.
- Higher yield depends upon intensive inputs (other than the crop), thus bringing further problems of agri-environmental sustainability.

For those reasons, globalised bioenergy production has great potential to increase conflicts over land use and over agricultural resources more generally. A new industry, based on old and new monoculture crops, will provide extra drivers. If based on the current agbiotech and commodity trade systems, bioenergy production aggravates current threats, by further concentrating industrial agriculture and horizontally integrating its sectors. Monocultural systems have already generated competition between local food needs versus distant feed markets; now bioenergy uses extend that competition – which cannot be alleviated by novel GM crops, regardless of their yield.

Indeed, greater yield (or efficiency) provides greater incentives to extend intensive monoculture systems, mainly for non-food purposes. These incentives are adversely shifting land use in Argentina for bioenergy exports (Valente, 2005). Given the market and political pressures on land use in the Amazon region, greater adoption of GM soya would not avoid or solve these problems. Rather, its use for bioenergy would accelerate the current environmental destruction there by further facilitating monoculture farming and aerial herbicide spraying (as described in section 3.2).

As a related issue of agri-environmental sustainability, water resources also face threats from bioenergy crops. Agriculture uses at least 70% of all water used worldwide; this usage is being increased by crop cultivation for bioenergy purposes. Moreover, considerable water is required to process crops into biofuels; for example, 4 gallons of water are needed to produce 1 gallon of ethanol – far more than petroleum. Water consumption and shortages will be aggravated by crops that depend on intensive irrigation and by abstraction from declining reserves of fossil water (NRC, 2007).

These threats to water resources cannot be mitigated by GM bioenergy crops. On the contrary, any technical success in increasing yield would encourage shifts to intensive monoculture, thus increasing water usage. This depletion will overshadow any advantages from drought-resistant crops, if and when they appear.

4.2 Small-scale farmers under threat: examples

According to bioenergy proponents, small-scale farmers who own their own land can earn an independent livelihood from planting bioenergy crops. This is claimed especially in the cases of oil palm and jatropha, which cannot currently be harvested by mechanical means and so may be less amenable to agri-industrial systems.

Nevertheless small-scale farmers face dependencies upon exporters and creditors. Both oil palm and jatropha take several years to reach maturity and yield a crop. Smallholders sign multi-year contracts with companies, without much influence over the price obtained; they are easily caught in debt traps. They may have to pay many fees and be forced to take out loans to buy tools and seeds, as well as basic necessities at a price set by the companies. They are vulnerable to all the familiar problems of the small producer faced with a large, well-organised company that dominates the local infrastructure.
In such ways, large-scale monocultures threaten to degrade environments, undermine livelihoods and displace labour, especially independent small-scale producers. This pattern has been well established in the cases of oil palm and sugar cane; it is in danger of being repeated in the case of jatropha.

The threat has numerous sources: political-economic inequalities between smallholders (or small farmers) and large companies, the drive to centralisation for economies of scale, global market pressures for standard products, and pressures on governments to expand export industries to service the national debt – not inadequate yield of crops. GM crops cannot address those sources of threat and can readily aggravate them, as illustrated next by three brief examples.

4.2.1 Oil palm in Indonesia: more forest destruction?

In Indonesia, for a long time oil palm has been produced for food and cosmetics, among other uses. Controversy has continued over whether such production should be certified as 'sustainable' under a scheme sponsored by Unilever. Now bioenergy provides an extra stimulus for exporting palm oil. Large areas of peat forest are being destroyed for this purpose, thus turning the country into a major CO_2 emitter. Local people have little means to prevent this destruction, especially the external forces driving it (Colchester and Jiwan, 2006). The destruction could be stopped only through government control over land resources; strong enforceable titles to land could prevent its sale and land speculation.

GM techniques are being used to develop dwarf oil palm that matures earlier, to facilitate efforts at mechanising the harvest process. If such GM crops gain technical success, then their large-scale use would undermine smallholders as current producers of oil palm, while stimulating further environmental harm – more destruction of forests and more agrichemical usage for cultivation.
In the Brazilian sugar industry, by analogy, the threat of mechanisation deters workers' demands for better wages and conditions.

4.2.2 Oilseed rape in Transkei: fuel versus food

South Africa has announced plans for a half-million hectares of the former Transkei region to include production of oilseed rape (canola) for bioenergy, intended for export to Europe. 'The provincial government has allocated more than R1,5 billion for investment in a canola-based biofuels industry. A total of 500000 hectares of tribal land is to be converted into an intensive monoculture, using genetically modified crops to boost feed stock production' (Zvomuya, 2007).

Under the initial plan, the entire project would be run by corporations. However, mass protest opened up the way to involvement of small-scale farmers. Their fate will depend on the terms for producing and selling their crops. If farmers undergo pressure to sell to one company on its terms, then they could find themselves working a monoculture in a debt trap.

African NGOs have voiced fears that such monocultures will be used as an entry point for GM oilseed rape in the former Transkei. This high-quality arable region would be far better used for diverse food production that could include some bioenergy production for local use, according to several commentators. The conflict has not yet reached a resolution (Ntingi, 2007). If GM oilseed rape does increase yield, then this would further stimulate monocultural practices and displacement of local food production, with no means to counter market global forces.

Beyond the Transkei, Industrial Development Corporation (IDC) and its partners are investigating five biofuel projects. Under their plans, the Eastern Cape project would use sugar beet to produce about 90-million litres of biofuel a year, and the Mpumalanga project would manufacture 100-million litres of fuel from cane sugar. As a third project, 150-million litres of biofuel would be produced from sweet sorghum and sugar cane in Pondoland, which covers KwaZulu-Natal and the Eastern Cape. The fourth project being considered will aim for production of 150-million litres of biofuel a year from maize in Ogies, in Mpumlanga. The fifth project will involve the production of 100-million litres of biofuel from cassava in Makhathini, in KwaZulu-Natal (Barradas, 2007).

4.2.3 Jatropha in Tanzania: displacement of food production and people

An exception to a focus on food crops, jatropha is being strongly promoted for bioenergy. This crop can grow in marginal areas, needs little water and is poisonous. According to proponents, therefore, its use for fuel will not divert food resources. Jatropha has been used traditionally as hedging to protect fields from livestock. Oil from its seeds is used to produce soap and for many other traditional uses. It can also produce a good cheap biofuel. According to a local NGO, 'We could use jatropha oil for cooking and lighting, but we need to develop it in our own way, at our own pace.'

Yet large-scale jatropha cultivation is already generating conflicts in Africa and Asia. Appropriation of land for jatropha entirely displaces food crops, thus intensifying competition for land use among crops and among farmers. Yields are greatly increased when the jatropha plants are adequately watered (Van Eijck and Romijn, 2008: 320), so a drive for higher yield may undermine water resources for other uses.

Jatropha is promoted on the basis that it grows well in dry areas on poor soil. Yet in Tanzania European companies have been buying up good-quality, well-watered land, where jatropha grows better. The drive for higher yield pushes farmers off such land, where they formerly produced food for local consumption, thus marginalising food production to arid regions. Thousands of peasant farmers in Tanzania's Kisarawe district are being cleared from nine thousand hectares of land to make way for a jatropha biofuels project (Edwin, 2007). Even if peasants are paid compensation, their only alternative is to move to poorer land or become urban migrants.

This programme is being driven by Sun Biofuels PLC, a British firm with support from the Tanzanian government (African Press Agency, 2007). The region is comparatively well-watered and highly populated. This is an ideal place to grow food, yet such production is being displaced by jatropha – supposedly an ideal crop for 'marginal' land.

More time would be needed to plan land use and farmer support for developing bioenergy crops alongside food production. Instead, the Tanzanian government is inviting companies to develop jatropha according to their priorities – to produce as much as possible under the best conditions as soon as possible, for a potentially global market.

In Zambia, by analogy, farmers are signing multi-year contracts for jatropha cultivation. To pay for tools and inputs, they are offered loans, repayable when the jatropha begins to yield a harvest. They have to pay many fees and costs as well. But they may only sell their produce only to the company issuing the contract (Africa Biodiversity Network, 2007).

Tanzania faces a stark conflict between global market forces versus local needs for food, fuel and environmental protection:

> There is indeed a danger that if investment in Jatropha does begin to take off in earnest, the sector could be taken over by big commercial players interested in setting up large plantations. In this scenario, less

> glamorous but socially useful small-scale projects aimed at energy provision by and for local communities could lose out.
> An influx of large investors could also lead to undesirable competition with food crops. Although Jatropha can grow in hostile conditions, there is increasing evidence that seed yields are sensitive to soil fertility and water availability. Farmers could be induced to become outgrowers for large buyers, converting too much prime crop land to Jatropha cultivation. Poor villagers could also be induced to sell their land to large investors, while it is still unclear whether their short-term gains would constitute adequate compensation for long-term loss of livelihoods and loss of land for food production (Van Eijck and Romijn, 2008: 324).

Given those forces driving a shift towards intensive land use for jatropha as a global commodity, how could GM techniques make a difference? Jatropha has not been a priority for GM techniques; this crop has so far attracted little research, although a company has been accused of stealing jatropha germplasm from India (GRAIN, 2006). In any case, no genetic change could counter the negative effect of the above drivers. If GM jatropha ever provides higher-yield agri-industrial production, moreover, then this would intensify the forces now undermining sustainable agriculture and land-use for local food needs.

4.3 Food production crowded out – by contamination too?

As described above, political-economic pressures readily displace local food production in favour of animal feed, increasingly in combination with bioenergy. Displacement can also happen through agri-environmental pressures and GM contamination, as described next.

Some GM crops could crowd out food production through biological competition among plants. Invasive plants are a serious, growing threat around the world. Traits deemed ideal in a bioenergy crop are also commonly found among invasive species. Bioenergy crops could crowd out others, especially if GM techniques extend the range of an invasive species such as eucalyptus. 'Weedy attributes of ideal biofuel plants include hardiness, water thrift, a paucity of pests or diseases, and an ability to out-compete other plants', according to a recent report. It looks at the invasive and weedy capacity of plants such as jatropha and switchgrass, currently being advocated as bioenergy sources (Low and Booth, 2007).

Contamination from GM bioenergy crops may further complicate land use for food production. R&D trials alone have caused contamination from GM crops, despite rules on segregation. Such problems have arisen from GM crops that have not been commercially approved, or not approved for the relevant jurisdiction, or have been approved only for import, not cultivation.

Some examples of known contamination:

- In 2006 two experimental varieties of rice that were only field tested in the US between 1998-2001 (LL601 and LL604) and never approved or commercialised, were found to have contaminated rice in the US, from where it was exported to many other countries. No-one knows how the contamination happened, and it may never be known because there are no records available.
- In 2005 maize imports to the EU from the USA were found to be contaminated with a GM maize called Bt10, which was not approved in the EU.
- In 2006 an unapproved GM rice, Bt63, was found in China and also in Europe, mainly in baby food.
- In 2005 GM canola imported from Canada began to escape into the wild around major shipping ports in Japan. Since then it has spread along transport routes throughout Japan. The milder Japanese winters are turning it into a bushy perennial plant. Some plants have been found that are tolerant to two herbicides, even though no such variety has ever been produced, thus indicating that it resulted from cross-pollination, perhaps in Japan.

Such cases have serious implications for GM bioenergy crops. With GM techniques, food crops such as maize and soya are being modified with traits specifically for bioenergy production and/or animal feed, e.g. Syngenta's enzyme maize and Monsanto's Mavera corn. A bioenergy crop could thus become unsuitable for human consumption, or at least raise doubts about its safety. Yet there is little prospect of fully segregating the different GM varieties. Hence there is interest in genetic use restriction technologies (GURTs) so that a crop will produce sterile seed. Technical success would require several complex genetic processes working in strict order, with reversibility; GURTs would carry multiple risks of their own if they are ever made to work.

Coexistence between GM crops and other crops has already become a difficult issue, especially in Europe. In order to prevent contamination, rules have been widely proposed for the planting, harvesting and movement of GM crops, to avoid cross pollination and seed admixture. Proposed rules are generally complex and place a burden on non-GM crop producers too. There is strong disagreement – about how strict the rules should be, about the thresholds of permitted contamination, especially of seeds, and about separation distances. As the examples above show, it is difficult to prevent admixture at all points during the chain between field and end product. Even with strict segregation rules and thresholds, significant contamination could occur over time.

Consequently, conflicts over segregation could aggravate competition for land use between energy versus food. Regardless of whether or when GM bioenergy crops are commercialised, spread of their traits through field trials or illegal contamination could complicate the food supply, as has already happened with current GM crops.

4.4 European context for GM bioenergy crops

Answers to the main questions above – regarding sustainability and land-use problems – do not depend upon possible changes in European public attitudes towards GM food (a sub-question of the WBGU brief). Such attitudes would matter only if the same GM crops were being developed mainly to produce food and energy; but this is not the case, as shown above. In any case, there are no grounds to expect a shift in public attitudes along lines more favourable to GM crops for food uses, regardless of whether GM crops enhance bioenergy uses. Unease towards GM crops involves many concerns – uncertain health and environmental risks, 'patents on life', control over the agri-food chain by multinational companies, cultural meanings of food, etc. These concerns seem likely to continue, regardless of uses for bioenergy, higher yields, etc.

Regardless of public attitudes towards GM food products, GM crops may be used to produce bioenergy in Europe. GM crops with agronomic traits already have commercial authorization; novel ones more specifically for feed and/or fuel purposes may gain approval in the near future. Their usage for bioenergy would bypass a key blockage – European food retail chains which have excluded GM from their food products. Nevertheless public controversy may continue over agri-environmental issues, e.g. regarding potential harm from broad-spectrum herbicides and Bt insecticidal genes, as well as GM contamination of conventional food.

There are claims that bioenergy expansion can improve commodity prices for European farmers and provide a stimulus for rural livelihoods there, thus helping rural regeneration. Gains for rural economies are disputed; different informants give very different figures for likely benefits and their social distribution, according to background information cited in EU documents (CEC, 2006b). If bioenergy production enhances farm-gate prices, then this may be beneficial for farmers, at least in the short term. But such production has potentially negative effects, such as higher costs of staple foods, and shifts in land use away from food production, and more intensive cultivation methods.

The implications for agri-environmental sustainability and land-use competition depend upon various EU and national policies. These have greater scope to avoid negative societal consequences than bioenergy production in the global South – where bioenergy production is being more closely integrated into global markets, and where protest can be more readily suppressed or ignored. Regardless of bioenergy production in Europe, efforts to fulfil EU targets depend greatly upon imports from the global South, whose context is therefore the main focus of this report.

5 Sustainable production being pre-empted

From the optimistic expectations for GM crops as bioenergy sources, several dangers arise. The R&D efforts could simply fail, or their commercial success could have harmful outcomes for agri-environmental sustainability and land use. More fundamentally, the current focus on GM crops reinforces many assumptions: that societal conflicts over bioenergy result from inadequate yield, that agri-industrial monocultures are the only path towards societal progress, and that alternatives are inherently unrealistic or marginal. These assumptions may become a self-fulfilling prophecy, thus pre-empting current and future alternatives for sustainable crop production.

5.1 Alternatives threatened

Alternatives should be considered for several reasons:

- Small-scale, less-intensive locally focused, diverse agriculture already fulfils nutritional needs for hundreds of millions of people in the global South.
- Given their biodiversity, such systems may be more resilient to shifts in climate and water resources than large-scale monocultures.
- Such systems could also produce bioenergy in ways which are socially and environmentally less harmful, while still giving priority to local food needs, thus minimising competition for land use.
- Such actual or potential alternatives are threatened by the current expansion of bioenergy (and feed) crops through monocultural systems, for which GM crops are being mainly designed.

Comparisons between agri-production systems can be deceptive if focused on global commodity crops, whose productive efficiency is specific to that context. Large-scale monocropping conceals any unfavourable comparisons with land productivity under multi-cropping systems. Through a broader comparison, by contrast:

> In Mexico, 1.73 ha of land has to be planted with maize to produce as much food as one hectare planted with a mixture of maize, squash, and beans. In addition, a maize–squash–bean polyculture can produce up to 4 tons/ha of dry matter for plowing into the soil, compared with 2 tons in a maize monoculture (Altieri, 1999).

This comparison illustrates the narrow criteria in productivity claims for agri-industrial systems. Organic farming can produce the same yields of corn and soybeans as does conventional farming, but uses 30% less energy, less water and no pesticides. These conclusions were drawn by Cornell University Professor David Pimentel, reviewing a 22-year farming trial study (Newswise, 2005).

If farming is designed as a mosaic, rather than as a monoculture, then diverse ecosystems and cultivars can perform similar functions. Available methods include:

- intercropping different species (or different varieties of the same crop), multi-level planting for shade and conservation of soil and water, careful use of water, mulching, green manure cover, integrated pest management, etc.
- careful adaptation of seed to regions, by leaving nearby areas for biodiversity, beneficial predators, etc.
- genetic diversity for adaptation to threats (climate change, pests, drought or flood);
- good husbandry based on diversity, intercropping, companion planting , low inputs, closed system in which outputs are returned to the system, etc:

With such methods, crops could be grown for local energy uses. In addition, bioenergy could be obtained from gas or from waste plant material where this is not required to nourish the soil, e.g. vegetable waste. Another possibility is producing fuel (biomethane) from anaerobic digesters with fertiliser as a by-product. These feasible alternatives do not depend upon changes in current crop varieties, though they could benefit from farmer-led improvements which retain seed diversity and local knowledge. Such prospects could fulfil local needs – which are threatened by agri-industrial bioenergy production for global export.

Soil erosion is a central issue for sustainable crop production. According to proponents of herbicide-tolerant GM crops, the cultivation with broad-spectrum herbicides facilitate low-till or no-till agricultural methods, thus avoiding soil erosion. However, the herbicides harm soil fertility, while also generating resistant weeds, thus leading to multiple herbicide usages. Alternative low-till methods can avoid such problems.

Although industrial agriculture dominates the global agricultural market, millions of small-scale farmers still operate independently outside it. They contribute substantially to household and local-regional food supply. They are vital to social health, rural life and knowledge for crop cultivation. Farmer-based research could address their problems, including the need for infrastructure that answers their needs. Resources should be invested in such alternatives, through the following activities:

- Farmer empowerment
- Farmer-defined issues, such as health, education, access to credit
- Varieties and seed conservation led by farmers
- Infrastructure developments under their control

Similar support is needed for agri-ecological methods in Europe, which could provide a basis for regenerative raw materials to supply bioenergy sources for local use (Alliance 90/The Greens, 2006).

In sum, agri-ecological methods conflict with dominant policies on global commerce, proprietary knowledge and seed registration (see section 6.2). Farmer-bred varieties and *in situ* crop breeding are undermined by the agri-industrial model, which instead favours patented seed in packages with inputs and associated contracts. Benign alternatives need support from civil society and expert bodies in order to change government policy. A platform is needed for the voices of small-scale farmers who articulate current threats and potential alternatives (Econexus et al., 2007: 33-34).

5.2 Monocultures normalised

Regardless of whether or when GM crops fulfill their optimistic expectations as bioenergy, the R&D efforts serve an ideological role. According to bioenergy proponents, governments must make commitments to the first generation in order to stimulate novel crops with higher yields, especially through GM techniques. Through this focus, the current harm being caused by bioenergy crops is seen as a temporarily necessary evil, while diverting attention from political-economic forces which will continue to drive bioenergy production. Optimistic expectations for GM crops justify a policy framework of state and market incentives to expand bioenergy crops, while avoiding responsibility for the harmful consequences, pending an eventual techno-fix. Once a government is committed to the agri-industrial path for energy production, it will be more difficult to reverse later.

Governments have made great commitments to bioenergy from agriculture, while diverting resources away from alternatives which may be more technically feasible and socially benign. Prevalent R&D efforts define crop improvement according to the requirements of the agri-industrial system, seeking global markets for standard commodities. Such priorities devalue current crop varieties (or crop improvements) more appropriate for less-intensive agri-production systems.

The current situation echoes biotech industry promises in the late 1990s for 'second-generation' GM crops for consumer benefits; these remain elusive, even after many years of research. Such hypothetical futures have helped to maintain government and commercial interest in current GM crops, despite widespread public resistance. 'Next-generation' bioenergy crops will likewise remain elusive. Meanwhile governments can be kept on the bioenergy track. Optimistic expectations for GM crops serve to normalise the expansion of agri-industrial monocultures for energy usage, especially for export from the global South to the North. Thus the current focus on GM crops helps to normalise one pathway as obvious, while marginalising current and future alternatives.

6 Drivers of GM crops for bioenergy

Bioenergy has been promoted in the name of a common societal interest – especially in mitigating climate change, enhancing energy security, minimising environmental harm from energy production, and providing employment. Despite the officially stated aims for bioenergy promotion, it has been increasingly driven by political-economic interests. In particular, corporations seek to increase sales and expand their markets, in ways corresponding to agri-industrial monocultures, as this section shows.

6.1 Agri-industrial bioenergy agenda

Three major GM crops undergoing research for bioenergy (maize, soya, oilseed rape) are grown more for animal feed than for direct human consumption. The feed industry is linked with industries promoting intensive animal production. They benefit from aspirational shifts in diets (e.g. in China and India) to a meat base, which demands far more grain input for animals than direct grain consumption by humans.

Such companies now perceive a new opportunity: the production of biofuel, while also producing animal feed from the residue as a co-product. The corporations involved are already set up to benefit from this business. Between them they have the infrastructure to move the crop between field and feedlot. To diversify into fuel is a profitable add-on that can exploit and build on existing infrastructure.

The 'biorefinery' concept signals such integration, as noted earlier (EuropaBio, 2007: 6). It links the interests and experience of the major agricultural industries (e.g. seed, fertilizer, pesticide, commodities and biotechnology) with the energy sector, including the oil, power and automotive industries. In such ways, bioenergy involves a novel convergence through both a horizontal and vertical integration; this includes thermo-chemical and biotechnological processes, as well as industrial products such as plastics. A European R&D consortium searches for genetic changes in crops which would be available in large quantities 'with the potential to produce both chemicals and biofuels in an integrated biorefinery' (EPOBIO, 2006: 10)

As an infrastructural change, biorefineries will have a major impact on land use, as they will also cluster biomass and intensive animal production around them. They will have a strong effect on local water resources and waste-water production, with implications for waste treatment and land-use planning. Claims for 'sustainability' downplay these issues, while emphasising input-output efficiency in integrating industries and resource usage.

6.2 Policy support

Industry lobbying for biofuels has included interests much broader than the incipient biofuel industry alone, especially agbiotech promoters. Pressed by the agri-energy industrial complex, the EU set a target for bioenergy early on. In the name of those common interests, EU policy has set targets for 10% of all energy to come from bioenergy sources by 2010, and 20% overall from renewables by 2020. This commitment helps to reassure and encourage investors, as well as signalling an offer of EU subsidies and R&D funds.

As Europe's largest fuel consumer, the German government has gone beyond the EU's biofuel targets. According to its Biofuels Roadmap, Germany would massively increase the country's biofuels target, doubling it from 5% by 2010 to 10% by that year, and to 20% by 2020. Already using 13% of its arable for energy crops, Germany plans to double or even triple that proportion. 'The move is seen as a strategy to speed up the development of next-generation biofuels' (Checkbiotech, 2007). For this policy, the German government has cited advice of the agriculture, automotive and oil industries.

From the beginning, the bioenergy industry has been dependent on state subsidy for its development, including R&D with GM techniques. In both developed and in many developing countries, government subsidy is increasingly captured by large-scale farms, agribusiness and other major companies in biofuels networks. In the USA, in particular, 'Large agricultural corporations, which are also involved in ethanol production, benefit disproportionately from the maize and ethanol subsidies' (Kojima and Johnson, 2005: 34).

> Massive increases in ethanol production would be impossible without significant government subsidies. U.S. federal and state subsidies push the real price of ethanol beyond $7 for the ethanol equivalent of a gallon of gasoline. This is the actual cost to taxpayers, many of whom may never use ethanol or even drive a vehicle. Even in Brazil, which relies on sugar cane-based ethanol that has a much higher net energy return than the corn-based ethanol popular in the U.S., the government subsidies equal 150 percent of the price to consumers (Barbara, 2007: 20).

Industry has been dependent on subsidy for agbiotech research as well as bioenergy production. The US Dept of Energy (2007) funds many companies worldwide in their research on genetically modifying ligno-cellulosic fuels and related aspects. The EU funds R&D in GM crops which could be used as bioenergy, explicitly linked with trade liberalisation for importing bioenergy materials from the global South. This budget comes under the broad slogan of the 'knowledge-based bio-economy' (CEC, 2006). GM crops for bioenergy exemplify EU policy promoting capital-intensive investment for economic competitiveness in the global economy. This illustrates how EU policy has been captured by interests promoting such innovations (CEO, 2007b).

6.2.1 Research privatised

R&D on GM bioenergy crops is carried out mainly in private companies in industrialised countries, especially in the USA and the EU, with significant subsidy from governments there (as above). Some R&D funds come also from newly industrializing countries, e.g. India, China, and Brazil. Indian research is focusing on GM castor bean and jatropha.

The emerging bioenergy sector has a greater mutual dependence between public and private sectors, especially in the USA and EU. This exemplifies a wider, longer-term policy shift. In recent decades, governments have become increasingly dependent on private companies to deliver what used to be public services. They are also more dependent on economic growth to deliver funds for government programmes, which are increasingly carried out with the private sector. Corporate enterprises have gained enormous influence over R&D priorities, as exemplified by the agri-industrial sector.

Given the increasing privatisation of agricultural research, it has become dependent upon attracting investors and pleasing the stock market, rather than responding to human needs and ecological constraints. In this context, holding or gaining a large portfolio of intellectual property is a key attractor for investment. Research is directed towards goals that will benefit the corporation by increasing sales. A related driver is horizontal and vertical integration of agribusiness corporations; their cycles of competition and collaboration also drive biotech developments, creating synergies for the promotion of proprietary products, such as crops with novel traits that can be patented (Kilman, 2007).

Horizontal and vertical integration of industry – including mergers, diversification, the creation of subsidiaries and commercial agreements for mutual advantage – means fewer main players across the market. For those interests that gain control, such integration provides greater flexibility for decisions about what crops are produced where, the purposes for which they are sold, etc. This control increases pressure for intensive agriculture, competition with food uses, international trade in commodities, etc. These dynamics contradict the aim of supplying energy needs in the most socially and environmentally benign ways.

6.2.2 Seeds privatised and standardised

Agri-environmental sustainability depends upon crop diversity, seed exchanges and farmer improvement. Small-scale farmers select and exchange diverse varieties, and may sow more than one variety to protect crops against environmental threats. Farmer-saved seed represents up to 90% of seed planted – up to 60% even in some industrialised countries.

For a long time, seed companies have lobbied governments to prevent farmers from saving seeds. Such prohibition would mean greatly enlarged profits. According to a 1991 agreement of UPOV (Union for Protection of New Plant Varieties), farmers may not save seed from their own harvests and replant them, unless a government grants exemptions. Governments face constant pressure to adopt the UPOV 1991 agreement. Wherever industrialised farming prevails, locally adapted farmer varieties of staple crops may be lost, along with all the diversity that was bred into them, sometimes over centuries.

The agbiotech industry has already succeeded in gaining full patent protection for GM seeds; major companies have been consolidating their control over the seed industry worldwide over the last decade. Consequently, investigation of non-patentable shared knowledge – about ecology and varieties of crops developed, selected and exchanged among farmers – becomes financially less viable. The immense wealth of knowledge and practice about agriculture that is held by small farmers around the world is only of interest as raw material to which to add traits. It is far more profitable to develop a package of herbicide tolerant seed, herbicide, fertiliser and other inputs for sale for mass markets.

Changes in the seeds industry have already lost many crop varieties and a narrower base for staple crops upon which society depends. Patents become a key focus of research because companies can control patented products and gain royalties from other users. Breeders' rights on crops increasingly resemble patents. GM crops can be highly profitable products; patented seeds command higher prices and are protected by sanctions against anyone not paying to use them. If novel GM crops are commercialised for bioenergy production, their design and usage will further narrow genetic diversity.

7 Conclusions: what sustainable crop production?

Bioenergy production has generated conflicts over land-use and agri-environmental sustainability. GM crops have been promoted as a future means to avoid those problems, especially through higher yield. Such optimistic expectations depend upon specific assumptions – which are doubtful or are even contradicted by relevant experience, as shown in this report.

7.1 Sustainability for what?

When GM bioenergy crops are promoted as means of 'sustainable production', especially through various forms of higher yield, this solution generally takes for granted the norms of intensive monocultural systems. Favouring an input-output efficiency of resource usage, this 'sustainability' counts mainly the costs and benefits to the producer, while ignoring wider effects on resources such as the water supply, soil quality, crop biodiversity, plant defences, etc. Such resources are sacrificed for producing standard commodities for a global market. Leftover agricultural material is understood as 'waste' biomass, without any other use. These norms contrast with a different, agri-ecological understanding of sustainability: less-intensive cultivation methods can use local resources, promote seeds diversity, avoid pest problems and sustain rural livelihoods and provide food security.

Related to the norms of intensive monocultural systems, optimistic hopes for higher yield GM crops also involve specific assumptions about the cause of current problems. Those assumptions are contradicted by analogous experiences of other crops and drivers of biofuel production, as shown in Table 1 (just before the References). These experiences long pre-date GM crops but have been aggravated by them, given their prevalent design for intensive monoculture systems.

Conflicts over land-use competition and agri-environmental sustainability will continue to result from crop monocultures producing bioenergy sources for global markets, especially when linked with other industrial products such as animal feed. Any higher yield will provide greater economic incentives for those developments. GM crops cannot mitigate the conflicts and will arguably aggravate them. Future harm could be greater than from previous crop monocultures because the new ‘biorefinery’ links several commercial interests, products and drivers.

Bioenergy expansion now targets crops (such as soya and maize) whose intensive cultivation has already caused ecological and societal damage by several means – by stimulating land-use changes, encouraging inputs that facilitate monoculture production, requiring more natural resources for cultivation (nutrients and water, e.g. through irrigation), and stimulating greater use of agrichemical inputs to counter new agronomic problems (from pests, weeds and diseases). Any greater yield for bioenergy would likewise depend upon agronomic inputs, not simply upon novel characteristics of a crop.

To the extent that these R&D efforts are technically successful for bioenergy production, new GM crops would provide a commercial incentive for even more intensive use of resources on the same land and/or on newly cultivated land. To facilitate that intensification, traits for greater energy-extraction would likely be stacked along with agronomic genes now commonplace in current GM crops. Their commercial use has already supplemented the pesticide treadmill with a genetic treadmill. Herbicide-tolerance traits, facilitating the use of broad-spectrum herbicides, have accelerated the systematic loss of biodiversity. By using such herbicides on a large scale, recent practices have generated herbicide-tolerant weeds, in turn leading many farmers to use tank mixes of multiple herbicides. Through intensive monocultures, GM crops would extend the conflicts over sustainability of agri-industrial systems, as already manifest in the current use of GM and bioenergy crops.

Economic incentives have promoted large-scale monocultures that in turn undermine independent rural livelihoods and food production, while marginalizing and even poisoning rural communities. Long before the rise of bioenergy crops, a shift to soya for animal feed already caused major adverse changes in land use and rural life, especially in South America. This competition for land use results from political-economic forces, including the globalised circulation of commodity crops, rather than from low yield or inefficient production.

Current R&D priorities for GM crops are designed to sustain agri-industrial monoculture systems, operating economies of scale and producing uniform products for industrial processing. R&D specifically for bioenergy aims to make crops more flexible, efficient sources of energy as a global commodity. Some research aims to increase energy yield, e.g. improving access to cellulose, facilitating its breakdown, etc. Other research aims to induce tolerance to stresses, e.g. to salt or drought, so that crops could be grown under adverse climatic conditions on land assumed to be ‘marginal’. Yet such land may have economic importance for nearby populations who find themselves excluded from access by various means. First-generation GM crops stimulated a shift in land use towards non-food uses (animal feed and fabrics); novel GM crops, integrating bioenergy with other industrial uses, would aggravate that competition with local food needs.

The recent push for bioenergy has many drivers – e.g., price rises of other energy sources, government targets for biofuels, subsidies for their development, and integrated production of fuel with feed. These provide greater incentives for even more international trade in the key crops for feed and/or fuel, thus extending recent shifts in land use. This land-use competition cannot be alleviated by higher-yield crops, especially by the novel traits now being pursued. On the contrary, such GM crops would increase the incentives to use crops for energy and/or feed purposes, as well as to change land use along those lines, by whatever means necessary.

By contrast to the prevalent R&D for GM crops, some novel crops may contribute to ‘sustainable’ bioenergy production in many senses of the word. They could be grown with extensive methods on truly marginal land that would otherwise remain out of cultivation. For example, molecular markers have been used to breed a camelina variety to tolerate environmental stresses. However, market pressures may provide incentives to increase productivity by using extra agrichemicals, irrigation, etc.

7.2 Doubtful feasibility

GM techniques are being used in efforts to enhance yield in various senses of the word – regarding fuel, feed and other industrial products. Such prospects depend upon further assumptions:

- about crop metabolism: that metabolic energy can be redistributed to specific functions within a crop or perhaps increased overall;
- about plant cell regulation: that these functions can be precisely changed in ways which enhance productive growth but without weakening the plant's defences; and
- about gene function: that crop limitations can be overcome singly, beyond the interactive nature of agricultural ecology.

These assumptions are doubtful. The necessary changes are complex, involving numerous genes, whose function lies beyond current scientific knowledge. Next-generation GM crops may not work effectively for a long time, especially in time to help mitigate climate change – a supposed rationale for their development. Most novel GM crops now foreseen specially for bioenergy remain many years away from development and even further from commercial use. Consequently, any estimates of yield increase remain purely speculative; quantitative estimates would be meaningless or deceptive. For the foreseeable future, bioenergy production will need to rely primarily on currently available crops, including GM crops with agronomic genes.

Contamination problems could aggravate the current competition for land use. Some conventional food products have been illegally contaminated with GM varieties not approved anywhere for commercial use, or not approved in the relevant jurisdiction, thus complicating the food market and crop cultivation. Regardless of whether R&D efforts lead to GM bioenergy crops which are commercially attractive for farmers, R&D trials could plausibly gain some technical success. This may happen before the GM trait is evaluated and approved for safety, or without societal acceptance of safety for human consumption. By analogy to recent crises, the prospect of contaminating conventional crops could deter their cultivation or complicate their food uses. If GM crops are used commercially for bioenergy purposes, moreover, then more widespread contamination with conventional crops may bring market difficulties for conventional food crops.

Other plausible kinds of harm could arise from specific genetic changes in novel GM crops. Traits such as lower-lignin or auto-enzymatic breakdown may carry environmental risks, especially if they are transferred to other crops or wild plants. Some crops targeted for bioenergy production have weedy characteristics and so could crowd out other crops or valuable plants. In efforts to alter metabolic functions, GM techniques may jeopardise traits important for plant health and other functions. GM crops may also pose unforeseen risks.

7.3 False solution to the wrong problem

Despite strong doubts about the societal benefits and technical feasibility of GM crops for bioenergy production, these R&D efforts attract enormous resources. In both developed and in many developing countries, government subsidy is increasingly captured by large-scale farms, agribusiness and other major companies in global biofuels networks. An extra driver is government subsidy for R&D – especially in the USA and increasingly in the EU, linked with trade liberalisation for energy imports.

Given the optimistic expectations for GM crops as bioenergy sources, the danger is not simply technical failure – or success causing harm. More fundamentally, the focus on GM crops diverts attention away from political-economic drivers of the current conflicts. It also reinforces dominant agri-industrial assumptions: namely, that societal conflicts over bioenergy result from inadequate yield, that agri-industrial monocultures are the only path towards societal progress, and that alternatives are inherently unrealistic or marginal.

These assumptions may become a self-fulfilling prophecy, thus pre-empting current and future alternatives. A more diverse, sustainable agriculture could yield more per hectare and could include some intercropping with bioenergy crops for local use. Instead the current expansion of bioenergy is undermining a less-intensive basis for rural livelihoods, food sufficiency and fuel needs. Hope for an eventual techno-fix helps to justify that expansion. GM crops for bioenergy are a false solution to the wrong problem: how to increase yield for a biorefinery producing animal feed, fuel and other industrial products.

Thus the current focus on GM crops plays an ideological role by normalising one societal pathway as obvious, while pre-empting alternative futures. Optimistic expectations justify a policy framework of state and market incentives to expand bioenergy production, especially for production in the global South for export to the North. Meanwhile governments can avoid responsibility for the harmful consequences, as if they were temporary problem which can be solved later by GM crops.

Techo-fixes such as GM crops cannot address the basic conflicts – over land use, access to land, resources and food. Government policy on bioenergy is based on doubtful assumptions rather than upon evidence. The commitment to biofuels is making a momentous choice as if it were an objective imperative. This should be opened up to critical examination and comparison with alternatives, including means of reducing energy consumption and favouring food production in agriculture.

Table 1: Assumptions about higher yield as solution

	Assumptions	Experiences
Political economy	Competition for land use results mainly from low yield and so could be avoided by higher-yield crops.	Sustainability problems and land-use competition arise from the drive for intensive monoculture, rather than from low yield.
Markets	A finite biomass production is needed for a particular geospatial unit, such that more production can alleviate competition among diverse uses within that unit.	Biofuel crop expansion responds to global markets, whose high prices and greater demands readily consume any extra production or yield, especially given the global linkage of feed and fuel markets.
Agronomy	Genetic changes could increase yield independently of other intensive inputs, or at least with no consequent problems of agri-environmental sustainability. .	Higher yield from a crop generally depends upon intensive inputs – e.g., fertilizers, aerial herbicide sprays and extra water usage – thus generating problems of agri-environmental sustainability, including new pests.
Feed-fuel links	With novel GM crops, plant residues can be used more efficiently by producing animal feed as a by-product, thus minimising waste and enhancing sustainability.	More efficient use increases economic incentives for monocultural systems to supply biomass for 'biorefineries' (for various industrial products including feed and fuel), thus displacing food production.
'Waste' biomass	GM techniques can alter plant residues from agricultural fields for more efficient breakdown into bioenergy, thus using waste biomass which otherwise has no use.	So-called 'waste' biomass is essential for soil fertility and nutrients. If removed in large quantities, then this biomass will be replaced by chemical fertilisers, whose usage causes direct and indirect harm.

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