BIOTECHNOLOGY BRIEFING

A technology we do not need

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A *Lean Economy* Paper

2 October 2003

Lean Economy papers are contributions to current debate
adapted from David Fleming's book,
The Lean Economy: A Vision of Civility for a World in Trouble,
which is due to be published in 2004.

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Research for this paper was made possible by Sanders Research Associates
and was first published on the SRA website www.sandersresearch.com
The support of Elm Farm Research Centre for *The Lean Economy* project
is acknowledged with thanks.

Introduction

Biotechnology seems to have a lot to offer. It can extract genes from the plants and animals in which they evolved, and insert them in other species. It can design altered species with useful qualities such as better resistance to pests, drought and toxic chemicals. It can produce crops with more vitamins and the ability to use sunlight more efficiently. This is a technology that comes bearing gifts.

Agriculture, on the other hand, is in trouble. Its long record of rising productivity is faltering; the resistance of crops to pests and diseases is declining; weeds are becoming harder to manage. The natural resources on which it depends are at risk: gas, the main raw material for fertilizer and pesticides, and oil, the fuel for all other tasks and transport, are close to peak and decline; water is approaching critical scarcity in the main food-producing regions of the world; soil fertility itself is being depleted as industrial agriculture neglects the rotations and care needed by a living soil. And along with the fertility, freedom is in retreat – the freedom of farmers to make their own decisions, to keep their own seed, to apply intelligence, experience and local knowledge, to make at least some of the food they produce informally available in the community. Locally-skilled farming is being eliminated. Farmers are losing their right to think.

But those are not problems which the new technology can cure. On the contrary, biotechnology reinforces all that is wrong with industrial agriculture, postponing the needed reform, and enabling agriculture's problems to mature to the point at which reform itself ceases to be an option. The gifts being borne by this technology are not benign.

To some extent, those gifts have already been accepted: the agricultural industries of Canada, the U.S., Argentina and China have in varying degrees done so, but other countries are debating it. Two conditions should be present in a public debate: (a) the public should be reasonably well informed in the subject, and (b) both (or all) of the options under discussion should in fact be feasible and reasonable ways forward, so that the choice is a matter of preference rather than a discussion about whether or not to make a catastrophic error. In the case of biotechnology and the use of genetically-modified organisms (GMOs), neither of these conditions apply – or not yet: the first of them, at least, should not be impossible to meet, for (as the first part of this paper explains) there are just seven central but simple points to note:

1. GMOs do not, in general, produce more food.
2. GMOs do not improve crops' resistance to pests and diseases except for short periods.
3. GMOs increase weeds' resistance to herbicides.
4. GMOs are unmanageable: they cannot be controlled or contained.
5. GMOs are unpredictable: the full effects of transplanting a gene between species are unknown.
6. GMOs increase the risk to food security arising from depletion of oil, gas, water and fertility.
7. GMOs are unnecessary.

The second part considers a single question: Why is the case for GMOs so strongly pressed?

Notes on a flawed technology

GMOs do not, in general, produce more food.

For most of its history, the productivity of agriculture has been growing. One of the periods of most rapid advance was the twentieth century, when yields rose dramatically, keeping roughly in step with the rising population – although the actual benefits of this have been mixed (see box).

Yield

Agriculture is producing much more grain now, but is that all we want it to produce?

Higher yields. The transformation in the productivity of cereals in recent times began with the Japanese dwarf strains of rice. Until the late nineteenth century, a mere 20% of the photosynthate (the production of plant material by photosynthesis) was turned into seed; the rest went into the straw, the roots and the leaves. Selective plant breeding since then has progressively raised this "harvest index" to not far short of the theoretical maximum of 60%; it produces massive heads of seed, but it cannot be taken very much further without reducing the stalk, the leaves and the roots to the point at which there is no viable plant there at all. Breeding also developed plants' ability to survive high densities – for instance by selecting for plants with leaves that point upwards to catch the sun in a field of densely-packed grain. And these hyper-productive cereals, in turn, allow much greater applications of fertiliser and water than before; when the old thin-strawed varieties were heavily fertilised, they promptly collapsed under the weight of their seed-heads. It is this interaction between breeding, fertiliser and water which drove the "Green Revolution", and which has taken the productivity of plants about as far as it will go.[1]

There is more to "yield" than just grain. Productivity is not just a matter of the amount of grain a crop produces. Industrial agriculture, which is committed to the principle of uniformity, concentrates on a narrow range of crops, and it is concerned only with the primary product (the grain) without regard to any of the other resources that the crop can provide. These vital secondary products include fibre, fuel, fodder and medicines; and they include water conservation, organic matter for soil conditioning, and the broader role of the crop as a resource for a stable local ecology which keeps pests in balance. They also include useful plants growing in association with the primary crop. For example, the green leafy vegetable, bathua (fat hen, or Good King Henry) which normally grows as an associate of wheat, has very high nutritive value, rich in vitamin A and iron, and a is remedy for intestinal worms. Together with the wheat, it contributes to a high *combined* yield – but, dismissed by industrial agriculture merely as a competitor of wheat, it is declared a "weed", and is efficiently killed with herbicides.[2]

Industrial agriculture does not allow these essential secondary products to intrude on the simply-defined and simply-measured goal of yield. And yet, it is the total yield of all parts of the plant that really matters to local people, particularly in the third world. The combined yield of a traditional harvest may well be, in terms of value to local people, greater than the simple yield of grain provided by the Green Revolution and its GM sequel; high commercial productivity is obtained at the cost to local communities of profoundly reduced useful yield.[3]

Now the hope is that GMOs will be able to pick up on the record of growth and take it yet further, but this is unlikely. Not only is the harvest index already close to its best, but the genetic engineering of plants to improve their resistance to pests and herbicides has generally tended to *reduce* yields: a study of recent experience in North America shows that the yield of soya fell by between 1 percent and 19 percent, with a typical reduction of about 10 percent; the yield from some maize, engineered for pest resistance, rose very slightly, but in the case of oilseed rape, the study found a 7.5 percent reduction. There is as yet little experience of using GMOs explicitly to improve yields as distinct from protecting crops from pests and weeds, and GM traits were initially introduced only into a few varieties, so that some yield problems may have been due to unsuitable varieties being used for local conditions. Now a greater range of varieties is available, and yet the reductions in yield (e.g. the 7.5 percent fall in the case of rape) and the unpredictability of yields indicates a problem which may be expected to persist.[4]

GMOs do not improve crops' resistance to pests and diseases except for very short periods.

The pesticide which is chiefly used by GMOs is *Bacillus thuringiensis (Bt).* This is the latest in a sequence of pesticides, each used for a decade or so before losing its potency (see box).

The pesticides arms-race

Pesticides have a useful life of about ten years before the pests become immune to them

Pesticides of various kinds have been doing a useful job in the protection of crops for centuries, but the practice of relying almost exclusively on them for the control of pests did not come until the arrival of neurotoxins with the lethal persistence required to defend a crop from predators throughout the growing season. First to arrive were the organochlorates, including DDT, deildrin and chlorane, whose effects on the natural environment were described by Rachel Carson in *Silent Spring.* By the end of the 1960s, however, the pests which they were designed to control had built up an immunity, and it became necessary to turn to something stronger. The solution was provided in part by the organophosphates – parathion, malathion, chlorpyrifos and others – and Rachel Carson describes one experiment to assess the toxicity of parathion:

> A chemist, thinking to learn by the most direct possible means the dose acutely toxic to human beings, swallowed a minute amount, equivalent to about 0.00424 oz. Paralysis followed so instantaneously that he could not reach the antidotes he had prepared at hand, and so he died.[5]

The organophosphates were used together with an even more powerful group of neurotoxins, but less persistent – the carbamates, which included insecticides such as aldicarb, carbofuran, carbaryl and oxamyl. Together, the organophosphates and carbamates provided protection from insect predators through the 1980s until their effectiveness, too, started to decline. By the 1980s, farmers would have run short of defences had it not been for yet another group of chemicals, the pyrethroids. They were derived originally from chrysanthemums but, in their synthetic form (permethrin, cypermethrin, esfenvalerate), they were the most potent of all: applied at the rate of just one tenth of the carbamates, they provided protection through the 1990s.[6] The agricultural industry was able, for a little longer, to remain defended, not just against pests and diseases, but against any real incentive to think again about its methods.[7]

Then, in the mid 1990s, a new technical fix became necessary, and the sequence moved on to *Bacillus thuringiensis (Bt).*

Bt is a bacterium originally found in 1911 as a pathogen of flour moths in Thuringia in Germany, whose cells contain a powerful insecticide protein which is of exceptional value. It is safe for humans and for all other higher animals, and the most widely-used strain (kurstaki) is safe also for insects, but *Bt* is lethal for the lepidoptera larva (caterpillars) that are the primary predators of crops. The reason for this is clever: the toxin itself, *delta endotoxin*, is contained in a protein which is insoluble in normal conditions; it is only in the highly reducing conditions (with a pH of 9.5 or more) which exist in the gut of lepidoptera larva that it becomes soluble – and when it dissolves, it releases the very powerful toxin which is rapidly lethal. Newly-developed strains of *Bt* are effective against the larva of other pests, including mosquitoes, some flies and gnats, Colorado beetles and elm leaf beetles. These properties – the combination of effectiveness where it is needed, coupled with harmlessness at all other times – may be unique; should *Bt* become ineffective, there are no close substitutes.[8]

The use of *Bt* in the form of a spray requires skilled planning. It degrades quickly in sunlight, it must be applied at the right stage in the development of the larva, at the correct temperature and before the pest has bored into the crop plant where it will be protected – and it must be actually eaten by the larva.[9] For all these reasons it has in the past been applied strategically to deal with particular problems. The only way in which it can be effective as a routine defence is by integrating it into the tissue of the crop itself, which becomes possible with the use of GM technology: the gene which produces *Bt* is inserted into the DNA of the crop. However, it has no more chance than any other routinely-used pesticide of preventing pests from building up their resistance. *Bt* is claimed by the agronomists to be a miracle; for the pests with predatory designs on the crops, it is at first a tricky problem in chemistry; but then, all too soon, it is lunch. As the environmentalist Jonathon Porritt writes,

> It is astonishing that serious scientists can be so childishly enthusiastic at the prospect of swapping today's chemical treadmill for tomorrow's genetic treadmill, all in pursuit of the unattainable dream of pest-eradication.[10]

The pattern is now established: as pests develop a resistance to the toxins that are designed to destroy them, the toxins have to be made more powerful, and the technologies become more cunning, so the pests adapt, and the technologies raise their game yet further... GMOs, in the end, make little difference to this arms-race other than to speed it up: when the genetically-engineered insecticide is present permanently in several different crops and at constant concentrations, it provides ideal conditions for the pests to develop immunity at their leisure. For pest control in agriculture to be effective, there has to be flexibility; whereas sprays can at least be switched around, forcing the pests to deal with a variety of different chemicals, GMOs are limited to a very narrow range of chemicals – and for the early years *Bt* has been doing the job virtually on its own. It is unlikely that genetic engineering has other insecticides on the way with an effectiveness anything like as great as *Bt*, and the risk of finding that there is no effective replacement for it is real. Global harvests depend on the biotechnology of the future finding another way of achieving the exceptional effectiveness of *Bt* – and then continuing to achieve it every ten years indefinitely.

In response to this problem, industrial agriculture is starting to turn to the development of completely new toxins: just moving genes around is no longer enough; it is necessary to start from scratch. Nanotechnology is likely to be used to build toxins, behaviours and properties that have never previously existed, and produces new creations – a combination of genetics, robotics, information technology and nanotechnology (GRINs). There may be some consumer-resistance to GRINs becoming integrated into the daily diet. They can also be expected to escape into the wild ecology, and it is likely that, in due course, it will be possible to hack into GRINs and maliciously insert or develop a virus intended to cause trouble.

GMOs increase weeds' resistance to herbicides.

The other main use of GMOs is to enable industrial agriculture to rely exclusively on herbicides for the control of weeds. Intensive applications of herbicides have become necessary as the only way of dealing with weeds which have become viciously persistent after years of selection for their ability to survive them; the problem is that the quantity now needed to kill the weeds is enough to kill the crops too. The solution offered by GMOs is to insert a gene into the crop to confer resistance to the most widely-used weed-killers – glyphosate, or "Round-Up" (Monsanto), glufosinate (Aventis), and imidazolinone (Cynamid).[11]

This is, however, only a short-term solution for, as the herbicide doses increase, so does immunity of the weeds (see box). "Inevitably", writes the agronomist Charles Benbrook, "the use rates of herbicides will trend upwards" – that is, until the trend reaches its limit. That limit is set when the quantity of herbicide used makes the crop unfit for consumption, or when the soil becomes so degraded that it is unable to support crops, or when farmers can no longer afford to buy the quantity of herbicide that is needed. Limits could also be set by the build-up of herbicide in the local drinking water, or by the presence of weeds which are so resistant to herbicides that cultivation of a tolerably clean crop is no longer possible.[12]

Tough weeds I
Weeds that rise to the challenge of GMOs

Horseweed, a prolific weed in the soya crops of Mississippi, quickly developed an immunity which required a six- to thirteen-fold increase in the amount of glyphosate to achieve the same level of control as normal horseweed. Velvet leaf developed a tolerance for quantities of glufosinate larger than many farmers could afford; water hemp's response to glyphosate application was simply to delay germination until after it had been applied. In Iowa, after a few years of GM use, the 10 percent most heavily-treated fields required at least 34 times more herbicide than fields in which GM varieties were not used.[13]

Here, too, the response in the long term might be expected to take the form of GRIN technology. It will, of course, call for exhaustive testing, requiring many years to reach any measure of assurance that the newly-invented herbicides can be used safely – but the incentive to develop the new technology more speedily than that will be hard to resist.

GMOs are unmanageable: they cannot be controlled or contained.

GM crops are unmanageable in three ways. First, persistence: GM varieties have a persistence which can – and, with increasing frequency, does – place them beyond the control of standard agricultural practice. Secondly, contamination: they cannot be prevented from invading agricultural and natural ecosystems extending far beyond those for which they were intended. Thirdly, uniformity: if a new disease becomes established anywhere in the world, the use of genetically uniform crops will ensure that nothing impedes its march.

1. Persistence.

When a farmer plants a new crop, he has to be confident that the crop which grew in the previous year will not try to come back in force; at the very least, he needs to have the option of using herbicide to eradicate newly-germinated plants from the previous crop (farmers call them "volunteers"). However, if the volunteers happen to be genetically engineered to survive applications of the normal herbicides (glyphosate, etc), the remaining options are to turn to intensely toxic chemicals such as 2,4-D and paraquat, or to weed the fields by hand, or to abandon any pretence of variety and to grow the same crop for years on end without a break.[14]

Tough weeds II
When last-year's crop comes back, and back, and back

In 1997, Tony Huether, who farms in northern Alberta, planted three different kinds of GM oilseed rape resistant to, respectively, Monsanto's glyphosate, Aventis's glufosinate, and Cynamid's imidazolinones. The following year, he found his fields invaded by strains of oilseed rape which had acquired genes giving them resistance to all three herbicides: in order to clear his land, he had to use 2,4-D. In Manitoba, Monsanto has been reduced to sending out teams of students to weed out indestructible volunteer rape plants by hand.[15]

If the previous years' crops cannot be eradicated from this year's crop, then the only solution available within the reach of GM agriculture is to abandon rotations altogether, raising the same crop in the same place for year after year. This affront to the most elementary principle of husbandry is a guarantee that pests and weeds, and the ineradicable remains of previous crops (which do not breed true), will become firmly established. Agricultural ecology in this condition is unmanageable. The application of yet stronger chemicals reaches its intrinsic limit when the land becomes unable to support any crops fit for human consumption. The changes to the composition of the soil due to the presence of GMOs include microorganisms, seeds and other genetic material which, through reproduction, persist indefinitely, so that there could be effects which cannot be eradicated. The degree to which reconversion or "decommissioning" can subsequently restore the land for conventional or sustainable agriculture is not known.

2. Contamination.

The genes that have been inserted into the crop do not stay put; they spread themselves around in three ways:

Pollen and seeds. Pollen spreads GM genes fast and far. Tree pollen can travel 600 kilometres on the wind; pollen from all plants is industriously spread through the locality by birds, bees, insects, fungi, bacteria and rain. When this year's pollen has gone as far as it can, it fertilises the plant which will be the starting-point for next year's journey. And, not far behind the pollen come the seeds, spread by the wind, by birds, by the transport of grain, the contamination of grain elevators and combine harvesters. There is no effective way of containing genetic pollution. In Saskatchewan in Canada, almost the whole organic oilseed rape sector has already been lost; in fact, the cultivation of GM-free crops of maize, oilseed rape and soya, is for practical purposes no longer possible anywhere in Canada.[16]

Competition. GM plants do not necessarily have a competitive advantage in the natural world with non-GM plants, but in some cases their advantage could be decisive. GM trees containing insecticide-producing genes, for instance, will be able to invade wild ecosystems with ease, disrupting the system as they go.[17]

The wandering gene. When a gene is inserted in the DNA of an organism, it is bundled together in a "construct" with genes needed for various functions such as inserting the gene, activating it and identifying it. The constructs are designed to be mobile – and that mobility persists so that, when the gene has moved in, it is reasonable to suspect that it could all too easily move out again, in a process known as "horizontal transfer".[18] There is growing evidence that the mobile properties conferred on a gene are indeed likely to work in both directions. Among the accessible organisms into which the wandering gene can migrate are the gut bacteria of the animals (insects, bees, cattle and humans) that eat the GM food, although it is not known to what extent the gene can continue to function after the transfer. There is also evidence that the transfer can occur among fungi and bacteria in the soil, spreading among the microorganisms and fungi that sustain the soil and the natural environment.[19]

3. *Uniformity: crops without boundaries*

All hybrid crops produce uniformity, which helps in harvesting, in processing and in the identification of particular varieties and their breeders; it also helps sales of seed, since hybrids cannot themselves be successfully used for the following year's seed, so that farmers have to buy seed from the breeders every year. Naturally, the case for hybrids has been pressed by the seed industry rather than by farmers, and the dominance of hybrids in American agriculture was established in the 1930s following a vigorous campaign by the industry. The danger of this uniformity showed up in 1970: corn leaf blight swept through the southern states of America; it encountered no genetic resistance for thousands of miles.

GMOs make the evolution of a virus even more likely even than it is in the case of uniform non-GM hybrids. Conditions for the rapid evolution of viruses and pests are provided, for instance, by the permanent presence of a GM substance in every tissue of the crop, and as an example of that, we have the practice of engineering plants such as papaya and plum with genes instructing them to make viral proteins (which provide protection against the virus with which they are associated). If a different virus now invades the plant, it will have a ready-made supply of alien virus protein with which it can, in a process of viral recombination, evolve into a new form against which the plant has no defences. Another way in which a new virus, or a predator with new characteristics, could come into existence is simply by evolution in response to the constant presence of an engineered toxin. A third route, as explained below, is a direct but unintended consequence of importing alien genes into a cell: it is not known in detail what those consequences are: it is likely, however, that some of the unexpected effects will survive and multiply.

GMOs are unpredictable: the full effects of transplanting a gene between species are unknown.

Almost all commercial operations in the late market economy involve some degree of asset-striping from of the natural environment. Biotechnology takes this down to the detail of DNA; it claims that what it is doing is science, and that criticism of GM technology is criticism of science. However, this is as accurate as the idea that opponents of logging are anti-forest, or opponents of industrial fishing are anti-fish.

The principle on which GM technology is based – so simple that it should immediately arouse suspicions – is that, when a gene is extracted from the DNA of its own species and implanted in another, it will carry on doing the same job as before. On this assumption, useful characteristics can be fitted together almost at will to produce a designer-organism, so that the range of new plants and creatures that can be created and brought to life is limited only by the imagination: "...furniture that is grown rather than made; clothing that eats the dead skin its wearer sheds; miniature pet dragons (fire-breathing optional) as household pets".[20] It is, perhaps, fortunate that this vision of the future from *The Economist* magazine is an extreme case of the banal, kitsch and dispiriting, since this tempers the disappointment of discovering that, actually, the function of DNA is not as easy as that: it is not a self-service counter at which biotechnologists can simply pile up their plates with whatever combination of goodies they wish. What the science actually tells us is that the gene's activity depends on its interactions with the proteins and other constituents of the cell and that, when a gene finds itself in a new biological environment, this collaboration is disrupted. The biologist Barry Commoner explains:

> The living cell is a unique network of interacting components, dynamic yet sufficiently stable to survive. [It] is made fit to survive by evolution; the marvellously intricate behaviour of the nucleoprotein site of DNA synthesis is as much a product of natural selection as the bee and the buttercup.[21]

It is, therefore, only to be expected that the organisms into which genes have been implanted usually die, and that most of the survivors are damaged. Those with obvious damage are weeded out; the less obvious failures are those that survive but have a defect which becomes apparent later, in subtle ways. Some curious effects are being observed by farmers in the form of unexplained interactions between crops and the animals that eat them (or refuse to eat them). There are the pigs that do not farrow (conceive) when they are fed on GM grain, the cows, elk and rats that refuse to eat it, the soya plants whose stems split open before the harvest, that fall victim to pests that the farmers have never seen before, that refuse to germinate, that prove to be highly unstable in successive generations.[22] The studies which could show for certain whether such effects are due to GMOs or to some other cause, and which could explain why they occur, have not yet been done; all that can be said for the time being is that these effects are linked by experienced observers to the presence of GM crops, and that they are indications that the technology has unintended consequences.

Such practical experience by GMO growers is commonly dismissed as the effect of the weather, as anecdotal, or as evidence of poor husbandry. What we have here, however, is a technology built on unknowns. This is not the first time the application of a new technology has developed far beyond the understanding of the science on which it is based; there is an honourable, if painful, tradition of trial and error in every field from flight to medicine, but in the case of biotechnology, there are three differences. The first is that the error tends to be suppressed and denied because the flaws that are revealed are to be so fundamental that they threaten the existence of the entire technology. The second is that GMOs seem to be so very innocuous: a GM plant looks so like a non-GM plant that any concern about the GM process can be maliciously derided as paranoia. Thirdly, many of the errors which can be expected to occur in the case of GMOs do not become apparent until after they are already established as unwanted mutations in living and reproducing organisms in the environment. They can then reveal their true characteristics at leisure.

GMOs increase the risk to food supplies arising from depletion of oil, gas, water and fertility.

Industrial agriculture depends on a steady flow of cheap oil and gas, on abundant supplies of water, and on its inherited capital of fertile land. All of these, to varying degrees, are at risk, and it is here that we see the chief threat to the security of supply of food. GM technology, far from offering a solution, actually intensifies the problem.

First, oil: GMOs are designed for large-scale production of single, uniform crops, using giant labour-saving equipment, and backed by long distance transport with central processing and distribution. Industrial agriculture is already vulnerable to any interruption in the event of a breakdown in the flow of oil but it would, in principle, be possible to convert to an energy-efficient, localised form; eventually the chemical residues in the soil would decompose, and fertility would rebuild. In the case of GMOs, however, decommissioning from GMOs to conventional crops may be a very lengthy process, or impractical. The heavy energy-dependency of agriculture becomes irreversible.

Secondly, gas: GM systems are dependent on gas as the raw material for chemicals and fertiliser.[23] GMOs reduce yet further or eliminate the use of good fertility-building practices such as mixed farming, the composting and re-use of organic material, and rotations – the practice of switching crops around in successive years and using fallow periods to prevent the build-up of pests and diseases and to build fertility. Dependence on artificial fertiliser becomes even more deeply entrenched.

In the case of water, the effect of GMOs is more ambiguous. Crops which are engineered for herbicide resistance make it possible for farmers to prepare the land for next year's crop by spraying their fields with a powerful herbicide, instead of ploughing. This "no-till" cultivation has the advantages that it does not disturb the soil, and leaves a covering of dead plants (a kind of mulch) on the land which protects it from erosion and helps it to conserve water. It may well be, therefore, that in the short term, biotechnology is consistent with water conservation. The disadvantage is that, with the heavy application of herbicide and the lack of rotations, the fertility of the soil can be expected to deteriorate, ruling out any savings in water. An adequate analysis is still lacking; current knowledge of fertile soils, however, indicates that the water-retention properties of an impoverished soil are poor. Moreover, crops which are engineered to be drought-resistant would be no compensation for the loss of a water-retaining fertile soil.

Fourthly, fertility itself is directly eroded by GMOs. Genetic modification is intended, amongst other things, to eliminate the need for crop rotations. In fact, soil that has been repeatedly treated with herbicides which only a GM crop can withstand will not be able to support any other crop, and it may even be poisoned by *Bt* toxin exuded through the roots of the GM crop. Cropland which lacks rotations is drenched with toxic chemicals and drained of much of its organic content cannot be regarded as fertile.

GMOs are unnecessary.

There might conceivably be a case for putting up with the array of problems and dangers presented by GMOs if there were no alternative. However, genetic engineering is an unnecessary technology. Much better results – higher yield and more jobs – can be delivered in other ways, at much lower cost, and with a protected environment. GMOs are an extended – or overextended – development of industrial agriculture, and the alternative to them lies in an alternative to industrial agriculture itself. This is a practical, down-to-earth way forward, and it has two central defining features: it builds and conserves fertility by using rotations and recycling nutrients, and it controls pests and diseases effectively by intelligent local management of plants and predators. From those two starting-points, it is possible to develop other opportunities which include conserving water both in the soil and as a productive resource in aquaculture, conserving and using the farm's endowment of renewable energy, and sustaining cooperative relationships with consumers and other farmers in the locality.[24]

Sustainable agriculture, freed from the paralysis of chemical-dependent technology, is capable of being extremely productive: it produces a lot of food. In developing countries, for example, the yields achieved by farmers using sustainable agriculture – though variable, depending on the crop and the particular circumstances – have been shown to average almost twice the yield obtained from the conventional combination of fertilisers and pesticides. As shown in a recent survey by Jules Pretty and Rachel Hine, soil erosion can actually be reversed, with the soil increasing in depth and recovering its ability to retain water and nutrients; water needed for irrigation can be reduced by as much as 80 percent; pesticides can be cut by two thirds, or eliminated entirely. And secondary benefits follow, such as the opportunity to produce fish in the pesticide-free water of paddy-fields and freedom to experiment in ways which combine modern science and local knowledge. Examples of this kind of local innovation include the newly developed "System of Rice Intensification" in Madagascar which improves productivity by between three- and six-fold, the design of cultivation systems for salt water in Vietnam, and the two-orders-of-magnitude increase in local organic production achieved during the 1990s in Cuba.[25]

In comparison with advances in husbandry such as these, GMOs are an irrelevance. The technology is simply *unnecessary* for sustained or expanded food production – and not just in the third world. In the industrialised countries, yield is not in itself the major issue; farmers already produce too much. What matters here is, first of all, the high cost of industrial agriculture, mainly in the form of subsidies; the other three problems are the acute vulnerability to an interruption in the supply of oil and gas, the damaging impact of agriculture on the environment, and the increasing resistance of weeds, pests and diseases to industrial biocides. GMOs are, at best, neutral with respect to the first of these (cost), and the next two problems are intensified rather than relieved by GMOs. Only in the case of overcoming resistance could GMOs have, in theory, a useful part to play – but here, too, we have seen how the brief mitigation of crops' vulnerability to pests and weeds quickly breaks down. The only coherent response to all these four issues confronting modern agriculture is to approach them in a completely different way: sustainable agriculture consists of working *with* the local ecology, using the enduringly effective services it provides for free.

GMOs, then, are a technology we do not need. Even the special services it is claimed to supply turn out to have doubtful value. One example of this is the case of Golden Rice, that famous source of vitamin A: it turns out that a person would have to consume some nine kilograms of cooked rice, twelve times the normal intake, to get the necessary vitamins. The rational way of supplying vitamin A, and a lot of other nutrients at the same time would be to eat green vegetables.[26] Even drought-resistant GM grain is at best an imitation of the many drought resistant varieties now being revived in India after becoming temporarily obsolete during fifty years of profligate irrigation in the twentieth century.[27]

And – beyond food production itself – there is the matter of the production of industrial materials which, as is now beginning to be recognised, can be provided in immense and unexplored variety by the application of good science to materials derived from plants, animals and microorganisms. Do we need biotechnology to make this happen? The materials scientist, Paul Geiser, thinks not:

> ... the technological possibilities for new industrial materials based on natural processes are rich and varied enough that it appears unnecessary to leap to gene-altering technologies that raise unexplored risks. A rush to invest in genetically modified industrial materials or materials development processes appears cavalier when so many natural processes remain unexplored and untapped.[28]

In medical research, too, it is now recognised that GMOs are not simply unnecessary; as the medical scientist David Horrobin, explains, the technology has become a handicap:

> From the 1930s to the 1960s, biomedical science bore some resemblance to an integrated whole. There were researchers working at every level of biological organisation – from sub-cellular biochemistry, to whole cells, to organs, to animals, to humans. This was a golden age.

> But, starting in the 1960s, molecular biologists and genomics specialists took over biomedical science. Everything was to be understood completely at the molecular genomic level. Everything was to be reduced to the genome. Now we have an almost wholly reductionist biomedical community, which repeatedly makes exaggerated claims about how it is going to revolutionise medical treatment – and which repeatedly fails to achieve anything. The idea that genomics is going to make a major contribution to human health in the near future is laughable. But the tragedy is that the whole-organism biologists and clinicians who might have helped to unravel the complexity have almost all gone, destroyed by the reductionists.[29]

Unnecessary: we do not *need* to launch ourselves onto this sea of troubles.

Why, then, is the case for GMOs so strongly pressed?

Why, then, has the momentum behind GMOs developed so far? Why does it remain, it seems, unstoppable? Four reasons are particularly relevant.

The technology. Technology has advanced faster than our understanding of how to handle it. We are still at the naive, even primitive, stage at which we regard technology with awe and reverence, sacrificing to it whatever it demands. What we get back is a host of problems – but they turn out to be rather useful, for they call for *another* technical fix, so that the need for technical advance becomes greater than ever. The result is an endless series of technical fixes, each one more remote from the husbandry at the start of it all; each fix demands greater sacrifices and prepares the ground for a sequence which, for some key industrial and academic interests, is a source of income.[30]

The problem is that GMOs are embedded in a debased scientific culture which sees it as desirable to *avoid* the application of critical judgment. This is a "hands-off" approach to science: there is an ostensible commitment to intellectual rigour, which is sought by allowing the evidence to "speak for itself", without contamination by the application of critical judgment, or by any interpretation of how it fits into a wider picture. The price of this rigour is simplification and reductionism, substituting a neat model for the turbulence of the real thing; the prize is certainty, an escape from the systems-literate, scientific reality that it is the *connections* that matter and that a degree of uncertainty and unexpectedness is intrinsic to any grounded understanding. We see the effect of this parody of science in the brilliant, yet socially and culturally empty mathematical modelling which has been so influential in the development of academic economics;[31] we see it in statistics, where the ideal of allowing the numbers for speak for themselves, explicitly avoiding the error of thinking about the issue itself, has led to improbable but influential conclusions about the environment.[32] It is there in the reduction of biology to genomics, as David Horrobin (above) explains. And we see it, as Larry Siedentop notes, in the narrowing and fragmentation of intellectual life as a whole:

> At first glance the separation of philosophy, economics and political science into distinct

> "subjects" has brought to them far greater precision and sophistication, and nowhere more so than in the development of economic theory. [But it] has fostered a widespread fear about straying outside one's subject, outside the discourse of any profession. ...Those concerned with the nature and operation of political systems – 'political scientists' as they are now called – have by and large ceased to operate with any conception of human well-being or flourishing. They shun passion.[33]

There is no reason why agriculture should be exempt from the curse of reductionism. This means that, in a sense, the debate about GMOs is vetoed before it has started: the technologists are self-appointed guardians of the thin and infantile specialisms they misrepresent as "science"; any attempt to apply judgment which challenges or even attempts to understand the direction of technology can in this way be simply ruled out of order on the grounds that it is anti-science or – as one leading representative of this view, John Maddox, puts it – "so partial and deliberately biased as to be misinformation".[34]

The logic. The case that is made for GMOs typically employs a logical fallacy of a particular kind: "begging the question" – *petitio principii.* An argument begs the question when it uses the *assumption* that a proposition is true as the basis on which to *argue* that it is true. For example, the statement, "We have to use GMOs in order to feed the world" contains within it the assumption that GMOs *can* (safely and sustainably) feed the world, but the question as to whether GMOs can actually do so is precisely what the debate is about – and it follows that a statement which takes this as a given begs the question: it is a pointless but misleading statement, and it should be as unacceptable for a politician as the related misdemeanours of telling lies or taking bribes. The standard of logic-literacy at present is poor, so the error is almost never recognised or picked up; even the term "begging the question" is used mainly in the different sense of "raising a new question". In fact, the use of the fallacy is often merely a warm-up act for a restatement of it in a yet more logically-collapsed form, e.g.: "By opposing GMOs, you are condemning millions to starvation".[35]

Corrupt argument, once established, tends to pollute the entire debate: "After a pointless experiment that involved feeding rats with potatoes modified to produce a poison," writes *The Economist*, "parts of Europe developed mass hysteria."[36] This hyperbole refers to a careful experiment by Dr Arpad Pusztai which compared the effect of the non-toxic snowdrop lectin (GNA) administered to rats in identical quantities by (a) engineering the gene into the potatoes, and (b) adding lectin itself to the potatoes. The rats fed GM potatoes showed significant changes, notably increases in the mucosal thickness of the stomach and the crypt length of the intestines, indicating that the GM process itself has consequences which we know nothing about. Dr Pusztai notes, "it is therefore imperative that the effects on the gut structure and metabolism of all other GM crops developed using similar techniques and genetic vectors should be thoroughly investigated before their release into the food chain."[37]

This issue of safety is assumed away by advocates of GMOs: the neglect of the safety of GMOs in a culture of paranoia about the safety of long-standing assets such as local abattoirs, smallscale cheese production, homoeopathic remedies and children's swings seems to be an indication not just of logical error but of a pathology of public debate which has deteriorated to the point of derangement. In a debate without logic, there are no links, no "therefores"; instead, as Pusztai calmly reflects, "most of the adverse comments on this *Lancet* paper were personal, non-peer reviewed opinions and, as such, of limited scientific value".[38]

The economics. The obvious alternative to using GMOs would be simply to stop using them. However, this would be resisted for two reasons. First, the seed and chemical providers like Monsanto, which have not been making the large profits from GMOs that they expected, and are already faced with mounting litigation, and would quickly be bankrupted. Monsanto's patent on the world's leading weed-killer, glyphosate, ran out in 2000, and the genetic engineering of crops which were resistant exclusively to glyphosate was at first sight a clever response. The industry now has the motivation, resources, politics and persuasive skills to mount a formidable defence.[39]

Secondly, industrial agriculture already has difficulties of its own – notably the increasing persistence of pests, diseases and weeds. The solution to this is to reform agriculture as a whole, rebuilding it on the principle of sustainable husbandry and moving away, substantially or completely, from dependence on agricultural chemicals. Although the economic benefits of this would be immense, there is inertia: changes not just in the use of GMOs but in the nature and fundamental principles of the whole agricultural industry worldwide would be a massive undertaking, involving loss of face, loss of revenue, and unbearable changes to life-long, industry-defining mindsets.

One of the powerful advantages which the agricultural chemicals industry has in its defence is that the alternative – sustainable agriculture – is so *detailed*, so diverse, so local. These are not problems; they are the content of the discipline of husbandry; they are its reality, as distinct from the quick fixes of industrial agriculture, which are its drug. Sustainable agriculture would restore to farmers the power to make decisions in the light of their own needs and experience; it would lift the burden of regulation and distrust from the food producers of the world. Simple, global rules are easy to devise and administer but complex local detail is impervious to central administration; local sustainable agriculture would therefore spell redundancy not only for the agricultural chemical industry, but also for regulators and bureaucrats. However, control is addictive; naturally, the controllers, too, will use every means they can to defend themselves.

The soil. Once GMOs have been used in an area, it will not be easy to go back to GM-free husbandry. A changed soil and resistant weeds are to be expected; uncontaminated seed has become hard to get in areas where GMOs are widely used; conventional *Bt* spray is becoming less effective as a result of over-use by GM crops, eliminating one of the main lines of defence open to sustainable agriculture; habitats for the predators of crop pests are altered, particularly as GM crops spread to forestry; the produce of farms can no longer be guaranteed to be free of GMOs, and will remain suspect for many years. The technology is unforgiving; there is a sense that, once it has started, it will never go away, and that there is no choice but to develop constant new fixes to try to control it. Governments and companies, having started down that path, and having produced something which threatens to be unstoppable, are likely to be driven by fear.

Now for the positive feedback: the most effective way of allaying fear of something which is suspected to be unstoppable is to *join* it, to maintain the pretence that actually you are using its powers for your own ends, that you are in control. With each rise in the level of fear, the industry's standing as the only body with the power and the expertise to solve the problem is advanced; the incentive for an alliance between the industry and the authorities gets stronger. All regimes built on fear are extremely stable; after along delay, they are eventually destroyed – rather suddenly.

Conclusion

Can genetic engineering be stopped? It can. However, there are difficulties. First, in the countries where it has already become established, the many technical problems we have noted in this paper would not end immediately upon a decision to stop using GMOs; and yet, the presumption has to be that these difficulties are not insuperable. In the many countries where GM crops have not yet been grown commercially, the technical difficulties are of course drastically reduced, though some contamination from testing sites is to be expected. Secondly, there are the borderline cases between medicine and agriculture – the breeding of pigs for spare parts surgery, for example. The arguments for and against this are not the same as those relating to agriculture, but the two uses of biotechnology are similar enough to complicate the debate: Where exactly is the borderline to be drawn between the engineering of pigs to be used for agriculture, and pigs to be used for spare parts? Where do you stop? This "slippery slope" objection, though logically trivial, is effective in sabotaging sensible debate and decisive action. Thirdly, there are weighty political and commercial interests in favour of continuing with the technology. Fourthly, our society has a poor record in the field of science policy: there are instances, such as human cloning, where an informed public choice has been insisted-upon, but the usual presumption is that where technology leads, society should follow.

There is a real prospect of the technology being prevented in the countries where it has not yet become established, but it is far from certain that it will be stopped throughout the large areas the primary bread-baskets of the world, where it is already used. It should be ended, everywhere, unequivocally. The way forward is to reform agriculture, root and branch, starting now – to focus policy on a farmer-centred, localised, deregulated, scientifically-coherent, sustainable agriculture. Ultimate aim: to feed the world, sustainably.

Endnotes over the page...

Notes

1. For a review of changes in grain yields see Lester Brown and Hal Kane (1995), *Full House: Reassessing the Earth's Population Carrying Capacity,* London: Earthscan, chapter 10.
2. Vandana Shiva (1993), *Monocultures of the Mind*, London: Zed Books, p 113.
3. Shiva (1993), p 50.
4. Hugh Warwick and Gundula Meziani (2003), *Seeds of Doubt: North American Farmers' Experience of GM Crops,* Bristol: The Soil Association, chapter 4. (Available on Soil Association website).
5. Rachel Carson (1962), *Silent Sparing*, New York: Houghton Mifflin (Penguin 1965), p 43.
6. Pyrethroids: http://ace.ace.orst.edu/info/extoxnet/pips/pyrethri.htm
7. Charles Benbrook (2001), "Do GM Crops Mean Less Pesticide Use?", *Pesticide Outlook*, in www.mindfully.org/Pesticide/More-GMOs-Less-Pesticide.htm
8. For details on *Bt* see, for instance, http://helios.bto.ed.ac.uk/bto/microbes/bt.htm and http://www.colostate.edu/Depts/IPM/ento/j556.html
9. Most formulations last for up to a week; some of the newer formulations decay within 24 hours.

10 Jonathon Porritt (2000), *Playing Safe: Science and the Environment*, London: Thames & Hudson, p 85

11 "In 2002 ... the dominant traits continued to be herbicide tolerance (75%), insect resistance (17%) and both traits (8%)" Genewatch UK (2003), *Genetic Technologies: A review of Developments in 2002*, http://www.genewatch.org/publications/Briefs/brief22.pdf

12. See Warwick and Meziani (2003), chapter 4.
13. *Ibid.*
14. Warwick and Meziani (2003), chapter 6.
15. *Ibid.*
16. See Viola Sampson and Larry Lohmann (2000), "Genetic Dialectic: The Biological Politics of Genetically Modified Trees", *The Corner House Briefing*, Sturminster Newton: The Corner House. Warwick and Meziani (2003), chapter 7.
17. See Sampson and Lohmann (2000).
18. Mae-Wan Ho (2003), Institute of Science in Society *Recent Evidence Confirms Risks of Horizontal Gene Transfer*. For full reference see http://www.greens.org/s-r/30/30-14.html
19. For non technical background to this, see Nathan Batalion, "Biotechnology is a Vital Issue that Impacts All of Us", at www.mercola.com/2002/pct/30.biotechnology.htm
20. Geoffrey Carr (2003), "Planting a Seed", in *Climbing the Helical Staircase*, survey in *The Economist*, 29 March, p 18.
21. Barry Commoner (2003), "How Well Can Science Predict GM Impacts?", paper presented at the Gene Futures Conference, 11 February, (abridged), at http://www.genewatch.org/Debate/GeneFutures/GeneFutures_Speeches.htm
22. Warwick and Meziani (2003), chapter 8.
23. It is probable that crops could be engineered to develop the ability to fix nitrogen, theoretically eliminating the need to use artificial nitrogen fertiliser, but this is not a solution: GM crops are more dependent than non-GM crops on fertiliser, because they are essentially inconsistent with normally fertility-building rotations. The release of newly-evolved nitrogen fixing varieties into the environment would be a major intervention without knowledge of the consequences.

24. Jules Pretty (2002), *Agri-Culture: Reconnecting People, Land an Nature*, London: Earthscan, chapter 4.

25. Jules Pretty and Rachel Hine (2001), *Reducing Food Poverty with Sustainable Agriculture: A Summary of New Evidence*, Final Report from the SAFE-World Research Project, Colchester: University of Essex. Main points summarised in Pretty (2002), chapter 4.

26. Bran Halweil (2002), "Farming in the Public Interest", in Christopher Flavin et al, *State of the World 2002*, Washington: Worldwatch Institute / London: Earthscan, chapter 3, p 58.

27. Rahul Nellithanam, Jacob Nellithanam and Sarvodaya Shikshan Saiti (1998), "Return of the Native Seeds", *The Ecologist*, vol 28, 1, Jan/Feb, pp 29-33.

28. Kenneth Geiser (2001), *Materials Matter: Towards a Sustainable Materials Policy*, Cambridge, Mass: MIT, p 304.

29. David Horrobin (2003), "Not in the Genes", *The Guardian*, 12 February, at http://www.guardian.co.uk/genes/article/0,2763,893869,00.html

30. For a discussion of the "continuous cascade of ingenuity absorbing technical fixes", see Sampson and Lohmann (2000), p 10.

31. See, for instance, Herman Daly and John Cobb (1990), *For the Common Good: Redirecting the Economy Towards the Community, the Environment and a Sustainable Future*, London: Green Print, Part One.

32. See Bjørn Lomborg (2001), *The Skeptical Environmentalist*, Cambridge University Press, especially Part 3, section 11, "Energy", pp 118-136. See also the critique by Stephen Schneider, John P. Holdren, John Bongaarts and Thomas Lovejoy. Introduction by John Rennie; "Misleading Math about the Earth", *Scientific American*, January 2002.

33. Larry Siedentop (2000), *Democracy in Europe*, London: Allen Lane; (Penguin, 2000), p 57.

34. John Maddox (2003), "We should be told", *Times Literary Supplement*, 25 April, p 3.

35. See, for instance, Frans H. van Eemeren and Rob Grootendorst (1992), *Argumentation, Communication and Fallacies*, Hillsdale, New Jersey: Lawrence Erlbaum, pp 153-154, 214.

36. Carr (2003), p 11.

37. Arpad Pusztai (2001), "Genetically Modified Foods: Are they a Risk to Human Health?" in Actionbioscience.org: http://www.actionbioscience.org/biotech/pusztai.html

38. *Ibid.*

39. Warwick and Meziani (2003), p 59