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# Biotechnology and the Environment: Issues and Linkages

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## Abstract

*The rapidity of change has left scant opportunity for investigation of the consequences of biotechnology adoption on long-term ecosystem or economic system functioning. Economic theory suggests that, if the "Biotechnology Revolution" is left to market forces alone, there will be neglected public goods. Theory and limited empirical evidence suggests that there are significant incentives for private firms to discount and neglect negative environmental impacts and to develop products that meet only the needs of those able and willing to pay. Negative distributional impacts on rural societies and economies will not normally enter the private calculus nor will the long-term problems of insect and plant resistance. Furthermore, economists have shown the detrimental effects from excessive market power on prices, product quality and innovation. For example, the growing concentration in the biotechnology industry may dampen incentives to assure adequate diversity in plant germplasm. The authors suggest adoption of the precautionary approach in weighing the adoption of new agricultural biotechnologies.*

Agricultural biotechnology has been described as a tsunami washing over agriculture—with fundamental impacts on how we grow and market our food and fiber. While some argue that current biotechnology innovations are just the next step in a long history of plant and animal breeding, others strongly disagree. Modern biotechnology involves genetic manipulations of transferring DNA from one organism to another. Therefore, unlike conventional plant or animal breeding, most biotechnology products are not something that could occur "naturally." For many, these unique attributes of agricultural biotechnology are cause for concern. While often these concerns involve the concentration of ownership of agricultural assets, food safety issues, or ethical questions, there are also concerns about biotechnology products' impacts on the environment.

These latter environmental concerns can be explored within the framework of three themes. First, agricultural biotechnology has a high potential for social good–literally improving the lives of billions of people. However, biotechnology is a "technology push" revolution, made possible through the rapid commercialization of recent scientific advances. Because the current biotechnology path has not been shaped by public investment or regulation, nor induced by growing scarcity in key inputs, and not pulled along by robust consumer markets, there is a particular need for careful public scrutiny. These missing forces may mean that the social decision calculus for biotechnology is not well informed by the full range and distribution of benefits and costs.

The second theme is that missing markets for environmental and other attributes, as well as incomplete regulatory frameworks, may hinder agricultural biotechnology from reaching its potential for social good because important social costs are not reflected in the prices of inputs or outputs. Many critics claim that the current regulatory frameworks for agricultural biotechnology are inadequate to address these costs.

The third theme explores whether biotechnology is necessary for the protection of wildlife habitat and wilderness and to feed the world's population. While some claim that biotechnology is the answer to both food security and a healthy planet, others demur.

# The Environmental Promise of Agricultural Biotechnology

There are at least four areas of potential biotechnology contributions (Ervin, 1999; Office of Technology Assessment, 1991):

- gains in yields through new plants resistant to environmental stresses,
- lower costs of labor and agriculture inputs (including irrigation water),
- higher-quality food and value-added products, and
- environmentally benign methods of managing weeds and insect pests.

Many of these potential contributions are environmental (Ervin, 1999). For example, the new transgenic crops could reduce the use of chemical pesticides and lower the environmental risks of pesticides still in use. There may also be savings in energy and air emissions from more efficient transport of less perishable products. If drought resistant transgenic plants become a reality, not only could yield losses be minimized, but irrigation water could be reduced allowing for better protection of environmental values, such as adequate in-stream flows (e.g., fish habitat). Also, if transgenic crops translate into higher yields, there might be a reduction in the amount of grassland or forest land converted into agricultural production—with attendant environmental benefits. While the potential for these environmental benefits from agricultural biotechnology is real, it is yet unrealized.

Agricultural biotechnology is clearly in its infancy—emphasizing first generation input traits such as herbicide resistance. The next wave of output quality traits is on the horizon. While environmental benefits may be forthcoming from both of these generations of products, there is little research or empirical evidence to date as to whether such benefits are significant. In addition, there are concerns that unintended negative environmental impacts will emerge and accumulate. These concerns have been heightened not only by the rapid pace of product innovation, but also by recognition that the biotechnology products are possible because of the existence of a new technology, one with which the world has little experience.

# Theme One: Biotechnology as a Technology-Push Revolution

The greatest growth in transgenic products has been in crops with "built-in" protection from pests, such as *Bacillus thuringiensis* (*Bt*), or those that are herbicide tolerant.[1] The planting of both types of seeds has been rapid–from the early 1990s when there was none to the current 100 million acres (40 million hectares) (The Economist, 1999).

The ability to move cells and the information embedded in them—from one plant or animal to another—has preceded a market demand for the resultant products. Some authors therefore, refer to biotechnology products as "technology-push" (as opposed to demand-pull) innovations (Krimsky and Wrubel, 1996; Russell, 1991; Hackings, 1986). In Hicksian terms, biotechnology is an "autonomous" rather than an "induced" innovation; that is, biotechnology is a "technology in search of applications" (Hackings, 1986, p. 2). For the private commercial sector, this search translates into a search for applications that can be patented and from which rents can be appropriated. The autonomous technology must ultimately be accepted by buyers to pass the market test, but its initial path may vary from a similar innovation spawned by rising prices of key inputs.

Consider, for example, herbicide resistant plants such as "Round up Ready ®" soybeans. There are numerous alternatives to such herbicide resistant varieties as a means of managing weeds. As one critic notes:

> "Ridge tillage, no-till, banding, improved cultivars, newly registered post-emergent herbicides and new planting systems gave farmers many new options [for weed management]. The chemical toolbox is overflowing–more than a dozen new active ingredients have been registered in several families of chemistries" (Benbrook, 1999, p. 10).

An urgent demand for improved weed management does not, therefore appear to be the main motivator for the development of "Round-up Ready ®" soybeans. Rather, biotechnology, as a method, provided Monsanto a way to protect the profits from their highly successful herbicide, Round-up ®, after Monsanto's patent expires in 2000. A unique business opportunity could be captured by developing "packages" where newly patented herbicide resistant seeds are first linked with specific chemicals, then sold with a technology fee (Just and Hueth, 1993; Hubbell and Welsh, 1998; Benbrook, 1999).[2]

Because of the manner in which the products are regulated in the U.S., this biotechnology approach is particularly attractive to companies. In the U.S., the time required to approve a new biotechnology product is about one-half the time of approving a new chemical pesticide compound. The cost to approval for the biotechnology product is only one-fifth to one-seventh that of a chemical (Ollinger and Fernandez-Cornejo, 1995).

The differences between these autonomous innovations and induced innovations technology suggest an hypothesis worthy of further exploration. The working hypothesis is: technologies that are pulled along by consumer demands or by producers to lower costs are more likely to be guided by full social values, provided by either markets or extra-market (e.g., regulatory) institutions, than the "technology-push" variety. Autonomous innovations arise largely in response to scientific advances. Only when they enter the market, can consumers and producers express their preferences (i.e., provide feedback) and shape their development trajectory.

This possibility that social goods may be neglected by autonomous innovations is heightened by the dominance of the private sector in the biotechnology arena. It is more likely that autonomous innovations that arise primarily from the private sector, such as biotechnology, will catch public regulatory bodies unprepared for unintended social consequences. Unless forced by a regulatory requirement (i.e., an effective performance standard) existing incentives are for the private sector to neglect public goods such as protection of surface water or preservation of wildlife (Batie and Ervin, 1999).

Also, because autonomous, directed innovations tend to emerge from private laboratories with little contact with farmers or consumers, there may be less sensitivity to farming and eating as part of ecological and cultural systems. Thus, important factors underlying the social desirability of the product may be neglected (Busch, et al., 1991). In the U.S., the widespread adoption of herbicide-resistant soybeans or *Bt* corn and cotton suggests that many farmers believe the new transgenic pest management features are worth the cost. However, refusals of European and Japanese consumers as well as some U.S. firms (e.g., Gerber and Heinz) to purchase products containing transgenic plants suggests some consumers do not find net benefits in the products.

# Theme Two: Missing Markets

The "Biotechnology Revolution" is being criticized for ignoring or exacerbating environmental problems. The "under supply" of environmental benefits or the "over supply" of environmental costs[3] of biotechnology are classic examples of "missing markets"—where the normal workings of a private market exclude consideration of important outcomes off the farm and in the future. The potential environmental benefits of first generation products relate to whether there is an actual reduction of use in the more toxic pesticides due to the adoption of biotechnology herbicide resistant or *Bt* crop seeds. The potential environmental costs relate to whether transgenic crops can harm the environment through negative impacts on non-target species or bio-diversity, on pest or virus resistance, and on transfer of genes to wild relatives or to conventional crops (The Royal Society, 1998).

While environmental problems can emanate from non-engineered crops, concern with transgenics is heightened because of the novelty of the traits (e.g., tolerance to cold obtained from other species' genes) and because of the possible amount of acreage dedicated to such crops. Furthermore, because the private benefits of transgenics will occur sooner and to a more focused set of beneficiaries than will any unintended environmental costs, there can be a discounting of those costs by both private companies and regulatory institutions (Batie and Schweikhardt, 1995). The same could be said for some non-transgenic products and practices. However, the rapid development and adoption of transgenics adds a particular urgency for analysis that may be unique to these products.

Such analysis is challenging; not only does each biotechnology product pose its own potential benefit, it also poses its own unique environment (and health) risk (Pretty, 1999). Differentiating between types of products and/or technologies is essential for analysis. Furthermore, there is not yet a strong, credible scientific information base with which to address many of these concerns. The paucity of such information is exacerbated by the reluctance of private companies to share information on their products, since such information is a crucial component determining return on their investments in transgenics. What follows then, is a brief sketch of these concerns, not a definitive, research-based determination of their validity.

# Biotechnology and the Environment

The concerns surrounding potential negative environmental and eco-system function outcomes of agricultural biotechnology include impacts stemming from changes in pesticide use, impacts on non-target species, and pest and virus resistance.

<u>Pesticide Use Impacts</u>. An environmental concern with respect to genetically engineered crops is whether they will be able to provide more environmentally benign methods of managing weeds and insect pests, as promised. Unfortunately, an accurate assessment of the contribution of herbicide-tolerant or *Bt* crops to either to environmental improvements or producer profits will require a decade or more of actual field use (Gianessi and Carpenter, 1999). This long evaluation period is necessitated by the variability in weather, market prices, and pest infestation across regions.

Preliminary evidence from the few years of experience with transgenic crops in the U.S., as well as evidence from field experiments suggests that changes in pesticide use rates have been variable (Gianessi and Carpenter, 1999). For example, a recent USDA study (Economic Research Service, 1999) found that as more U.S. farmers adopted herbicide-tolerant soybeans, the use of glyphosate herbicides such as Roundup ® increased.[4] However, other chemicals decreased in use—leading to an overall decrease of herbicides over time. In contrast, when U.S. cotton farmers adopted *Bt* cotton in the Southeast, farmers did not use less of the organophosphate or pyrethrin insecticides, but did reduce aldicarb insecticides. In some cases, there were more pesticide applications on *Bt* cotton than before because the number of pests not susceptible to *Bt* increased following the adoption of *Bt* cotton. The introduction of genetically transformed potato plants did not have a major impact on insecticide use. Such variable outcomes could be the result of early adoption problems or the severity of pest problems and may not be representative of results over longer periods of time.

Because of changes in types and severity of pest infestations and hence chemical use, the overall impact on the environment from agro-chemical use following the adoption of transgenics, then, depends on the toxicity of and exposure to the chemicals used compared with the pre-transgenic chemical portfolio. There may also be offsetting environmental impacts. For example, herbicide-resistant plants may also allow reductions in plowing (as opposed to pre-transgenic chemical portfolios) and thus reduce wind and water sediment damages. However, at least to date, there is not enough evidence to conclude whether overall pesticide damages to the environment are reduced due to the adoption of biotechnology products.

<u>Non-target Species Impacts</u>. Although nearly half of the U.S.' major crop acreage is in transgenics, there has not been an independent assessment of whether certain species are benefitting or being harmed by the transgenics. Many crops are habitat to a range of insects or predatory arthropods that prey on unwanted insect pests, that provide food for birds, and that pollinate plants. These insects are referred to as "beneficials" in integrated pest

management strategies. *Bt* toxins can harm both pests and "beneficials"—although so can conventional insecticides. There is a laboratory research result that *Bt* transgenic plants pollen kills non-target Monarch butterfly larvae, if the larvae are exposed to *Bt* pollen (Losey, et al., 1999; Gianessi and Carpenter, 1999). Whether wild Monarchs—whose larvae prefer to eat milkweed and not corn—will actually be killed in significant numbers by *Bt* crops, however, is not yet resolved.[5] For another example, no harm has been shown to come to bees from *Bt* toxins (The Royal Society, 1998).

*Bt* is only the first generation of built-in plant toxin; patents have already been secured on genes for toxins from scorpions, cone snails, funnel spiders and wasps (Pretty, 1999). The impact of the successful expression of these genes on non-target species appears to be unknown. Other concerns include whether there can be a disruption of soil ecological functioning from the breakdown of crop tissue and release of toxins or if sequestration of toxins by herbivores could have unintended secondary effects on their predators (Pretty, 1999) or on the herbivore (e.g., cattle) themselves.

A fundamental concern with respect to biotechnological impacts transcends the potential unintended impact on any single species. It relates to whether the reduction in diversity of crop and wild plant and animal species creates a more fragile, less sustainable agricultural system (Hubbell and Welsh, 1998; Hassebrook, 1989). Such narrowing of diversity has been happening for sometime, but could be accelerated by biotechnology (The Royal Society, 1999). The concern is that the very uniformity demanded and rewarded by the emerging food system creates greater environmental risks for system collapse or biological damage.

Another broad ecosystem concern is the potential effects of introducing multiple biotechnology products. A strong conclusion in the 1998 Royal Society Statement is the need for evaluating the environmental effects of transgenic crops as a whole rather than with case-by-case regulatory reviews. Such an individual crop approach will not likely capture the full set of long-term continued effects of transgenic crops on whole ecosystems, whether positive or negative. Moreover, the case-by-case analysis will miss possible interaction (synergistic) and scale effects. This error may occur, for example, if different transgenic crops exert common environmental influences. Individual reviews also will miss threshold issues that may occur if common environmental effects of transgenic crops are aggregated across the countryside (e.g., predator-prey relationships) (Ervin, 1999).

Pest and Virus Resistance. Another major environmental concern is that engineered plants will either become weeds themselves or will transfer pollen to wild relatives that will become weeds (Hubbell and Welsh, 1998; Linder and Schmidt, 1995; Rissler and Mellon, 1996; Krimsky and Wrubel, 1996; The Royal Society, 1998). If these weeds are herbicide-resistant, they may become extremely difficult to control in agricultural settings.[6] Thus, in regions where plants have weedy relatives, resistant weeds may pose a threat and may out-compete native plants. Such competition could alter the current eco-system of a region and/or threaten wild crop gene pools.

Such threats appear to be probable. For example, a team of scientists advised the Rockefeller Foundation that the likelihood of gene transfer from cultivated Asian rice to weedy relatives was of such a magnitude that it will probably occur (Conway, 1999). There are also numerous cases where "exotics" associated with agriculture have caused problems and where genetic diversity has been diminished by the introduction of crops (Rissler and Mellon, 1996; U.S. Congress, OTA, 1993).

Similar concerns relate to the possibility of intensifying existing or creating new viruses (Rissler and Mellon, 1996). Viral epidemics from natural recombinations have already occurred. For example, the African cassava mosaic virus is just such an epidemic (Conway, 1999).

An additional concern addresses organic agriculture. Should key pests develop resistance to *Bt*, organic growers will have lost a major pest control tool.[7] Susceptible insects can be thought of as an open access resource. Economic theory suggests that if the benefits of drawing on this stock of susceptibility is high enough, the stock will be drawn down too fast from a social accounting perspective (Clark and Carlson, 1990; Barnett and Gibson, 1999). The ultimate impact on the environment of herbicide-tolerant insects could be negative, as organic farmers resort to other insect control chemicals and practices.

One approach to managing pest resistance has been to require farmers using *Bt* crops to plant refuges with non *Bt* crops. The intention is to dilute the frequency of recessive resistant traits in the population of target insects (Barnett and Gibson, 1999; Hargrove, 1999). Unfortunately, there is limited scientific information to date on how to best design a refuge to protect *Bt* susceptible genes. Furthermore, for any farmer, there is little incentive to invest in protecting the open access resource—the potential to "free ride" on the efforts of others is high (Barnett and Gibson, 1999; Hargrove, 1999). Because of these concerns, it is unknown whether a refuge will be adequate to avert or delay pest resistance.

A more fundamental criticism of the biotechnological approach to pest control is that it continues along the path of providing a single control component per pest and thus encourages dependence on pesticides (Hubbell and Welsh, 1998). Not only does such a path assure that there will soon be pests that are resistant to the control of the crops (Hubbell and Welsh, 1998; Hassebrook, 1989; Rissler and Mellor, 1996), such a path also diverts attention from whole system management techniques undergirded with understanding of ecological connections (Krimsky and Wrubel, 1996). Thus, the critics worry that there will be less research and development into non-pesticide alternatives such as reintroduction of valuable crop rotations, biological controls, cover crops, or intercropping (Cramer, et al., 1999; Liebman and Janke, 1990). This criticism is not unique to the "Biotechnology Revolution." It is the same criticism leveled at the agricultural system since it became chemically dependent.

An alternative, less chemical dependent path could be supported by different biotechnology products than those that are currently emerging. Many argue that the alternative path is more socially desirable and can be yield-enhancing (Pretty, 1999). But it is a path that requires a reorientation of agricultural research in ways that embed the lessons of evolutionary biology (Benbrook, 1999). However, it is difficult to capture the profits from many of these alternatives, thus they tend to be neglected by the private sector.

# Theme Three: Biotechnology and Habitat Conservation

An issue related to the environment pertains to whether biotechnological products will result in less need for cultivated land, and therefore result in more natural habitat (Avery, 1994; Shapiro, 1999). This issue usually is framed as the need to feed a hungry world while protecting the environment. Such a framing of the issue subsumes several assumptions:

a. that people are or will be hungry because of low agricultural yields and higher costs of food,
b. biotechnology products are necessary to adequately raise yields, and
c. as society meets food needs with expanded acreage devoted to agriculture, more natural habitat will be lost—unless there are offsetting higher yields on existing cropland acreage.[8]

Like many arguments about biotechnology, this one appears to be oversimplified.

## Feeding the Poor

First, it is well-known that, at least on the global scale, people are not hungry because of insufficient agricultural yields. Rather people are hungry because they are poor (Serageldin, 1999; Conway, 1997). Consider the Green Revolution[9] which was motivated by the public concerns to feed a hungry world. The hybrid vigor and dwarf plant characteristics that resulted meant that overall food production of major cereal crops doubled or even tripled in some regions (Lipton and Longhurst, 1989). Despite such successes, the extent to which the poor actually benefitted from the "Green Revolution" has been the subject of much debate (Conway, 1997; Lipton and Longhurst, 1989; Hazell and Ramasamy, 1991). In many countries, the major benefits of new varieties accrued to the landowner elites and not the laborers. The ultimate impact of the "Green Revolution" on the poor has depended on the geographic, social and political circumstances and has been quite uneven across the globe (Conway, 1997).

While the "Green Revolution's" high-yielding varieties were potentially poverty-alleviating, a broader context of appropriate non-distortionary agricultural and rural development and economic policies was needed. Until food access for the population who lie outside of the market is resolved, growing more corn, soybeans, or wheat will do little to feed the world's hungry (Benbrook, 1999).

## Yield Increases and Biotechnology

While there is not a direct relationship between increased world crop yields and food security for the poor, fewer acres have been devoted to agricultural purposes than if yield increases had not occurred. Without continual agricultural yield improvements, many more millions of acres will have to be devoted to agricultural uses as world population grows and as incomes and diets improve (Shapiro, 1999; Conway, 1997). However, the question remains whether biotechnology is the only or best way to achieve these yield increases, as well as whether biotechnology will increase yields in the location and crops most advantageous to the poor.

While some assert biotechnology is <u>the</u> solution to achieving a high yield, environmentally protecting agriculture (Shapiro, 1999); others suggest it should be considered an essential partner with more ecological approaches such as integrated pest management and with improved economic policies (Conway, 1999). Still others contest whether modern biotechnology is necessary to achieve yield advances. For many reasons, many farmers around the world are not near the potential of their land using either conventional or (non-biotechnological) alternative practices (Ruttan, 1999; Pretty, 1999. Thus, some argue, and some studies (Pretty, 1999) suggest, that biotechnology is only one of a suite of possibilities for raising world food yields. Many assert that building human capital, not technological fixes, should be the key investment in pushing the developing countries toward higher sustained food production (Crosson and Anderson, 1992). Human capital is essential to devising agricultural systems that fit the physical, biological, economic, social and cultural bases that govern food production in those countries. Finally, some doubt that adequate investments are being made to break the physiological constraints that limit future increases in crop yields, and thus "it would appear exceedingly rash to predict that...[there will be] any measurable impact on production in the next several decades" (Ruttan, 1999 referencing Duvick, 1996).

Since the "Biotechnology Revolution" is being led by private companies, there is little reason to believe the products that emerge are destined to feed the billions on the planet or to protect the environment. Because the private sector is motivated by incentives such as profits, timely return to stockholders, and market share, it is not surprising that the genetic manipulation funded by the private sector would emphasize certain "Research and Development" (R&D) investments and product attributes that would differ from that of a more complete public agenda (Heffernan, 1999). Put more formally, one would expect the private sector to invest in low exclusion goods[10] such as seed-chemical-machinery "packages" or value-added foods and neglect high exclusion goods, such as protection of biodiversity or the improvement of minor traditional crops in the developing world. Private investments can thus be expected to focus on high-value crops, on labor-saving technologies, and the needs of capital intensive farming in order to feed those who can pay not on the needs of the smallholder farmers in the developing world nor environmental conservation (Conway, 1997).

Nevertheless, there are cases where private companies have partnered with public institutions or foundations to focus on the needs of poor people. For example, Monsanto has entered into agreements with both Kenyan and Mexican research institutions for the development of virus resistant crops (Serageldin, 1999). While these partnerships appear to be working well, they are few in number, modest components of philanthropic programs. And, many argue that public or foundation funding for biotechnology products geared to environmental protection or the needs of the poor are quite inadequate (Ruttan, 1999; Serageldin, 1999).

There may also be barriers to more innovations directed at the needs of the poor. Even if barriers posed by the high cost of biotechnology research drops, new firms and public institutions may be unable to gain access to the information for, or the right to, create new products—such as customized seeds for micro-climates or transgenic crops that do not require pesticides (Conway, 1999). "Public sector plant breeders ... are handicapped by the high disparity in resources and negotiating power between themselves and the companies [who closely guard their proprietary technologies]" (Conway, 1999).

# Yields and Wildlife

Finally, it is not obvious that high yields correlate well with acreage in wilderness and enhanced benefits for wildlife nor that low yields are necessarily detrimental to wildlife. Wildlife and agriculture, for example, are not necessarily incompatible—farmland can support a broad diversity of wildlife as well as water quality and flood control benefits (Pretty, et al., 1998). And, while expansion of agriculture into wilderness areas can occur because of high prices for commercially traded foods and fibers—perhaps as a result of low yields relative to quantities demanded—expansion can also occur as poor farmers pursue low-input extractive farming systems for a subsistence living. The latter motivation may have little to do with world yields or prices. A study of the Amazon forest, for example, found that intensifying existing cropland use did not remove the pressures of deforestation (Carpentier, et al., forthcoming).

# On Defining a Precautionary Approach to Biotechnology and the

## Environment

The pace of biotechnology advances and adoption have been so rapid that they are outstripping our knowledge and the capacity of our institutions. Complicating the situation is the lack of a credible, mature information base by which to evaluate environmental concerns; empirical evidence is just beginning to emerge. While some of the biotechnology firms have information on biotechnology product performance, at least some of this information is guarded as intellectual property (Ransom, et al., 1998).

The outstripping of our science knowledge combined with missing markets implies that responsible regulatory agencies have little information to assess the long term effects of biotechnologies. While the U.S. federal government has protocols in place to evaluate biotechnologies for expected environmental effects, a unified approach across agencies, responsive to the missing markets discussed above, does not exist. This lack of adequate regulatory framework is complicated by the need for countries to adopt acceptable rules and regulations that govern the trading of biotechnology products.

## Elements of a Precautionary Approach

For these reasons, a cautious approach to approving and diffusing biotechnologies seems appropriate. The global cost of being cautious generally should not be large. Transgenic crop technology can come on stream rapidly after more science has accumulated, and after adequate monitoring and reviews have been conducted, to assure that excessive environmental and other risks are not present. To continue with the current aggressive effort to market the technology carries two different risks. One, the potential costs of not being cautious are serious environmental effects, some may be irreversible. Two, the loss of the technology is possible if large damages or a strong public backlash prematurely stops development and diffusion.

Having made the argument for caution, a moratorium on all biotechnologies in all countries does not follow. Pretty (1999) and the Royal Society (1998) have made clear that this technology has very different strands, some for which we have good science with little apparent risk, and others for which we have only meager understanding with large potential environmental effects. Thus, adopting a precautionary approach does not mean suspending development and diffusion of all products or in all countries. If a product shows genuine productivity or other benefits such as, economic, health, or environmental advantages, with little risk, it should be a prime candidate to move to practice. That judgment or decision will likely depend on the particular country's economic, social and environmental conditions, and cannot be generalized.

We envision four elements in a precautionary approach to biotechnology:

*1. Build a credible scientific base, including a comprehensive monitoring system, by which to evaluate biotechnologies and their impact.*

Wise decisions about the development and diffusion of biotechnologies must begin with sound understandings of their productivity, economic, health, environmental, and social effects. We have emphasized the absence of such a knowledge base and the importance for avoiding negative effects and capturing the full potential benefits of the technology.

*2. Increase investment in public research and development for biotechnology to assure that the public good aspects of biotechnology receive adequate attention.*

The growth of private funding, particularly when coupled with difficulties in access to certain germplasm because of patent laws, can lead to neglect of research with high rates of social return but with low rates of short and/or long-term private profits. This research includes basic research as well as research such as that addressing conservation and the environmental problems, alternative farming systems, rural development impacts, and nutrition and food access issues (Merrigan, 1999; Welsh, 1999).

*3. Reform institutions that concentrate control of the development and diffusion of biotechnologies (e.g., U.S. intellectual property) and thereby diminish product access and diversity.*

Much of economic theory argues that patents serve many useful purposes—such as motivating inventions and leading to commercialization of products (Mazzolini and Nelson, 1998). However, the most basic question of whether and under what circumstances patents stimulate or interfere with technical advance remains unanswered (Mazzolini and Nelson, 1998). The privatization of information including germplasm has serious implications with respect to the provision of public goods as well as the distribution of biotechnology benefits to the less fortunate of the world. As one observer asserts,

> "We've lost the proper balance between private and public interests and have failed to establish a public commons. ... In cyberspace, the new information economy, and the university, connectivity and openness should be paramount. Lately we've been heading the other way" (Charles Nesson as reported by Dodds, 1999).

As a response, one expert on patent law recommends setting aside public domain information preserves as well as updating antitrust law to prohibit "conceptual monopolies" from controlling ownership to particular fields of knowledge (Dodds, 1999; King and Stabinsky, 1999). Others (e.g., Merrigan, 1999; Welsh, 1999) acknowledge deep concerns, but call for creative legal research to reform intellectual property rights.

*4. Develop appropriate regulatory frameworks for biotechnological products.*

Given the vast importance of the agricultural biotechnological revolution for food, energy, human health and the environment, an independent over-arching body commissioned by the government may be needed to evaluate the full sweep of issues emerging from the transgenic crops. The Royal Society Committee endorsed the creation of such a body in the U.K. The U.S. does not have such a body. Building such as institution in developing countries with little science infrastructure or regulatory apparatus will be a formidable challenge. The greatest challenge may be in creating an effective international institution empowered to govern the diffusion of biotechnologies that carry transboundary environmental risks. None exists at this point.

# Conclusion

The stakes for assuring sound oversight and decisions about transgenic crops and animals are large. Designing appropriate regulatory institutions is not only in the interests of those concerned about negative environmental effects, but of the industry as well. If a large human or environmental health catastrophe emerges due to poor national or international oversight, it could not only cause a short-term setback for the industry, but also jeopardize the entire future of biotechnology and its considerable potential. In the U.S., the nuclear power industry experienced this set of events and has never fully recovered. Hence, sound precautionary approaches that create ex ante safe minimum standards and avoid large irreversible losses for industry and the environment seem prudent.

# Endnotes

[1] Insect resistance is achieved with *Bt* crops—mainly corn and cotton—when the *Bt* insecticidal toxin is expressed by all the cells of the plant, thereby killing pests that feed on the leaves and presumably reducing the need to use certain conventional pesticides (Pretty, 1999). Herbicide tolerance in crops such as soybeans, canola, and sugar beets, allows for application of broad spectrum herbicides to the desired crop without damage, but with the suppression of weeds (Pretty, 1999).

[2] Obtaining the intellectual property rights for certain germplasm also better positions companies to profit from the second generation of agricultural biotechnology products—output quality traits.

[3] For the purposes of this paper, we are not addressing possible food safety issues such as possible toxic or allergenic effects from inserted genes, from non-food genes inserted in foods, antibiotic resistance or from unintended expression of other plant traits due to insertion of new genes (see, The Royal Society, 1998).

[4] Yields results have been quite variable with some crop/region combinations not seeing yield differences and some with spectacular yield results. In one Midwest region, farmers planting *Bt* corn had yields 30 percent higher than conventional, non-modified crops.

[5] To be meaningful, the comparison should be the number of Monarch butterflies killed with the trangenics and without the transgenics, but with the use of conventional pesticides.

[6] Furthermore, if farmers have to resort to pre-emergent herbicides, they may negate the benefits from the planting of herbicide tolerant plants (Hubbell and Welsh, 1998).

[7] Dr. Bruce Tabashnik, Head of Entomology at the University of Arizona notes that there is already evidence of *Bt* resistance for several insects in the U.S., Central America and Asia (Hargrove, 1998).

[8] There is an additional assumption embedded in this argument: once a nation’s agricultural needs are met, cultivated land will be returned to wild habitat (Pretty, et al., 1998).

[9] The Green Revolution was primarily driven by public investments in plant breeding (Conway, 1997). As early as the 1950s, plant breeders of the sixteen International Agricultural Research Centers (IARC’s) supported by the Consultative Group on International Research (CGIAR) as well as National Agricultural Research Systems (NARS) developed modern varieties of plants to be grown in a wide variety of conditions in the less developed world.

[10] Low exclusion goods are goods which are relatively easy to "privatize"; that is, there are low transaction costs to exclude any potential user from access to the good is low. In contrast, high exclusion goods are

characterized by high costs to exclusion.

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