cloning farm animals, the easier it will be to clone humans.

In addition, there is the question of the impetus underlying farm animal cloning. Why is this technology being pushed so hard in a society that has an overabundance of cheap food? There is clearly no need for additional calories in the US and Europe, and the majority of the US population say they would not eat meat from cloned animals[17]. Assuming that the undertaking becomes economically viable, the only benefactors of farm animal cloning, aside from a few individuals with prize animals, will be the companies that own the technology. Perhaps it is the goal of agribusiness to control our food supply through the introduction of patented genetically manipulated and cloned agricultural products. This goal is close to being achieved in the arena of seed production[18], and the next logical step is the farm animal. If animal clones and their derivatives achieve the legal status of the GM crop plant, then patent law could dominate the animal side of our food chain just as it now does with corn and soybeans.

Finally, the FDA has stated that there will be no mandatory labeling of food derived from cloned animals or their progeny. Exactly as was done with GM crops[19], the FDA has determined that the product is indistinguishable from the original on the basis of meager compositional data from research funded by those who own the technology[1,3–5]. As the FDA is determining if cloned animal products are safe, it has decreed that there is no need for consumers to know what they are eating. In concert, the producers claim that once the product is available to the public, the market will determine its viability. These statements are clearly contradictory, for unless consumers know what they are purchasing based upon required labeling, they have no basis on which to make a choice and thereby influence the market. Therefore, there is clearly not only a right to know what is on the dinner plate, but based upon the uncertainties and risks associated with farm biotech, a need to know as well.

COMPETING INTERESTS STATEMENT

The author declares that he has no competing financial interests.

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Biofuels and biocontainment

To the editor:

If the large spread on alternative fuels in last July's issue is any indication, there are both economic and environmental benefits to replacing fossil fuels with biofuels[1]. It is difficult to imagine that transgenic technologies will not be pivotal in transforming the process of going from grass to gas[2], in particular enhancing the production of lignocellulosic-based plant feedstock and its conversion into ethanol or biodiesel. Although biotech has an opportunity to increase yields and efficiency of bioenergy crop production as well as aid the conversion of complex carbohydrates and plant oils to fuels, unless modifications are performed with an eye to meet future regulatory and consumer issues, these potential benefits might never be realized. Here, I outline some important issues concerning containment as they relate to the future development of bioenergy crops.

Biotech can be envisaged as an aid in plant-based feedstock development in at least two ways. First, as many plants that could be used in bioenergy are wild to semidomesticated in nature and not amenable for optimal controlled growth and harvest, molecular approaches can hasten improvements in domestication and productivity. For example, using green revolution genes identified through several recent genomics efforts, mutant alleles could be overexpressed in transgenic plants or RNA interference used to silence endogenous genes. Second, as many of the proposed feedstocks pose significant challenges to current processing and fermentation technology, biotechnological enhancements can be used to improve bioenergy-related traits of the plants themselves. Thus, cell wall components could be altered to produce substrates that are more easily converted to bioethanol. Examples include the decrease of lignin and simultaneous increase of cellulose components in cell walls or the direct overexpression of cellulases in plant cells to drastically decrease the cost of conversion of cell walls to ethanol[3]. For biodiesel crops, oil traits could be potentially altered for better processing and usability features. These are all within the realm of today's biotech.

There are two schools of thought concerning the choice of bioenergy crop development for bioethanol and biodiesel. One school holds that current crops have the most promise. The second approach is to adopt new and potentially novel bioenergy crops. Although the former approach might have the most immediate impact, it is fraught with biocontainment issues.

In the United States, nearly all bioethanol comes from corn seed. Many people are quick to point out that the 'stover' or straw, the non-grain part of the plant, is currently wasted and could potentially be used for lignocellulosic conversion[4]. On the biodiesel side, traditional oilseed crops, such as soybean, are touted as the most appropriate bioenergy crop candidates[1]. There is merit to these arguments as farmers are already well versed in cultivating these crops and could use existing harvesting and processing equipment. Why reinvent the wheel?

There are several reasons why this is a bad idea. Other than the potential ethical dilemma of having to choose whether to use biomass for fuel rather than food or feed (although the use of stover obviates that question), genetic modification of a food crop for industrial purposes poses biosafety and regulatory issues that might be irreconcilable. The most obvious problem is the segregation of a genetically modified industrial bioenergy crop in time and space from its counterpart used for food or feed. Certainly, genetic engineering of enhanced domestication traits would be less of an issue than for bioenergy traits themselves. But biotechnological manipulation of cellulases or other cell wall composition traits in corn, soybean or other food crops would likely raise new concerns from regulatory and consumer perspectives.

On the regulatory side, history has shown that it is nearly impossible to prevent industrial or pharmaceutical crops from entering the human food chain or feed when grown in proximity to one another. Low levels of adventitious presence of agronomic traits have been tolerated to some degree, but there is less tolerance for pharmaceutical and industrial transgene adventitious presence in the food chain.

From the consumer perspective, public acceptance of transgenic energy crops—which is likely to depend on how well the issue of admixture with crops intended for consumption is addressed—will be especially important early on in the process of adoption. It is easy to imagine rising fuel prices at the pumps compelling biotech solutions for bioenergy attractive to consumers, but not at the cost of compromising real or perceived food safety. Last year, Anheuser Busch (St. Louis, MO, USA), the beer company, actively opposed Ventria BioScience's (Sacramento, CA, USA) cultivation of a pharmaceutical-expressing transgenic rice near commercial rice-growing areas in Missouri because of worries of adventitious presence. In the same vein, in 2003, the Grocery Manufacturers of America (GMA) and other commercial food associations filed a comment to the US Department of Agriculture Animal and Plant Health Inspection Service (Washington, DC) concerning regulation of transgenic plant trials to reiterate GMA's position on protecting food from the adventitious presence of pharmaceutical and industrial transgenes[5]. Adventitious presence is simply a risk that the food industry is not willing to encumber in these instances. Thus, it currently appears that genetically modifying a food crop or a plant that is sexually compatible with a food crop is a nonstarter for bioenergy applications. This leaves us with the second option of using biotech to help create new bioenergy crops that are not related to food crops.

Examples of such plants are poplar, switchgrass, miscanthus and big bluestem, which are considered to have energetic, economic and environmental advantages over food crops[1]. Taking the first two as examples, poplar is amenable for genetic transformation, has a great deal of genomic resources (including a draft sequenced genome[6]) and is a candidate for short-rotation cropping every five years or so; on the downside (like other trees), it disperses its seed and pollen much farther than other crops, it does so for many years before harvesting and it has many wild relatives into which it can outcross. Switchgrass, on the other hand, is a perennial grass and is amenable to high-throughput transformation[7]. On the downside, it has comparatively limited genomic resources available (although the US Department of Energy Joint Genome Institute has undertaken an expressed sequence tag sequencing project). Both these species are native to North America where they could be grown as bioenergy crops, thus regulators and the public will probably desire that transgenes be contained in commercial fields of poplar or switchgrass and not flow to wild populations.

As poplar is typically established using vegetative cuttings, complete ablation of flowering (that is, complete sterility) would be the best means of containment as stand establishment would not be compromised[8]. In fact, because both seeds and pollen can move long distances in nature, absolute sterility is the only fail-safe containment method. Until now, sterility technologies have proven difficult to put into practice. Currently, delayed flowering and removal of transgenes in pollen through site-specific recombination are the most feasible techniques to decrease gene flow from transgenic poplar[8].

Switchgrass, once it is established in a field by seed (most likely) or cuttings, would remain in a stand permanently, only to be mown for regrowth several times per year. This harvesting of above-ground biomass will strongly mitigate gene flow to wild populations in switchgrass and other perennial grasses. Even so, as with poplar, delaying flowering and transgene excision from pollen would provide a fail-safe for biocontainment, in which the predominant possible route of gene escape to native populations would be through pollen flow.

It is important that biotechnological improvements for bioenergy crops are carefully considered for biosafety features now before burgeoning resources are spent to develop transgenic varieties. Given that growing genetically modified food crops containing bioenergy-explicit traits will be difficult, at best, for regulatory control and consumer acceptance, the optimal types of specialized biofuel crops are likely to be perennial and perhaps indigenous plants currently well adapted for growth on agriculturally marginal land. The issue of endogeny is of special importance because transgene-flow control in geographic centers of diversity is also an ecological concern[9]. Because large tracts of land will likely be planted in bioenergy crops, there are important ecological considerations for sustainability. We need to prepare now to detour obvious roadblocks on the road to biofuels sustainability. One enduring lesson from agricultural biotech is that it is a huge mistake to underestimate biosafety concerns. A corollary is that Nature will always find a way; Murphy's law implies that no matter how unlikely it seems that genes will flow, they eventually will.

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