Benefits to farmers and others. The total benefits from farmers adopting any new cropping technology are approximately equal to the benefits per acre times the number of acres affected. With pest-resistant crop varieties, these benefits come primarily from reduced costs for applying chemical pesticides and increased yields, after an allowance for regulatory requirements for refugia to manage resistance. The distribution of these total benefits between farmers (and ultimately food and fiber consumers) on the one hand, and the technology suppliers on the other, is determined by the size of the premium charged for the use of the new technology, but this premium also affects the incentives for farmers to adopt the technology.

Economic studies suggest that farmers and biotech companies have shared in the benefits of biotech crops and that the net benefits have been large. Gianessi et al. (2002) conducted 40 detailed U.S. case studies of biotech cultivars. They estimated that in 2001, eight biotech cultivars adopted by U.S. growers provided a net value of $1.5 billion to growers, reflecting increased crop values and cost savings. They further estimated that the 32 other case-study cultivars would have generated an additional $1 billion in benefits to growers if they had been adopted, bringing the total potential benefit in 2001 to $2.5 billion. Of this annual total, the lion's share was for herbicide-tolerant crops ($1.5 billion per year), followed by insect-resistant crops ($370 million per year). These estimates do not represent the total economic impact because the geographic analysis was limited in scope, and they do not include any benefits to the seed companies and biotech firms that produced the technology.

Environmental concerns. Private benefits and costs from biotech crops accrue to growers and consumers of the products, along with seed companies and biotech firms. If the new technology involves environmental risks (as some fear may be the case with biotech crops) or replaces technology that involves environmental risks, there will

Diversity of horticultural biotech crops contributes to market hurdles

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Why is the acreage of biotech agronomic crops continuing to increase while commercialization of horticultural biotech products stagnates? Representatives of the horticultural industry offered a variety of explanations at a workshop in Monterey in March 2002 (see acknowledgments below).

Species diversity. Virtually all of the biotech crops currently grown are in four species (soybean, corn, cotton and canola). This contrasts with the hundreds of horticultural species and thousands of fruit, vegetable and ornamental crop varieties. In most cases, specific procedures are required to genetically transform each species, and the ease with which different varieties can be transformed varies widely. Introducing a trait into a specific crop and variety may require considerable research and development. The diversity of propagation and marketing mechanisms also presents challenges, as many horticultural crops are vegetatively propagated from cuttings or grafting rather than by seed, or are perennial, bringing different issues for containment, stewardship and value.

Multiple niche markets. Unlike the commodity agronomic crops, horticultural markets are highly segmented by factors such as location, season and consumer preferences. The horticultural market is composed of many niche markets, and any single product may be successful in just a few of those niches. People in different countries or regions prefer different colors, shapes, sizes and flavors of melons, for example. Diseases vary by location, so the types of resistant varieties required also vary. Diverse growing conditions and seasons require multiple adapted varieties — even if the product, such as broccoli, appears virtually identical — to assure availability in the market every day of the year. Consumers often prefer different colors of their favorite flower. Introducing a trait into a horticultural species likely requires its introduction into multiple varieties to achieve market success.

Limited market windows. The niche market for horticultural crops also means that any single variety is likely to be successful in only a small fraction of the crop's total market. In California lettuce production, a given variety may have a market window of only a few weeks in a specific location as production moves seasonally around the state. The potential acreage (and sales) of a variety is limited, and unless development and regulatory costs can be spread over multiple varieties, the potential returns on a biotech trait are often too small to be economically feasible (see page 106).

Many processed products are marketed internationally and regulatory approval is required in each importing country, possibly with each having different testing or labeling requirements.

Processor requirements. For most processed crops, the processor specifies the varieties grown and the raw-product standards. While existing biotech traits would be beneficial to processors, such as high viscosity in tomatoes or insect resistance in sweet corn, processors are also highly sensitive to consumer preferences and often have recognizable brand names that are much more valuable than any single product. Processors are wary of jeopardizing their overall market position by risking pickets or protests from anti-biotech activists. For example, Dole would have little interest in helping its lettuce growers control weeds with herbicide-tolerant lettuce if that would put its global pineapple and banana markets at risk.

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With regard to horticultural crops, consumer preferences vary. They may want several different melon varieties or flower colors, *left.* Garden and lawn-care products such as turfgrass, *right*, could provide inroads for genetically engineered varieties.

In addition, many processed products are marketed internationally and regulatory approval is required in each importing country, possibly with each having different testing or labeling requirements. Segregating or channeling processed products for different markets is possible, but requires extensive (and expensive) changes in current production and distribution systems.

Distribution requirements. The distribution and retailing of horticultural products is increasingly global and concentrated (see page 82). Large distribution firms can dictate standards independent of any regulatory system, so whether they agree to market a particular product can mean the difference between success and failure. Labeling on the basis of whether recombinant DNA techniques were used is not required in the United States, but it is in many other countries. There is still no consistency among countries about what should be on such a label, how much information it should provide or whether it should be voluntary or mandatory.

Traceability is the ability to track a product from the market back to the field or greenhouse where it was produced. While this is possible with some items, such as fresh flowers, fruits and vegetables, it is more difficult with products commingled during processing such as canned vegetables and fruits. Segregation of products is possible, as for organic foods, but associated costs often require higher prices for profitability.

Liability is a critical issue, as demonstrated by recalls following the discovery of Starlink corn in tortilla chips, when the transgenic variety had not been approved for human consumption. The food industry is leery of any situation where its products might be considered adulterated and require a recall. Without practical thresholds for adventitious (unexpected or accidental) presence of biotech DNA or protein in the processed product (as there are for things like insects found in agricultural products), the risk is high with little benefit to the distributor.

Consumer benefits. While the first wave of biotech products was targeted primarily to growers, incentives are needed throughout the marketing chain to share both the risks and the benefits. Products with clear benefits for consumers may be needed to develop demand; these will also likely require a premium price to compensate for the tracking and segregation needed to ensure that the promised quality is delivered. As biotechnology moves beyond the initial phase of input traits and begins to develop output and consumer traits, its developers must pay attention to the interests, concerns and requirements of all participants in the production, processing, distribution and marketing chain.

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"The Workshop on Biotechnology for Horticultural Crops: Challenges and Opportunities," held in Monterey in March 2002, was sponsored by the Giannini Foundation, UC BioStar Project, UC Davis College of Agricultural and Environmental Sciences, UC Division of Agriculture and Natural Resources, UC Agricultural Issues Center and UC Davis Seed Biotechnology Center. Presenters included Ted Batkin (California Commodities Committee and Citrus Research Board), Fred Bliss (Seminis Vegetable Seeds), Neal Gutterson (formerly of DNA Plant Technology), Susan Harlander (BioRational Consultants), Kathy Means (Produce Marketing Association), Irvin Mettler (formerly of Seminis Vegetable Seeds), Carlos Reyes (Monsanto), Chuck Rivara (California Tomato Research Institute), David Schmidt (International Food Information Council), Terry Stone (Monsanto), Larry Stults (Syngenta) and Mary Zischke (Dole Fresh Vegetables).