who did not use the technology.

The report says, however, that not all Bt crops fared as well. Although 14 million acres (5.7 million hectares) of U.S. cornfields—about one-fifth of the total corn acreage in the United States—were planted with Bt corn in 1998, the increased profits from higher corn yields did not cover the extra cost of the Bt corn seed. In addition, the Bt crop saved only 2 million of those acres (800,000 hectares) from chemical insecticides because most farmers don't bother to spray for corn borers because spraying often doesn't protect the corn. Researchers also worry that pest insects could develop resistance to the Bt toxins over the next several years because the bacteria is now so widespread. That would make *Bt* sprays ineffective, eliminating one of the few effective pest-control strategies available to organic farmers, who forswear chemical pesticides.

Another recent report takes a look at the pros and cons of Roundup Ready soybeans—a herbicide-resistant line from Monsanto—and concludes that the results were mixed. On the plus side, says report author Charles Benbrook, an independent consultant to consumer and environmental groups in Sand Point, Idaho, and a former executive director of the National Research Council's Board on Agriculture, Roundup Ready soybeans allow farmers to substitute Roundup for more hazardous and long-lasting herbicides like acetochlor. And they reduce the need for farmers to till the soil to ward off weeds, which reduces soil erosion.

But Benbrook's findings did not support industry claims that the Roundup Ready beans reduce herbicide use by allowing farmers to kill weeds with one dose of Roundup after the soybean plants have sprouted instead of dosing the fields with a variety of herbicides before and during the growing season. Instead, the Benbrook reported concluded, farmers applied two to five times more herbicides of all kinds to their GM soybean fields than to fields growing conventional soybeans. And in contrast to industry claims, a recent study by agricultural economist Michael Duffy of Iowa State University showed that Roundup Ready beans made Iowa soybean farmers no more money than farmers growing ordinary beans. Despite the increased herbicide usage, applications costs were lower, but so were yields from the GM soybeans. "You had lower income and lower costs, so it was kind of a wash," Duffy says.

Even if the technology has yielded few clear-cut benefits in the developed world, agbiotech backers say that in the developing world, new crops in the pipeline could improve yields for farmers and make tremendous strides toward reducing malnutrition and environmental degradation. A genetically engineered line of rice reported earlier this year, for example, can make more vitamin A precursor and accumulate more iron, which could prevent infections, blindness, and anemia in people in the developing world (*Science*, 13 August, p. 994). Other researchers are developing plant-based vaccines to prevent diarrheal and other diseases in the developing world, says plant biochemist Charles Arntzen, president of the Boyce-Thompson Institute for Plant Research in Ithaca, New York.

And a Cornell group is engineering a virus-resistant papaya plant that could save crops in Brazil, Puerto Rico, and Jamaica. A version of the plant, which resists the papaya ringspot virus, has already revived Hawaii's papaya groves, devastated by the virus in the mid-1990s, says plant pathologist Dennis Gonsalves, who leads the effort. "You should go back and look now—it's beautiful," he says.

But before farmers sow GM crops around the world, researchers and regulators need to do a better job assessing the ecological risks, says Ohio State's Snow: "We shouldn't just be waving our hands. There really are not enough ecologists doing this research," in part because research funds are scarce. And even biotech backers acknowledge the need for better data. "I would say that the benefits totally outweigh the risks, but we can't ignore the risks," Washington State's Cook says. **–DAN FERBER**

Dan Ferber is a writer in Urbana, Illinois.

FOOD FIGHT

▶INDUSTRY RESPONSE

Ag Biotech Moves to Mollify Its Critics

As protests continue, the developers of genetically modified crops contemplate steps, such as labeling GM foods, once considered anathema

When two of Monsanto's top executives boarded a jet this summer to take them from St. Louis to London, it wasn't just a routine business trip. They were headed for a secret meeting with the leaders of the British environmental movement—the very people who had branded the company's genetically modified (GM) food products as potential health hazards and ecological time bombs, and whose actions had helped trigger tabloid headlines like *Frankenstein Foods* and *Farmageddon*. These, the executives knew, had led an entire nation to avoid their products like poison. In short, they were going to confront their worst nightmare.

Seeing red. Protesters demand the labeling of GM foods at a demonstration held in August in Cologne, Germany.

CREDIT: SPECHT/LAIF

Monsanto was in a predicament—which is far from over—that called for drastic action. Although some studies have raised concerns about GM foods (see p. 1662), so far, there is little evidence to suggest that those currently on the market are harmful, either to human health or ecosystems. Even so, the resistance to GM foods, which largely originated in Britain, is spilling into other European countries and the developing world. Companies such as Monsanto that have bet billions of dollars—and perhaps their futures—on GM crops are suddenly looking vulnerable, as are farmers who have staked their livelihoods on the new seeds. And development experts who are counting on the new technology to feed a growing world population are looking on nervously.

"The opposition is astonishing. There's no way you can sell products in Britain that contain genetically modified organisms anytime soon. Forget it," says Julian Kinderlerer, a researcher at the Institute of Biotechnological Law and Ethics at the University of Sheffield in the United Kingdom. Even in the United States,

which has seen far less furor over the issue, leading baby food manufacturers Gerber and Heinz announced that they would permit no GM foods in their products. Worried by these developments, U.S. farmers, who have largely been embracing the new technology, are starting to balk. "Some of them are going to go back to traditional varieties next year," predicts Charles Benbrook, an independent agricultural policy analyst in Sand Point, Idaho.

Indeed, most agree that the next couple of years will be crucial for the future of GM crops—and that in the end consumers, rather than the farmers that the industry has long considered its primary customers, will decide the fate of GM foods. "It's a different ball game today," says Mike Phillips of the Biotech Industry Organization (BIO), a lobby group in Washington, D.C. "It's finally dawning on Monsanto, as well as other companies, that it's what the consumer wants [that counts]." And to placate that consumer, some companies are contemplating taking steps, such as separating biotech and nonbiotech foods and labeling those that have been modified, that the industry has always opposed.

Until recently, GM foods have been a success story. In the United States, over 40 transgenic crops have been approved for marketing, and farmers have planted an area larger than Great Britain with transgenic soy, corn, canola, potatoes, and cotton. Among U.S. consumers, the revolution has caused nary a ripple—partly, perhaps, because most people aren't aware that they're eating GM foods, as labeling isn't required. And worldwide, land area planted to GM crops grew 40% this year, to over 40 million hectares, according to industry figures.

But as GM products found their way around the globe, resistance grew, especially in Britain, where the bovine spongiform encephalopathy crisis, as well as several *Salmonella* outbreaks, have eroded public trust in food safety regulation (*Science*, 7 August 1998, p. 768). A controversial study by food scientist Arpad Pusztai of the Rowett Research Institute in Aberdeen, Scotland, which claimed to show that GM potatoes could stunt rats' growth, further fueled the flames this year (*Science*, 19 February, p. 1094), as did a May statement by the British Medical Association, which called for a moratorium on the release of new GM crops, pending further study of their health effects.

Reacting to the escalating public concern, several European supermarket chains banned GM products from their house brands, or even from their shelves. In Britain, subsidiaries of two major European food producers, Unilever and Nestlé, announced that they would phase out genetically modified ingredients in their products, and big fast-food chains like McDonald's, Burger King, and Kentucky Fried Chicken took GM food off their menus. Meanwhile, the European Union (EU) has decided that products in which more than 1% of one of the ingredients is transgenic should be labeled; and in June of this year, the EU dealt the industry a major blow by suspending the introduction of new GM crops for several years.

Headline hysteria. GM foods hit the front pages of British newspapers dozens of times this year. The headlines helped drive the foods from grocery shelves.

Monsanto and other biotech companies have also heard rumbles of unrest from the financial world. Two gloomy reports, issued by Deutsche Bank analysts last May and July, even advised investors to back out of biotech companies. Although GM crops might be perfectly safe, they may soon "be perceived as a pariah," said one of the reports, entitled "Genetically Modified Organisms Are Dead." According to the bank, a two-tier market system will likely arise, with non-GM organisms the more desirable, and thus more valuable, commodity. Indeed, one of the largest traders in corn and soybeans, Archer Daniels Midland (ADM) in Decatur, Illinois, started offering farmers a premium of 18 cents per bushel for non-GM soybeans this spring.

For years, Monsanto, backed by the U.S. government, had insisted that the European resistance was irrational and unscientific, and that there was no legal basis for stemming the flow of GM products. But those reassurances did little to win hearts and minds. On the contrary; a confident ad campaign touting the marvels of biotechnology in Britain last year backfired, says Neil Verlander, a spokesperson for Friends of the Earth, because it didn't seem to take the concerns seriously. "They got it wrong, and it hurt their image," says Verlander. The fact that the campaign coincided with a piece in *The Daily Telegraph*, in which Prince Charles declared that genetic engineering "takes mankind into realms that belong to God and God alone" didn't help Monsanto either.

But this summer, with the protests mounting, Monsanto shifted gears. Some credit Gordon Conway, president of The Rockefeller Foundation—a U.S. charity that has invested $100 million in genetic research benefiting the developing world—for pointing out to Monsanto executives that they had to change their tactics, lest biotech food become unmarketable altogether. Monsanto's trip to London, where executives met representatives of organizations such as Friends of the Earth and the Soil Association, was one of the first signs that something had changed. The trip resulted in a "healthy exchange of ideas," says Verlander. And on 6 October, Monsanto CEO Robert Shapiro personally put on the hair shirt when he addressed a Greenpeace business convention in London through a satellite link. The company's attitude had "widely been seen, and understandably so, as condescension or indeed arrogance," Shapiro admitted. "Because we thought it was our job to persuade, too often we forgot to listen."

That confession came 2 days after Monsanto had taken another step to pacify opponents. The company renounced the so-called "terminator technology," which renders the seeds produced by transgenic plants sterile—forcing farmers to buy new seed every year.

But just how much effect such conciliatory gestures will have on the market is uncertain. In early September, just before the harvest, ADM and another company, Consolidated Grain and Barge, started encouraging farmers to keep conventional and transgenic crops segregated, to make sure their products wouldn't be shut out of the market. The announcements rattled farmers, who worried that they might have bet on a doomed technology. "For a farmer, whose crop is his lifeblood, that's pretty hard to take when you're about to climb on the combine," says Tamara White, director of commodities at the Illinois Farm Bureau.

As a result, some predict that as early as

next year, many growers may switch back to non-GM varieties. For instance, the National Corn Growers Association, which unites a minority of U.S. corn growers and has taken a stance against the introduction of biotech, predicts a big backlash. Some farmers are already ordering their soybeans to plant in the spring, says Lynn Clarkson, a corn and soy trader in Serro Gordo, Illinois, because they're afraid that non-GM seeds will have run out by January, when they would normally order. They will do the same to avoid corn engineered to produce a natural pesticide, the *Bacillus thuringiensis* toxin, he says. Policy analyst Benbrook, too, predicts that sales of GM seeds will plunge for the first time next year.

The threat of falling sales has led some companies to rethink more than just their PR strategy. For years, they have resisted mandatory labeling of GM products, arguing that there was no scientific basis for concern, and that consumers might interpret the labels as indicating that the products are unsafe. Together with the U.S. government, the companies branded the European insistence on labeling a form of protectionism. The issue is on the agenda of the next ministerial meeting of the World Trade Organization, starting 29 November in Seattle.

But the tide may be turning. Novartis, for instance, doesn't object to mandatory labeling, a position that was once seen as maverick within the industry but is now gaining acceptance, says Willy De Greef, head of regulatory and government affairs at Novartis Seeds. Labeling, says De Greef, "is also a way to show confidence ... in the safety and quality of our products." And it may not be the consumer turnoff that many fear, he says. In the Netherlands, GM foods have carried the neutral phrase "produced with modern biotechnology" since 1997. "There were some jitters at first, but eventually sales have stabilized," De Greef says.

Within the U.S. government, too, there are signs that a compromise on the thorny issue may at least be up for discussion. "I have a sense that the consumers have spoken, and they say: 'We want the damned stuff labeled,' " said U.S. Undersecretary of State for Global Affairs Frank Loy at a recent meeting at the New York University School of Law, "so one ought to discuss labels."

But there's a catch: Farmers and traders will have to segregate their crops. And although that may work for small markets, it will pose problems for crops such as soy and corn, which are brought together in huge quantities and then shipped by rail or barge. Keeping GM and non-GM crops apart on a large scale, the BIO's Phillips says, would require huge investments in infrastructure. "The Europeans will have to pay for that," he adds.

Meanwhile, the industry is hoping that a new wave of GM products receives a warmer welcome. Most transgenic crops so far have made life easier for farmers and seed producers, but offer little to the consumer. A "second generation" of products in the pipeline may be better accepted. Some plants will lack allergenic proteins, for example, or have a healthier oil composition. They may also provide benefits for developing countries, such as the pro–vitamin A and iron-enriched rice produced earlier this year (*Science*, 13 August, p. 994).

The big question, however, is whether developing countries will carry out their own risk analysis or simply adopt the European angst, says Sheffield's Kinderlerer, who has acted as a biotechnology consultant to governments in Asia, Africa, and Latin America. Already, "people are saying, if Europe is scared, shouldn't we be?" he says. "That's worrying, because we don't really need the technology. They do." **–MARTIN ENSERINK**

ART AND SCIENCE

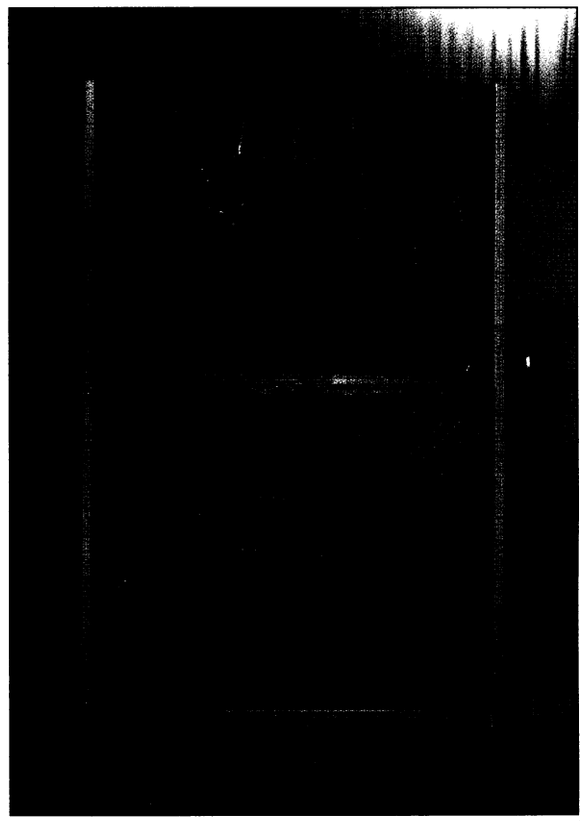
Duchamp and Poincaré Renew an Old Acquaintance

What did the groundbreaking modernist painter learn from the father of chaos? Art historians and mathematicians debate the question

It was not your usual scientific conference. Talks on algebraic topology took turns with passages from Mallarmé's poems. Lectures on Duchamp's Large Glass shared an auditorium with sessions on celestial mechanics. But that's what you get when mathematicians and historians of science lock horns with art historians and postmodern theorists, as they did at Harvard University, 5 to 7 November.

Some 200 scholars crossed higher-than-usual disciplinary walls to attend "Methods of Understanding in Art and Science: The Case of Duchamp and Poincaré," a conference organized by Rhonda Roland Shearer, a New York City–based artist, and her husband, Harvard biologist Stephen Jay Gould. (Gould is also the president of AAAS, which publishes *Science*.) The conference was a coming-out party of sorts for Shearer's recent findings—or flights of fancy, as skeptics see them—regarding the pioneering modern artist Marcel Duchamp and his take on the writings of the mathematician Henri Poincaré. Shearer and Gould, who co-authored a recent essay in *Science* (5 November, p. 1093) on the relationship of art and science, founded the Art Science Research Lab in their New York home to take a fresh look at Duchamp's oeuvre. With colleagues including Richard Brandt, a physicist at New York University (NYU), they have gathered evidence that Poincarean ideas lurk behind several of the artist's most famous works—and as a result, these works are not what they appear to be.

In a way, that's not surprising. Duchamp (1887–1968), widely regarded as the founder of modern art, loved to foil his



"The Bride Stripped Bare By Her Bachelors, Even." Also known as the Large Glass, it may reflect Poincaré's ideas about creativity.

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