Economist Online Debate on Motion –
"Biotech and sustainable ag go together, not against each other."

Benbrook Opening

Biotechnology is not a system of farming. It reflects no specific philosophy nor is it guided by a set of principles or performance criteria. It's a bag of tools than can be used for good or evil, and lots in between.

Virtually all contemporary applications of molecular biology, in any field, are part of biotechnology and many aspects of biotechnology can and should be tapped to advance science and promote sustainable agriculture on all types of farms – large, small, conventional, sustainable, or organic.

But that is not what this debate is about. The issue at hand is whether genetically engineered (GE) seeds "go together" with sustainable agriculture. This debate must be grounded in how, and for what purposes, genetic engineering is used today on the farm, in contrast to sustainable agriculture.

Sustainable agriculture, otherwise known as agroecology –

- Integrates crop farming with livestock;
- Promotes diversity in the crops a farmer grows, livestock enterprises, and in human diets, which in turn promotes health, system resiliency and minimizes risk of catastrophic crop failure;
- Relies as fully as possible on local resources, and farmer skills and labor, while lessening dependence on off-farm inputs;
- Builds soil quality and fertility to produce higher-yielding crops (i.e., the "brown revolution" recently called for by Howard Buffet);
- Strives to prevent problems by altering the biology and/or ecology of system interactions, rather than treating problems by adding a new input, practice, or technology into the system.

Today, biotechnology on the farm consists almost exclusively of corn, cotton, and soybeans engineered to make plants herbicide-tolerant (HT) and/or resistant to certain insects. HT crops account for 84% of the global biotech acreage, 62% as a stand-alone trait and 22% combined with insect resistance.

HT technology allows farmers to rely largely or exclusively on one broad-spectrum herbicide. Multiple herbicide applications can be made, including after the crop has germinated, applications not possible prior to HT technology because the crop would be damaged too.

Scientists accurately predicted the dominant impact of HT technology – an increase in reliance on chemical herbicides and, in particular, on one herbicide (glyphosate, or Roundup).

In light of the intended purpose and impacts of HT crops, let's assess whether biotechnology and sustainable agriculture "go together."

Does HT technology help or hinder integration of crop farming with livestock? It is essentially neutral.

Does HT technology promote diversity in crop rotations and human diets? No on both counts. It promotes specialization and farm consolidation, and shifts acres to grain crops mostly fed to animals, or used for ethanol or food processing ingredients. In Argentina, HT soybeans have displaced 4.6 million hectares of diverse crops and pasture, reducing local access to a healthy, diverse diet.

Does it seek to make full use of local resources and farmer skills? No, HT crops reduce the need for labor and skill, and increase reliance on high-cost, often proprietary inputs from outside the region.

Does HT technology help prevent problems through management? Definitely not. It is a treatment-based intervention that when overused, creates new weed problems. In the case of HT soybeans, it also impairs the uptake of micronutrients from the soil and worsens some plant diseases.

It's hard to get to "Yes," biotech and sustainable agriculture go together, with one neutral and three "No" answers to the above questions.

Corn and cotton have also been genetically engineered to manufacture natural toxins from a soil bacterium that are lethal to some insects. *Bacillus thuriengensis* (*Bt*) crops account for 38% of biotech acres worldwide, of which 22% are combined with the HT trait.

Bt corn and cotton are largely neutral in terms of crop-livestock integration, and like HT crops, do not promote diversity in food production nor self-reliance. They do help reduce insect feeding damage and lessen the need for toxic, broad-spectrum insecticides, and as a result, help build populations of beneficial insects and promote above-ground biodiversity, two key sustainable farm management goals.

But these *Bt* crop benefits come at a cost. Toxins are produced 24/7 in all plant tissues, not when and only where they are needed. This increases the risk that common corn and cotton insects will develop resistance. In regions where *Bt*-resistant insects routinely overwinter in fruit and vegetable crops, farmers will no longer be able to rely on *Bt* insecticide sprays, which are currently their safest and cheapest option. Technologies that solve one problem at the expense of others cut against the grain of prevention-based sustainable agriculture.

Single-tactic solutions to complex farming system problems often work well for a while, but organisms and systems co-evolve, often opening the door to new problems. Multiple-tactic systems composed of "many little hammers" offer the best hope for sustained progress. Biotechnology can help create new hammers and harden existing ones through marker-assisted breeding and the development of new diagnostic tools, vaccines, biopesticides, and soil inoculants. But not the way it is being used today on the farm.

Ronald Opening

The number of people on Earth is expected to increase from the current 6.7 billion to 9 billion by 2050 with food demands expected to rise by 70%. How will we feed them? If we continue with current farming practices, vast amounts of wilderness will be lost, millions of birds and billions of insects will die, scarce water will be wasted, greenhouse gas emissions will increase and farm workers will be exposed to harmful chemicals (http://www.sciencemag.org/cgi/content/abstract/307/5709/550). Clearly, the future of our planet requires that we maximize the positive environmental, economic and social impacts of our global farming systems-- the three essential pillars of sustainable agriculture. Genetically engineered crops will continue to play an important role in this future (http://www.national-academies.org/morenews/20100413.html).

After 10,000 years of crop domestication and innovation, virtually everything we eat has been genetically altered and every farm today grows such crops. Genetic engineering differs from conventional methods of crop modification in two basic ways: GE introduces one to a few of well-characterized genes and, with GE, genes from any species can be introduced into a plant. In contrast most conventional methods of genetic alteration (artificial selection, forced inter-specific transfer, random mutagenesis and grafting of two species to create a new variety) introduce many uncharacterized genes from closely related species.

There is broad scientific consensus that GE crops currently on the market are safe to eat. (http://www.nap.edu/catalog.php?record_id=10977). The National Research Council (http://sites.nationalacademies.org/NRC/index.htm), a nonprofit institution that provides science, technology and health policy advice to congress and the world, reports that the process of genetic engineering poses similar risk of unintended consequences as conventional approaches of genetic alteration. After 14 years of cultivation and a cumulative total of 2 billion acres planted, GE crops have not caused a single instance of harm to human health or the environment (http://www.nap.edu/openbook.php?isbn=0309082633). In contrast, every year there are thousands of reported pesticide poisonings (ca. 1200 each year in California alone; 300,000 deaths globally). The NRC findings have been confirmed by top scientific agencies around the world. For instance, the Joint Research Centre, the European Union's scientific and technical research laboratory and an integral part of the European Commission recently concluded that there is a comprehensive body of knowledge that adequately addresses the food safety issue of GE crops and that the crops currently on the market have not caused any known health effects (http://ec.europa.eu/dgs/jrc/downloads/jrc_20080910_GEo_study_en.pdf).

Well documented benefits of GE crops include massive reductions of insecticides in the environment (http://www.sciencemag.org/cgi/content/abstract/299/5608/900) (http://www.sciencemag.org/cgi/content/full/308/5722/688), improved soil quality and reduced erosion (http://www.national-academies.org/morenews/20100413.html), prevention of destruction of the Hawaiian papaya industry (http://www.ars.usda.gov/research/publications/publications.htm?SEQ_NO_115=17807), proven health benefits to farmers and families growing GE crops due to reduced exposure to harsh chemicals (http://www.sciencemag.org/cgi/content/abstract/295/5555/674) (NRC) (http://www.sciencemag.org/cgi/content/abstract/sci;308/5722/688?maxtoshow=&hits=10&RESULTFORMAT=&fulltext=Insect-resistant+GE+rice+in+farmers%92+%26%2364257%3Belds%3A+Assessing+productivity+and+health+e%26%2364256%3Bects+&searchid=1&FIRSTINDEX=0&resourcetype=HWCIT), economic benefits to local communities (Sadashivappa and Qaim, Annual review of Resource Economics, 1:655 (2009)), enhanced biodiversity of beneficial insects (http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1457091/), reduction in the number of pest outbreaks on GE farms and neighboring non-GE farms and increased profits to farmers (http://www.sciencemag.org/cgi/content/summary/sci;330/6001/189?maxtoshow=&hits=10&RESULTFORMAT=&fulltext=tabashnik&searchid=1&FIRSTINDEX=0&resourcetype=HWCIT).

GE crops have also dramatically increased crop yields (greater than 30%) in some farming communities (Sadashivappa and Qaim, Annual review of Resource Economics, 1:655 (2009)). Because substantial greenhouse gases are emitted from agricultural systems, and because the net effect of higher yields is a dramatic reduction in carbon emissions, development and deployment of such high-yielding varieties will be a critical component of a future sustainable agriculture (http://www.pnas.org/content/107/26/12052.full).

In the near future, conservative models predict that planting of Golden rice, a rice engineered to produce provitamin A, will reduce diseases caused by vitamin A deficiency, saving the lives of thousands of children http://www.ajstein.de/cv/golden_rice.htm). Golden rice is likely to be more cost-effective than alternative vitamin A interventions, such as food supplementation or fortification. In Africa, where three-quarters of the world's severe droughts have occurred over the past 10 years, the introduction of genetically engineered drought tolerant corn, the most important African staple food crop, is predicted to dramatically increase yields for poor farmers.(http://www.aatf-africa.org/userfiles/PressRelease-WEMA-CFT.pdf.

A premise basic to almost every agricultural system (e.g., conventional, organic and everything in between) is that seed can only take us so far. The farming practices used to cultivate the seed are equally important. GE crops alone won't provide all the changes needed in agriculture. Ecologically-based farming systems and other technological changes, as well as modified government policies, undoubtedly are also required. Yet it is hard to avoid the conclusion that ecological farming practices using genetically engineered seed will play an increasingly important role in a future sustainable agriculture. Each new variety will need to be tested on a case-by case basis in light of the criteria for a sustainable agricultural system.

There is now clear scientific consensus that GE crops and ecological farming practices can coexist -- and if we are serious about building a future sustainable agriculture, they must.

Benbrook Rebuttal –

I agree with Pam that rapid and sustained progress must be made toward food security if there is to be any hope of a more peaceful and healthy world. But in terms of meeting the food needs of the world's poor, today's GE crops have not made much of an impact. Over three-quarters of the grain from GE corn and soybeans is fed to pigs, chickens and cows for the benefit of the approximate one billion richest people on earth. An increasing share of GE corn is also going to ethanol, and indeed, the diversion of land and crops to biofuels looms as one of the most destabilizing developments in human history.

<u>Feeding the World</u> Those advocating GE as the solution to world hunger seem to gloss over the fact that poverty is clearly the primary cause of hunger. Three currents of change must come together with rural economic development to advance food security:

1. Pest losses and food waste must be cut dramatically (e.g., by one-half).

2. Dietary patterns must shift toward crops that provide more human food calories and diverse nutrients per acre/hectare (e.g., potatoes, squash, beans, berries), with relatively less reliance on grain-fed livestock products.

3. Soil organic matter must be restored to allow sustainable yields to increase.

Policy changes and targeted investments are needed to systematically channel these three “currents” to close the gap between food needs and supplies, so that international food aid and regional storage schemes can largely eliminate chronic hunger.

Will insights and innovation made possible by biotechnology help? Of course, by helping create new biopesticides, soil inoculants, vaccines, plant varieties resistant to new and old pests, and advanced diagnostic tools.

Will herbicide-tolerant corn and soybeans, today’s GE heavy hitters, make a significant contribution? Not likely.

Yields Pam claims that in some areas GE crops have “dramatically increased yields (greater than 30%)…” The two hot new GE crops for 2010 in the U.S. were Roundup Ready 2 (RR2) soybeans and SmartStax corn. The former is a new, “improved” version of old herbicide-tolerant (HT), Roundup Ready soybeans, and SmartStax is a Dow-Monsanto corn hybrid with eight GE traits, six different *Bts* to control two major insects, and two HT traits.

Monsanto claimed these new GE products would increase yields over 10% and charged dramatically higher prices per bag of seed in 2010 compared to 2009 – <42% higher in the case of RR2 beans and 36% higher for SmartStax corn; http://www.organic-center.org/reportfiles/SeedPricesReport.pdf >. The promised yield increases did not materialize in several parts of the country, triggering legal action by one state Attorney General who wants to <access and review; http://www.bloomberg.com/news/2010-10-25/west-virginia-ag-sues-monsanto-over-soybeans.html> the basis for Monsanto’s pre-season yield claims.

Today’s GE crops were not intended to increase yield potential, but they can help reduce pest losses. Where farmers are not successfully managing pests, a GE crop can help sometimes, and has in some places. But benefits to farmers cover GE seed price premiums in some but not all cases. Plus, <herbicide use and expenditures;http://www.organic-center.org/reportfiles/GE13YearsReport.pdf > have risen dramatically in recent years on HT crop acres because of the spread of resistant weeds.

Alternative systems can often increase yields more so than GE seeds. A recent FAO <review of sustainable agriculture systems; http://www.un.org/esa/dsd/resources/res_pdfs/publications/ib/no7.pdf> concluded that yields were increased an average of 79% across eight systems of agriculture, compared to conventional “best practices.” One specific alternative, the <“Sustainable Rice Intensification”; http://www.fao.org/fileadmin/templates/agphome/documents/Rice/sustintriceprod.pdf> (SRI) system, entails an integrated set of management changes that enhance positive biological interactions within rice fields, leading to a six-fold yield increase in Gambia and 50%-100% increases in several other countries. The system also cuts water use about 40%, reduces chemical use by 40%, and cuts costs over 20%.

System changes can produce broad-based, sustained benefits; a new trait added to a transgenic crop can improve performance under specific circumstances, but rarely match the cost-benefit ratio of successful system innovation.

Safety Contrary to Pam’s opening statement, recent reports from the U.S. National Academy of Sciences acknowledge that there are important GE crop food safety and environmental issues in need of ongoing management (e.g., vastly increased herbicide use, preventing resistance, gene flow) and more careful research (e.g., allergenicity, changes in soil microbial communities). In addition, risk assessment challenges entailed in analyzing the nutritional quality and safety of GE foods will mushroom in importance and complexity if/as GE fruits and vegetables, or salmon, are approved and commercialized.

I am not among those who believe that there is now strong evidence of significant food safety risks from today's GE crops, but those who think the "science" is settled on questions of food safety for all GE foods, forever, are either blinded by an overdose of wishful thinking or unaware of a growing list of concerns raised by scientists from all over the world.

Our moderator has challenged Pam and I to get beyond the "familiar 'GE versus organic' arguments" and he wants us to explore common ground. In an attempt to do so, I will describe some ways to determine which GE technology applications "go together" with sustainable agriculture, and which do not. I will share my list with Pam before we do our closing statements and invite Pam will do the same. At a minimum, such an exchange of ideas might serve as a useful starting point for the next round in this ongoing debate.

Ronald Rebuttal –

I agree with Charles Benbrook that "*Bt* crops have helped reduce insect feeding damage and lessened the need for toxic, broad-spectrum insecticides, and as a result, helped build populations of beneficial insects and promote above-ground biodiversity, two key sustainable farm-management goals."

I also wholeheartedly agree with his statements that "Multiple-tactic systems composed of 'many little hammers' offer the best hope for sustained progress" and "Biotechnology can help create new hammers and harden existing ones".

However, he incorrectly implies that GE crops are not being used as part of multiple-tactic systems today.

Bt crops are one of the few examples where a mandatory crop diversity strategy has been implemented. Global pest monitoring data suggest that this approach has helped to sustain the efficacy of *Bt* crops against most pests for more than a decade.
http://www.nature.com/nbt/journal/v26/n2/full/nbt1382.html

For example, in Arizona, where an integrated pest management programme for Bt cotton is in effect, growers reduced insecticide use by 70% and saved more than $200 million.
http://www.ncbi.nlm.nih.gov/pubmed/19834884

Mr Benbrook describes an unlikely hypothetical scenario in which farmers can no longer rely on safe and cheap *Bt* insecticide sprays because *Bt*-resistant insects from cotton and corn "routinely overwinter in fruit and vegetable crops". This has not occurred yet despite more than a decade of use of *Bt* crops on a cumulative total of more than 200m ha worldwide. http://www.absp2.cornell.edu/resources/bio-engineeredcrops/

Moreover, while some pests of corn and cotton have evolved resistance to *Bt* toxins in GE crops, the first cases of insect resistance to *Bt* toxins occurred in response to spraying *Bt* insecticides on conventional vegetable crops—an approach favoured by organic farmers, who are not allowed to use transgenics. http://www.pnas.org/content/88/12/5119.abstract?sid=26ca2135-7f01-43b8-b74d-148ef12de967 To help delay resistance, many newer varieties of *Bt* crops produce two or more *Bt* toxins with different modes of action. http://www.pnas.org/content/105/49/19029.full

The bottom line is that strategies for managing pest resistance are needed whether farmers use GE crops or conventional crops.

Contrary to Mr Benbrook's assertion, *Bt* crops do promote self-reliance. Although farmers must buy the seed, this is the norm in any non-subsistence farming system where hybrid seed is used (organic and conventional). The advantage is that they do not need to buy and spray insecticides.

Mr Benbrook and I agree that overuse of a single herbicide can lead to the evolution of weeds that are resistant to that herbicide, which is problematic for farmers. Grower decisions to use repeated applications of particular herbicides have led to the evolution of resistant weeds. http://www.national-academies.org/morenews/20100413.html It is clear that herbicide tolerant (HT) crops need to be managed better for sustainability, rotating them with other crops or weed control methods. But this is also true of herbicide resistance traits developed through selective breeding or mutagenesis.

However, Mr Benbrook's argument neglects an important aspect of HT crops that are resistant to the herbicide glyphosate (aka Roundup). Glyphosate (a class IV herbicide) has displaced much more toxic herbicides (classes I, II and III). In Argentina, HT soyabean farmers were able to reduce 83-100% of toxicity class II and III herbicides. In North Carolina, the pesticide leaching was 25% lower in HT cotton fields compared with that of conventional cotton. http://www.nature.com/nbt/journal/v28/n4/abs/nbt0410-319.html Thus the main problem with weed resistance in HT fields is that it forces farmers to go back to the more harmful compounds that were in use before the widespread adoption of HT crops.

To mitigate the evolution of weed resistance, the newest HT varieties will have tolerance to more than one herbicide, which will allow easier herbicide rotation or mixing, and, in theory, help to improve the durability of herbicide effectiveness. Implementation of a mandatory crop diversity strategy would also greatly reduce weed resistance. These are also multi-tactic strategies.

Mr Benbrook's account also does not consider other benefits of HT crops to sustainable agriculture. HT crops have been associated with an increased use of conservation tillage, in particular no-till methods, that can improve water quality and reduce soil erosion. That farmers who use GE crops are more likely to practice conservation tillage suggests the two technologies are complementary. http://www.national-academies.org/morenews/20100413.html

In Argentina and the United States, the use of HT soyabeans was associated with a 25-58% decrease in the number of tillage operations. http://www.nature.com/nbt/journal/v28/n4/abs/nbt0410-319.html Such reduced tillage practices correlate with a significant reduction in greenhouse gas emissions, which, in 2005, was equivalent to removing 4m cars from the roads. http://www.agbioforum.org/v9n3/v9n3a02-brookes.htm

Finally, by limiting the scope of his discussion to only two traits, Mr Benbrook overlooks the benefits of other GE crops on the market. For example, in the early 1990s, Hawaii's papaya industry was facing disaster because of the deadly papaya ringspot virus (plants, like people, are susceptible to viral infection). The introduction of GE papaya resistant to the disease rescued the state's papaya industry. http://www.apsnet.org/publications/apsnetfeatures/Pages/PapayaHawaiianRainbow.aspx Today, 80-90% of Hawaiian papaya is genetically engineered, and there is still no conventional or organic method to control the ringspot virus.

In many regions, the use of biotech seeds allows successful organic production, an important marketing niche, by reducing disease spread, while enabling the remaining 97% of agriculture to become more sustainable by reducing insecticide use. This is true for organic cotton in Arizona and organic papaya in Hawaii.

Mr Benbrook's opening statement fails to address the dozens of other useful traits in the pipeline, including nitrogen use efficiency, provitamin A-enriched rice and drought tolerance.

http://www.nature.com/nbt/journal/v28/n10/full/nbt1010-1012.html

Fourteen years of extensive field studies have demonstrated that genetically engineered crops are tools that, when integrated with optimal management practices, help make farms more sustainable. The vast benefits accrued to farmers, the environment and consumers explain the widespread popularity of the technology in many regions of the world. http://www.nature.com/nbt/journal/v28/n4/abs/nbt0410-319.html

Howard Minigh* Invited Contribution (posted 11/4/10) –

Farmers have always been faced with the challenge of feeding the world's population despite pests, diseases, adverse weather and limited natural resources. Some would say they are in a constant battle with nature in order to secure our food supply. Today, more than ever, farmers are burdened with many challenges: feeding an increasing world population; producing crops despite extreme growing conditions brought on by climate change; preserving and improving scarce natural resources such as water, soil, energy, forests and air—while also stewarding the land for future generations.

To meet all these challenges, farmers must adopt sustainable agricultural practices. It is critical that farmers have access to a full range of farming tools, including everything from training in farming techniques, to machinery and equipment, to choice in inputs and seeds.

Innovative plant science technologies, including biotech crops, already play a critical role in helping growers farm more sustainably. Since 1996, when the first biotech crops were planted, farmers, consumers and the environment have all benefited from plant biotechnology. More than 14m farmers worldwide have chosen biotech crops because they increase productivity and farm incomes by streamlining farming techniques, efficiently using natural resources, increasing crop yields and helping preserve the land.

- Adoption of no-till farming. Perhaps the most profound and far-reaching environmental impact of biotech crops has been the rapid increase in no-till agriculture, a farming practice that avoids ploughing the soil for weed control in order to better conserve topsoil and moisture while reducing erosion. No-till farming is made possible through the use of herbicide-tolerant biotech crops and herbicides. Eliminating ploughing results in significant benefits in soil health, biodiversity and improved water retention in the soil.
- Improved pest management. In many parts of the world, farmers lose up to 90% of a crop harvest because of pest infestations. Biotechnology enables pest control measures that are more precisely targeted at specific pests, while dramatically reducing impacts on non-target species. Since their introduction, biotech crops have reduced pesticide applications by nearly 7%.
- Increased productivity helps to protect threatened ecosystems. As agricultural demands increase, ecosystems such as rainforests are increasingly under threat of being converted to farmland. Biotech crops

increase yields on existing farmland, which decreases the pressure from increased demand to convert more natural habitat to agriculture. Studies show that if biotech crops had not been available in 2008, achieving 2008 production levels would have required additional planting of 4.6m hectares of soyabeans, 3.5m hectares of corn, 2.2m hectares of cotton and 300,000 hectares of canola. This total area is equivalent to about 21% of the arable land in Brazil. In the future, biotech crops will be grown more sustainably by utilising nitrogen more efficiently, and by further increasing crop yields so more natural habitat and forests can remain untouched.

- Adapting to climate change and extreme growing climates. Today's biotech crops are able to maintain and increase yields despite pest, weed and virus pressures. In the future, biotech crops will provide more tolerance to drought conditions, will be able to grow in soils with a higher salt content, and will tolerate more extreme temperatures brought on by climate change. The adoption of no-till agriculture reduces the use of agricultural machinery in fields, which leads to a reduction in greenhouse gas emissions from farm equipment. Studies show that biotech crops have saved farmers 441m gallons of fuel through reduced mechanical operations. This has enabled 14 billion kilograms fewer carbon dioxide emissions—equivalent to removing 7m cars from the road. As our world is increasingly transformed by climate change, innovative plant sciences will play a role in preserving carbon sinks and decreasing greenhouse gas emissions.

The deployment and further development of plant science technologies offer real solutions in addressing food security and climate change through sustainable agricultural practices. CropLife International and its members are committed to making available the best technologies to help achieve sufficient, safe and healthy food production, improved livelihoods and the preservation of non-renewable resources. The use of plant biotechnology can increase the productivity of land already cultivated, reduce the need to farm additional land, and thus contribute to conservation of biodiversity and preservation of natural resources.

* Howard Minigh has served as president and CEO of CropLife International, a global federation representing the plant science industry, since June 1st 2006. He is the founder of HM Advisors LLC, a management advisory firm, and he was a partner at Trishul Capital Partners. From 2000 to 2003 he served as group vice-president of agriculture and nutrition at DuPont, and from 1995 to 2000 he was president of Cyanamid Global Agricultural Products, a division of American Home Products.

Moderator’s Intro to Rebuttal Round –

It is good to see the debate focusing on the pros and cons of biotechnology as it exists now, rather than what might be possible in the future. GM crops are out there today in large quantities, and the question is whether they are contributing to sustainability or not.

In her opening statement, Pamela Ronald outlined the benefits that biotechnology is, in her view, already delivering: reduced use of insecticides, less soil erosion, a "halo effect" protecting neighbouring farms from pests, increased profits for farmers, and of course higher yields. Only then did she move on to the potential benefits that biotechnology might provide in the future; her argument is not based on what might be possible, but what is already being done.

Charles Benbrook, interestingly, seemed to concede that biotechnology might indeed have a role to play in promoting sustainability. But he detailed his objections to the ways in which biotechnology is being deployed at the moment, which are, in his view, failing to do so.

Biotechnology reduces the need for labour, for example, promotes farm consolidation and does not encourage the integration of crop farming with livestock. His definition of sustainability is rather broader than Ms Ronald's, in other words, though both of them look beyond environmental impact; whether sustainability necessarily entails the preservation of farm jobs, for example, is for our audience to decide.

We have had many informative comments, and it has been good to hear directly from several farmers. Coffeefarmer, a grower of heirloom coffee varieties in Hawaii, expressed opposition to GM crops on ethical grounds, because of the patenting of genetic material. VKV.Ravichandran, a farmer writing from India, took the opposite view, citing his own experience of growing GM cotton, which has seen his expenditure on pesticides fall by 96%. BrianUSA called for a broader definition of biotechnology to include not just GM but also marker-assisted breeding, or the use of plant extracts as biopesticides, both of which would be "consistent with organic farming as it is currently practised". Jose Fernandez Calvo, writing from Argentina, spoke up in support of GM crops, and the wealth they have produced for his country, a major food exporter. Mark Wells was one of several commenters who referred to the rejection of GM crops by the IAASTD report, drawn up by a panel of experts at the behest of the World Bank and the UN Food & Agriculture Organisation, as strong evidence for the limitations of GM.

In their rebuttal statements, Ms Ronald and Mr Benbrook will address in detail specific points made in the opening statements. I hope it will then become apparent where the strongest areas of disagreement lie—while also allowing the common ground between them, if there is any, to be identified in the final round.

Benbrook Closing –

First, thanks to "The Economist" for the chance to participate and to all commentators for adding so much to this debate.

In the 1980s scientists gained the ability to <move genes; http://mmbr.asm.org/cgi/content/abstract/53/2/242> from outside the plant kingdom into it. Changes in intellectual property law in the 1980s and 1990s allowed the patenting of GE crops, vastly increasing profit potential and triggering the essentially hostile takeover of the seed industry by the larger, more profitable pesticide industry.

Since the late 1990s, strategies to increase private sector profits through <higher priced transgenic seeds; http://www.organic-center.org/reportfiles/Seed%20Premium-Farm%20Income%20Database.pdf> have driven plant breeding priorities in corn, soybeans, and cotton.

Prior to the GE seed era, plant breeding was among the most important areas of basic and applied science serving the needs of farmers and society. It was controlled to a large degree by academic programs.

In its pre-DuPont era, the Pioneer seed company was respected by competitors and admired by farmers because the company delivered consistently on a corporate pledge to price new seed so that it delivers $3 in return for every $1 the farmer spends. That level of return is long gone and a rising percent of farmers planting GE seeds in the U.S. <don't even break even; http://www.agrisk.umn.edu/cache/ARL02660.pdf>.

The pesticide-seed-biotech industry now drives plant breeding priorities and investments for major crops, and its "technology packages" exert increasing influence on farming system changes, except in the sustainable agriculture community.

Preserving the integrity of sustainable agriculture is vital for innovation and is, moreover, a sound investment in preventing problems at their biological roots. The cutting edge of sustainable agriculture is also where farmers, scientists, and businesses are promoting soil, plant, animal, and human health, as well as food quality and flavor, through systems-based "technology packages," and earning a profit doing so with next to no help from government subsidies or preferential policy.

Feeding the World Arguments

Biotech advocates are eager to bet on western-style GE technology on behalf of the world's poor, a bet I see as reckless and misguided.

Sure, large portions of African agriculture could someday look much like Iowa, using similar GE seeds, equipment, and fertilizers, but achieving this goal will require enormous investment in infrastructure and willingness to accept unimaginable social upheaval. What will Africa have to give up attracting the huge inflow of foreign capital needed for such a transformation?

Plus, it is clear that Iowa's current energy-dependent agriculture model is not sustainable, so why push Africa to replicate what will have to change in one or two decades?

The Costs of GE Crop Technology

Developing, testing, and growing commercial quantities of seed for a novel GE crop variety takes about as long as conventional breeding, and it costs far more. Dr. Major Goodman, a maize breeder at North Carolina State University, has <analyzed (live link to http://www.cropsci.ncsu.edu/maize/publications/NewSources.pdf)> the process, steps, and cost of bringing GE corn varieties onto the market.

He concludes that the minimal cost of a novel GE maize hybrid is $60 million, compared to about $1 million for a conventionally bred hybrid, a 60-fold difference. Why?

Moving foreign DNA into a crop genome is <highly imprecise; http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1559911/>, whether done with a gene gun or virus-based vector. There is no way to control where the foreign DNA lands, how many copies become active, and what turns the foreign genes on and off.

The exceptionally high cost of developing novel GE crop varieties is why the transgenic crop compartment of the biotech toolkit thus far has mostly been used on major row crops with billion dollar-plus seed markets.

Contrary to the assertions made by the CropLife Guest Commentator and others, GE crops have not significantly increased dependence on no-till in the U.S. No-till acreage <grew rapidly in the U.S. from the late 1980s through the mid-1990s; http://www.ctic.purdue.edu/CRM/>, before GE crops had gained much market share. The percent of corn acres planted using no-till rose from 8.5% in 1990 to 17% in 1996, but then only to 19% and 21% in 2002 and 2008.

The emergence of resistant weeds is driving <herbicide use far higher; http://www.organic-center.org/science.pest.php?action=view&report_id=159> on acres planted to herbicide-tolerant crops, and many farmers must now also apply older, higher-risk herbicides that increase the <risk of birth defects; http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1241584/ >.

The industry is addressing the problems posed by herbicide resistant weeds by creating new GE crops resistant to multiple herbicides, so even more herbicide "firepower" can be deployed. The logic supporting this strategy is profoundly flawed and surely does not "go together" with sustainable agriculture.

Moving Forward

First, credible, independent research needs to confirm that ***any*** proposed transgenic technology works, is safe, and is not likely to lead to other problems.

Applications of biotechnology designed to better understand soil-plant-pest-animal interactions (i.e., probes and diagnostics), prevent animal diseases (i.e., vaccines), or enhance the cost-effectiveness of conventional plant and animal breeding (i.e. marker-assisted breeding) are compatible with sustainable agriculture if cost-effective and delivered without strings attached that abridge the farmer's freedom to innovate.

The well-defined principles of agroecology as set forth in the recent international <IAASTD report: http://www.agassessment.org/reports/IAASTD/EN/Agriculture%20at%20a%20Crossroads_Synthesis%20Report%20(English).pdf > should shape and drive the evolution of agricultural systems in developing countries. If and as this comes to pass, the actual and perceived threat to sustainable agriculture posed by biotechnology will subside, making it less risky to explore where and how biotechnology can strengthen sustainable agriculture systems.

through Transgenic microbial soil, compost, rumen, or seed inoculants should be considered on a case-by-case basis, as long as the technology does not involve the transfer of genes from unrelated organisms (i.e., a fish, tomato, or pine tree gene into a rhizobium soil bacterium).

Research should continue on ways to move foreign DNA into food crops to produce toxins, but no such technologies should be approved in human food crops that are consumed fresh or in lightly processed forms until more is understood about how to evaluate possible environmental and human health impacts.