Sowing the Future: Biotechnology and Climate Change

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As the world enters an era of unprecedented environmental challenges and changing climate patterns, food must take the stage, front and center. As an essential element of life, food affects political, social, and economic welfare. Food production is inherently linked to climate conditions and the environment and is therefore undeniably connected to the world's agricultural paradigm. One such area of food policy is biotechnology. Biotechnology is currently being explored as a potential solution to climate problems through the creation of crops that are designed to meet the challenges of a new climate era. This paper further explores the potential of genetically modified crops to transcend agriculture's contribution to climate change as well as the ability of these modifications to help mitigate the impacts of climate change. There is great potential for biotechnology to reduce environmental impacts associated with agriculture and food and to increase yields without further harming the climate. However, there is also concern that this technology will further degrade the environment and promote dangerous agricultural norms. This paper analyzes the benefits and potential challenges of this relationship in order to determine the feasibility and political implications of using biotechnology as a mitigation and adaptation strategy for climate change.

The importance of this analysis begins with the simple fact that food is an essential element to human survival. Determining the best ways to anticipate and meet the food needs of coming generations is of great political and social importance. Biotechnology, of which genetic modification is a primary component, is one proposed solution to cope with changing food needs through improved production methods and to address agriculture-related climate change.[1] This paper demonstrates how biotechnology could be used

[1] There are other forms of low-impact agriculture, such as organic farming and permaculture, that rely on little technological input. These low-impact forms often rely on ecological farming procedures such as crop rotation, integrated pest-management systems, and organic fertilizers.

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to improve the current system of agriculture through lower greenhouse gas emissions and increased adaptability to climate change. These improvements will add a previously missing element of environmental sustainability to the existing practices of industrial agriculture.

Climate Change and the Evolution of Industrial Agriculture

In the face of growing concern and urgency associated with climate change, it is important that the link between climate and biotechnology be explored. Climate change is one of the most pressing and widespread challenges facing the world in the twenty-first century. According to the Environmental Protection Agency (EPA), climate change is caused by a buildup of greenhouse gases (GHGs) in the earth's atmosphere that prevent heat from escaping. As human civilization has grown and modernized, the amount of GHGs released into the atmosphere has also grown, and has led to an increase in anthropogenic changes in climate.[2] The 2006 Stern Report warned that temperatures could increase by 2 to 3 degrees Celsius in the next 50 years, causing sea levels to rise and changing patterns of vegetation and animal migration. These changes are directly linked to increased GHG emissions caused by human activity. One of the leading contributors to these changes in climate and GHG emissions is agriculture, with the highest impact coming from the use of industrialized inputs such as machinery and fertilizers.[3] With the ability to create or control certain beneficial traits that increase crop yields or promote environmental health, biotechnology can be used to address pertinent concerns regarding climate change and agricultural production.

Agriculture is the world's largest industry. According to the United Nations Food and Agriculture Organization (FAO), more area is under agricultural management than is covered by woodlands and forests, and conversion continues at 13 million hectares per year.[4] As agricultural yields are affected by changing climate conditions, agricultural practices must be adapted to meet the changing needs of the planet. Before examining these changes, it is important to understand the contextual background of the current industrial agriculture system, and its effect on climate change.

"Industrial agriculture" describes post–green revolution methods. The green revolution is the term used to refer to the introduction of scientific technology into agriculture, specifically with hybrid seeds and chemical inputs such as fertilizers and pesticides. The green revolution changed agricul-

[2] Environmental Protection Agency, "Agriculture and Food Supply," http://www.epa.gov/climatechange/effects/agriculture.html.
[3] Gary Yohe and Richard Tol, "Report on Reports — The Stern Review: Implications for Climate Change," *Environment* (2007), http://www.environmentmagazine.org/Archives/Back% 20Issues/March% 202007/Yohe-full.html.
[4] Food and Agriculture Organization, "Agriculture and Environment: Time to Act Globally," http://www.fao.org/ag/magazine/0704sp1.htm.

ture from a predominantly ecological process to one of continual technological developments that revolutionized the world's food systems. Before the 1900s, farming around the world employed the same basic techniques that had been in use a thousand years earlier. Animals and human muscle were used instead of machinery to manage a diverse array of crops, and fertilizers were made of animal waste, crop residue, and local organic matter. Somewhere between 70 and 90 percent of the world's population worked in this low-input, labor-intensive activity.[5] "Agricultural yields were modest but stable. Production was safeguarded by growing more than one crop or variety in a field as insurance against pest outbreaks or severe weather."[6] Without high levels of industrial inputs, farmers had to rely more heavily on natural processes of the earth. In this system, the connection between agriculture and ecology was strong, and the success of the crops often depended on farmers' understanding of ecological processes. The Industrial Revolution and spread of mechanized farming in the green revolution led this early agrarian system away from traditional ecological methods. As populations began to expand and fears of future food shortages emerged, alternative systems of agriculture became a central part of government policy. Modern machinery and technology were already revolutionizing the face of society. From the steam engine to mass-produced cars, technological advancement became central to progress. With the help of government support, the adoption of fuel-dependent machinery such as tractors and combines accelerated around the 1930s in the U.S. and after 1950 in Europe.[7] The use of machinery greatly reduced the human input necessary for farming and greatly increased the technological input.

This increase in technology brought about changes in crop methodology. It became cheaper and easier to grow monoculture crops that could be maintained and harvested by a single type of machinery. Along with the increase in efficiency came an increase in emissions. This industrial technology boom changed both the agrarian system and social norms. As the need for human input in agriculture decreased, urbanization and factory workforces increased. People migrated away from the agrarian lifestyle and into urban areas where infrastructure and employment opportunities could meet their changing needs. This new industrialized society created a system based on technological and energy inputs.[8]

Technology further revolutionized agriculture as the green revolution gained momentum in the 1960s and 70s. Norman Borlaug has been called the father of the green revolution for his development of high-yielding hybrid semidwarf wheat in Mexico in the 1940s. These hybrid plants were designed

[5] J.R. McNeill, *Something New Under the Sun* (New York: W.W. Norton, 2000), 215.
[6] Miguel Altiere, "The Ecological Impacts of Industrial Agriculture," in *Fatal Harvest* (Sausalito, CA: Foundation for Deep Ecology, 2002), 197.
[7] McNeill 2000, 217.
[8] Altiere 2002, 197.

to produce higher yields when combined with modern agricultural inputs such as pesticides and fertilizers. Hybrid plants had been used for decades before Borlaug's research, but it was his combinations of wheat varieties that sparked a global interest and allowed Mexico's green revolution to spread worldwide. With funding from the FAO, the United States Agency for International Development (USAID), and the Ford and Rockefeller foundations, hybrid technology made its way to India, Asia, and across Europe.[9]

The green revolution met its goals of increasing yields to feed growing populations. "The miracle of the twentieth century was that the amount of food produced worldwide doubled and tripled, while the amount of land farmed stayed the same."[10] With an increase in production, the green revolution further promoted principles of efficiency embraced in the industrial revolution. These hybrid seeds had to be purchased and needed chemical fertilizers to produce the highest yields. Inputs were specific to a single crop, which further encouraged monocultures and presented a danger of pest problems. The pests were tackled with pesticide inputs. However, with the spread of hybrid seeds, dependence on chemical inputs grew. While this system appeared beneficial at first, many problems and unforeseen complications emerged over time.[11] Specifically, the environmental consequences of agricultural practices, particularly agricultural GHG emissions, are a result of the green revolution's technological progress in agriculture.

Agriculture is the second largest industrial-sector contributor to greenhouse gases (second to electrical and heat generation). According to the FAO in 2007, agricultural practices, including deforestation, cattle feedlots, fertilizer use, and harvesting methods, accounted for about 25 percent of GHG emissions. In the United States, it is estimated that on-farm activities are the most significant single factor in GHG emissions. Therefore, reducing these emissions is an essential strategy for climate change mitigation. The emissions cover a wide range of U.S. farming practices. Nitrogen oxide (NOx) emissions are caused by excessive use of synthetic fertilizers, which are released into the atmosphere and watersheds through soil emissions, water runoff, and poor manure management. Carbon dioxide (CO_2) emissions come from the fueling and manufacturing of farm machinery as well as the manufacturing and transport of fertilizers. And in the U.S., the largest source of agricultural emissions is methane released from animals.[12]

With such a large impact on climate change, it is important to limit all aspects of these agricultural emissions. While biotechnology is not the only

[9] Gurdev Khush, *Green Revolution: Preparing for the 21st Century* (Ottawa: National Research Council of Canada, 1999), 649.
[10] Nina Fedoroff and Nancy Brown, *Mendel in the Kitchen* (Washington, DC: Joseph Henry Press, 1999), 264.
[11] McNeill 2000, 224.
[12] Jennifer Edwards, Jim Kleinschmit, and Heather Schoonover, "Identifying Our Climate "Foodprint": Assessing and Reducing the Global Warming Impacts of Food and Agriculture in the U.S.," *Institute for Agriculture and Trade Policy* (2009), http://www.iatp.org/.

method for reducing these emissions, it has promise to provide solutions and mitigation strategies of value to the planet's climate. The agricultural aspect of climate change is predominately a technical problem. Technological advancements throughout the history of agriculture have created a system that thrives on technological inputs and relies on technological fixes to emerging problems. This is not to say that social and political factors do not influence the problems related to agriculture and climate change. In fact, political power and government structures within the U.S. have a drastic impact on the creation and longevity of agricultural practices. This can be seen in the success of certain cash crops, specifically corn, that are supported by government subsidies. These subsidies help support systems of large-scale monocropping that lead to high chemical inputs, high mechanical inputs, and high GHG outputs. These political forces must be taken into account when considering agricultural solutions to climate change. Unfortunately, the current use of genetically modified (GM) crops further enforces a system of large-scale monocropping and government influence over large sectors of American agriculture. However, despite political and social limitations, there are immediate benefits of biotechnology in agriculture that can be seen working in the current agricultural system. It is these benefits that hold the promise for reducing the immediate impact of agriculture on climate change and addressing the urgent problem of GHG emissions.

Revolutionizing the entire agricultural system is a noble and important goal, often manifested in idealistic, small-scale, sustainable farms such as Polyface Farm in Pollan's *The Omnivore's Dilemma*. Polyface aims to mimic natural systems in its farming methods for both plants and animals, and calls its methods "beyond organic" because they combine principles of organic and local farming.[13] Polyface and similar sustainable farms reduce climate change impacts while supporting local communities and an agricultural system that is relatively independent of the government. This alternative form of agriculture is "rising up on the margins"[14] and creating a movement for a changing food system. In the face of climate change, this changing food system is essential. However, it is not the only essential change. While it is important for the alternative movement to continue growing and supporting an entire systematic agricultural change, it is also essential to immediately change the current system of industrial agriculture. A majority of the food in the United States is still produced through large-scale industrial agriculture.[15] Specifically, packaged and processed foods rely heavily on the production of U.S. cash crops such as corn and soy. The industrial farming methods used to produce these crops in mass quantities account for the majority of agricultural causes of climate change. It is therefore essential to find

[13] Polyface Farms, http://www.polyfacefarms.com/default.aspx.
[14] Michael Pollan, *The Omnivore's Dilemma: A Natural History of Four Meals* (New York: Penguin, 2006), 261.
[15] Ibid., 43.

ways to immediately tackle the GHG emissions from large-scale, industrial farms. Biotechnology holds one such immediate solution.

The FAO says agriculture "can be part of the solution by contributing to climate change mitigation, through carbon conservation, sequestration and substitution, and establishing agricultural systems that can buffer extreme events."[16] The next section analyzes how biotechnology can help by creating adaptation techniques, mitigation strategies, and reduced-impact agriculture methods. In addressing these solutions, it is also crucial to take into account the controversy surrounding GM crops and the potential challenges to reducing agricultural impacts on climate change through biotechnology.

Specific Benefits and Challenges of Biotechnology for Climate Change Mitigation

When biotechnology is used to create genetically modified crops, these crops are being technologically designed to have a reduced environmental impact. Studies have repeatedly shown that "agricultural biotechnology has helped enable large shifts in agronomic practices that have led to significant and widespread environmental benefits."[17] Biotechnology reduces on-farm fuel consumption through reduced chemical inputs and low-till agriculture methods. Fertilizers, along with herbicides and pesticides, have become a common input in industrial agriculture worldwide. While these inputs tend to accelerate crop growth and increase yields, their effects on climate change are becoming increasingly evident. Specifically, fertilizers are high in nitrous oxide, a leading GHG contributing to climate change. Nitrous oxide (N_20) has a global warming potential (GWP) of 296, which is approximately 300 times greater than the GWP of CO_2.[18] This means that every pound of N_2O emitted is the equivalent of 296 pounds of CO_2. The 2006 Stern report estimated that approximately a third of agriculture's GHGs are produced by N_2O. N_2O is released into the atmosphere when nitrogen fertilizers interact with common soil bacteria.

Biotechnology offers a valuable solution for reducing the amount of fertilizer needed in conventional farming, thereby reducing the amount of GHGs released into the atmosphere. The ability to reduce fertilizer use has been evident from the early stages of biotechnology implementations. "In 1998, 8.2 million fewer pounds of active [fertilizers] were used on corn, cotton, and soybeans than in 1997 and corresponded to an increase in the adoption of genetically engineered crops."[19] This reduction is the result of the development of GM seeds that have low fertilizer input needs. For example,

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[16] Food and Agriculture Organization, 2007.
[17] Biotechnology Industry Organization, "Agricultural Biotechnology Delivering Benefits for Farmers, Consumers, and the Environment," http://bio.org/foodag/.
[18] EuropaBio, "Green Biotechnology and Climate Change" (2009), http://www.europabio.org/, 5.
[19] L.L. Wolfenbarger and P.R. Phifer, "The Ecological Risks and Benefits of Genetically Engineered Plants," *Science* 290.5499 (Dec. 15, 2000), 2090.

Arcadia Biosciences has developed strands of rice and canola that are specifically designed to help mitigate climate change through reduced fertilizer needs. These GM strands of rice and canola are genetically modified to use nitrogen more efficiently, resulting in less need for fertilizer inputs. This technology is referred to as Nitrogen Use Efficiency (NUE) and allows farmers to produce yields that are equivalent to conventional agriculture methods with a significant reduction in nitrogen fertilizers. In addition, fuel consumption is reduced because of decreased necessity for fertilizer application.[20] With less nitrogen fertilizer being added to the soil, the interactions of nitrogen inputs and the soil bacteria are decreased, thereby reducing the amount of agricultural nitrogen emissions contributing to climate change.

Biotechnology is not the only method for increasing nitrogen efficiency. Monocropping decreases the nitrogen efficiency of the soil, making it necessary to add some type of artificial nitrogen fertilizer or genetic modification in order for the plants to grow successfully.[21] This problem can partially be avoided with the incorporation of nitrogen-fixing plants, such as legume trees, as well as crop rotations and organic fertilizers, such as compost, that can be used to ensure efficient levels of soil nitrogen. These alternatives are important for farmers to consider: they work well in small-scale farms with access to useful amounts of natural fertilizers, but are often implausible in large-scale, monocropping agricultural systems that are aimed at producing high yields of specific cash crops.

Critics of crop biotechnology fear that over time, these nitrogen-efficient seeds will lose their alleged efficiency and need continually increasing amounts of nitrogen fertilizers. However, there is limited research behind this fear, which grows from similar studies on the potential for GM crops to require increased herbicide use over time.[22] Additional skepticism emerges from the newness of this nitrogen-efficient technology. As more nitrogen-efficient seeds are used, studies will be able to more accurately depict the long-term success of nitrogen efficiency in limiting fertilizer use. However, the immediate use of these seeds shows a current reduction in nitrogen fertilizer application, which is beneficial in mitigating agriculture-related climate change. [23]

Additionally, limiting the necessity for fertilizer application is an important strategy for reducing farm fuel consumption and CO_2 emissions. In a 2006 study conducted by Brookes and Barfoot, each liter of tractor diesel burned contributed approximately 2.75 kg of CO_2 into the atmosphere. Tractors are burning diesel by making spray runs for fertilizers, pesticides, and

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[20] EuropaBio, 5.

[21] It is important to note that fertilizers are added in many types of farming and even gardening methods and is not exclusive to monocropping systems.

[22] Union of Concerned Scientists 2004. http://www.ucsusa.org/food_and_agriculture/science_and_impacts/impacts_genetic_engineering/genetically-engineered-crops.html.

[23] EuropaBio, 5.

herbicides.[24] If farmers are able to make fewer tractor spray runs, then CO_2 emissions will be reduced. The study estimates that in 2005, over 962 million kg of CO_2 were saved by a reduction in necessary spray runs with the use of GM crops.[25] However, other studies suggest that over time, the need for fertilizer application will rise, thereby increasing CO_2 emissions from tractor runs.[26] To counteract this concern, biotechnologists are constantly working to improve seeds and genetic modifications to eliminate potential for raised fertilizer application needs. With the combination of initial CO_2 reductions and further improvements in biotechnology research, it is likely that GM crops will continue to reduce GHG emissions through reduced fertilizer applications.

Another potential environmental benefit of GM crops is no-till farming practices. No-till farming means that crops are specifically designed to reduce the impacts of soil preparation through plowing, ripping, or turning the soil. Conventional tillage means that the soil is completely tilled with the intent of reducing the need for weed control.[27] Tillage was first started as a method for farmers to control weeds and receive higher yields. However, this method causes high erosion rates and the release of CO_2 into the atmosphere. As tillage increased the availability of oxygen in the soil, the speed at which decomposition of organic matter occurs increases. Tillage results in soil erosion and the release of CO_2 into the atmosphere and the loss of other nutrients from the soil. One alternative method to conventional tillage is conservation tillage, which leaves approximately 30 percent of crop residue on the land to help reduce erosion and to protect the soil from wind and rain. Conservation tillage is viewed as being the superior environmental option because it reduces erosion and sedimentation in nearby waterways and allows for more natural soil cycles.[28] However, with conservation tillage, farmers must still till part of the land (releasing CO_2) and maintain an alternative method of weed control.

Biotechnology takes conservation tillage a step further by creating herbicide-tolerant (HT) seeds that flourish with no-till agriculture. Since the seeds

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[24] GM crops have characteristics that can reduce both pesticides and herbicides in addition to reducing fertilizer inputs. Ronald Bailey found that "U.S. cotton farmers alone avoided spraying 2.7 million pounds of insecticides and made 15 million fewer pesticide applications per year by switching to biotechnologies" ("Biotech Cornucopia," in *Liberation Biology: The Scientific and Moral Case for the Biotech Revolution* [New York: Prometheus Books, 2005], 190). This is evidence of the possible reduction in all types of agricultural impacts through the use of biotech seeds and thereby, an inevitable reduction in CO_2 emissions for input applications.

[25] Graham Brookes and Peter Barfoot, "GM Crops: The First Ten Years — Global Socio-Economic and Environmental Impacts," *The International Service for the Acquisition of Agri-biotech Applications,* Brief no. 36 (2006), 98.

[26] *The Future of Food*. DVD, directed by Deborah Koons Garcia (Mill Valley, CA: Lily Films, 2004).

[27] Richard Fawcett and Dan Towery, "Conservation Tillage and Plant Biotechnology: How New Technologies Can Improve the Environment by Reducing the Need to Plow," *Conservation Technology Information Center* (2002), 3.

[28] EuropaBio, 4.

are HT, farmers are able to effectively use herbicides to control weeds as opposed to soil tillage. With HT crops, farmers can apply herbicides to emerging weeds rather than incorporating herbicide into the soil through tillage methods. This method has been made effective solely through the use of biotechnology. Without GM seeds, the herbicides would kill both the crops and weeds. Critics of genetically modified crops are greatly concerned about HT seeds, fearing that farmers will need to use continually increasing amounts of herbicides to maintain these no-till farming practices. There is also a fear that overuse of herbicides would cause detrimental effects to surrounding environments such as watersheds and animal habitats.[29] However, the main purpose of herbicide-resistant plants is to decrease tillage. This decrease actually provides protection to nearby environments through reduced erosion and enhanced soil sequestration. It is unfounded to assume that farmers will over-apply herbicides just because their crops can withstand it. Over-application incurs economic costs (the farmer will be paying for more herbicide than is necessary) and is therefore not in the farmer's best interest.

Another subject of concern is "super-weeds" and "super-pests." These are pests and weeds that could result from a resistance developed over time to the herbicides and pesticides associated with GM crops. Margaret Mellon, Program Director for the Food and Environment Program at the Union of Concerned Scientists says, "a technology based on moving genes from one organism to another may have unpredictable and dangerous consequences. GM crops could 'escape' cultivation and become nuisance weeds, impossible to kill. Or, insect pests and weeds could evolve resistance to GM crops or the herbicides used to treat them."[30] The climatic danger with resistant pests and weeds is that if these strains occur, it will require more applications of pesticides and herbicides, causing more GHG emissions. However, GM crops are designed to reduce the total amount of inputs needed and therefore initially have less total inputs than conventional agriculture methods. If resistant weeds and increased input usage does occur as a result of GM crops, it is not certain that the emissions from these unplanned inputs would exceed the high baseline amount associated with conventional agriculture. These potential risks are unlikely to occur in all cases, thereby still providing an overall decrease in the necessary chemical inputs and GHG outputs. Therefore, in terms of carbon sequestration and reduced GHG emissions, it is clear that HT seeds are beneficial for climate change mitigation.

HT seeds allow farmers to kill only the weeds, thereby reducing the GHG-intensive process of the traditional tillage weed-control method. This allows for more carbon to remain sequestered in the soil. As can be seen in

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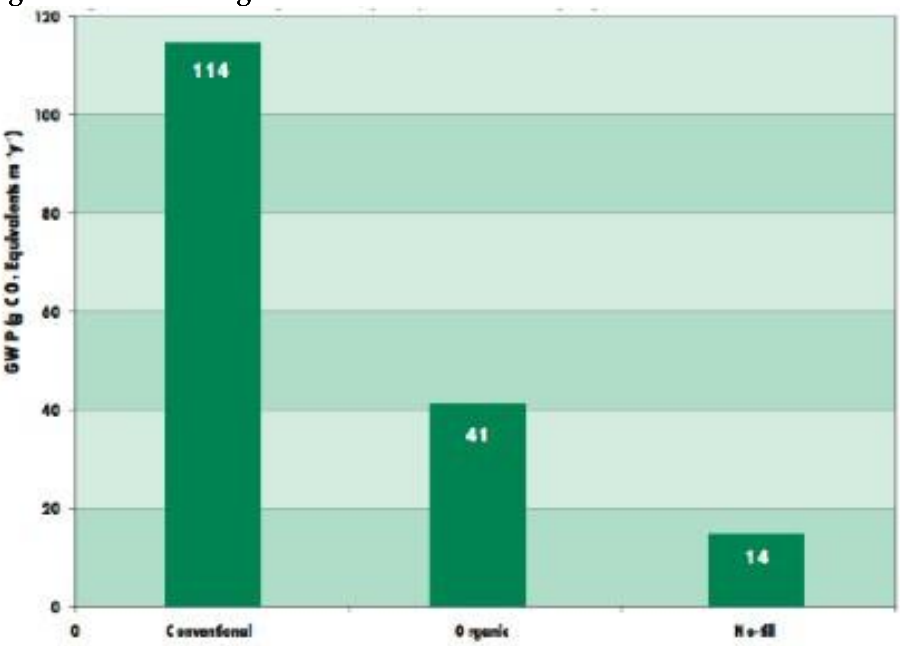
[29] Joseph Mendelson III, "Untested, Unlabeled, and You're Eating It," in *Fatal Harvest: The Tragedy of Industrialized Agriculture*, ed. Andrew Kimbrell (Sausalito, CA: Foundation for Deep Ecology, 2002), 215.

[30] The Osgood File, "Population Boom," *CBS Radio* (February 19, 2006), http://www.acfnewsource.org/science/population_boom.html.

the following figure, the gross GWP for no-till agriculture is drastically lower than both traditional tillage and organic (typically conservation tillage) agriculture.

Figure 1: Agricultural Till Methods and GWP



Source: Fawcett and Towery, 4

In addition to more carbon sequestration, the benefits of no-till agriculture extend to reduced consumption of fuel to operate equipment and thereby, reduced CO_2 emissions.[31] No-till agriculture allows for a reduction in GHGs by decreasing the amount of plowing necessary to prepare fields. A reduction in plowing means a decrease in the number tractor trips across a field, resulting in fuel savings and a reduction in GHG emission. “Looking at the impact on greenhouse gas emissions, the technology has helped deliver important savings,” says Graham Brookes, an agricultural economist and director of U.K.-based PG Economics. “In 2004, 10 billion kilograms less carbon dioxide have been released into the atmosphere. And that’s equivalent to taking 20 percent of the cars in the United Kingdom off the road for a year.”[32] In the following table, reproduced from a 2008 study by Brookes and Barfoot, the breakdown of fuel use can be seen using different tillage sys-

[31] Fawcett and Towery 2002, 4.

[32] Monsanto, “Biotechnology Contributes to Significant Decrease in Plowing,” *Conversations About Plant Biotechnology*, http://www.monsanto.com/biotech-gmo/asp/topic.asp?id=ConservationTillage.

tems. In this study, using no-till agriculture shows savings of 32.53 liters of fuel per hectare.

Table 1: Tractor Fuel Consumption by Tillage Method

Tillage System	Litre/ha
Traditional Cultivation: mouldboard plow, disc and seed planting, etc.	46.65
Conservation Cultivation: chisel plow, disc and seed planting	28.83
No-till (fertilizer knife, seed planting plus 2 sprays: pre-plant burn down and post-emergent)	14.12

Source: Brookes and Barfoot, 10

Reducing on-farm fuel consumption is an essential mitigation strategy to climate change that is greatly enhanced by using biotech crops. In order to understand the practical context of the GHG reduction impact resulting from GM crops, the following table breaks down the car-equivalents of CO_2 sequestered through reduced fuel use and more effective carbon sinks resulting from specific examples of no-till agriculture.

Table 2: Context of Carbon Sequestration Impact 2006: Car Equivalents

Crop/Trait/Country	Permanent carbon dioxide savings arising from reduced fuel use (million kg of carbon dioxide)	Average family car equivalents removed from the road for a year from the permanent fuel savings	Potential additional soil carbon sequestration savings [from reduced soil decomposition] (million kg of carbon dioxide)	Average family car equivalents removed for a year from the potential additional soil carbon sequestration
U.S.: GM HT soybeans	245	108,877	4,064	1,806,345
Argentina: GM HT soybeans	659	293,094	6,994	3,108,408
Other: GM HT soybeans	77	34,091	813	361,547
Canada: GM HT canola	136	60,541	1,677	745,304
Global: GM IR cotton	98	43,582	0	0
Total	1,215	540,186	13,549	6,021,604

Source: Brookes and Barfoot, 18.

This table clearly shows the potential mitigation benefits from combining reduced tractor use and improved sequestration from reduced decomposition rates. The combination of these two variables indicates that no-till agriculture with HT seeds is an effective method for reducing agriculture's impact on climate change.

Potential Benefits of Crop Adaptation to Climate Change

In addition to helping mitigate climate change, it is important to look at adaptation strategies for the effects of climate change that are already in progress. Climate change poses threats to agricultural land and freshwater use. With rising sea levels, water salinity and forced migrations are both on the rise. This will result in greater population density with less access to viable cropland and fresh water for irrigation. Biotechnology will help by creating plants that will adapt to these new agricultural conditions.

In terms of water, the agriculture sector is a major consumer of fresh water. Seventy percent of water currently consumed by humans is in the agriculture sector.[33] This amount is likely to rise with increased drought conditions associated with climate change. An increase in harsh growing conditions will force plants to use more energy, and therefore, more water to grow. Adding to the problem, rising sea levels will decrease available land area and freshwater sources. "This fact [limited fresh water] underscores the need for an agriculture that truly conserves both water and land — and still grows more food to feed the growing cities."[34] Biotechnology can be used to create a type of agriculture that will be more water-efficient in large-scale production methods.

Genetic modification can be used to address these coming problems by creating seeds that are tolerant of new agriculture conditions. As droughts and water scarcity become more prevalent, biotechnology will create plants that can withstand these harsh conditions. M.S. Swaminathan, UNESCO Chairman in Ecotechnology and Chairman of the National Commission on Agriculture, Food and Nutrition Security of India, explains that "climate change results in drought: moisture stress because of higher temperature and lack of rainfall. We must therefore develop less water demanding plants. Biotechnology can offer new ways to address climate change. Drought tolerance can be built into crops, for instance rice, by transferring genes."[35] These new climate-resistant seeds are already in development and in test markets. For example, drought-tolerant maize and oilseed canola have both been developed. Drought-tolerant oilseed canola is engineered to reduce levels of key stress-related proteins in plants.[36] This results in a plant that is better able to survive droughts. Bayer CropScience tested this plant in drought-like conditions in the summer of 2006 and the resulting harvest showed increased yields of up to 44 percent compared to regular varieties.[37] Drought-tolerant maize is also in development stages by Bayer Crop Science as well as Pioneer Hi-Bred International, a Dupont subsidiary, which is already testing their drought-resistant version. Pioneer maize is designed to maintain high yields in high-stress seasons by using water more efficiently. This reduces irrigation needs while maintaining high crop yields and farmer profit-

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[33] John Ruane, Andrea Sonnino, Pasquale Steduto, and Christine Deane, "Coping with Water Scarcity in Developing Countries: What Role for Agriculture Biotechnologies?" *Food and Agriculture Organization* (2008), 5.
[34] Fedoroff and Brown 1999, 264.
[35] M.S. Swaminathan, interview by *Global Change*, http://www.globalchangediscussion.org/interview/ms_swaminathan/full_interview.
[36] EuropaBio, 7.
[37] Agricultural Biotechnology Council, "What Is Agricultural Biotechnology?" http://www.abcinformation.org/index.php?page=whatisagriculturalbiotechnology.

ability. Monsanto is also in the process of making drought-resistant corn, using genes from plants that are already highly drought resistant.[38] As can be seen through these various examples of drought-resistant crops from many different biotech companies, the possible solutions for coping with harsh growing conditions are widespread and diversified across many inputs. Additionally, new areas of research in biotechnology are working towards creating plants that are resistant to salt. Introducing a gene from salt-tolerant mangroves into food crops creates this resistance. With this technology, available water sources can be used more efficiently and lands near rising oceans that are subject to groundwater salination will become fertile for these salt-tolerant seeds.[39] With more research and investment in these adaptive seeds, biotechnology will play a key role in the adaptation of agriculture to new climate realities.

In addition to hardier and more water-efficient plants, biotechnology is also creating more space-efficient plants. With climate change threatening large portions of land areas, it is inevitable that population migration will occur. This means more people will be living in concentrated areas, specifically in the developing world, and will need access to reliable food sources. Adding to the problem of food supply, populations are predicted to significantly increase. According to the United Nations Population Fund, by 2025 there will be 2.5 billion more people to feed. This population increase will require a 35 percent increase in food supply, meaning that many farmers will need to at least double their production over the next 15–25 years.[40] The demand for rising food levels in the face of harsh growing conditions can be met in part through biotechnology. One of the visions for biotechnology is to "enhance agricultural productivity and maximize the productive capacity of our diminishing resources."[41] This vision is met through crops with enhanced yield production, pest and disease resistance, and diversified growing capabilities.

The work being done to meet this vision can be seen across biotech companies like Monsanto. In 2002, it was estimated that around 90 percent of acreage of GM crops were planted with Monsanto seeds, giving Monsanto controlling stake in the overall biotechnology market.[42] Monsanto is working to develop ways in which agriculture can produce the same or greater yields while using fewer resources. This year, Monsanto advanced its development of drought-tolerant corn and hopes to have the necessary approvals for planting in the U.S. cornbelt within three years. Robert Fraley, executive vice president of Monsanto, says, "more than five years of drought research trials

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[38] EuropaBio, 7.
[39] M.S. Swaminathan.
[40] United Nations Population Fund, "State of World Population, 2001, Chapter 2: Environment trends, Moving Towards Food Security" (2001).
[41] EuropaBio, 8.
[42] Frances Lappé and Anna Lappé, *Hope's Edge: The Next Diet for a Small Planet* (New York: Putnam, 2002), 139.

across the United States tell us corn plants with this technology yield between 6 and 10 percent more grain in the face of limited water; effectively sipping their water rather than gulping it down."[43] Creating plants with increased yields means less land will be needed to plant and grow food. With growing populations and climate-induced land loss, producing higher yields on less land will become an essential component of agriculture.

Limitations of Biotechnology Research

In order to assess the arguments both for and against GMOs, the validity and relevance of the research supporting these arguments must be addressed. The research behind biotechnology use is limited by several factors. First, GM crops represent an industry. The U.S. owns 90 percent of all patents for genetically modified organisms (GMO) and a majority of those are held by the five top companies: Monsanto, Dupont, Bayer, Segenta, and Dow. The U.S. has dominated production, experimentation, research, and development of GM crops.[44] With such a controlled market in place, it is easy for these top companies to control the GM industry and research behind GM crops. Skeptics of GM crops argue that these powerful biotech companies are preventing full research on the consequences of GM crops from being conducted. In the *New York Times* (Feb. 2009), an article featured scientists complaining about their lack of access to biotech research projects. "No truly independent research can be legally conducted on many critical [GMO] questions … The problem is that farmers and other buyers of genetically engineered seeds have to sign an agreement meant to ensure that growers honor company patent rights and environmental regulations. But the agreement also prohibits growing the crops for research purposes."[45] The scientists making this argument do not all claim to be against GM–crops, but rather in favor of creating more extensive research and methodologies for how to best use (or not use) GM crops. It is important to realize that not all arguments against limited GM research are aimed at providing evidence against GMO benefits.

While it is true that research limited to GM companies has the potential to be portrayed in an artificially positive light, there are other factors to consider. William S. Niebur, vice president of crop research for Dupont, explains that because the government regulates GM crops, the companies must be careful to police how the crops are grown. GM companies must protect their relationship with government agencies and therefore strictly control proprie-

[43] Robert Fraley, "Coping with Drought Via Seed Technology," *Denver Post* (Feb. 11, 2009), http://www.denverpost.com/headlines/ci_11673009.
[44] Nicholas Kalaitzandonakes, "Agrobiotechnology and Competitiveness," in *American Journal of Agricultural Economics* 5 (2000), 1226.
[45] Andrew Pollack, "Crop Scientists Say Biotechnology Seed Companies Are Thwarting Research," in *The New York Times* (February 19, 2009), http://www.nytimes.com/2009/02/20/business/20crop.html?_r=2&adxnnl=1&emc=eta1&adxnnlx=1242063241-/jx+9tyhYxx/FmL9dJ3Lfg.

tary GM technologies.[46] This response indicates that there are varying political and legal issues surrounding the research associated with GM crops. Monsanto and Syngenta have similar responses to limitations of GM research. They claim that in limiting research on their crops, they are attempting to protect intellectual property rights, honor contracts with seed buyers, and meet regulatory obligations.[47] In looking at these responses, it is important to realize that these seed companies are not necessarily limiting what can be said in studies of GM crops, but rather how they can be conducted.

While it may be the case that GM companies are eager to protect their own self-interest, it cannot be assumed that they are not also considering the interests of the greater good. In a capitalistic society, it cannot be denied that these companies are out to make a profit, but it is also evident that the existence of these companies is based on a demand for improving agricultural methods and outputs in order to benefit society as a whole. For example, the pledge of Monsanto is "to make the world a better place for future generations."[48] Likewise, Syngenta is "committed to sustainable agriculture — farming with future generations in mind."[49] Both of these companies plan to meet these goals by increasing productivity through innovation and technology. The goals of other large GM companies are unsurprisingly similar. Therefore, it should not be assumed that the company studies conducted on GM crops represent only profit-driven data. While it may be idealistic to assume complete validity for these biotechnology company goals, it is important to recognize purposes other than profit. The crops being developed by these companies are designed to benefit societies across generations by promoting sustainable farming practices, protecting the environment, and finding ways to increase food yields to feed growing populations. While profit cannot be removed from the equation (for a company to be successful, it must make a profit), it is fair to assume that these seed companies are driven by both profit and their broader visions. Tests run by these companies on their products should also reflect both of these motivations. While I agree that expanding studies to more outside organizations would be beneficial to GM research, this does not negate the validity of the current industry-funded studies (such as the study by Brookes and Barfoot presented earlier in this paper). Many GM food skeptics argue that biotech companies are limiting outside research to prevent the true dangers of GM food from being discovered and are presenting only positive documentations of GM foods. We cannot currently know if this claim is valid. However, based on the biotechnology companies' commitments to sustainable agriculture, it behooves them to provide studies that reflect a full analysis of the environmental and agricul-

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[46] Ibid.

[47] Meredith Niles, "How Biotech Companies Control Research on GMO Crops," *Grist* (February 22, 2009), http://www.grist.org/article/Genetically-modified-science.

[48] http://www.monsanto.com/responsibility/our_pledge.asp.

[49] http://www.syngenta.com/en/about_syngenta/vision.html.

tural impacts of GM crops. Ideally, biotechnology company studies will evolve to reflect a broader representation of social and environmental effects that GM crops can have, both positive and negative. At this early stage in the overall development of biotechnology as an industry, it is unknown whether the studies conducted on GM foods are fully assessing all possible outcomes. However, it is false to assume that limited types of GMO studies will not provide the necessary data. The fact that such a debate about GMO usage is currently in play demonstrates that further research is needed on both the benefits and consequences of GMOs.

The root of the problem does not exist entirely in the content of the GM company studies, but rather in the governmental system of patent control and regulations. Meredith Niles explains that "the problem lies in the control that biotech companies have over seeds, given to them by patent rights. Effectively, patent protection allows a company to determine who can purchase its products and for what purpose."[50] The patent laws and the structure of government in the U.S. dictate the system under which GM companies function. This system is designed to promote large-scale capitalistic interests and profit maximization. While some skepticism and regulation towards the GM companies' control over the seed market and seed studies is essential to maintain balance and accuracy, it cannot be assumed that the GM companies will only use patent laws to their profit advantage. They are also responsible to their mission and goals, which should lead the companies to conduct studies that accurately reflect the reality of GM crops.

In the face of GMO controversy, there has been progress in the realistic depiction of GM crops. This can be seen in the fact that outside studies, while limited in number, do exist. Despite the criticisms against patent laws and GM companies for limiting research, numerous outside reports have still been conducted. For example, the Union of Concerned Scientists released a report in April 2009 (based on more than 20 academic studies) evaluating the performance of GM crops. This report concludes that GM crops have failed to show increased yields over the last 20 years of research. The report further states that yields are unlikely to increase in the near future, and therefore GM cropping methods are inferior to proven yield-enhancing methods such as modern conventional plant breeding and sustainable organic farming.[51] However, it is important to note the GM crops put into use thus far are not aimed only at increasing yields. Rather, they are aimed at maintaining yields and reducing environmental and social impacts. For example, GMOs can be used to control viruses that would otherwise destroy crops and leave people vulnerable to food insecurity. In Hawaii, the papaya mosaic virus destroyed the crops of most papaya farmers and devastated them economically. Biotechnology enabled researchers to create a new variety of papaya that was

[50] Niles 2009, 1.
[51] Doug Gurian-Sherman, *Failure to Yield: Evaluating the Performance of Genetically Engineered Crops* (Union of Concerned Scientists, 2009).

genetically resistant to the virus. "As a result, Hawaiian papaya orchards are producing again, and the virus-resistant variety is being made available to developing countries."[52] This is one example of how biotech can be used to the benefit of farmers and countries by maintaining and protecting yields that would otherwise suffer.

Brad Mitchell, director of public affairs at Monsanto, explains: "The main uses of GM crops are to make them insect tolerant and herbicide tolerant. They don't inherently increase the yield. They protect the yield."[53] The distinction between what GM crops can currently do for the environment and what they do for yield is crucial to the argument of this paper. In terms of GM crops contributing to climate change mitigation in the immediate future, the insect- and herbicide-tolerant genes are essential for reducing agricultural GHG emissions. The Union of Concerned Scientists study does not present any evidence against insect and herbicide tolerance in protecting yield. Additionally, the ability for GM crops to adapt to climate changes in the future will play an important role in affecting yields.

The results of the Union of Concerned Scientists study is valid at depicting one potential example of how GM crops currently affect yields. However, given the changing climate and resulting impediments to agricultural production, GM crops still hold an important promise for increasing yields in the future. As climate factors such as decreased water availability, increased water salination, and extreme drought become increasingly prevalent, GM crops will have the potential to thrive and increase or at least maintain otherwise failing yields in these harsh environments. While this yield increase lies ahead only as a promise of GM crops, it is reasonable to assume that agricultural adaptations will be essential in the face of climate change. These adaptations can be achieved through GM crops designed to specifically meet changing climate conditions. This is a promise that cannot be ignored and requires further research and study by both GM companies and outside organizations.

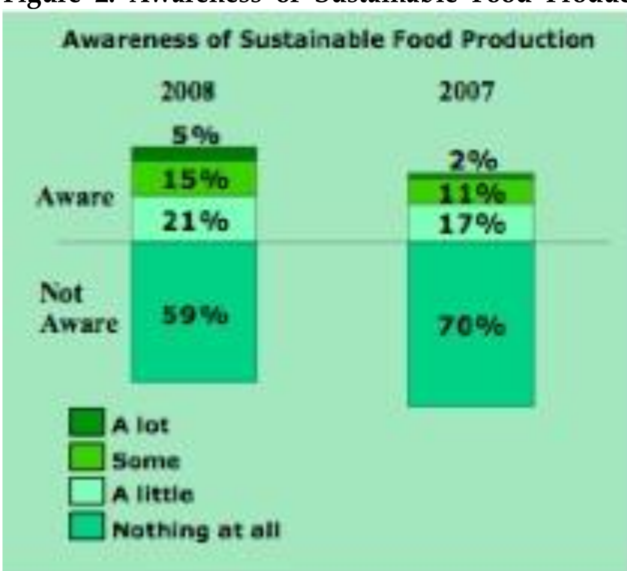
Urgency of Climate Change and Agricultural Action

After years of extensive research on climate change, it has finally become accepted as a mainstream problem. According to Lisa Jackson, the administrator of the EPA, "The U.S. government now fully acknowledges the urgency and complexity of climate change challenges. And we know full well that a meaningful U.S. response to this challenge is absolutely essential."[54] As shown, agriculture has a major impact in contributing to climate change and

[52] Bailey 2005, 193.
[53] Emma Ritch, *Monsanto Strikes Back at Germany, UCS* (Cleantech Group, April 17, 2009), http://cleantech.com/news/4377/monsanto-strikes-back-germany-ucs.
[54] Alessandra Rizzo, "U.S. Delivers Message of Urgency on Climate Change," *SF Gate* (April 23, 2009), http://www.sfgate.com/cgi-bin/article.cgi?file=/n/a/2009/04/23/international/i132116D34.DTL.

will also be one of the most affected industries. There are numerous proposed solutions to mitigating climate change within the agriculture sector. Sustainable organic agriculture, local foods, and community share agriculture are a few current catchphrases that are suggested methods of changing our current agriculture system. These are all beneficial and effective means of reducing agricultural GHG emissions. However, they are small-scale and will require a significant amount of time to reach widespread adoption. The existence of farmers' markets with local produce and community share agriculture systems have been on the rise in the last few years. However, these more sustainable methods comprise only a small portion of overall food production within the U.S. and other countries that practice industrialized agriculture. The following chart from the International Food Information Council shows the awareness that U.S. consumers had of sustainable food production in 2007 and 2008. Even though awareness is increasing, it is far from having a drastic effect on the food system. And even people who are aware of sustainable food systems will not necessarily purchase this food in an amount that will help mitigate climate change.

Figure 2: Awareness of Sustainable Food Production in 2007 and 2008



Source: *International Food Information Council*

The important realization here is that while biotechnology is not the only solution to climate-related agriculture problems, it is one immediate solution with promising results. The urgency of climate change means that large-scale solutions must be implemented immediately. "It is becoming clear that climate change will be the most important constraint on our ability to feed ourselves in the coming decades. We cannot afford to just sit and wait for things to get worse. Instead, we must do everything we can to transform our food production system to help combat global warming and, at the same time, to feed ourselves, in what will almost certainly be far less favorable conditions."[55] Biotechnology is one feasible large-scale solution for taking immediate action against climate change. Additionally, because biotechnology can create crops that will adapt to our changing needs, it can create sustainability across time. If we look at biotechnology as one solution to climate change, then we have the potential to jump across the gap between science and ecology and create sustainable agriculture through biotechnology.

Biotechnology and Sustainable Agriculture

In using biotechnology to help mitigate and adapt to climate change, science creates a solution to a critical problem. However, since climate change is anthropogenic, it is important to look at methods for changing the root causes of the problem and not just creating solutions. One danger of biotechnology is that it can be seen as an easy way to escape dealing with the real causes of climate change and ecological degradation associated with agriculture. Michael Pollan explains that we turn to solutions such as biotechnology "because it's easier to find a technological fix than to address the root cause of such a problem. This has always been the genius of industrial capitalism — to take its failings and turn them into exciting new business opportunities."[56] Pollan fears that by turning to technology, we are ignoring the fact that industrial problems such as climate change are not an unavoidable byproduct of agriculture but rather a human-created condition. Biotechnology could easily be just another capitalistic, technological fix that overlooks the root causes behind agricultural causes of climate change — a system that relies on petroleum and GHG-intensive methods or production. However, biotechnology also has the potential to serve as more than just a solution to climate change. Once the urgency of climate change is addressed, biotechnology can help create a new food system, based on sustainable agriculture. Many opponents of biotechnology see sustainable agriculture as the superior choice in mitigating climate change. However, I see the greatest and most effective long-term solution to climate change being the use of biotechnology in conjunction with and as a part of sustainable agriculture.

Seed companies such as Monsanto are already working to mix biotechnology with sustainable agriculture. Monsanto pledges to help farmers produce and conserve more by developing seeds that will increase yields, use fewer resources, and improve the lives of farmers who use their products. "That's sustainable agriculture. And that's what Monsanto seeds are all

[55] *Institute of Science in Society*, "Feeding the World Under Climate Change" (2004), http://www.i-sis.org.uk/FTWUCC.php.
[56] Michael Pollan, "The Vegetable-Industrial Complex," *The New York Times Magazine* (October 2006), http://www.michaelpollan.com/article.php?id=84.

about."[57] Determining what exactly sustainable agriculture means can be a challenging feat. The catchphrase has taken on many definitions, some of which blatantly exclude biotechnology methods. However, most definitions are centered on environmental, community, and economic sustainability, meaning methods of producing a food supply that prevents environmental damage, maintains appropriate social factors within communities, and allows farmers and consumers to maintain a reasonable economic status across generations. Essentially, these three principles are also represented in the goals of biotech companies like Monsanto. If we begin to use biotech as an immediate solution in industrialized agriculture for urgent climate change issues, the technology can create more sustainable systems, both within industrial agriculture and alternative farming methods. "The challenge to biotechnologists is to produce crop varieties that move us away from chemically dependent agriculture, while maintaining yields and sustaining farmland-dependent biodiversity. This is surely the goal of real agricultural sustainability."[58] Through biotechnology as a method for climate change mitigation and adaptation, a new system of agriculture can emerge and begin to move the entire industry towards sustainability.

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[57] Monsanto, "Sustainable Agriculture," http://www.monsanto.com/responsibility/sustainable-ag/.

[58] Brian Johnson and Anna Hope, "GM Crops and Equivocal Environmental Benefits," in *Genetically Modified Foods* (New York: Prometheus Books, 2002), 333.