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Agricultural Biotechnology to 2030

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Abbreviation List

AIDS	Acquired immune deficiency syndrome
ASEAN	Association of Southeast Asian Nations
BSE	Bovine spongiform encephalopathy
CDC	Centers for Disease Control and Prevention
DNA	Deoxyribonucleic acid
FAO	Food and Agriculture Organisation
GDP	Gross domestic product
GHG	Greenhouse gas
GM	Genetic modification *or* Genetically modified
GMO	Genetically modified organism
IMF	International Monetary Fund
MNC	Multinational corporation
NATO	North Atlantic Treaty Organisation
NGO	Nongovernmental organisation
OECD	Organisation for Economic Cooperation and Development
PDA	Personal digital assistant
S&T	Science and technology
SME	Small and medium enterprise
UN	United Nations
UNICEF	United Nations Children's Fund
WHO	World Health Organisation
WTO	World Trade Organisation

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1. Steady Progress on Agricultural Biotechnology

1.1 General

By 2030, the global population has risen significantly, with the majority of this increase occurring in developing and underdeveloped economies. Although birth rates in developed countries have fallen well below replacement rates, they have managed to maintain constant population sizes through continual immigration. The immigration policies of developed countries have largely focussed on attracting affluent and educated individuals, which has continued to reinforce the affluent and high standard of living enjoyed by these countries. The various cultures of the immigrating persons have created a multicultural mosaic, informing the values and traditions of these societies.

Developed countries have large purchasing power and demand luxuries "with all the bells and whistles" yet are educated and highly aware of their connectedness to one another and the Earth. This sense of global stewardship and responsibility to diminish mankind's environmental footprint was engendered by the younger generation which was more "connected" and aware of global issues on a "moment by moment" basis. Youth viewed the natural disasters associated with global warming (*e.g.* starving polar bears, homes and industry destroyed along flooding coastlines, thousands of deaths from extreme storms such as tsunamis) and global poverty (*e.g.* mass exodus of refugees, starvation, disease) through the aperture of "real time" TV and internet feeling a sense of responsibility and desire to correct the wrongs of past generations. While distinct consumer markets were demanding luxury products and services to maximise their personal time, given their fast-paced urban lives, the majority were insisting on environmental sustainability in products and a stewardship approach from the companies that they supported.

Developing countries such as China, India, and Indonesia along with key communities in South America (*e.g.* Brazil and Mexico) have experienced continued population increases and strong economic growth. Though similarly challenged by the effects of climate change (*e.g.* drought, erratic weather), these communities had the means to develop effective infrastructure and expertise in technology as well as to attract foreign investment. As a result, multinational corporations (MNCs) are a prominent part of the business landscape in these countries in both manufacturing and trade. These countries have experienced a large increase in standard of living leading to increased material consumption and greater demand for luxury products (*e.g.* cars, high technology entertainment, computers, and cell phones) and more expensive foods such as meat and oils.

Meanwhile, underdeveloped countries in sub-Saharan Africa continued to languish in poverty and suffer under prolonged drought, which decimated already faltering agricultural industries. Starvation and illness (an escalation in AIDS particularly in Western and Southern Africa) reached unprecedented levels. Effective public information campaigns and increased attention from media, as well as immediate coverage on heavily trafficked websites, informed the younger generation and inspired youth to want to make amends for the failed attempts of older generations. This younger generation was both sensitive to the human footprint and other social causes and was the driving force behind organised efforts to pressure governments to take action.

Under increasing public pressure, governments in OECD countries made a renewed commitment to foreign aid goals and forgiving African debt. Developed countries increased the levels of food aid to Africa and began to export large quantities of biotech health and diagnostics and new crop and livestock technologies to assist African countries in their fight to rebuild.

1.2. Climate Change and Population Increases Driving Technological Advancement

By 2030, both the global temperature and the frequency of severe weather conditions have increased more than had been predicted earlier in the century. Many previously productive agricultural centres (*e.g.* Australia, Brazil, the United States, and countries in southern Europe) have struggled to maintain productivity in the face of the increasingly unpredictable weather. These environmental pressures, coupled with surging global demand for higher-value food commodities, have led private industry to invest heavily in new technologies to keep pace with markets. Biotechnology has provided the means to increase yield in drought conditions and provide the value-added traits (such as enhanced nutrition, taste, and ease of preparation) demanded by consumers in both crop commodities and livestock varieties.

With the increased temperatures associated with climate change, the conditions ripened for pest infestations and disease. Molecular biology advances such as viral coat protein technologies provided protection from viruses found in wheat, rice, and potatoes. As a large portion of the major and minor crops used in agriculture had known DNA profiles, because of continued investment in DNA databanks and sharing amongst trading partners, some minor crops also benefited from virus reduction technologies through adoption of the new technologies with simple and cost effective practices. Additionally, gene sequence transfers worked to confer resistance to plant nematode infestations and fungal infections that had increased in frequency in the most used global crops (soybeans, maize, rice, potatoes). These molecular biology and genetics advances enabled the agricultural sector to maintain stability in agricultural production in spite of increased pest and disease challenges.

The early concerns in 2005 to 2015 regarding the limited availability of biomass and societal tension over crops for food versus fuel diminished as biotech and seed development industry invested in new technologies that made available high-yield food crops adapted to grow in the changing climate, and dedicated energy crops much like *Jatropha*, *Miscanthus*, and Switchgrasses that were not suitable for eating yet grew on marginal lands. The introduction of more effective processing technologies and refineries that required less energy and provided maximum product increased the efficiency of “whole usage” crops and decreased the volume grown in the field.

The forestry industry also increased investments in biotechnology to develop tree varieties adapted for drought and increased temperature conditions. Additionally, industry developed varieties adapted for salinity, to cope with saline soil developing in drought conditions, and adapted to combat pest and disease brought upon with warmer climate and stressed trees. Tree varieties grown on company plantations in southern locals (in South America) were destined for the global pulp and paper industry, while varieties grown on plantations in northern locals with successful forestry industries (such as Canada and Russia) were destined for high value structural timber and composite wood products.

In specific areas along coastal China, eastern India, and the Gulf of Mexico, regions moved forward with the purchase of generic brands of genetically modified (GM) marine plants to remediate surrounding coastal waters. Marine areas that had become “dead zones” through industrial pollution or agricultural run-off were revitalised through the use of adapted marine plants. While countries bordering the Adriatic and Baltic Seas, in addition to coastal Argentina and Brazil, would have benefited from this technology, public concern over the spread of such plants into adjacent coastal waters was too voracious, so regional governments banned the use of such plants.

Driven by the tangible evidence of climate change and significant waste disposal challenges, affluent consumers began increasing demand for so-called “green” products, produced from renewable materials (*e.g.* agricultural crops) and the use of sustainable production methods by

industry. By 2030, there is wide-scale market acceptance of these renewable products as biotech has provided the tools to produce and market them in a cost competitive manner.

1.3 Differentiated Markets Beckon Industry to Deliver Distinct Food Products

In 2030, developed countries and affluent markets (prominently in China and India) are demanding foods with value-added features such as enhanced nutritional qualities, tastes, while low in calories and requiring a short preparation time. Applications of nanotechnology that developed for cosmetics and medicines have benefited food industry by delivering applications that enhance tastes and textures in foods.

Developing countries exhibit a growing middle class that has increased purchasing power and demands a broader range of foods including meats and oils. This demand for meats was part of the driver to adopt genetically modified crops to ensure feed supply for livestock. Additionally, the increased demand for oils placed pressure on crop yields and biotechnology to secure the supply.

1.3.1 Health as a driver for developed countries and affluent markets in China and India

With new approaches to health management contributing significantly to extend and improve quality of life, average life expectancies continued to increase world-wide. Scientific advances to health management included biotech-derived medicines and diagnostics, advances in quality and preservation of foods, and the availability of foods enriched with value-added nutrients while remaining low in caloric content.

Developed countries (particularly the United Kingdom and the United States), which were characterised by aging, predominantly urban, largely sedentary populations, continued to experience increased rates of obesity to 2015. In response, these countries invested heavily in healthful urban planning (*e.g.* tax credits encouraging builders to build small marketplaces and parks within subdivisions to encourage walking and exercise), and health-related solutions in their foods (*e.g.* nutritional attributes and bioactive ingredients to stimulate optimal health and counter health challenges).

The first generation of health-related solutions in foods were achieved through genetic and molecular advances and included bioactive ingredients to combat common illnesses such as antioxidants to fight cancer, vitamin B and niacin to combat heart disease, and polyphenols and fatty acids to fight cardiovascular ailments. Additionally, functional food products such as foods enriched with enzymes to metabolise sugars in the stomach before absorption and coenzymes to stimulate metabolism, were developed to combat obesity and weight gain.

The second generation of health-related solutions in foods was the product of "nutrigenomics" research, in which foods were developed to cater to specific groups of people according to their life stage or genetic makeup. For instance, foods were developed for children and adolescents infused with vitamin B and folates to support rapid growth and development. Such products were labelled as being fortified with nutrients for this age group and vigorously marketed.

Public support for biotechnology to adapt crops and livestock for food purposes began with the young generation through increased knowledge about science and its role in advancing their quality of lives. Research became available that indicated no long term ill effects from biotechnology and genetic modification in particular. Support from older generations spread

as foods became available with direct health benefits and these products were marketed as the product of advanced science.

It should be noted that the niche market for organics popular at the turn of the century still exists, but in a much diminished capacity. The organics market was a result of the poor acceptance of GM food when first introduced in 1996. While the market spurred investment in non-GM food biotechnologies such as Marker Assisted Selective Breeding early in the new millennium, these technologies have provided modest gains and continue to remain in the shadow of more precise technologies such as GM and nanotechnology.

1.3.2 Several technologies advance to provide affordable food security and traceability systems

With the increased adoption of GM seeds sold at a premium to express agronomic and consumer desired traits there was financial incentive for industry to invest in accurate technologies to separate and identify these seeds. Additionally as plants were engineered to produce non-food products such as industrial compounds or medicines for the health sector, industry placed increased investments in security and traceability technologies to ensure separation of such products from the food and feed system.

Public and private investment was made in the development of several technologies (including molecular and genetic diagnostics, nanotechnology, and information technology) to make food safety and traceability systems widely affordable and accessible. For example, rapid response biosensors to identify nanoparticles of toxins, pathogens, or unwanted industrial products became widely available for use in agriculture and the agri-food industry between 2020 and 2025. As well, rapid genomic diagnostics to identify specific crop varieties became affordable and widely available.

In addition to the food safety improvements brought forward by advancements in crop biotechnology, a number of already available techniques developed further, came down in price, and were widely available. For instance, the traceability systems developed at the turn of the century in response to the Bovine Spongiform Encephalopathy (BSE) crisis in the United Kingdom led to the development of advanced tracking systems. Microchips and accompanying scanners provided information on the health and movements of each animal from birth to present day. These applications advanced, came down in price, and were used widely by developed and select developing countries who wanted to keep pace with trading partners. In some cases, increased application of security and traceability measures was facilitated by World Trade Organisation (WTO) agreements (such as those requiring export countries to make full-records on all livestock available for importing countries).

1.3.3 Markets for biotech livestock and fish

In developed countries, at the turn of the century, biotechnology in the form of marker assisted breeding programs was widely used to adapt livestock varieties with consumer preferred qualities such as tender meat or increased fatty acid content. Toward 2015, health biotechnology advanced to make available precise diagnostics for livestock health and therapeutics for common diseases, such technologies gradually came down in price and were widely accepted and used in OECD countries.

Between 2010 and 2015, research into animal cloning advanced, on a limited scale, as regulatory authorities in North America and New Zealand continued to rule that such livestock was safe to eat. However, strong public opposition ensured that animal cloning in OECD countries remained uncommon. Distinct communities in Asia, such as China and

Japan, moved forward with animal cloning as a strategic move to provide food for their surging populations.

Argentina and New Zealand were the first countries to move forward with biotech animals used to produce pharmaceuticals in their milk. As first adopters they gained tremendous economic benefit and prestige associated with this technological advancement. Specialised agriculture in Australia and New Zealand continue to prosper as they are two of the key developed communities who provide the much needed vaccines and medicines to developing and poor countries identified as needing aid by the United Nations (UN). OECD countries came together in agreement in 2020 to pay suppliers and provide cheap medicines as part of aid to such countries. This work was facilitated by strong pressure from public, NGOs, and contributions from foundations (such as the Bill & Melinda Gates Foundation).

A further opportunity seized by the Asian-Pacific countries was the widespread investment and adoption of biotechnology in aquaculture. Already a signature part of the Asian-Pacific diet, fish, shrimp, and molluscs were engineered to maximise size, reproduction, health, and enhance taste and texture preferred by customers. Although cloning plays a fundamental role in their breeding programs, consumers in North America and pockets of the eastern European Union are largely willing to overlook "the method of production" in order to benefit from the inexpensive and high quality produce.

1.4 Non-Food Products

1.4.1 Biotechnology provides tools for biofuels, bioproducts, and biorefineries

Between 2005 and 2015, a combination of factors drove advancements in industrial biotech that directly impacted agriculture. The combination of climate change and declining global petroleum stores suggested the need for non-petroleum based products. For agriculture, this presented an opportunity to diversify. Farmers, farm lobby organisations, and other interested parties began to aggressively promote agriculture as a solution provider for societal challenges including the environment and the availability of energy.

As a result, there was a global surge of investment in the development of crops with enhanced quality traits to maximise their plant chemistry for the extraction of biofuels, valued chemicals, and biomolecules. Research also increased in new and more efficient uses for plant and animal wastes (*e.g.* for energy production). Low nutrition grasses were used to develop dedicated energy crops with enhanced starch or fatty-acid content, altered lignin and protein composition as inputs for biofuels and as industrial feedstocks for the extraction of high and low value co-products.

In conjunction with the development of crops to produce non-food products was the development of processing plants to extract the desired products. Biorefineries developed, at first in the United States and followed by European Union countries, allowed for the efficient "total use" of crop inputs. Similar to petro-chemical refineries, these sophisticated processing plants had the flexibility of switching which products were extracted in response to market cues (*e.g.* price of energy). The products extracted include: biofuels, high-value oleochemicals and biolubricants desired by the chemical and manufacturing industries, and molecules used to build renewable materials (bioplastics) sought by the automotive and manufacturing industries.

Though parts of the biofuels industry continued to wrestle with economic feasibility challenges, subsidies from developed countries continued to ensure biofuels as one source of diversification into "greener" pastures. By 2015, industry was developing second generation

biofuels that included cellulosic ethanol. Though wastes from biorefineries and forestry were ideal inputs for this generation of biofuels, industry struggled to obtain the inputs close enough to refineries (to limit transportation costs). Industry invested in biotechnology to generate fast-growing plantations of dedicated trees located nearby processing plants. Trees had enhanced traits for biofuel production and pest resistance to combat pest infestations linked to increasing global temperature.

As the infrastructure (such as processing plants, transportation, agronomic and biotech expertise) for plants producing biofuels and biomaterials became firmly established (2015), diversification opportunities arose to produce plant-based components for a variety of diverse sectors. Plants were genetically modified to grow crystals for use in magnetoelectronics, plant-based metals and inks for computer hard drives, and substances mimicking silicone to use as semiconductors. These genetically adapted plants were developed in parallel with the processing facilities that extracted reliable products with high levels of chemical purity.

In addition to the development of plants modified to produce components for the electronics industry, plants modified to produce human cells for the health sector provided an additional diversification opportunity for the agricultural sector. GM plants were grown to produce simple human tissues like collagen, cartilage, and neurologia, and research is under way to develop the plant's capability to grow more complex body tissues such as intestines, arteries, and muscle tissue. Though the growth of these plants receives top dollar, most of it transpires in greenhouses, so the involvement of the agricultural sector is minimal (producers as employees in rural settings).

1.5 Economic development supporting the bioeconomy

1.5.1 Cost of inputs and consumers drive industry

Within affluent consumer markets there had been tension between the materialistic end (desiring all of the "bells and whistles") of the consumer spectrum and the altruistic end (wanting global stewardship and to reduce mankind's environmental footprint). This dynamic push and pull resulted in a strong market differentiation and numerous consumer demand profiles. Competition for consumers was fierce and no business model survived without constantly innovating to serve customers better.

Consumers drove industry to invest in technology to remain competitive and search out mergers and acquisitions to take advantage of the expertise of one sector to the advantage of another. For example, automotive MNCs bought up smaller biotechnology firms, fuel giants diversified and invested in agronomy and botany, and chemical monoliths purchased biotech and seed development firms creating new value chains and corners of industry.

1.5.2 Green products

Affluent consumers also beckoned industry to produce "green" products and use sustainable processes. Industry moved slowly at first making small changes and marketing them relentlessly. However, the media savvy society of the 2020s made decisions based upon the true "green" worth of products and the track record of the companies selling them and not on flashy marketing campaigns. This provided pressure on industry to invest in biotechnology as a tool to providing the alternative products demanded by consumers, such as "green" fibres, plastics, chemicals, and energy.

For industry, environmentally sustainable products and processes were often cost effective. For example, companies sought out alternatives to rising input costs related to precious or depleted commodities, including petroleum, energy, and water. Industries which had relied on

petroleum diversified by investing in alternatives, such as GM agricultural crops and processing plants improved by biotechnology, to produce “green” alternatives such as biofuels and molecules to make biodegradable products.

1.5.3 Water

Consumers had long been worried about the availability and quality of the water supply and this was made even more acute during the period 2015 to 2030 in the face of severe droughts affecting agriculture and water shortages impacting new housing developments. This uncertainty drove up prices for water, which served as an incentive for significant new investments world-wide in water related R&D (such as water conservation and desalination technologies, and alternative technologies that did not require water).

Bioremediation techniques, irrigation technology and water conservation technologies were all greatly improved during this period benefiting potable water for the individual and commercial practices for a variety of industries. Industries relying on natural resources (such as mining, forestry, minerals, and biofineries) had required significant amounts of water for processing and now benefit from improved technologies (such as water reuse systems, low friction machinery, alternate technologies) that have reduced water usage, reducing input costs and providing the sustainable practices demanded by consumers.

Agriculture industries operating in countries that had experienced prolonged drought (*e.g.* Australia, China, India, and the United States) invested in water conservation technologies, spurred on by domestic policies that established strict water conservation regulations. In addition to GM crops adapted for drought, and nanotech-altered soil to decrease water evaporation, industry invested in technologies ranging from anti-leakage technology, desalination near coastal areas, slow drip watering powered by solar power, to erecting geographic barriers to decrease wind and evaporation.

MNCs not only diversified into new technologies, but also moved their operations to developing countries where water conservation regulations had not yet been established. Such developing nations were willing to sacrifice their national resources for the short-term economic gain. Concerned NGOs tried to actively track and publish the names of MNCs who followed this unethical practice. However, they were challenged to keep track of all such business arrangements and they faced a good deal of apathy amongst developed countries that were largely encouraged by the rates of economic growth in these developing countries.

1.5.4 Carbon trading

One of the systems proposed by early sustainability experts was a carbon trading market, which would require international acceptance of carbon limits. Although the carbon limits proposed under the Kyoto Protocol did not receive broad acceptance, the Protocol was successful in fuelling the discussion. It led to significant investments into the impact of carbon increases on climate patterns, carbon limits (sequestration markets), how carbon markets could work, and cost/benefit analyses of carbon reductions. This research helped foster a pragmatic approach to the highly sensitive topic.

In the face of overwhelming data, both developed and developing countries began to accept that rising carbon emissions were having a negative impact on the earth’s climate. Mounting global public pressure led to the establishment of international measures to combat the problem, including the introduction of a global carbon trading system. China and the United States were reluctant adopters but eventually realised that, once in place, carbon markets could provide significant opportunities for innovation.

For industry emitting carbon into the atmosphere, the carbon cap and trade market imposed by OECD countries and adopted by most large emitters pressed industry to invest in alternatives to carbon emitting technologies. Driven by public pressure on governments to take action, the current agreement on emissions limits was ratified in 2025. Built upon the "lessons learned" from the failed Kyoto Accord, the current agreement put forth achievable targets with innovative market-based solutions. Under the agreement, a global framework for carbon trading was established that placed absolute caps on the quantity of carbon that could be released by each country. Individual countries were given carbon limits, which were distributed to industry based upon current greenhouse gas (GHG) emissions. The agreement took 10 years to ratify as there were many challenges including the cost of regulatory enforcement, accurate monitoring, auditing, and individual emissions caps.

1.5.5 Countries that capture the benefits of the bioeconomy

Overall, the innovations brought forward through modern biotechnology have benefited numerous countries directly with additional benefits spreading to countries that were not part of the revolution. Countries directly involved in biotech benefited from increased technological expertise, better infrastructure (transportation), and adaptive/supportive business climates (financial incentives, regulations) for innovation and emerging industries. By 2030, the benefits accrued to biotech innovators spilled over to other countries, where successful and proven technologies were implemented wherever possible. This movement towards wide scale application of biotechnologies reduced negative perceptions of the technology and biotech became part of the mainstream.

While developed countries (particularly Japan and the United States) have remained centres for innovation and industry investment, developing economies like China and India have made the largest gains in the bioeconomy. With strong technological expertise and flexible regulatory systems, these developing economies captured the first mover advantages associated with early discovery and adoption. Though they struggled with an inferior infrastructure and against exploitation of their intellectual resources (*e.g.* off-shoring), these economies have now become competitive with developed countries.

1.5.6 International trade

Throughout the entire time period 2005 to 2030, trade liberalisation talks and negotiations continued. However, only marginal gains were made as economic powers struggled with one another to both gain from trade while also protecting their domestic interests. The WTO, although somewhat stalled by constant standoffs, continues to provide a forum for trade while most countries push forward with bilateral and multilateral agreements with like-minded countries.

Within the WTO regulatory agreements, biotech advancements in food safety allowed the *Sanitary and Phytosanitary Measures and Technical Barriers to Trade Agreements* to continue and to work effectively. In the early part of the century there had been a significant increase in the incidences of contamination, mostly due to emerging economies such as China and Indonesia not having the appropriate regulatory systems in place. However, effective food safety technologies, improved tracking/tracing and better sanitised food processing factories led to a drastic reduction in the number of contaminated food events.

2. Disruptive Change

2.1 Introduction

By 2030, several events had transpired over the previous 20 years that affected global government priorities and impacted global agriculture. Two events that triggered dramatic impacts were i) terrorist attacks on the United States, including an attack on American oil refineries, and ii) a zoonotic disease originating in China which ultimately turned into a pandemic. These events caused a shift in global government priorities away from environmental sustainability and hunger reduction toward a domestic security particularly in the areas of health, food, energy, and water.

The renewable feedstock economy that benefited from environmental priorities in the "steady progress on agricultural biotechnology" scenario has taken a back seat to the development of an economy centred on domestic security priorities. However, for many technologies this was simply a change in their rationale for adoption as many of the technologies promoted to support earlier environmental priorities were now being developed for security initiatives. For agriculture, biotechnologies and other enabling technologies, developed in support of security priorities such as nanotechnology, biosensing, molecular and genetic diagnostics, had only modest benefits for agricultural practices and production.

2.2 A World of Increased Security and Defence (2001-2016)

In the post September 11th world (from 2001 to 2016) there had been a strong push particularly in the United Kingdom, the United States and allied nations for increased security and defence policies with these nations spending billions of dollars on defence, military operations, and numerous security initiatives. While their citizens were reminiscent of the terrorist attacks, such as those that occurred during September 11th or the July 7th London subway bombings, that had inspired the costly defence and security spending, they were aware of the possible consequences of militarily focused government budgeting on the overall economy and other domestic initiatives.

Domestic security policies in these countries were strong and aimed to protect their populations from harm. However, intensified airport and border security received criticism from inconvenienced travellers and strained the business environment. Legislation put in place to provide government authorities with increased powers have been increasingly perceived to be a potential violation of civil rights and the nascent foundations of a police state. This back and forth between security and privacy was reported by domestic and international media and viewed by an increasingly interconnected global population through readily available satellite TV as well as the Internet.

Globally, economies had experienced moderate economic development with growth particularly in developing countries and China and India. Developing nations and those uninvolved in the global tensions were experiencing an increased standard of living with more available money to buy items such as meats and oils. For developed countries this prosperity had been increasingly held back by fiscal constraints caused by growing military budgets. However, there continued to be a growing class of affluent people in both the developed and developing countries with increased disposable incomes vying for luxury items to which they were accustomed (*e.g.* PDAs, remote controls, computers, satellite phones, cars).

There has been an increasing divide between consumers who preferred luxury and advanced goods and those that felt restraint should be used to place resources toward improving domestic security. These markets supported broad investment in information and communications technologies, which made working on the other side of the world like sitting

in the next room. As such, technology advanced in urban regions of countries like Brazil, China and India, where strong government investments in technological expertise have paid off, as MNCs continue to set up R&D labs, manufacturing plants and call centres, buoyed by low cost inputs, growing research competency, and government induced incentives. China in particular became a hub for foreign investment in manufacturing, while countries such as Canada, Russia, and Ukraine experienced heavy investment in natural resource sectors (such as forestry and mining). Food production increased in South American countries such as Argentina and Brazil owing to lower cost inputs and increased adoption of high yield genetically modified organisms (GMOs). However, most other countries continued to support domestic production to avoid security risks associated with importing food.

Citizens who were focussed on national defence, security, and self-reliance supported biofuels as an energy security alternative, thought biofuels received inconsistent government investment, as attentions were continually redirected toward security, military, and defence initiatives. Renewable fuels had not successfully moved beyond first generation technology and the long-promised cellulosic ethanol technology continued to flounder. Industry showed only modest incentive to improve this technology as oil prices remained relatively stable and research continued to show renewable alternatives as more expensive than the existing non-green counterparts

Profiles for the global consumer during this period were characterised by those consumers focused on domestic security or those exhibiting indifference to security issues instead preferring increasing materialism. The profiles evident in 2016 evolved after the events that took place 2017.

2.3 Shocking News – American Oil Refineries Targeted in Terrorist Attack

The temporary pause in global tension ended in 2017 as the United States was once again the target of international terrorism. On May 11th, 2017 five concurrent attacks on oil refineries in Louisiana, Mississippi, and Texas paralysed oil production in the U.S and sent shock waves through the American public whom vividly recalled the events of September 11th.

The attack sent the price of oil to over USD 150 per barrel for nearly one year as capacity built back up, eventually levelling around USD 120 per barrel. The American economy had been on a steady decline between 2010 to 2016 owing to large expenditures on defence and mounting debt, and high oil prices exacerbated the situation.

Because of the United States' high integration in the global markets, the slowing economy in the United States had significant ripple effects on the global economy. Countries that were heavily invested in the United States tried to prop up the economy but most foreign investors began to look elsewhere for better long term investment returns. This resulted in a slowing of the global economy. Despite the slowed economy, the American administration nevertheless intensified military spending elevating security status as the dominant priority for the nation, and severely limiting spending in other policy areas.

2.3.1 Intensifying investment in defence and security

Between 2017 and 2025, the United States poured funds into military technologies and put forward a several pronged security strategy, which focused on funding for energy, health, food, and water security. Due to a slowed economic environment, fiscal restraint and borrowing, innovative solutions were needed to finance technologies for defence and security.

In addition to large resources spent internally, the United States looked to other countries to adopt innovations. Science and technology (S&T) powerhouses like China, India, Japan, Singapore, and northern Europe (Finland, Iceland, and Sweden) had continued their investments in S&T during the 2010s developing an array of technologies from which the United States and its allies could advance their defence and security agendas.

Most nations looked to benefit financially from trading military goods while some nations shared their technology advancements in weapons engineering and intelligence gathering to show support for the United States and allies. For instance, the United States and its many allies, such as those within the North Atlantic Treaty Organisation (NATO), enacted bilateral agreements to provide market access on key imported items in exchange for military goods and technology. The United States formed agreements with Finland, Ireland, Japan, Sweden, and Switzerland reducing tariffs on cars, steel, electronics, and other goods, which gave them greater access to the American market in exchange for military and security technologies. Technologies such as electrical engineering and informatics for military equipment also informed the development of scanners, microchips, and electronic identification technologies used to maintain personal security, trace movement of individuals and goods, and security and traceability of food commodities.

2.3.2 Broad impacts on global and environmental stewardship

Given the focus on defence and security, little concentration and money were devoted to global stewardship and environmental sustainability. Impoverished nations continued to suffer malnutrition and disease, while governments in developed countries made small uncoordinated efforts toward each individual crisis. Their inadequate responses could not address the root causes, thus wide spread hunger and sickness continued unabated and in some cases increased.

Governments in developed countries identified very modest domestic goals toward environmental sustainability that were designed to be met without much investment from government. Renewable biomaterials (such as biodegradable oils, plastics, and industrial inputs) received minimal attention as public and consumer markets were distracted by fundamental concerns over security and had less disposable income for the extras. Sustainable environmental practices and products remained at very low levels and continued to be solely the cause of seemingly detached environmentalists. For farmers this meant returning to their traditional role as food providers. Dedicated energy crops and other agbiotech advancements developed for environmental purposes downscaled production and research. Farmers had to find other ways to enhance the value of their crops focusing where possible on benefits such as organic production and sustainable farming practices to provide additional economic returns.

Moreover, environmentalists continued to report that carbons in the atmosphere were steadily on the rise, as was evidenced by the results of climate change, such as extreme weather patterns and melting of the ice caps at both poles. Though the evidence of pollution and climate change from industrialisation were mounting, little consensus could be achieved at an international level. Select countries in southern Europe, such as France, Greece, Italy, and Spain, had begun to experience reduced tourism on account of the intense heat and increased incidence of fires. Such countries had relied upon tourism for a portion of their GDP and as such were suffering (given the already depressed conditions in the global economy) and clamouring for international effort on environmental sustainability. Countries, such as The Netherlands and parts of the United Kingdom, with low lying areas suffered flooding which impacted upon their populations and strained commerce in these areas.

While globally governments had abandoned coordinated efforts toward an environmental agenda, sustainable technologies moved forward in distinct regions to resolve domestic or regional problems. For example, China and Japan developed technologies to address the need for alternate energy sources and clean water. They developed "cascading use" processing plants that incinerate wastes and incinerate in a cascading manner utilising and eliminating waste at every level of energy use. Such plants have been established in heavily populated urban sites and serve as both waste disposal in addition to generating electricity used by domestic industry in place of coal and petrol.

Another example was research by Nobel Prize winning scientists in India who developed an ocean thermal conversion process which saw continued investment in view of energy and water security priorities. This technology is now used by several countries with deep ocean access (India, Japan, the United Kingdom, and the United States). These innovative processing plants are located in deep ocean waters and generate electricity for industry located along industrialised coastal regions, and desalinised water for human consumption. Warm ocean water is captured in large low pressure tanks where it boils, and expanding steam powers a turbine producing electricity. The steam, cooled by exposure to cold deep-sea waters, provides a fresh water source that is then transported for human consumption.

Another example of sustainable technology development was the collaborative effort by scientists from northern latitudes like Canada, Russia, and the Scandinavian countries who developed GM trees as a solution to land erosion. The development of rapidly growing GM trees with deep roots had been patented back in 2010, but had received limited use because of early public discomfort over potential spread of the trees into natural stands. However, the extreme nature of flooding in low lying areas (particularly India, Japan, Malaysia, and the United Kingdom) provided the pressure for publics in these regions to accept GM trees as a solution to mitigate erosion and restore land.

One last example of technology advancement to provide domestic independence was the development of water conservation and purification technologies. Investment occurred in technologically advanced nations (Australia, China, India, and Eastern Europe) who were suffering water shortages and those whom had domestic security agendas (the United States). With accelerated increases in temperature and drought, in addition to increases in manufacturing industries requiring water as inputs, countries such as Australia, China, and India were investing in dam projects, desalinisation, and water recycling and conservation technologies.

2.3.3 Broad impacts on agricultural biotechnology

The investment in technologies for domestic security goals or response to distinct regional issues had small spill-over effects for agricultural production and processing practices. For example, the development of water conservation and purification technologies for the purposes of domestic water security and industry development had positive impacts on agricultural production in numerous countries (Australia, Canada, the United States, and Eastern Europe) who were suffering drought.

Food safety provided another example where innovative technologies that were developed for energy security (such as incineration) had spill-over impacts on the development of food safety technologies designed to sanitise food commodities of bacteria or introduced pathogens. These tools had come down in price and were now accessible and available for grocery stores, and commonly required by government regulations. Developments in nanotechnology and information technology for defence purposes were being adapted in developed countries (Australia, Canada, the United Kingdom, and the United States) for food security and traceability.

While GM crop technology had progressed slowly forward for the purposes of maintaining yield in warmer weather and drought conditions, GM crop technology was not being used for quality food attributes (such as enhanced taste, nutrition, or fast prep time). Similarly, biotech animals and aquatics had crawled forward in Asia to improve yield, but had not advanced to provide "the extras."

While governments and multilateral organisations and corporations focused on national and global initiatives, consumers were faced with individual choices in their daily lives. Consumers were seeking safe foods that were comfortably familiar and likely grown regionally when possible. Consumers were seeking staples rather than innovative foods enriched with nutrients and taste and low caloric content. The movement toward organic foods increased as consumers associated organic with safe and conscientious farmers. Markets in developed and security conscious nations looked for "local food" labels showing the distance travelled by a food commodity on its package. "Food miles" were shown and referred to the distance food travelled from the time of its production until it reached the consumer. Although originally developed to assess the environmental impact of food, it was now used to assess its security, assuming that every unit of distance it travelled increases its chances of being tampered. To avoid huge food price increases, consumers were willing to forego some foods they had become accustomed to and did a better job of eating foods they were more readily available ("in season")

In this changing marketplace, governments and MNCs in developed countries played the major role in food safety and traceability technologies. Most of the technology was adapted from military, IT, nanotech, and molecular biology arms of huge monolithic companies that were focussed on serving defence and security priorities. Agbiotech small and medium enterprises (SMEs) had all but disappeared as government funding, venture capital, and sustained funding dried up. This was a significant R&D change as the role that SMEs had played in the past as R&D innovators had been greatly reduced. Scientists realised that this would have a large impact in the long term on innovation and technological advancement as basic and early stage research has been diminished.

While developed countries established bilateral agreements, developing nations such as China, India, and Indonesia were not part of this shift as they did not see the immense costs of implementing traceability as worth the possible benefits. Large rural populations and subsistence farming in these countries made for a difficult situation in effectively adopting food safety and traceability innovations. Moreover, these countries were not as focused on domestic security as they were not a part of the allied nations which had been the target of terrorism.

For countries who created or reaffirmed bilateral treaties there was also a heightened need for traceability to ensure safe trade even between allies. Technologies that were receiving investment for defence and health security applications (such as nanotech and biosensing) received further investment to support food security and traceability applications. For example, nanotech and biosensing technologies merged to provide biosensors capable of identifying nanoparticles of a pathogen or contaminant in crop or livestock shipments. In addition, sensors capable of instantly identifying DNA in crops or livestock were adopted to identify incongruent DNA types and point out when crop or livestock shipments contained more than one DNA type (*i.e.* unwanted adventitious presence). A microchip, rather than paperwork, would accompany shipments and contain detailed information on a shipment, its origin, and intended destination

Additionally, some of the other technologies aimed at food security that arrived in the marketplace were: innovative pasteurisation techniques that could assure no pathogens, while preserving the quality attributes of the food, innovative packaging that could identify

nanoparticles of bacteria thus indicated a food's shelf life or when contamination had occurred, and high-pressure washing that instantly rid food of contaminants while preserving food quality.

Although there were a number of innovations in the "farm to fork" chain very few of the innovations dispersed to developing countries farmers. Even in developed countries most innovations happened beyond the farmer level leaving livestock farmers in developing countries still particularly susceptible to disease and contamination.

2.4 We Knew it was Coming – Zoonotic Disease Hits Vietnam and Spreads

The first influenza outbreak of the 21st century had been long overdue, but when its third wave hit Southeast Asia in 2020 not enough research and precaution had been taken to prevent the spread of this highly infectious viral disease setting off a global panic. The World Health Organisation (WHO) and international organisations like the early International Partnership on Avian and Pandemic Influenza had tried to prepare for this virulent strain (next generation post H5N1), but society had been distracted by global tensions and health biotechnology had been focussed on the spread of pathogens and contaminants most likely to be introduced purposefully.

The avian influenza was among many infectious livestock diseases that received modest research. The influenza started in Vietnam in domestic duck and spread rapidly to poultry and humans in close proximity reaching pandemic status when it began spreading between humans. Fortunately, the number of people quickly falling victim with similar symptoms set off alarm bells which were heard all over the globe. The WHO, the United Nations Children's Fund (UNICEF), and the US Centers for Disease Control and Prevention (CDC) immediately enacted an emergency response plan, restricting movement in/out of Asia, Europe, and North Africa, enacting world scale diagnostics and therapeutics to contain and treat the disease. The immediate action contained the outbreak to Cambodia, China, Indonesia, Thailand, and Vietnam. Overall, there were nearly 5 million deaths, a large proportion in China, where the outbreak started in rural agricultural areas and then spread to densely populated urban areas.

Immense damage was done to the perception of Southeast Asia as a safe place to visit and do business and their trading relationships suffered as a result of this outbreak. It was apparent to global trading powers that there was a distinct difference between the poultry raising practices in Southeast Asian countries and those in Europe and North America. For example, in Europe when the H5 and H7 strains had appeared the disease was contained and eradicated without creating a disaster. This distinction was not lost on these countries or their trading partners as trade and commerce with affected countries temporarily halted and caused a serious re-examination of food and agriculture infrastructure and regulations.

The short-term economic impacts of the "Southeast Asian flu" as it became known were significant as trade halted while the illness was contained. Once containment and treatment had begun, trade continued to be impacted in the short term. Countries who formerly imported food commodities from South East Asia (such as meats, oils, shrimp, molluscs, and rice) were very wary of such goods and trade fell by 75% for some products. Technology and manufacturing industries (such as electronics, computers, household items, and industrial parts) suffered lost productivity, causing an opportunity for other suppliers (most notably India and Japan) to take advantage of supply shortages.

Wary of any future epidemics, the so-called ASEAN+3 (China, Japan, Korea, and the Association of Southeast Asian Nations (ASEAN)) developed an immediate action plan to get "back to business" within 6 months. This goal was modestly achieved and a longer-term

action plan was put in place comprising diplomatic and communications efforts and a restructuring of the regulatory oversight of food commodities. Pressure remained on government budgets because of expenditures on hospital care, vaccinations, public safety and subsidies to businesses who sustained lost revenues. These budgetary constraints were felt over the longer term as governments worked to restructure food safety and security and tourism continued to suffer for the region.

Although, the infected areas were quarantined with millions of poultry being culled and hospitalisation/quarantined zones for affected humans, this outbreak highlighted the susceptibility of developing nations that did not have the basic safety measures to keep up with their growth. While a number of the these countries were seen as effectively dealing with the situation, the WHO, the Food and Agriculture Organisation (FAO), the World Organisation for Animal Health and NGOs continued to emphasise the need for comprehensive growth bringing in line health and safety with development. The WHO also emphasised health and safety risk mitigation strategies to deal with possible additional effects of the "Southeast Asian flu" while the IMF and World Bank used support that had been pledged to counteract the fiscal challenges faced by these countries. Regional organisations like ASEAN were the most effective players dealing with the crisis and worked as a strong intermediary balancing the interests of individual countries, with those of the region, and the international community.

Once the initial impacts of the flu pandemic subsided, a global shift took place with more citizens demanding greater individual health and safety, with increased recognition of the social and economic reasons to improve animal welfare. With a greater emphasis on human and animal health and safety, all countries, particularly developed countries began to expect increased detection, investigation, and containment capacity from their trading partners.

2.4.1 Post-pandemic impacts on agricultural biotechnology

One of the first policy changes in Southeast Asia was to overhaul regulatory oversight of food commodities. ASEAN, the UN, and the WTO worked together using regulatory frameworks from developed nations as benchmarks and put in place their own standards, guidelines, and a system for licensing and monitoring. China, Thailand, and Vietnam were able to take on the infrastructure changes necessary to accommodate these new frameworks, and viewed this step as crucial to getting "back to business."

With this regulatory overhaul came a policy decision to restructure agricultural sectors. Poor isolated farmers kept their produce for domestic purposes and received information on appropriate animal husbandry, while farmers with commercial operations in less isolated areas benefited from opportunities through wide-spread agri-business MNC expansion and to a smaller degree their local co-op or jobs on government farms.

With this new regulatory structure came the need for technology and tools to support it. Research and development went into genomics to develop hearty varieties of livestock, and crops that would be more resistant to future diseases. Increases in R&D were experienced not only in poultry, but in hogs, goats, beef as well as rice, wheat, potatoes, peanuts, oilseeds. An important area of research was the preservation of exact biological records of old and new varieties, to be better positioned for future diseases and hereditary challenges. Extensive gene banks were developed and shared with trading partners, as proof of their commitment.

As part of their communications strategy, China, Thailand, and Vietnam conveyed an "openness" with trading partners through virtual and personal tours of cooperative farms and government agricultural centres, interactive biotech games, and strong biotech branding initiatives. As research into animal health and to a lesser extent crop health was accumulated,

this knowledge was shared with trading partners to communicate the advances being made in South East Asia. This expertise benefited developed and developing nations in their own efforts toward food security and safety.

Advancements that had been made in the United Kingdom and the United States as part of their concentrated agenda toward defence and security were adopted in South East Asia as they attracted scientists and engineers with those key expertises. Highly innovative researchers were attracted to South East Asia as their policy agendas toward research were less restrictive than those in Europe and North America, which were now very directed in their S&T investments. Nano, molecular, and biosensing technology advancements that had been made years earlier under in the United Kingdom and the United States informed the development of newer versions of those technologies that were affordable and produced at large scale. The technologies included: biosensors capable of detecting nanoparticles of pathogen and disease, skin tag scanners that identified livestock varieties within seconds, and microchips and accompanying scanners that provided a detailed history of the individual animal.

There were policies for widespread vaccination of livestock to prevent future outbreaks of known diseases. To provide the quantity of vaccines needed, ASEAN and the UN negotiated with companies based in France, Germany, and New Zealand, to obtain licences for patented biotechnologies to assist in the wide scale development of vaccines produced in livestock milk. These vaccines were then produced in large quantities on government farms in China, Thailand, and Vietnam to inoculate livestock herds and human populations in South East Asia and to export back to the donating countries such as France, Germany, and New Zealand for domestic use.

The knowledge that was gained through advancements in genetic and molecular engineering for vaccines produced in livestock milk lead to diversification into other active biologics (like nutrients, pharmaceuticals, enzymes) produced in livestock milk. Through this development, these countries were able to recuperate some of the financial investment and expenses placed in regulatory infrastructure and technology. With reliable and consistent doses now available, a number of developed and developing countries were benefiting from readily available, inexpensive medications and functional foods. This proved to be a tipping point in aid to Africa and poor nations, as philanthropic and humanitarian efforts combined with available, low cost medicines. Developed nations coordinated by the UN provided much needed medicines and some functional food commodities to countries in need.

2.5 Ending Remarks

The purpose of the “Disruptive Change” scenario was to think about the types of events that would change the course established in the “Steady Progress on Agricultural Biotechnology” scenario. Although the events could be debated at length, the goal of the “Disruptive Change” scenario was to create a disruption(s) and describe possible impacts for agricultural biotechnology and other enabling technologies.

In the “Disruptive Change” scenario, events have disrupted investment and advancement in agricultural biotechnologies. Globally, governments were focussed on defence and security agendas so money was invested in technologies to support those agendas. Among those technologies were nanotechnology and information technologies, which had spill-over impacts for food security and traceability.

Genetic modification in crops crawled forward and GM crops were adapted to weather and pest conditions, rather than value-added features (such as enhanced taste, nutrition, fast preparation). Biotech animals moved forward in Asia (around 2015), where the technology

investment continued while developed nations were distracted with global tensions. Animal biotech received heightened investment following the zoonotic disease (2020), which lead to advancements in agricultural infrastructure, livestock diagnoses and therapeutics, and the development of medicines in livestock milk.

Overall, it is felt that there could be many disruptive events that could take resources away from promising technologies; conversely, there are events that could stimulate increased investment in technologies that would benefit agriculture. The impacts of these investments are extremely difficult to forecast and it will be interesting to see the role that emerging technologies, such as agricultural biotechnology, will play in the future.