# THE FUTURE OF FOOD:

# NOURISHING THE NEXT BILLION

## A PRELIMINARY RESEARCH STUDY

### FEBRUARY 2018

Contents

## HOW TO USE THE REPORT

This paper is organized according to XPRIZE's ImpactMap development process: Insight, Foresight, Action:

- Insight: hi-fidelity research is conducted, aimed at establishing a baseline, that is, a description of the current state of affairs in a given field (or fields). Establishing this baseline is crucial to identifying gaps, which potential XPRIZEs could solve.
- Foresight: forecasting techniques are employed to determine the baseline scenario (extrapolating the current state into the future), and a preferred future, which will require a series of XPRIZEs in order to be achieved.
- Action: ideation techniques are used in order to identify potential breakthroughs, which could later become XPRIZEs.

## BACKGROUND

In 1970, about one out of every four people was hungry or undernourished. Today, the proportion has fallen to about one out of 10. In addition, hundreds of millions of people in Asia, Latin America, and Africa have lifted themselves from destitution to the middle class. No one knows whether the rise can continue, or whether our current affluence can be sustained. Most demographers believe that by about 2050, the global population will be around 10 billion, up from about 7 billion today. At the same time, economists say, the world's development will most likely continue, however unevenly. This means 3 billion more middle-class appetites. How can we make sure they are satisfied? How can we provide for everyone without making the planet uninhabitable?

To solve the agricultural challenges ahead, those with the view that science and technology, when properly applied, will let us produce a way out of our predicament, hope for a new Norman Borlaug to appear. Borlaug was the best-known researcher in the 1960s whose work led to the Green Revolution, the combination of high-yielding crop varieties and agronomic techniques that increased grain harvests around the world, helping avert tens of millions of deaths from hunger. To Borlaug, affluence was not the problem but the solution. He believed only by getting richer and more knowledgeable can humankind create the science to resolve our environmental dilemma.

The other camp, led by William Vogt, developed the basic ideas for the modern environmental movement. Many of his followers believe that unless humankind drastically reduces consumption and limits population, it will ravage global ecosystems. Vogt argued that affluence is not our greatest achievement, it's our biggest problem. If humankind takes more than the Earth can give, the result will be devastation on a global scale. High-intensity, Borlaug-style industrial farming may pay off in the short run, but in the long run, will increase the severity of ecological reckoning.

Even though the global population in 2050 will be just 25% higher than it is now, typical projections claim that farmers will have to boost food output by 50% to 100%. Given these numbers, it appears that we need a second Green Revolution[1]. However, some of the strategies that existed during the first Green Revolution aren't available anymore. Farmers cannot plant much more land, because just about every accessible acre of arable soil is already in use. Nor can the use of fertilizer be increased; it is already being overused everywhere except some parts of Africa, and the runoff is

[1] The **Green Revolution** refers to a set of agricultural research initiatives and the global dissemination of technology transfer programs between the 1930s and late 1960s that greatly reduced hunger and poverty.

polluting rivers, lakes, and oceans. Irrigation too, cannot be greatly expanded–most irrigable land is already in use. Borlaug's followers think the best course is to use genetic modification to create more-productive crops. Some environmentalists see that as a route to further overwhelming the planet's carrying capacity. They believe we need to use less land, waste less water, and stop pouring chemicals into both. The clock is ticking. What breakthroughs can we identify and develop in order to feed the future?

# I. INSIGHT

## TREND ANALYSIS

### METHODOLOGICAL NOTE

Trend analysis is a method of analysis that allows us to identify the key drivers that will shape the future, how this future will look, and the key areas one needs to change or impact in order to shape a different, more desired future (from a subjective point of view). Another way to describe trend analysis in the context of XPRIZE's studies is environmental scanning - the possession and utilization of information about occasions, patterns, trends, and relationships within an organization's external environment.

### DESCRIPTION

There are several issues that will impact the world's supply and demand for food over the next 40 years. The primary demand factors are the world's growing population and rising incomes in developing countries. Food supply factors include increasing yields, expanding agricultural area, closing yield gaps and increasing the productivity of crop and animal agriculture. Additional issues revolve around reducing food waste, improving international trade and reducing/eliminating world hunger. Climate

change will also greatly impact future food supply and demand, especially in less developed countries.

## SOCIAL/DEMOGRAPHIC TRENDS

**The demand for food** is expected to grow substantially by 2050. A major factor for this increase is world population growth. By 2050, world population will reach almost 10 billion people, which will require farmers to produce 50% to 100% more food than is produced today.

Another major factor contributing to demand is **rising income**, especially for those living in less developed countries. Although higher income for millions of people around the world is a good thing, it does increase food consumption and places more pressure on the world's agricultural resources. It is expected that the middle-class will increase to more than 5 billion people by 2030.

**Rising income and the increasing dominance of the middle-class** also impacts the type of food consumed. As incomes rise, people tend to eat fewer grains and increase their consumption of meat and other high value foods (and are more inclined to obesity[2]). Per capita consumption of meat and milk has increased in both less developed and developed countries in recent decades. However, the increase in less developed countries has occurred more rapidly. There is also space for a large increase in the per capita consumption of meat and other animal products in less developed countries before it reaches the levels seen in developed countries. Current projections suggest that average daily energy availability could reach 3050 kcal per person by 2050 (2970 kcal in less developed countries), up from 2770 kcal in

[2] Studies show that obesity rises with a nation's economic development, and is also related to socioeconomic status. In lower-income countries, people with higher socioeconomic status are more likely to be obese.

2003/05[3]. However, the same projections suggest that increased production alone will not be sufficient to ensure food security for everyone.

**Urbanization** is expected to accelerate, with urban areas accounting for 70% of the world's population in 2050. Globally, agriculture has met the demand of this rapidly growing urban population by providing food that is more energy-, land-, water- and greenhouse gas emission-intensive. Still, hundreds of millions of urban dwellers suffer under-nutrition. The key issue in regard to agriculture and urbanization is whether the growing and changing demands for agricultural products from growing urban populations can be sustained and continue to underpin agricultural prosperity and reduce rural and urban poverty.

**Urban agriculture** is increasing as 10% of the world's population is engaged in some level of urban agriculture today, with total production accounting for 17% of the world's food.

**Women are key players in the agriculture sector**, accounting for 43% of the labor force globally, and over 50% in some countries in East Asia and Sub-Saharan Africa. But across all regions they own fewer assets (e.g., land, livestock, and human capital), and have less access to inputs (e.g., seeds, fertilizer, labor, and finance), and services (extension and insurance) than men do. Ensuring that women have the same access to assets, inputs, and services in agriculture as men could increase women's' yields on farms by 20-30% and potentially reduce the number of hungry people by 12-17%.

In addition, in many less developed countries, women lack discretionary income earning opportunities and labor-saving technologies. Making education, labor

[3] Energy availability is defined as energy obtained through oral nutrition minus energy expended during exercise

markets, and civil engagement as accessible to women as men is particularly important to improve the nutrition of the women themselves, as well as their children. The most relevant aspects of a women's empowerment for nutrition are: increasing access to and control over resources—primarily incomes; increasing decision-making power related to food purchase and preparation; and reducing time and labor constraints.

**Nutrition** – Globally, nearly 800 million people are undernourished while 1.2 billion are overweight or obese. The diet transitions experienced by many countries imply changes towards energy-dense diets high in fat, particularly saturated fat, sugar, and salt, and low in micronutrients, dietary fiber, and important bioactive phytochemicals. In combination with lifestyle changes largely associated with rapid urbanization, such transitions are often accompanied by a corresponding increase in diet-related chronic non-communicable diseases (NCDs). In many countries undergoing this transition, obesity-related NCDs appear even though health problems related to undernutrition in significant parts of their populations are still widely prevalent.

Despite significant progress**, 795 million people are not getting minimum dietary energy needs**. The majority of these individuals are in Sub-Saharan Africa, where 1 in 4 people are hungry; and in South Asia, where 1 in 6 people are hungry. More than 2 billion people are deficient in key vitamins and minerals that are necessary for growth, development, and disease prevention. Malnutrition imposes large human, economic, fiscal, and social costs. Malnutrition leads to maternal and child mortality, child stunting, poor learning capacity, lost productivity and lower incomes for adults, high health costs, and slower economic growth. It can also perpetuate poverty in affected populations.

**Energy and micronutrient deficiency** are contributors to the 165 million children under 5 who are stunted and cannot grow to achieve their full potential. Globally this number is equivalent to approximately 1 in 4 children under 5 years, with an even more concentrated situation in Sub-Saharan Africa and South Asia (1 in 3 children). Arguably child stunting is one of the biggest development challenges. If not addressed, it will profoundly undermine our ability to end poverty and promote shared prosperity.

## TECHNOLOGICAL

Innovative technology is creating new opportunities for income gains, entrepreneurship, and higher skilled jobs in the food system. Technologies that will have the largest impact on agricultural productivity in the next 10 years include innovations in the areas of genetically modified crops, soil and water management, pest control, and post-harvest processing. By 2040, the tools and advances of molecular biology applied to plants, livestock, and micro-organisms will most likely have the greatest impact on agricultural production. Today, however, financial risks as well as problems related to the commercialization of these technologies, could cause significant delays in their development.

**Crop Yields –** The potential to increase crop yields even with existing technologies seems plausible. Provided the appropriate socio-economic incentives are in place, there are still ample 'bridgeable' gaps in increasing yield (i.e., the difference between agro-ecologically attainable and actual yields) that could be exploited.

**Post-Harvest Processing -** Most of the technologies employed in the post-harvest processing sector are mature and reasonably effective. Application of existing irradiation technology could reduce crop losses, which can be as high as 50% in

developing countries. However, the technology in some places has been met with public resistance because of fear that basic food properties will be altered.

**Precision Agriculture** - Precision agriculture–the use of soil sensors and geolocation technologies for planting, watering, feeding, and harvesting–is associated with large-scale industrial agriculture practices. These practices predominate in wealthier more affluent regions in the Midwestern United States, southern Brazil, and parts of Canada, Germany, and Australia.

**Aquaculture** - Demand for aquaculture–the breeding, rearing, and harvesting of plants and animals in all types of water environments–will continue to grow in order to meet the world's demand for protein. According to a 2006 World Bank report, aquaculture producers will likely see growth rates ranging from 1.4% to 5.3% per year in the next 20 to 30 years. The key technologies required to produce this growth are all widely available today.

**Biofuels** - Over the next several decades, a transition to next-generation technologies that convert biomass (rather than food crops), to advanced biofuels and chemicals, will be essential to improve the security and affordability of the world's food supplies. Developers are just beginning to scale up the new biofuel technologies to commercial production, and still face significant technical and financial risks.

**Molecular Biology –** Advances in this sector could provide a means of making specific changes relatively quickly through over-expression or deletion of genes, or the introduction of foreign genes. With the molecular biology tools now available, plant breeders could potentially achieve grain yields sufficient to meet the world's food needs through 2040.

**Livestock** - Like plants, livestock breeding is taking advantage of developments in molecular biology to accelerate development of highly productive, healthy animals. Genetic analysis of animals through molecular biology has also improved the quality of livestock.

## ECONOMIC/FINANCIAL

**Market demand for food continues to grow**. The demand for meat will likely double between 2000 and 2050. Demand for cereals, for both food and animal feed is projected to reach some 3 billion tons by 2050, up from 2.1 billion tons today. The demand for other food products that are more responsive to higher incomes in less developed countries (e.g., livestock, dairy products, vegetable oils) will grow much faster than that of cereals.

**Trade in agricultural commodities** is also expected to expand considerably. For example, net cereal imports to less developed countries are likely to increase almost three-fold to nearly 300 million tons by 2050 and will account for some 14% of their cereal consumption, up from 9.2% in 2006/08. Cereal self-sufficiency will continue to be low in the regions most dependent on food imports (i.e., in the Near East/North Africa) falling from 59% in 2006/08 to 54% in 2050. At the other extreme, Latin America and the Caribbean, now a net cereals deficit area, may become fully self-sufficient reflecting the surplus production potential of major countries in the region. The other regions may see some decline in self-sufficiency, but they will remain in the 80% to 95% range compared with 83% to 100% at present. Concerning other major commodities, developing countries' net exports of oilseeds and vegetable oils are likely to more than triple by 2050 to some 25 million tons (in oil equivalent), and net exports of sugar double to some 20 million tons by 2050.

**75% of the poor in less developed countries live in rural areas** and derive significant parts of their livelihoods from agriculture and ag-related activities. The food sector (in its broader definition) employs the majority of people in less developed countries in both self- and wage-employment and will continue to do so for the foreseeable future. Self- and wage-employment in farming still generates a large share of rural incomes and can have large poverty-reducing effects. In many countries, the off-farm aspect of the food system accounts for a large share of the economy's manufacturing and services sectors. While the employment share in farming tends to decline as per capita incomes rise, the share of employment in food manufacturing and services tends to increase.

## ENVIRONMENTAL

While a rapid rise in agricultural production is required to meet growing demand, other important factors, chiefly environmental issues, come into play. **Climate change** has already begun to affect crop yields and threatens to cause greater damage as the century progresses. Increased incidences of **extreme weather** associated with climate change—such as **drought**, consecutive days of **extreme heat, and flooding**—are issues that might be even harder to solve. And the effects on less developed countries will be even more severe. Climate change is also restricting the means by which production can be ramped up. Because of the need to drastically reduce anthropogenic greenhouse gas emissions in order to avert the worst consequences of climate change, production gains must come largely from intensification of existing lands rather than expansion into new ones, which usually results in the increased emission of greenhouse gases as a result of deforestation or

the clearing of savanna[4]. This requires innovation along almost the entire agricultural value chain.

The **process of intensification is exacerbated by soil quality** issues in critical production and consumption regions. China relies on nearly 7% of global arable land to feed 20% of the world's population. Unfortunately, the Ministry of Land Resources recently reported that 19% of such land is polluted, more than 40% is degraded due to soil and water loss, soil impoverishment and salinization, and over 50% is severely deficient in total organic matter. High concentrations of heavy metals that have leached out of nearby mines and industrial sites is one of the biggest culprits, but excessive dependence on chemical fertilizers has also played a major role in degrading China's land. This degradation of land prevents China from producing much of the food its vast population requires.

Although there are a number of countries (in particular in the Near East/North Africa and South Asia), that have reached or are about to reach the limit of available land for farming, on a global scale, there are still **sufficient land resources available to feed the world's population for the foreseeable future**, provided that the investments required to develop these resources are carried out, and the level of agriculture research and development is increased.

**Land equipped for irrigation is expected to expand** by some 32 million hectares, while harvested irrigated land is expected to expand by 17%. This increase will be achieved primarily in less developed countries. Water withdrawals for irrigation will grow at a slower pace but still increase by 11% in 2050. The pressure

[4] Large areas of Australian and South American savannas have been cleared of trees, and this destruction continues today. In the past, 480,000 hectares of savanna were cleared annually in Australia alone in order to improve pasture production. Substantial savanna areas have been cleared of woody vegetation and much of the area that remains today is vegetation that has been disturbed by clearing or thinning at some point in the past.

on renewable water resources for irrigation will remain severe and could even increase slightly in several countries in the Near East/North Africa and South Asia.

Finally, the availability of **fresh water resources** bears resemblance to that of land availability (i.e., globally more than sufficient but very unevenly distributed), with an increasing number of countries or regions within countries reaching alarming levels of water scarcity. This is often the case in the same countries in the Near East/North Africa and South Asia that have few land resources left.

## POLITICAL

A year after being on the cusp of passing landmark legislation to cap greenhouse gases, "Greens" are coming to accept the fact that the **chance of national and international action on climate change has become more remote than ever**. The Environmental Protection Agency (EPA) is under attack by the new administration and argue that the very idea of environmental protection is unaffordable for the debt-ridden US.

Other policy considerations include a broader **commitment to agricultural research** in order to develop a new generation of technologies that can more efficiently deliver the triple win of higher productivity, greater resilience, and reduced greenhouse gas emissions, while delivering more sustainable ecological outcomes.

**Improved land governance** in less developed countries can significantly raise farm incomes and reduce poverty. Items include: improving tenure security over individual land and communal lands; increasing land access and tenure for women and for poor and vulnerable families; resolving land disputes; and better management of public land.

Governments also support smallholder farmers by reducing transaction costs, improving the structure of markets, and by providing better access to information in order to help increase prices farmers receive for their produce (e.g., crops, livestock, and fish). This is accomplished by addressing structural barriers such as movement restrictions and building roads to link smallholder farmers to major road networks; increasing competition in wholesale markets; streamlining or reducing taxes and fees; and encouraging private storage and handling.

## WHAT'S IN, WHAT'S OUT
## METHODOLOGICAL NOTE

Determining what the Future of Food study entails also means determining what it is not. Therefore, it is important to set boundaries and determine the scope, as they help focus activities and allow for significant creativity within the defined zone of focus.

## AREAS OF FOCUS

**Core:**

- Food demand (consumption)
- Food production – full value chain
- Food security
- Food waste and loss
- Food tech
- Ag tech
- Access to food
- Nutrition
- Industrial and small-scale farming
- Land use
- Natural resources (water, land etc.)

**Periphery:**

- Climate change (focus on emission)
- International trade
- Energy
- Food-industry-related workforce
- Poverty
- Ethnic eating driving production of new crops
- Food as medicine

## WHO'S DOING WHAT? (BENCHMARK ANALYSIS)

### METHODOLOGICAL NOTE

Benchmarking is a way of discovering the highest level of performance being achieved in a particular company, by a competitor, or by an entirely different industry. This information can then be used to identify gaps in an organization's processes in order to achieve a competitive advantage. However, unlike business-driven benchmark analysis, in the context of XPRIZE prize development, benchmark analysis is aimed at answering the following question: Who (e.g., innovators, academics, industry) is developing solutions to a similar problem? What solutions are they developing? And who is providing funding in this area?

### ANALYSIS

Governments, international institutions, NGOs, private companies and universities are all investing significant sums of money to develop innovative solutions to future-of-food related problems. Government support, in the form of basic research funding and other incentives, frequently acts as an important catalyst for innovation in the private sector. But impact lenders, foundations, and NGOs are also playing an ever-larger

role, especially in efforts to help small farmers increase their productivity and in the urban agriculture start-up scene thanks to innovative business models and a risk tolerance that governments generally cannot afford. Where these models have been successful, governments and transnational organizations have often stepped in to scale the projects. Several companies and institutions are also forging connections between sustainable agricultural technology providers and policymakers.

| TYPE | EXAMPLE ORGANIZATIONS | PROGRAMS/ PRODUCTS/ INNOVATIONS |
|---|---|---|
| **Global Organizations/ NGOs/ Academia** | **International Research Organizations:** Africa Rice Center (Cotonou, Benin); Bioversity International (Rome, Italy); CIAT—Centro Internacional de Agricultura Tropical (Cali, Colombia); CIFOR—Center for International Forestry Research (Bogor, Indonesia); CIMMYT—Centro Internacional de Mejoramiento de Maiz y Trigo (Mexico City, Mexico); CIP—Centro Internacional de la Papa (Lima, Peru); ICARDA—International Center for Agricultural Research in the Dry Areas (Aleppo, Syrian Arab Republic); ICRIAST—International Crops Research Institute for the Semi-Arid Tropics (Patancheru, India);IFPRI—International Food Policy Research Institute (Washington, DC); IITA—International Institute of Tropical Agriculture (Ibadan, Nigeria);ILRI—International Livestock Research Institute (Nairobi, Kenya); IRRI—International Rice Research Institute (Los Banos, Philippines); IWMI—International Water Management Institute (Colombo, Sri Lanka); World | International research organizations are a source of innovative agricultural technology. The most widely known are the 15 international agricultural research centers, supported by the Consultative Group on International Agricultural Research (CGIAR), which carry out research on various agricultural commodities, livestock, fish, water, forests, and policy and management. |

| TYPE | EXAMPLE ORGANIZATIONS | PROGRAMS/ PRODUCTS/ INNOVATIONS |
|---|---|---|
| | Agroforestry Centre (Nairobi, Kenya); World Fish Center (Penang, Malaysia) | |
| | Smart Agriculture Analytics (SAA) - China | SAA has positioned itself as the link between China's agricultural sector and small to mid-sized companies that own best-in-class technologies. Launched in 2012, SAA offers online subscriptions to tailored data feeds that provide subscribers with information. This information is collected from Chinese data sources that SAA translates to English, on potential opportunities for their products as well as policy shifts that often create such opportunities. |
| | United Nations - Food and Agricultural Organization (FAO) | FAO has teamed up with municipalities in several Latin American and African countries on "micro-gardening" projects where low-income residents employ intensive vegetable production techniques on small urban plots. |
| **Governments/ Academia** | United States Department of Agriculture (USDA)/Agricultural Research Service (ARS) | The Agricultural Research Service (ARS) of the USDA has a broad research agenda that addresses most technological issues facing agricultural development; over its many decades of existence, it has been the source of innovative technologies. Its research includes over 1000 research projects organized into four research programs:<br>• Nutrition, Food Safety, and Quality<br>• Animal Production and Protection |

| TYPE | EXAMPLE ORGANIZATIONS | PROGRAMS/ PRODUCTS/ INNOVATIONS |
|---|---|---|
| | | • Natural Resources and Sustainable Agricultural Systems<br>• Crop Production and Protection |
| | Feed the Future: US Government Global Hunger and Food Security Initiative | The initiative works to give families and communities in some of the world's poorest countries the freedom and opportunity to lift themselves out of destitution. By equipping people with the knowledge and tools to feed themselves, we are addressing the root causes of poverty and hunger, helping people end their reliance on aid, and creating important opportunities for a new generation of young people, while building a more stable world.<br><br>These efforts are:<br><br>• Generating economic growth and rising incomes<br>• Creating new opportunities for trade in emerging markets<br>• Building opportunities for meaningful work for at-risk communities near their homes<br>• Boosting agricultural productivity<br>• Improving family nutrition, which is essential to mental and physical development and healthy populations<br>• Strengthening agricultural research |

| TYPE | EXAMPLE ORGANIZATIONS | PROGRAMS/ PRODUCTS/ INNOVATIONS |
|---|---|---|
| | | • Scaling existing, proven technologies to benefit more people<br>• Increasing resilience to prevent recurrent crises and help communities better withstand and bounce back from crises when they do happen |
| | Chinese Government: Smart agriculture | Under its Soil Pollution Action Plan, the Chinese central government is funding six protection and remediation pilot projects, each receiving ¥ 1-1.5bn RMB (US$160-240mn). It is expected that the government will eventually invest a much larger sum to roll out the most successful **soil remediation policies and technologies.** |
| | UKAID, USAID, NASA, Columbia University and others | **Connecting global knowledge networks to improve policymaking.** The Agricultural Model Intercomparison and Improvement Project (AgMIP) also coordinates global actors in the agricultural value chain, connecting policymakers with the best scientific work on how climate change and policy decisions could affect their agricultural systems. |
| | USDA and the National Science Foundation (NSF) | Dr. Stephen Moose, a professor of plant genomics at the University of Illinois, has been leading research into **how corn uses nitrogen,** focusing on the genes that control when the plant uses, versus storing, the element. |
| **Private Sector** | Metzer Group, Netafim | **Advanced drip-irrigations systems,** vapor transfer irrigation, and hydroponic greenhouse |

| TYPE | EXAMPLE ORGANIZATIONS | PROGRAMS/ PRODUCTS/ INNOVATIONS |
|---|---|---|
| | | technologies are being developed and employed to enhance the efficiency of water utilization in agriculture. |
| | International Rice Research Institute (IRRI) | **Drought-tolerant and salt-tolerant plants,** which are being developed by using molecular biology techniques, employ emerging technologies that can reduce the consumption of freshwater sources. |
| | Yara N-Senso | **Use of Sensors to Adjust Fertilizer Application** - This high-clearance sprayer makes variable-rate nitrogen applications to corn based on sensor readings. The sensors –the white camera-like modules on the outriggers–monitor plant stresses that are frequently related to nitrogen status. |
| | Trimble | **Use of Global Positioning System (GPS)** - In Missouri, an agricultural engineer examines corn from this combine's grain flow sensor. The combine is linked to the satellite-based GPS, allowing precise yield and location data to be correlated with soil samples taken earlier throughout the field. This information will help growers plan best fertilizer rates for the next crop |
| | Skygreen Singapore, Farmedhere Chicago, Mirai Corp Japan, Aerofarms Newark | **Urban Agriculture + Automated vertical farms** - stacking farms on top of another and using automation, vertical farms can produce 100x more effectively per acre than conventional agricultural techniques. |
| | Pentair | **Aquaponics** - a unique combination of fish farming (aquaculture) with hydroponics. Fish convert their food |

| TYPE | EXAMPLE ORGANIZATIONS | PROGRAMS/ PRODUCTS/ INNOVATIONS |
|---|---|---|
| | | into nutrients that plants can absorb, while the plants clean the water for the fish. Compared to conventional farming, this technology uses about half of the water, while increasing the yield of the crops grown. As a bonus, it also can raise a significant amount of fish. |
| | Memphis meat | **In vitro meats** - self-replicating muscle tissue cultures are grown and fed nutrients in a broth, and bypass the need for having living animals altogether. |
| | IndieBio | **Artificial animal products -** They use machine learning to grasp the complex chemistry and textures behind these products, and to find ways to replicate them. This has already been done for mayonnaise – and it's in the works for eggs, milk, and cheese as well. |

## GAP ANALYSIS

### METHODOLOGICAL NOTE

Gap analysis involves the comparison of actual performance with potential or desired performance. Simply put, gap analysis addresses three questions:

1. Where are we? (the present state)
2. Where do we want to go? (the target state)
3. What needs to be addressed to get from today to the target?

The first question is answered through the previous research components, that is, the trend and benchmark analysis. These two components are basically a description of the present state and the elements that will shape the future. The second question is answered through the description of the desired end-state (as was described in the hypothesis section). So, if we know where we are (current state), what the desired state is, and who is working on solving related-challenges, we can also identify what areas are being neglected (and for which reasons). These areas (and reasons) are the gaps.

## GAP DESCRIPTION

**Currently, many of the biotechnologies that have been commercialized face resistance from the public and regulatory agencies -** Cross-pollination methods can cause damage to other organisms that thrive in the environment (e.g., pollen from the genetically modified plants will spread the transformation to non-transformed plants in nearby fields and that genetically modified foods will be harmful to human health). In addition, for many of the emerging technologies to be deployed globally, they will have to be adapted to the mix of commodities produced, production practices, and environmental conditions of different localities. Local implementation might require additional factors such as investments in agricultural research at the developing-country level, as well as in agricultural human capital and infrastructure.

**Agricultural productivity improvements** will require advances in other fields beyond molecular biology, including chemistry, electrical engineering, remote sensing, and computer science. The tools from these fields are not necessarily developed specifically for agriculture, but their application can make improvements in controlling the management of soil, water, crop, and energy inputs for agriculture.

**Precision Agriculture -** For precision agriculture technologies to diffuse on a wide scale in the future, they will need to scale down to work well for small plots in the developing world, where the greatest potential for productivity gains can be made.

**Post-Harvest Processing -** The technology has met with public resistance to its application because of fear that the basic food properties will be altered; and because of high costs that could be prohibitive to expansion.

**Production Costs -** The cost of genetically transformed seeds can be five to seven times higher than conventional seeds.

**Vertical Farms -** High cost is one of the primary challenges facing the expansion of vertical farms, and it is not clear when these technologies will be viable on a commercial basis.

**Some argue that a strategic shift that mainstreams nutritional considerations and outcomes** in agricultural and food security strategies is needed. Many developing countries have had success in reducing the incidence of hunger, typically through measures to increase production of selected staple grains and manage their price volatility. Nevertheless, these food security strategies have contributed less to reducing child stunting and population-wide micronutrient deficiencies, and even have shown trending toward higher obesity. In many developing countries, supporting primarily staple grains and export crops has created an uneven playing field with most public support going to only a portion of the farming sector. Efforts need to be stepped up to promote the diversity of production as well as consumption by strengthening farmers' knowledge, advisory and regulatory services, market infrastructure and connectivity, and the overall investment enabling environment for these traditionally under-supported foods that are important for nutrition.

**Food Waste –** High levels of food waste occur, particularly in high income, and to a lesser extent in middle income countries due to excess supply and/or the behavior of consumers and retailers. According to the FAO, every year, consumers in rich countries waste almost as much food (222 million tons) as the entire net food production of Sub-Saharan Africa (230 million tons). Not too long ago, France passed legislation that bans supermarkets from discarding unsold foods and instead requires them to donate unsold foods to charities and food banks.

**Nutrient-rich Crops –** Increasing nutrient content has not been a commonly used criterion for plant breeding except in very special cases such as biofortification. The traditional focus of plant breeding research has been on increasing the yield of staple crops—mainly rice, wheat, and maize—and their resistance to pests and diseases, and tolerance to droughts and floods. Breeding needs to be expanded to include a focus on nutrient content to improve access to nutrient-rich foods, and to a broader set of crops.

**Biofortified Crops –** Biofortification is a purposeful effort to breed plants to improve the nutrient content while not compromising on traditionally valued traits such as yields, resilience, and taste. Efforts need to increase to add nutrient-dense traits to traditional staple crops including maize, rice, millet, beans, and cassava. Nutrient content should be the main criterion for plant breeding. Biofortification offers a promising approach to help address micro-nutrient deficiencies, especially for people currently consuming and undiversified cereal-based diet.

**Diversified Production –** Many small-scale farmers engage in monocropping (the agricultural practice of growing a single crop year after year on the same land), such as staple grains. The resulting household diet often lacks sufficient nutrient diversity and contributes to poor nutritional outcomes. When small farm households produce a

more diverse set of foods (e.g., fruits and vegetables, legumes, milk, eggs and fish), and receive nutrition awareness training, the result often is greater dietary diversity, higher micronutrient intake, and positive impacts on the nutritional status of children in the household.

**Opportunities for Women** – In many less developed countries, women lack discretionary income earning opportunities and labor-saving technologies. Making education, labor markets, and civil engagement as accessible to women as men is particularly important to improve nutrition of the women themselves, and their children. The most relevant aspects of women's empowerment for nutrition are: increasing access to and control over resources—primarily incomes; increasing decision-making power related to food purchase and preparation; and reducing time and labor constraints.

## GRAND CHALLENGES

## METHODOLOGICAL NOTE

Grand Challenges (GCs) are lists of difficult but important problems articulated by the research team to encourage the discovery of (mainly) technological innovation (i.e., breakthroughs) that could potentially solve the core issues. In other words, a GC is one or more specific critical barrier(s) that, if removed, would help solve an important problem with a high likelihood of global impact through widespread implementation.

Articulating important challenges that have the potential to deliver real impact, and allocating significant resources to address these GCs later in the process, allows XPRIZE to bring the best minds to the table by engaging crowds who might not otherwise be engaged in global research.

## KEY CHALLENGES

- Sustainably improving agricultural productivity to meet increasing demand
- Ensuring a sustainable natural resource base
- Addressing climate change and intensification of natural hazards
- Eradicating extreme poverty and reducing inequality
- Ending hunger and all forms of malnutrition
- Eliminating food loss and waste
- Making food systems more efficient, inclusive and resilient
- Improving income earning opportunities in rural areas
- Building resilience to protracted crises, disasters and conflicts
- Preventing transboundary and emerging agriculture and food system threats
- Addressing the need for coherent and effective national and international governance

## FRAMING A GRAND CHALLENGE

- **Widely applicable problem...**The agricultural sector will face tremendous challenges in order to feed the 9.6 billion people that the FAO predicts are going to inhabit the planet by 2050. Food production must increase by 50% to 100%, and this has to be achieved in spite of the limited availability of arable lands, the increasing need for fresh water (agriculture consumes 70 % of the world's fresh water supply), and other less predictable factors, such as the impact of climate change which, according to a recent report by the UN, could lead to changes of seasonal events in the life cycle of plants and animals.
- **for which scientifically sound solutions are imaginable...**Low-cost greenhouses in dry and arid environments, skyscraper/vertical farms, C4 rice, meat from labs, etc.

- **but not quite at hand...**Some of these innovations like C4 rice and meat from labs are 20-30 years away.
- **with deep societal importance...**With 800 million people going to bed hungry every night, the world needs a sustainable food system that can feed every person, every day.

# II. FORESIGHT

## METHODOLOGICAL NOTE

Scenarios inform present-day decision-making by exploring different possible futures. In contrast to forecasting, scenarios examine what is most uncertain and surprising as a mechanism to generate insight and provoke action regarding future-focused risks and opportunities. Scenarios can stretch our thinking about divergent plausible futures. Importantly, the value of scenarios analysis is to examine all of the possible futures identified—rather than focusing on the more desirable ones—with the understanding that any scenario may occur. Thus, scenarios are a tool to uncover blind spots and broaden perspectives about alternative future environments in which today's decisions might play out. The implications drawn from the scenarios are designed to trigger discussion, rather than serving as prescriptive outcomes.

## BASELINE SCENARIOS

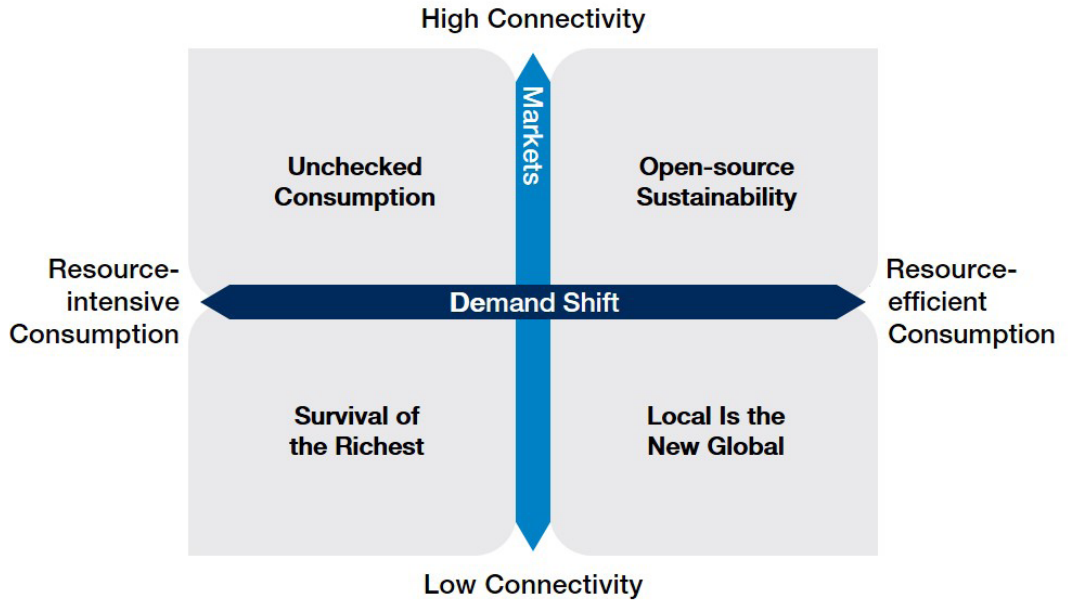
The projections show that feeding a world population of 9.1 billion people in 2050 would require raising overall food production by some 50% to 100% between 2005/07 and 2050. Production in the developing countries would need to almost double. This implies significant increases in the production of several key commodities. Annual cereal production, for instance, would have to grow by almost one billion tons, meat production by over 200 million tons to a total of 470 million tons in 2050, 72% of which is in developing countries, up from 58% today. Feeding the world's population adequately would also mean producing the kinds of foods that are necessary to ensure nutrition security.

## WORLD ECONOMIC FORUM SCENARIOS ANALYSIS

The World Economic Forum conducted a scenarios analysis to respond to the following focal question: How will food systems nutritiously and sustainably feed 8.5 billion people in 2030?

A scenarios analysis is built around the forces of change that will most profoundly and unpredictably impact the focal question. After compiling a long list, experts identified "demand shift" and "market connectivity" as the two most critical uncertainties.

1. **Demand shift:** The uncertainty encompasses the nature of future demand for food and agricultural commodities, with particular focus on the environmental impact and health implications of consumers' choices. Demand shift uncertainty is thus focused on whether demand will be relatively more resource-intensive versus resource-efficient.
2. **Market Connectivity:** This uncertainty pertains to the openness of trade, trust in and resilience of commodity markets, and inclusivity of technological innovations. This uncertainty focuses on whether markets will be defined by high connectivity versus low connectivity.




## THE SCENARIOS: FOUR POTENTIAL FUTURE WORLDS

1. **Survival of the Richest:** In a world of resource-intensive consumption and disconnected markets, there is a sluggish global economy and a stark division between the "haves" and "have-nots." In this scenario, a relatively few isolated, wealthy populations are able to produce and innovate to meet their needs, while isolated, poor or import-dependent markets are facing intensifying hunger and poverty. Population growth, rising inequality and food prices have led to increased conflict and migration, and intensifying resource needs have prompted a new wave of investments by foreign entities in land and water resources. Climate change continues unabated. Technology innovation is defined by a broad disparity of access and adoption. Reactionary decision-making and a crisis mindset are perpetuating a fragile system.
2. **Unchecked Consumption:** In this scenario, there is a combination of resource-intensive consumption and highly connected markets which has enabled rapid growth with serious consequences. Driven by ever-increasing demand, trade is accelerating as markets boom. Technology has spurred

efficiencies in food production and distribution, with yield improvements as the top priority. Obesity and health costs rise dramatically as billions of consumers transition to a high-volume, high-calorie, low nutrient-density diet. The "footprint" expands as natural resources—including water, biodiversity and land—are severely depleted and components of key ecosystems such as fisheries and dryland begin to collapse, increasing costs of water purification and intensifying impacts in other regions as consumers seek alternate sources of food.

3. **Open-source Sustainability:** In this scenario, a combination of resource-efficient consumption and highly connected markets enables a rise of greater transparency in business and in markets. Commodity markets have been stress-tested, and checks and balances instated, to reduce volatility and the risk of a crash. There is a proliferation of food sources, which reduces over-reliance on a few breadbaskets, improving the resilience of food systems. An increasingly interconnected trade system, however, still leaves the world susceptible to the effects of extreme weather events and other economic and political shocks. A stronger global economy enables more consumers to purchase food priced at its "real" cost, as influenced by new business models and policies that support sustainable choices and healthy diets. There is a movement towards personalized nutrition and healthcare, and more people use mobile apps to drive their shopping and eating habits. A rural transformation attracts youth to data-driven agriculture, but older farmers struggle to keep pace.
4. **Local is the New Global:** In this scenario, resource-efficient consumption and low connectivity of markets have led to fragmented food systems whereby nations rely heavily on self-sufficiency. There is a rise in local food movements as consumers increase their focus on sustainable local products. Consumers in developed countries rediscover and appreciate local diets and develop a new

> respect for food, taking additional measures to reduce food waste. Progressive policies have successfully reduced the price point for healthier diets relative to unhealthy diets. Together, these factors enable a shift toward more balanced diets and a reduction in obesity and related diseases. Shorter supply chains and increased plant-based diets reduce the strain on environmental resources. However, at the macro level, comparative advantages among food-producing regions are lost. Nations without good agricultural land struggle to meet demand and hunger hotspots proliferate.

The future is uncertain. And navigating uncertainty requires thoughtful consideration and contingency planning for unforeseen developments. Scenarios can be a powerful tool to explore potential futures, considering how key trends and uncertainties could lead to different outcomes. They can broaden our perspectives on the possibilities for what the future may hold, and the implications of the choices we make today. Scenarios are also important because they can provoke and challenge leaders to think in new ways about what the future may bring, and to motivate action on the key issues that will shape the future.

## PREFERRED FUTURE

The preferred future is typically captured as a vision. A vision is an image of the future. It creates an attractive mental picture of an outcome that people can strive towards. Most people think of the future in ideas rather than images. Attractive ideas are progress, security, enjoyment; unattractive ones include overpopulation, pollution, sickness, and death. None of these are visions because they are not images. What does it look like? How does it feel? What does it taste like, sound like? The vision is something tangible and concrete—something that excites people and enables them to take action in support of reaching the preferred future state.

A future of plenty or a future of scarcity is certainly not a given. It's possible to address system failures to leverage, shift, or even reverse trends—even global mega trends—by enabling and incentivizing bold actions. But to truly think boldly, we cannot start with today. It's imperative to start with a preferred future state. The following is an example of a preferred future.

"By 2040, everyone on the planet will have access to safe, healthy, affordable, and nutritious food at all times to support an active and healthy life."

# III. ACTION

## METHODOLOGICAL NOTE

Solving grand challenges is complex. XPRIZE only launches the most impactful prizes, those that when launched in conjunction with others will achieve a moonshot and radically transform a given domain. XPRIZE begins this process by developing a Futures ImpactMap that maps the full landscape of what is currently happening, what needs to change, and which breakthroughs would not happen unless the crowd was incentivized to develop radical innovations. Once we know which breakthroughs will not be achieved by traditional actors alone, XPRIZE sources brilliant Visioneers in the crowd to vet and evaluate which breakthroughs should become the next XPRIZE. Ensuring that the global population of the future has access to safe and nutritious food is a daunting challenge given climate change and a plethora of other constraints the world is currently facing. Only brave, radical new thinking will solve this Grand Challenge. Which breakthroughs can you identify that will transform agriculture and enable both people and the planet to prosper?

## CONCLUSION

Transformational change is the process of creating a new era. It begins with one or more bold leaders who see that the old era is no longer suitable for the present, much less the future. These bold visionaries articulate a preferred future for the new era, and enroll others in the campaign to bring that future about. These leaders and those that follow face enormous obstacles from the doubts and resistance of the majority, to the challenge of leaving behind old ways of doing things even before the new ones are ready. Nevertheless, they are compelled to engage in this work because it must be done sooner or later, and it's best to start today before the terms of change can be dictated.

## APPENDIX A: DEFINITIONS

1. **Breakthrough:** To overcome "Grand Challenges" and achieve a "Preferred Future," it's essential to identify potential breakthroughs that can create massive, global impact. Breakthroughs are evaluated based on 4 criteria: impact potential, level of audacity, market readiness level, and desired timeline for impact.
2. **Domain:** XPRIZE operates within 7 domains: shelter and infrastructure; energy and resources; planet and environment; health and wellness; learning and human potential; space and new frontiers; and civil society. Emerging exponential technologies and other innovations in policy and financing have the potential to address grand challenges in these areas, but require new action by key stakeholders and innovators from around the globe.
3. **Futures ImpactMap:** Is an analytical tool for understanding persistent problems and barriers that make up grand challenges in various domains as well as the actions that key stakeholders can take to overcome them and achieve a preferred future state. XPRIZE uses Futures ImpactMaps to help identify potential XPRIZE competitions and other actions that can accelerate a bridge to abundance for all across domains.
4. **Grand Challenge Area:** Is a topic area like "Nourishing the Next Billion," which comprises a combination of complex and overlapping social, technological, economic, environmental, and policy issues. Only the most effective actions will address these issues and accelerate progress toward a more positive future.
5. **Grand Challenge Statement:** A problem statement, which defines the issue to be solved.

6. **Preferred Future:** Is typically captured as a vision—an image of the future. It creates an attractive mental picture of an outcome that people can strive for.
7. **Scenario:** Scenarios inform present-day decision making by exploring different possible futures. In contrast to forecasting, scenarios examine what is most uncertain and surprising as a mechanism to generate insight and provoke action regarding future-focused risks and opportunities.
8. **XPRIZE:** The XPRIZE Foundation is the global leader in designing and implementing innovative competition models to solve the world's grandest challenges. XPRIZE utilizes a unique combination of gamification, crowdsourcing, incentive prize theory, prize philanthropy, and exponential technologies as a formula to make 10x (vs.10%) impact in the grand challenge domains facing our world. The XPRIZE philosophy is that—under the right circumstances—igniting rapid experimentation from a variety of diverse lenses is the most efficient and effective method to driving exponential impact and solutions to grand challenges.
9. **XPRIZE (competition):** An XPRIZE is an incentivized prize competition designed to create 10x impact on the world. The exponential trend of computing power has led us to this period in time, where technology that was just 30 years ago only available to industries like NASA is now on the smartphones in our pockets. XPRIZE competitions leverage this exponential technology with the power of the crowd to spur innovation in areas where there is market failure, empowering individuals across the globe to become the world's next change makers. The competitions are engineered for success: they are required to meet a series of 10 criteria through a rigorous evaluation at our Visioneers Summit in order to be deemed ready for launch. Each XPRIZE competition results in audacious breakthroughs that have scalable impact, leading us closer to the XPRIZE Foundation's vision of a future in which

humanity as a whole benefit by having access to what was once scarce, and is now made abundant.

## REFERENCES

(2016, June 9). The future of agriculture. Technology Quarterly, Economist. From https://www.economist.com/technology-quarterly/2016-06-09/factory-fresh

(2017, October 31). Guinea's Innovators plant the seeds for success. Feed the Future. From https://feedthefuture.gov/article/guineas-innovators-plant-seeds-success

(2017, October 31). Young entrepreneurs chase their agriculture dreams in Guatemala. Feed the Future. From https://feedthefuture.gov/article/young-entrepreneurs-chase-their-agriculture-dreams-guatemala

(2017, October 31). Making agriculture cool again for youth in Africa. Feed the Future. From https://feedthefuture.gov/article/making-agriculture-cool-again-youth-africa

Desjardins, J. (2017, September 6). The future of food: How tech is changing our food systems. Visual Capitalist. From http://www.visualcapitalist.com/future-of-food/

Future Food: The menu of 2030. Futurism. From https://futurism.com/images/future-food-menu-of-2030/

Feeding the future. (No date). Future Food Accelerator. From http://futurefood.network/accelerator/

Future food: The menu of 2030. (No date). Futurism. From https://futurism.com/images/future-food-menu-of-2030/

Guerrini, F. (2015, February 18). The future of agriculture? smart farming. Forbes. From https://www.forbes.com/sites/federicoguerrini/2015/02/18/the-future-of-agriculture-smart-farming/#6b9908f93c42

Issacson, B. (2015, October 22). To feed humankind, we need the farms of the future today. Newsweek. From http://www.newsweek.com/2015/10/30/feed-humankind-we-need-farms-future-today-385933.html

King, A. (2017, April 26). Technology: The future of agriculture. Outlook, Nature. From https://www.nature.com/articles/544S21a

Klytchnikova, I. et. al. (2015, October). Future of food, shaping a climate-smart global food system. World Bank Group. Washington, D.C. From http://documents.worldbank.org/curated/en/645981468189237140/Future-of-food-shaping-a-climate-smart-global-food-system

Mann, C. C. (2018, March). Can planet earth feed 10 billion people? Humanity has 30 years to find out. The Atlantic. From https://www.theatlantic.com/magazine/archive/2018/03/charles-mann-can-planet-earth-feed-10-billion-people/550928/

Prindle, D. (2017, April 25). Can tech help us feed a population of 9 billion-plus? Welcome to the future of food. Emerging Tech, Digital Trends. From https://www.digitaltrends.com/cool-tech/future-of-food-introduction/

Reliefweb. (2017, Feb 22). The future of food and agriculture: Trends and Challenges. Food and Agriculture Organization of the United Nations. Rome. From https://reliefweb.int/report/world/future-food-and-agriculture-trends-and-challenges

Thompson, A. (2017, December 8). Using ICT for agricultural markets: A Q&A with Tara Chiu of the feed the future assets and market access innovation lab. Agrilinks. From https://agrilinks.org/post/using-ict-agricultural-markets-qa-tara-chiu-assets-and-market-access-innovation-lab

Townsend, R. F. et. al. (2015, May). Ending poverty and hunger by 2030, an agenda for the global food system. World Bank Group (Second Edition). Washington, D.C. From

http://documents.worldbank.org/curated/en/700061468334490682/Ending-poverty-and-hunger-by-2030-an-agenda-for-the-global-food-system

Townsend R. F., Jaffee, S., Hoberg, Y. T. & Htenas, A. (2016, April). Future of Food, shaping the global food system to deliver improved nutrition and health. World Bank Group. Washington, D.C. From http://www.worldbank.org/en/topic/agriculture/publication/the-future-of-food-shaping-the-global-food-system-to-deliver-improved-nutrition-and-health

Townsend, R. F., Benfica, R., Prasann, A. & Lee, M. (2017, April). Future of Food, shaping the food system to deliver jobs. World Bank Group. Washington, D.C. From http://www.worldbank.org/en/topic/agriculture/publication/the-future-of-food-shaping-the-food-system-to-deliver-jobs

World Economic Forum. (No Date). The system initiative on shaping the future of food security and agriculture. World Economic Forum. Geneva. From https://www.weforum.org/system-initiatives/shaping-the-future-of-food-security-and-agriculture

World Economic Forum & Deloitte Consulting LLP. (2017, January). Shaping the future of global food systems: A scenarios analysis. World Economic Forum. Geneva. From http://www3.weforum.org/docs/IP/2016/NVA/WEF_FSA_FutureofGlobalFoodSystems.pdf