GFCC
Global Federation of Competitiveness Councils

Connecting Farm, City and Technology

Transforming Urban Food Ecosystems in the Developing World

Acknowledgments

We gratefully acknowledge the input and suggestions of the Global Federation of Competitiveness Councils (GFCC), Roberto dos Reis Alvarez, Alfred Watkins, Dylan Jones, Dave Dewar, Greg Treverton, Bob Barbour, Stephane Durand, Yvonne Papageorgiou, Steven Miller, Tania Nagpaul, Jonathan Chang, Jinwen Chen, Molly Jahn, Yasmin Hilpert and Joanna Seivard.

The Global Federation of Competitiveness Councils (GFCC) is an international network of leaders, non-profit organizations, government agencies, universities and companies working collaboratively to build sustained prosperity through innovation. The GFCC develops initiatives and tools to better understand and navigate the complex competitiveness landscape, and disseminates best practices.

The Global Federation of Competitiveness Councils (GFCC) is a nonprofit, 501(c)(3) organization as recognized by the U.S. Internal Revenue Service.

The GFCC's activities are funded by contributions from its member organizations.

Global Federation of Competitiveness Councils
900 17th Street, NW, Suite 700
Washington, DC 20006
USA
T 202 969 3382
www.thegfcc.org

Connecting Farm, City, and Technology to Transform Urban Food Ecosystems for the Developing World

Authored by Fred T. Davies and Banning Garrett

Dr. Fred T. Davies is Regents Professor Emeritus, Senior Borlaug Fellow in Horticulture, Borlaug Institute of International Agriculture, Texas A&M University; Senior Fellow, Global Federation of Competitiveness Councils; former Senior Science Advisor and Jefferson Fellow, USAID; and past President, American Society for Horticultural Sciences; f-davies@tamu.edu.

Dr. Banning Garrett is on the faculty at Singularity University; Senior Fellow, Global Federation of Competitiveness Councils and Global Urban Development; and a consultant to the United Nations and the World Bank; banninggarrett@gmail.com.

About the GFCC

The Global Federation of Competitiveness Councils (GFCC) is a network of leaders and organizations from around the world committed to competitiveness and higher living standards. Our members strive to achieve innovation, productivity and prosperity in their nations, regions and cities. The GFCC develops and implements concepts, initiatives and tools to navigate the complex competitiveness landscape and take action.

Thriving markets and people rely on both their own national policies and collaborations across the globe. In this spirit, the GFCC brings together experts for their mutual competitiveness and benefit, true to the motto of **Accelerating Competitiveness through Collaboration**.

Founded in 2010, the Global Federation of Competitiveness Councils brings together more than sixty member organizations and is currently represented in more than 35 different countries around a collection of shared principles to enhance regional, national and global prosperity.

The GFCC aims to enable mutual learning within its distinctive network as well as across the extended network of GFCC partners. This leads to development and implementation of original, creative ideas, concepts and tools for members to navigate today's complex competitiveness landscape.

The GFCC works with its members to catalyze cross-learning and creation of competitiveness and innovation strategies, policies and initiatives. For GFCC members, this is achieved through in-depth, high-level networking, analytical tools, advice and education.

Table of Contents

Letter from the President

A profound revolution in agriculture and food production is unfolding, just when we need one. With the global population expected to soar by more than two billion by 2050, and more than 800 million people worldwide undernourished today, the world needs to double food production – perhaps even triple production, according to John Deere's Chairman and CEO and Council on Competitiveness Chairman Emeritus Samuel Allen. But, much of the world's arable land is already in use, and the remaining land has serious soil and terrain constraints. Globally, agriculture accounts for 70 percent of water withdrawals, and consumes large amounts of energy, resources for which there are significant concerns about resource stress and sustainability. Moreover, we are seeing the largest wave of urban growth in history. Urban dwelling is expected to increase by 60 percent by 2050, from 4 billion to 6.3 billion people, almost two-thirds of the world's population, with most of this growth taking place in the developing world.

Urban communities face the challenge of feeding their populations and connecting their food markets to sustainable agricultural production of high productivity, especially in the developing world where population pressure is rising. The Global Federation of Competitiveness Councils' (GFCC) new report, *Connecting Farm, City and Technology to Transform Urban Food Ecosystems for the Developing World*, shows how a mix of new technologies – from digital connectivity, sensors and the Internet of Things, to blockchain, biotechnology and renewable energy – can integrate to create sustainable food ecosystems for the world's urban areas.

The Hon. Deborah L. Wince-Smith
President
Global Federation of Competitiveness Councils

Learn how farmers are applying biotech to grow: pest and disease resistant crops that increase yields; foods with more nutrition; and climate tolerant crops that could increase yields and establish agriculture where we cannot now. On farms and in fields, precision agriculture based on the building blocks of sensors, big data and the Internet of Things can optimize seed and land use, save water and energy by precisely delivering irrigation water when and where it is needed, and improve farm productivity and agricultural resource management. In connecting food production to urban consumers, the Internet of Things is creating smart supply chains from farm to fork, rationalizing transport and distribution, lowering costs and improving efficiency. For urban areas, vertical indoor farms use special nutrient formulas, tunable LED lighting and microclimates designed to optimize production. They deliver a leap in productivity, better food, incredible water savings and greater sustainability. And as new food ecosystems emerge and grow, there will be new opportunities for innovators, entrepreneurs, farmers and food producers – as well as new businesses and new jobs.

The GFCC is dedicated to sharing knowledge and best practices to accelerate innovation-based economic development, and promote higher standards of living, sustainability and global prosperity. This new report on building 21st century food ecosystems is a superb contribution in fulfilling this mission at the nexus of food, water and energy. We should reject the notion of scarcity and, instead, harness the power of disruptive technologies to create a new era of food abundance.

Executive Summary

Smart integration of technology can help create sustainable urban food ecosystems (UFEs) for the rapidly expanding urban population in the developing world. It can increase production of nutritious food in the cities and surrounding regions where the food is consumed. Technology, especially recent advances in digital-enabled devices based on internet connectivity, is essential for building UFEs at a time when food availability is not meeting demand. For the first time in human history, food production will be limited on a global scale by the availability of land, water and energy. By 2050, two thirds of the world will be urban, with a net world population growth of 2 billion people (increasing the global population to nearly 10 billion) — expected to occur in urban regions in the developing world.

The food challenge will be most critical in the developing world, where nearly a billion people go to bed hungry and suffer from food insecurity (lack of calories) and nutritional insecurity (lack of vitamins and essential minerals from a balanced diet of fruits, vegetables and animal protein). The focal point of this challenge will be developing resilient food production and distribution systems for servicing middle-class consumers with disposable income in urban and peri-urban markets. This includes increasing urban food production in cities through controlled environmental agriculture (CEA), rooftop farms, vertical farms, cultured meat, and other technology-enabled innovations. Also critical to UFEs, will be enhancing agricultural productivity and processing in rural and peri-urban areas and linking them to urban markets.

In much of the developing world, low adaption of mechanization and modern agricultural technologies impedes sustainable production. This productivity challenge is being exacerbated by the impact of unpredictable climate change on agriculture, especially from excessive heat, drought, and extreme weather events. Climate change and unrestrained urban sprawl will further reduce available, arable land. Only 5 percent of West African agricultural production is irrigated, for example, which is a recipe for disaster. A food crisis is looming, with the developing world ill-prepared to sustainably feed itself. To overcome this productivity stagnation, and to survive and compete, it is critical that farmers, producers and other entrepreneurs along the nodes of the food value chain become more digitally connected to modern agricultural technology in UFEs.

The rapid growth of urban and peri-urban populations and markets in the developing world is also creating unprecedented opportunities for smallholders to progress from subsistence farming to commercially producing niche, nutrient-dense, cash crops (horticulture) and animal protein (poultry, fish, pork, insects). Technology can be used to enable "nutrition-sensitive agriculture" of goods and services that align agricultural production with people's nutritional needs. This includes processed, healthy, nutritious, convenient, value-added foods to service middle-class markets.

At the same time, more people will be transitioning to off-farm jobs, in pursuit of other economic opportunities along the food value chain, including marketing, transporting, processing, food services, preparation and delivery.

These UFEs include a hybrid mix of rural, peri-urban (rural-urban transition zone), and urban agricultural production systems. The UFEs will need to employ good agriculture practices (GAPs) in both rural and urban food production, from non-organic to organic, and from field grown food on rural farms to CEA using "high-tunnels," "plasticulture," containerized systems, roof top farms, raised beds, greenhouses, and "vertical farms" with LED light sources. These diverse agricultural production systems will range from small to large farms, from low-tech to high-tech, that are niche oriented in delivering products and services to customers. "Off-the-shelf" precision agriculture technology will increasingly be the new norm, from smallholders to large producers.

The technology-enhanced UFEs we describe will, on the one hand, make on-farm production more resilient and tied to urban food systems; and on the other, create off-farm opportunities along the value chain, including food production in cities and serving customers with new goods and services. In addition, increasing regional and local production and sustainability will enhance resilience to climate change and to economic shocks, including the current backlash against globalization and unwanted immigration.[1] Technology-led jobs in UFEs will also provide new entrepreneurial opportunities to address bulging youth populations, unemployment, migration and civil unrest.

Technology can enable transformation of UFEs, from expanded production in cities, to more efficient and inclusive distribution and closer connections with rural farmers. Connecting food production and distribution to urban and peri-urban markets has many advantages. Road systems with closer proximity to markets tend to receive greater investment in their upkeep, increasing ease of transportation and reducing problems with perishability; reliable electricity is more available for refrigerated storage (cold-chain). These regions and markets favor high-value (cash), nutrient-dense crops (vegetables and fruits), which require less acreage and are more profitable per square meter than agronomic crops such as rice, corn and wheat. This creates new market niche opportunities for smallholders, many of whom are women.

We have identified 12 innovative technology platforms to advance the UFEs of the developing world:

1. Connectivity – information delivery and digital technology platforms;
2. Uberized services;
3. Precision agriculture – GPS, Internet of Things (IoT), artificial intelligence (AI), sensing technology;
4. CEA – controlled environment agriculture, including vertical farms;
5. Blockchain for greater transparency, food safety, identification;
6. Solar and wind power connected to microgrids;
7. High-quality, enhanced seeds for greater yield, nutrition, climate and pest resistance;
8. Advanced genetics: including gene editing, synthetic biology and cloud biology;
9. Biotechnology: including microbiome editing, soil biologicals, cultured meat, alternative proteins to meat and dairy;
10. Nanotechnology and advanced materials;
11. 3D printing/ additive manufacturing; and
12. Integration of underutilized, existing technologies with new technologies.

The new technology-enabled UFEs, linked to value chains, will create entrepreneurial opportunities and will more efficiently employ resources and people to connect the nexus of food, water, energy, nutrition and human health.

The key is developing farming systems using sustainable intensification – "doing more with less" – that are economically, environmentally and socially sustainable. The next generation UFEs will be part of the larger collaborative economy that is connected by digital platforms, the cloud, and the IoT, and uses multi-disciplinary approaches to connect producers, horticulturists, agronomists, plant biologists, distributers,

1 Jahn, M., B. Jayamaha, W.S. Mulhern, D. E. Ross, M. A. Rose and G. F. Treverton. (2018). Global Food System Stability and Risk: At the Nexus of Defense and Development. U.S. Army War College, U.S. Dept. Defense. Available online at: https://www.thomsonreuters.com/content/dam/ewp-m/documents/thomsonreuters/en/pdf/reports/globalfoodsystemstabilityandrisk.pdf.

traders, marketers, urban planners, nutritionists, chefs, educators, food processors, computer programmers, engineers (chemical, mechanical, electrical, environmental) and behavioral scientists.

Sustainable intensification of agriculture entails capitalizing on technology, innovations, and new business models. It offers the potential to feed a rapidly growing global urban population, while also creating economic opportunities for rural and peri-urban – as well as urban producers and value-chain players. The new technology-enabled UFEs, enhanced by smart government policies, will enable more efficient and effective use of resources and people to connect the nexus of food, water, energy, nutrition and human health. This will also contribute to development of a circular economy that is designed to be restorative and regenerative – minimizing waste and maximizing recycling and reuse – to build economic, natural and social capital.

Recommendations

Development of environmentally and economically sustainable and increasingly productive UFEs will require a comprehensive effort by business, government, NGOs, and other organizations. This will involve both "bottom-up" and "top-down" approaches with the private sector the primary engine of growth supported by enabling government policies and investments. Technology is not a "silver bullet" but rather a tool to be innovatively utilized, when appropriate, and supported by effective business models. The following is an initial list of goals, approaches and policy recommendations to promote technologically-enhanced urban food ecosystems from farm to city.

Goals and Approaches

- **Learn from the locals:** Locals know where the bottlenecks in the food ecosystem are and how they might be overcome. Their knowledge can be combined with available and affordable technologies to create new businesses within the food ecosystem.
- **Build resilience:** The UFEs must be integrative from multi-crop to multi-source protein production (livestock, poultry, fish, insect, etc.) to build resilience to climate and economic shocks.
- **Encourage diversity in the food ecosystem:** Agricultural practices will vary in a world of niches from small to large producers, offering different products and services, all linked to the marketplace and value chain.
- **Link multinational supermarkets to the rural/urban food ecosystem:** Supermarkets in the developed world such as Walmart and Carrefour are expanding into developing world cities and are looking for quality local produce to service middle-class markets.
- **Expand and maintain enabling infrastructure:** Accessible and affordable broadband for all citizens is a critical foundation for technology dissemination and connectivity, along with all-weather road networks, reliable electricity, water, sanitation, and other basic infrastructure.
- **Support producers' cooperatives:** Cooperatives and business associations can be critical local-level aggregations to provide producers with training and mentoring, enhanced production knowledge and techniques, reduced crop/animal losses, micro loans, warehouse storage, potential cold-chain support, transportation, and market information.
- **Support private sector innovations through mentoring:** Mentorship and business coaches (private-public) are needed throughout the UFEs from production, processing, storage and to delivery to end customers.
- **Encourage life-long learning and training:** Adapting and utilizing technology and innovative techniques requires life-long learning and continually retooling.

Collaborative Projects and Government Policies

City and regional governments, in collaboration with businesses, incubators and accelerators, civic organizations, and universities, could engage in a wide range of activities and collaborations to support development of technology-enhanced urban food ecosystems. These activities could include:

- **Gathering data to map the existing food ecosystem** to discover how food moves from farm to table in the region to provide a baseline for understanding the current system with its strengths, weaknesses, food deserts and bottlenecks.
- **Educating the senior leadership** of city and regional governments, businesses and key non-government stakeholders on the opportunities and challenges for developing UFEs.

- **Seek to build a consensus of key stakeholders for a vision** of a desirable and realistic future UFE for the city and region to develop specific goals, timelines and strategies for achieving that vision.
- **Develop a working UFE plan** based on this vision and set of goals and strategies for development of the UFE that integrates rural and peri-urban agriculture with urban food production, distribution and consumption systems.
- **Develop and implement "smart" policies** on land use and ownership, entrepreneurship, credit and market access, cooperatives, government transparency (rule of law), and investment in agriculture, all-weather roads and reliable electricity.
- **Establish strong public outreach**, including through social media, to communicate and encourage feedback on the UFE vision, goals, strategies and plans.
- **Strengthen ties with cities and urbanization organizations globally** to share experiences and learn from each other.
- **Build out the connectivity infrastructure** which undergirds UFEs, soon to be upgraded to ubiquitous 5G wireless networks, with the goal of bringing affordable and accessible broadband internet to all citizens.
- **Build capacity within the government** to exploit the opportunities and meet the challenges in building UFEs.
- **Promote the development of "Food Valleys"** composed of incubator systems with universities that attract industry as well as smaller, more flexible, innovative start-ups.[2]
- **Create regular symposia and UFE business/technology shows** to educate the public and bring together established companies and startups to network and to promote their businesses and technologies.
- **Stimulate innovation by establishing contests and "prizes"** for innovations that aid in advancing the UFE plan.
- **Champion the development of a new generation of "urban food producers"** as good, well-paying jobs and careers.

2 Terazono, E. (2018). Future of food: Inside Agritech's Silicon Valley. Financial Times, 14 Oct. 2018. Available online at: https://www.ft.com/content/199cae4c-cbc6-11e8-b276-b9069bde0956.

Introduction

Smart integration of technology can help create sustainable urban food ecosystems (UFEs) for the rapidly expanding urban population in the developing world.[3] Technology, especially recent advances in digital-enabled devices based on internet connectivity, are essential for building UFEs at a time when food production is increasingly limited on a global scale by the availability of land, water and energy. By 2050, two thirds of the world will be urban – and most of the net world population growth (expected to reach nearly 10 billion people) – will occur in urban regions in the developing world. Yet the developing world is ill-prepared to feed itself. Agricultural production in West Africa remains anemic, for example, while its population is expected to double in just 20 years. Moreover, two of the six largest global cities will be in West and Central Africa. There is chronic underuse of mechanization, basic fertilizer and irrigation inputs in the developing world, often with little adoption of modern agricultural and food technologies needed for sustainable intensification of food production (see Appendix I).

A food crisis is looming, and will be exacerbated in coming decades by the impact of climate change; bulging youth populations; large migrations from rural to urban; social unrest; and inadequate infrastructure, education and economic opportunities.[4] Current UFEs in the developing world are inefficient and critically inadequate to meet the inevitable challenges of the future.[5] This could have catastrophic economic, social and political consequences. The poorest urban households spend 60-80 percent of their meager income on food.[6] More than a billion people are currently living in developing world slums and that number could double by 2030.

The UFEs described also offer unique opportunities to create new small and medium size businesses (SMEs) that enable healthy eating and sustainable (environmental, economic, societal) agriculture. According to the 2019 Lancet Report on Obesity, malnutrition in all its forms – including obesity, undernutrition and other dietary risks – is the leading cause of poor health globally. The synergistically negative effects of the pandemics – obesity, undernutrition and climate change – represent three of the gravest threats to human health and survival.[7]

Technology-enhanced UFEs can also help reduce greenhouse gas emissions from agriculture and livestock. Agriculture impacted climate change prior to the industrial age with dramatic changes in population and agriculture land usage. By 1700, the European conquest of the Americas resulted in a 90 percent loss of native population, abandonment of farm land and subsequent revegetation of millions of hectares, reductions in atmospheric CO_2 and the "Little Ice Age" – with plummeting

3 Orsini, F., R.Kahane, R. Nono-Womdim, G. Gianquinto. (2013). Urban agriculture in the developing world: a review. *Agronomy for Sustainable Development*, Springer Verlag/EDP Sciences/INRA, 2013, 33 (4), pp.695-720.

4 Chatterjee, S. (2015). Promise or peril: Africa's 830 million young people by 2050. UNDP – United Nations Development Program. Available online at: http://www.africa.undp.org/content/rba/en/home/blog/2017/8/12/Promise-Or-Peril-Africa-s-830-Million-Young-People-By-2050.html.

5 van Ittersum, M.K., Cassman, K.G. et al. (2016). Sub-Saharan Africa's ability to feed itself. *Proced. Nat. Acad. Sci. (PNAS)*. 201610359; DOI:10.1073/pnas.1610359113.

6 Reardon, T.A., et al. (2016). Growing foods for growing cities: transforming food systems in an urbanizing world. *Chicago Council on Global Affairs*. Available online at: https://www.thechicagocouncil.org/sites/default/files/report_growingfoodforgrowingcities2.pdf.

7 Swinburn, B.A. et al. (2019).The global syndemic of obesity, undernutrition, and climate change: The Lancet Commission report. *Lancet*. Available online at: https://www.thelancet.com/commissions/global-syndemic.

temperatures in Europe.[8] The 21st century, technology-enabled UFEs, along with smart policy and land usage, will allow more efficient, sustainable intensification of productive agriculture lands, vertical production and intensive production with CEA. At the same time policy is needed to remove non-productive lands from agriculture usage and stimulate national revegetation programs to encourage carbon sinks for reducing climate-warming gasses. Concurrently, urban sprawl and loss of prime farmland needs to be dramatically reduced through smart land-management – as part of national and global security.

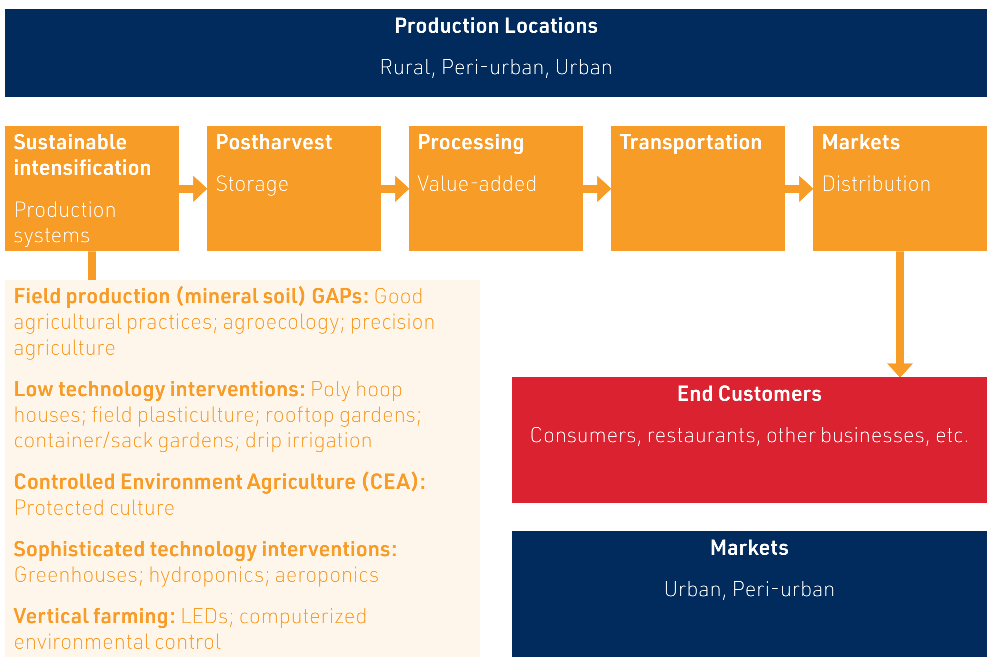
8 Koch, A., Brierley, C., Maslin, M.M., Lewis, S.L. (2019). Earth system impacts of the European arrival and great dying in the Americas after 1492. *Quaternary Sci. Rev.* 207:13-36. https://doi.org/10.1016/j.quascirev.2018.12.004.

Technology: Key to Sustainable Urban Food Ecosystems (UFEs)

A new path forward for UFEs needs to be found. The advancement should include increased productivity and environmental sustainability that links rural, peri-urban, and urban producers and consumers while increasing overall urban region food production[9] (Figure 1). Connecting food production and distribution to urban and peri-urban markets has many advantages. Road systems are better with closer proximity to markets, reducing problems with perishability and unreliable electricity for refrigerated storage (cold-chain). These regions and markets favor high-value (cash), nutrient-dense crops (vegetables and fruits), which require smaller acreage and are more profitable per square meter than agronomic crops such as rice, corn and wheat.[10] This creates market niche opportunities for smallholders, many of whom are women.[11] New technologies, coupled with new business models and supportive government policies, can revolutionize and create more resilient and productive UFEs for the 21st century. It will generate opportunities for entrepreneurs to create many new businesses and jobs.

Figure 1. The Rural/Urban Food Value Chain

The urban food value chain nodes from rural, peri-urban and urban producers to servicing end customers in urban and peri-urban markets.



These new UFEs also will create unprecedented opportunities for smallholders to progress from subsistence farming to commercially producing niche cash crops (horticulture) and animal protein (poultry, fish, pork, insects). There will be new opportunities within cities for the creation of "vertical farms" and other controlled environment agricultural (CEA) systems as well as

9 Addo, K.A. (2010). Urban and peri-urban agriculture in developing countries studied using remote sensing and in situ methods. *Remote Sensing 2*, 497-513; doi:10.3390/rs2020497.

10 Davies, F.T. and J. E. Bowman. (2016). Horticulture, food security, and the challenge of feeding the world. *Acta Horticulture* 1128: 1-6. Available online at: https://pubag.nal.usda.gov/catalog/5634560.

11 FAO. (2011). Women in Agriculture: Closing the gender gap for development. *The State of Food and Agriculture*. Rome: FAO – Food and Agriculture Organization of the United Nations. Available online at: http://www.fao.org/docrep/013/i2050e/i2050e.pdf.

for the production of plant-based and 3D-printed foods, cultured meat and fish.[12] Uberized facilitation of production and distribution of food will reduce bottlenecks and provide new business opportunities and jobs. "Off the shelf" precision agriculture technology will increasingly become the new norm for a range of producers from small to large.[13]

Rapid growth of urban markets is providing opportunities for new entrepreneurs and young people who have technological, business and interpersonal skills to build food production and distribution businesses facilitated by new technologies. These new entrepreneurs do not necessarily need a college education, but rather the ability to continually retool and keep up with technology and market opportunities. Moreover, technology is making UFEs exciting for young people to develop successful businesses that will enable them to "take ownership," innovate, make money and have meaningful careers. And it involves more than developing apps. Rather, the challenge is understanding where weak links exist along the value chain and exploiting innovative use of technology to create new businesses aimed at rectifying those shortcomings.

Middle-class consumers in the developing world have greater disposable income and want better, safer, fresh, healthy, *sustainably produced* food – including more protein-rich meat, poultry and fish. They also desire new services to facilitate merchandising, purchasing, and delivering food to their doorsteps. In addition, urban consumers are seeking more convenient food for consumption. This creates new product and market opportunities for producing ready-to-eat, processed food that is nutritionally fortified.

These opportunities can also extend to rural and peri-urban regions where technology can eliminate drudgery. A subsistence farmer's life of hoeing weeds and carrying jerry-cans full of water to irrigate does not attract young entrepreneurs. They quickly see the "Red Queen dilemma" of *Alice in Wonderland*: running just to stay in place and never advancing.

Labor is the greatest production cost in farming, exceeding other agricultural inputs and transportation. Technology can enable smallholder producers to increase productivity without increasing labor – allowing rural, peri-urban and urban producers to have better market and income-stream opportunities by servicing larger urban markets.[14] This will enable more smallholders to rise above subsistence and become commercially successful.

New urban and peri-urban market opportunities also are being created in the developing world by supermarket chains (Walmart, Carrefour, Pick-N-Pay, ShopRite, Tesco, Metro, Pingo Doce, etc.). They are looking for locally-sourced, high-value fruits, vegetables, flowering plants and animal protein to service rapidly growing urban populations. Walmart and its local affiliate, Hortifruiti, for example, have small-farmer-direct programs with strict product standards servicing larger cities in Central America. New technologies and business models are making such synergistic relationships increasingly viable.

12 Benke. K. and Tomkins, B. (2017) Future food-production systems: vertical farming and controlled-environment agriculture. *Sustainability: Science, Practice and Policy*, 13:1, 13-26, doi: 10.1080/15487733.2017.1394054.

13 Kite-Powell, J. (2018). Why precision agriculture will change how food is produced. *Forbes*. Available online at: https://www.forbes.com/sites/jenniferhicks/2018/04/30/why-precision-agriculture-will-change-how-food-is-produced/#6b3f03b06c65.

14 UNSDGs (2017). Uniting to deliver technology for the global goals. *The Global Goals for Sustainable Development – 2030 Vision Global Goals Technology Forum Full Report*. UNSD – United Nations Sustainable Development. Available online at: https://www.unglobalcompact.org/docs/publications/ARM_2030VisionReport.pdf.

The next generation UFEs, part of Agricultural Revolution 4.0 (see Appendix I), will be integrated with the larger collaborative economy that is connected by digital platforms, the cloud and the Internet of Things (IoT), and that is powered by artificial intelligence (AI). The new technology-enabled UFEs will more efficiently and effectively use resources and people to connect the nexus of food, water, energy, nutrition and human health. This will also contribute to development of a circular economy that is designed to be restorative and regenerative – minimizing waste and maximizing recycling and reuse to build economic, natural and social capital.

We have identified 12 innovative technology platforms (Figure 2) to advance the food ecosystems of the developing world that include: 1) connectivity: information delivery and digital technology platforms; 2) uberized services from producers to consumers; 3) precision agriculture (GPS, IoT, AI, sensing technology); 4) controlled environment agriculture (CEA), including vertical farms; 5) blockchain for greater transparency, food safety, identification; 6) solar and wind power connected to microgrids and storage; 7) high-quality, enhanced seeds for greater yield, nutrition, climate and pest resistance; 8) advanced genetics, including gene editing, synthetic biology and cloud biology; 9) biotechnology: including microbiome editing, soil biologicals, cultured meat, alternative proteins to meat and dairy; 10) nanotechnology and advanced materials; 11) 3D printing/additive manufacturing; and 12) integration of new technology to scale-up underutilized, existing technologies, such as efficient drip-irrigation with new precision soil sensors and solar-electric pumps to allow both "on" and "off-grid" usage.

The technology-enhanced UFEs will make on-farm production more resilient and more closely tied to urban food systems. It will also create off-farm opportunities in the value chain, including food production in cities and serving customers with new goods and services. Technology can enable transformation of UFEs, from expanded production in cities to more efficient and inclusive distribution and closer connections with rural farmers. Examples are in Figure 2, and Appendix II catalogues currently available, soon-to-be available and prospective commercialized technologies for creating more sustainable UFEs in the developing world.

Figure 2. Twelve Innovative Technology Platforms to Sustainably Intensify Urban Food Ecosystems (UFEs) of the Developing World

Holistic approach

Using technology to connect the **nexus** of food, water, energy, nutrition, medicine, health (people/nutrigenetics, plant, animal), sanitation, education, behavior change – with **sustainable intensification of urban food ecosystems** – integrating urban, peri-urban and rural environs.

1. Connectivity Info delivery and digital technology platforms: ICT, IOT, mobile money, finance	**2. Uberized services** Producers to consumers	**3. Precision agriculture** GPS, IOT, AI, sensing tech
4. Controlled Environment Agriculture Protected culture, vertical farming	**5. Blockchain** Traceability, food safety (postharvest), personal identification	**6. Solar electric** Energy, micro-grids and storage
7. High-quality enhanced seed Hybrids, climate and pest resilience	**8. Enhanced genetics** Gene editing, synthetic biology, cloud biology	**9. Biotechnology** Microbiome editing, soil biologicals, alternative proteins, plants as factories for drugs, meat substitution
10. Nanotechnology and advanced materials Seed coating, disease control, postharvest, etc.	**11. 3D printing/additive manufacturing** Food, parts production, machinery, structures	**12. Intervention of new tech with underutilized tech** "On-" and "off-grid" usage, i.e. precision soil sensors and solar pumps integrated with efficient drip irrigation, "packaging technologies"

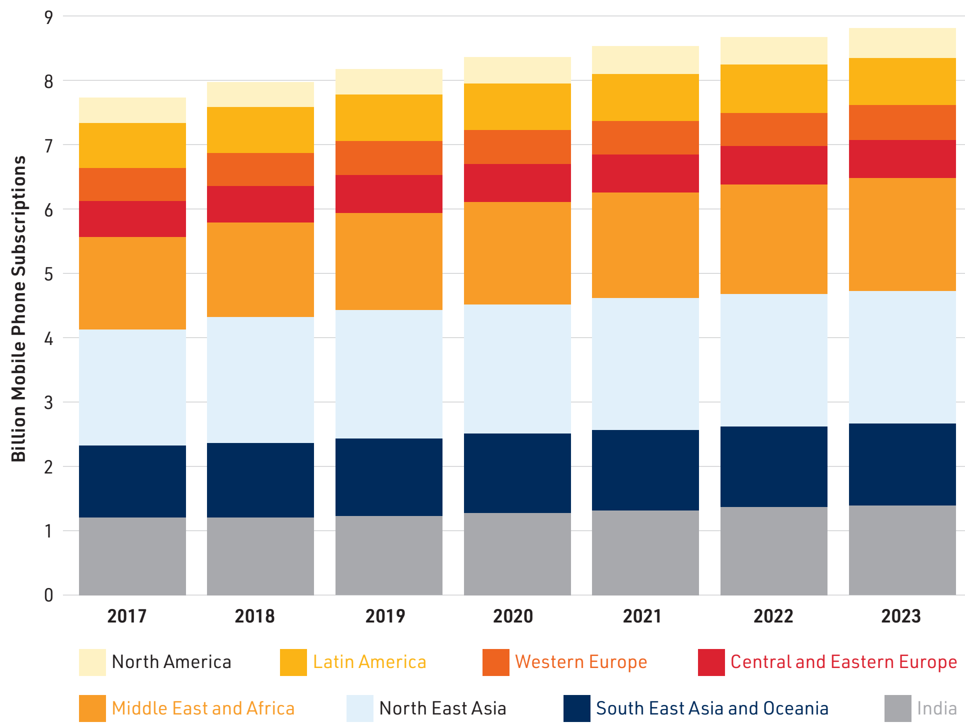
Connectivity for Information, Learning and Markets

Connectivity, from simple cell phone SMS communication to internet-enabled smart phones and cloud services, is providing platforms for increasingly powerful technologies that are enabling development of a new agricultural revolution. Internet connections currently reach more than 4 billion people, about 55 percent of the global population. Ericsson reports that there are some five billion smartphone subscriptions worldwide (some people have more than one smartphone), with an additional 2.7 billion basic mobile phone subscriptions, and predicts that there will be nearly 7.5 billion smartphone subscribers by 2023[15] (Figure 3).

Smart phones are often the first and only computer available to a small producer or a consumer in developing countries. It becomes their gateway to the world, from accessing relevant business and weather information to participating in online learning and acquiring data on their health. All of this can radically transform a family's economic and educational opportunities. More than 2 billion people actively use Facebook, which is often a platform for conducting business. Indonesia, a developing country, is the fourth largest Facebook

Figure 3. Scaling Up of Smart Phone Usage From 2010 to 2017 and Beyond

Credit: Ericsson Corp.



15 According to Internet World Stats 2018, the number of individuals using the internet worldwide at the end of 2017 was 4,156,932,140 out of a global population of 7,634,758,428, for a 54.4 percent penetration rate. Africa had the lowest penetration rate, 35.2 percent, or 453,329,534 Internet users out of a population 1,287,914,329. Some individuals may have more than one smartphone, so the number of subscriptions is greater than the number of individuals possessing smartphones. According to Ericsson, the number of non-smartphone mobile phone subscriptions has fallen precipitously from nearly 5 billion in 2011 to about 2.7 billion in 2018. Ericsson predicts that by 2023 there will be some 7.3 billion smartphones and only about 1.5 billion basic cell phones.

user, while India has twice as many users as the United States. Some 48 percent of Kenya's GDP flows through mobile money (M-Pesa) and 31 percent of eCommerce comes from mobile devices. More sub-Saharan African adults (12 percent) have mobile money accounts compared to just 2 percent global usage. Branch International is the number one finance app in Africa. It supplies micro-loans from $2 to $1,000 in Nigeria, Kenya and Tanzania. All of the credit transactions take place on mobile devices.

Financing entrepreneurs in the UFE value chain is essential. One model is the Piraeus Bank of Greece, which has a contract banking program to finance the food value chain. They finance agricultural enterprises, cooperatives and farmer groups with a goal of modernizing agricultural practices, increasing quality (crop & animal breeding programs) and reducing production costs through increased efficiencies. The vertically integrated program supports and finances the nexus of producers, traders and retailers through modernized trading, negotiated pricing, expanded retail networks for agro-food and development of local markets, including servicing tourist hotels with high-quality Greek agricultural products. They have an online payment platform to facilitate transactions between buyers and suppliers.

Agriculture is transitioning from input-intensive to more knowledge-intensive. Information and communications technologies (ICT) connect food value-chain actors, from producers to consumers, with: just-in-time data; enhanced good agricultural practices (GAPs); mobile money and credit; and market information and merchandising. In addition, ICT makes possible greater transparency and traceability of goods and services throughout the value chain and precision agriculture inputs (soil, weather data) to market conditions, enabling producers to make better, more informed planning and site-specific decisions.[16]

In East Africa, Shamba Shapeup is a "make-over" reality TV show that both informs and entertains farmers with on-site demonstrations of solutions to improve their plant and animal production practices and enhance their profitability (Figure 4). Technical expertise is used in developing Shamba programs, which reach a rural, peri-urban and urban audience of 10 million in Kenya, Uganda and Tanzania. No extension program in the U.S. or Europe has such

Figure 4. Information Communication Technology (ICT) is Reshaping the Developing World

Credit: Shamba Shape-Up

Communication technology opportunities

- Ubiquitous cell phone
- Some 70 percent of the world's seven billion people own or have inexpensive access to mobile phones
- A billion people actively use Facebook; Indonesia, developing country, is the fourth highest user
- Low-cost videos – Digital Green
- Shamba Shape-Up: Kenya's farm makeover reality TV show

16 Ekekwe, N. (2018). How Digital Technology Is Changing Farming in Africa. *Harvard Business Review*. Available online at: https://hbr.org/2017/05/how-digital-technology-is-changing-farming-in-africa.

a broad audience. The International Potato Center (CIP) supplied expertise for a series of Shamba programs on propagating, producing, harvesting, storing, processing and cooking orange-flesh sweet potato, which is underutilized in Africa; it is very nutritious, high in Vitamin A and can be processed and stored. Producers can use their cellphones to reach iShamba call centers to speak with experts as well as receive SMS messages on GAPs, market prices, financing, solar energy, low-cost drip irrigation, weather conditions, upcoming training sessions, etc.

The smartphone and basic cell phones using SMS have become the one-stop-shop for a smallholder to place orders, obtain technology information for "best management practices" (BMPs) and access market information to increase profitability. Hershey's CocoaLink in Ghana uses smart and cell phones for SMS text and voice messages with cocoa industry experts and smallholder producers (Figure 5). To better access information about GAPs and markets for

Figure 5. The Smart Phone, Cell Phone and SMS Messaging Are Transforming the Lives of Smallholder Farmers

Credit: Hershey Corp

coffee and cacao producers in the Democratic Republic of the Congo (DCR), Viamo developed the 3-2-1 Interactive Voice Response (IVR) cell phone service. It offers free on-demand access to information in five local languages to 12 million Vodacom subscribers. Technical teams worked closely with industry associations, exporters and agronomists to develop content for the 3-2-1 service.

Digital Green is a low cost, technology-enabled communication system in Asia and Africa to bring needed GAPs and BMPs to smallholder farmers in their own language and dialect by filming and recording successful farmers within their own communities. MFarm is a mobile app that connects Kenyan farmers with urban markets via SMS messaging. Farmerline and AgroCentral use mobile and the web as part of their business model in Africa to connect farmers with the services they need. This includes weather forecasts, market prices and GAPs.

Apps are being used by extension agents and farmer groups in Africa to accurately diagnose disease in the field and connected to mobile phone short messaging service (SMS) to alert farmers (Figure 6). This includes viral diseases in cassava to other diseases in crops such as banana, sweet potato and yam. The apps are available in local languages, in addition to English.

Figure 6. Using an App to Detect Viral Disease in Cassava and Alert Farmers with SMS Messaging

Credit: International Institute of Tropical Agriculture

- Apps to spot crop disease, alert African farmers.
- Cassava brown streak disease & cassava mosaic disease.
- Accurately diagnoses diseases in the field and use short message service (SMS) to alert farmers.

Uberized Connectivity for a Collaborative Economy

Uberized services, those that have introduced new ways of buying or using services within the market, can advance development of the urban food ecosystem across the spectrum, from rural to peri-urban to urban food production and distribution. These modern facilitators can strengthen the many weak links in the urban food ecosystem for producers, value-chain actors and consumers – using mobile devices for mobile money transactions and, when connected to the cloud, for on-demand goods and services. "Uberization" has embraced a variety of points along the value chain, including: planting and harvesting equipment; transportation vehicles; solar-powered cold-chain facilities for temporary storage of perishable product; and "cloud kitchens" that produce fresh meals to be delivered to urban customers. These advancements create further economic opportunities, as jobs have been created by these cloud kitchens, allowing young people with motorbikes and cell phones to become entrepreneurs or contractors delivering meals to urban customers.

Uberization of the urban food ecosystem can begin with rural producers. Mechanization and automation are vitally needed to reduce drudgery, increase efficiency and enhance profitability. "Custom harvesting" (renting) farm equipment creates business-to-business (B-to-B) opportunities for the developing world. Hello Tractor is an example of a custom harvesting company and is the "Uber" of small, 2-wheel tractors (Figure 7). It is a business platform of entrepreneurs operating in Africa, Central America and India. Smallholders use their cellphones to contract with Hello Tractor for tractors to plow and harvest their fields. They can track when the tractors will arrive and make mobile money payments for the service. Hello Tractor uses smart tractors linked to the cloud with a GPS antenna and international SIM card for remote monitoring – including maintenance scheduling of equipment.

In a private-public partnership, Hello Tractor has recently partnered with John Deere and the Nigerian Federal Ministry of Agriculture to utilize 10,000 tractors across Nigeria. CalAmp is also partnering with Hello Tractor and Aeris to equip John Deere tractors with intelligent telematics and wireless connectivity. These partnerships create a technology-sharing ecosystem that promotes economic growth by putting more land into production and creating jobs across the region.

The start-up, EM3 AgriServices in India, is an uberized facilitator that works with farmers owning tractors, harvesters and other mechanical implements to "rent" their equipment to smallholder producers, who in turn contract for plowing and harvesting without paying for capital investments – which they could not otherwise afford. The company is

Figure 7. Hello Tractor is the "Uber" of Small, 2- and 4-Wheel Tractors in Africa, Central America and India

Credit: Hello Tractor

- "Uber" for tractors
- A tractor that can plow fields and talk to the cloud
- Each Smart Tractor is embedded with monitoring hardware – equipped with a GPS antenna and international SIM card for remote Smart Tractor monitoring
- Hardware as stand-alone production to non-Smart Tractor owners, making their machines "smart" as well
- Business-to-business opportunities for entrepreneurs

"tech-enabled" rather than "tech" – since many in their customer base are not connected to the internet via smartphones. But farmers do use cell phones to call service centers operated by the company. The company also sends service representatives to meet with some 8,000 farmer clients. Producers in the developing world want "facetime" with competent experts in adapting and using new technologies.

The global trend in urban regions of using mobile phones to order food delivery is spreading to the developing world. Just as Airbnb owns no hotels but provides more than a million "hotel rooms" and Uber owns no taxis but provides urban mobility in hundreds of cities, GrubHub has no takeout restaurants - but supplies restaurant food to over 10 million customers in more than 1,300 cities in the US and the UK. Online food-delivery platforms are increasing efficiency, expanding choice and convenience, allowing customers to order from a wide array of restaurants with a single tap of their mobile phone.[17] Africa has a number of local, indigenous, online delivery services, from SoupDirect and EasyAppetite in Nigeria to FoodCourt in Rwanda. In India, food delivery apps are competing to gain market share, including Google's Aero,

Figure 8. Know Your Farmer – Know Your Food

Credit: U.S. Department of Agriculture

Slow food movements such as this U.S. Department of Agriculture program offer tremendous commercial opportunities for connecting smallholders with urban markets in the developing world.

17 Hirschberg, C., Rajko, A., Schumacher, T., and Wrulich, M. (2016). The changing market for food delivery. *Mckinsey & Co.* Available online at: https://www.mckinsey.com/industries/high-tech/our-insights/the-changing-market-for-food-delivery.

Uber Eats and Indian startups such as Swiggy and Zomato.[18] The Indian online delivery market is composed of aggregators and cloud kitchens where chefs prepare food at a physical outlet. The congestion of India's roads has created another down-stream, business opportunity to service Indian consumers who do not want to cook at home, but do not want to get stuck in traffic going to a restaurant.

Along with more efficient delivery of prepared food to consumers' homes, the slow food movement of "know your farmer – know your food" has tremendous commercial opportunities for connecting urban, peri-urban and rural markets in the developing world (Figure 8). Community-supported agriculture (CSA) enables consumers to contract local, seasonal food, directly from farmers, utilizing web-based platforms to link producers to consumers. This enhances planning and cash flow of producers, reduces food waste, more efficiently utilizes resources and local transportation, and develops new entrepreneurs and small businesses. The farmers are prepaid for "shares" by the consumer, which helps their cash-flow and seasonal planning for contracted rather than speculatively produced vegetables, fruits or meat products. Produce is delivered weekly to consumers during the harvest season. There are a number of web based apps, including Farmline and Farmigo for connecting to farmer's markets, farmstands and CSA.

"Food deserts," where affordable, nutritious fruits, vegetables and animal protein are not available, are a serious problem in both cities and rural areas throughout the developing and developed worlds. Low-income consumers are very susceptible to this predicament. Technology, such as GIS (geographic information systems), can be used to map food deserts and to develop strategies for providing better nutrition, urban planning and health education. GIS research can be used by businesses, nonprofits and government to improve diet and human health and develop sustainable businesses along nodes in UFEs.

Poor production, subpar transportation, inadequate storage (cold) and handling practices, contribute to high losses in the developing world. A third of the world's food goes to waste, including in the developing world. This is enough food to feed two billion people (Figure 9). Produce with unappealing shapes and appearances, such as "Imperfect Produce" and "Imperfect Picks," have created opportunities for marketing and distributing "ugly food." Such services supply consumers with cheaper, nutritious, tasty, healthy fruits and vegetables that would normally be discarded as culls due to imperfections in shape or size. Companies source directly from farms and deliver produce to customers' doorsteps for 30-50 percent less than grocery store prices. Farmers sell more produce, down-stream service/delivery jobs are created and consumers have access to more affordable, healthy and nutrient-dense food. Similar models could be used in the developing world.

There are a number of U.S. and international organizations and businesses that are fighting food loss and waste.[19] These food recovery networks utilize apps and mobile technology to collect and distribute excess food from restaurants, grocers, manufacturers and farms to community food programs, soup kitchens, shelters and food pantries.

18 Kashyap, K. (2017). The food delivery apps that are competing to gain market share In India. *Forbes*. Available online at: https://www.forbes.com/sites/krnkashyap/2017/06/26/the-food-delivery-apps-that-are-competing-to-gain-market-share-in-india/#d14dd219937a.

19 Furbank, L. (2017). 59 Organizations Fighting Food Loss and Waste. *Foodtank*. Available online at: https://foodtank.com/news/2016/07/fighting-food-loss-and-waste/.

FoodLoop of Germany developed a business model for selling deeply discounted food products that are nearing the end of their shelf-life and normally would be discarded. The company utilizes mobile apps that customize consumers' preferences and purchase history, and connects them to local retail stores. Food waste is reduced, retail food stores are compensated and the customer has access to more nutritious and affordable food.

Karma of England, works with restaurants, cafes and retail food stores. Its mobile technology platform links customers to retail food stores with surplus food that is marked down to a minimum 50 percent discount. The customer knows how many items are available and when to retrieve them.

Figure 9. Use of 'Ugly' Fruits and Vegetables Can Reduce World Hunger

Credit: Intermarche, Imperfect Produce

A third of the planet's food goes to waste, often because of its looks. That is enough to feed two billion people.

Precision Agriculture and Controlled Environmental Agriculture (CEA)

UFEs' production systems rely not only on field-grown crops, but also on production of food within cities.[20] Urban farming will become more technologically advanced and integrated into urban landscapes. It can be designed for more efficiently recycling and reusing resources in closed-loop (circular), sustainable systems. An example is Citizen Farm of Singapore with a circular facility that produces a wide-variety of greens and nutrient-dense crops (Figure 10).

There are a host of new, alternative production systems using "controlled environmental agriculture" (CEA). These range from low-cost, protected "poly hoop" houses, greenhouses, and roof-top and sack/container gardens, to vertical farms in buildings using artificial lighting.[21] With urban encroachment and the loss of arable land, more cities will need to utilize vertical space, such as rooftop farming. These can vary from open structures to low-tech, partially covered poly/shade cloth, inexpensive structures to state-of-the art CEA rooftop/greenhouse complexes, such as the rooftop farms complex in Singapore.

Many vegetables, greens, herbs and flowering plants can be commercially grown in containerized or trough/tubing

Figure 10. Citizen Farm of Singapore Supplies Restaurants with Greens

Credit: Citizen Farm of Singapore

Developers are integrating "urban farms" in their urban land planning, which adds value (economic, nutritional, quality of life) to the community.

20 Hallett, S., Hoagland, L. and Toner, E. (2016). Urban agriculture: environmental, economic, and social perspectives. (ed.) Janick, J. *Horticul*. Rev. 44, 65-120. Available online at: https://doi.org/10.1002/9781119281269.ch2.

21 FAO. (2011b). The place of urban and peri-urban agriculture (UPA) in national and food security programs. Rome: FAO – Food and Agriculture Organization of the United Nations. ISBN 978-92-5-106845-8. Available online at: http://www.fao.org/docrep/014/i2177e/i2177e00.pdf.

systems using "synthetic" high organic media as a solid substrate or in aeroponic and hydroponic environments, which require no media support. Vertical farms in buildings enable year-round production, regardless of weather, which will be increasingly important in response to global warming (Figure 11). LED lighting provides 24/7 production with the optimal amount of light quality and quantity for specific crop production requirements[22] and sensors and robotics provide the root system with the exact pH and micronutrients needed. Such precision farming can generate yields 200-400 percent above normal field production.[23] In addition, vertical farms reduce energy usage by 50 percent and land and water usage by 95 percent or more. Although vertical farming has great potential in the developing world for the production of selected greens and vegetables for urban markets, it is not generally cost-effective for producing all agricultural products – such as field crops, fruits and nuts.

Figure 11. Aerofarms Vertical Farm Production of Greens for High-end, Urban Markets

Credit: Aerofarms

Disruptive Technologies

- New paradigms – vertical farming
- Bringing farm to the city
- Local food production at scale
- Growing vegetables without sunshine using finely calibrated LEDs

Precision agriculture, CEA, agroecology systems and good agricultural practices offer the opportunity to produce sustainably (environmentally, economically, socially acceptable) and to reduce variability and waste in products and services along the UFE. Technology offers the opportunity to enhance uniformity and productivity, and to reduce waste or "muda," which is a key concept in lean-process thinking

22 Kozai, T., Fujiwara, K. and Runkle, E.S. (2016). LED Lighting for Urban Agriculture. New York: Springer. 1st Ed. ISBN-13: 978-9811018466.

23 Blomqvist, L. (2018). Precision Agriculture: bigger yields for smaller farms. *CGIAR: Research program on water, land and ecosystems*. CGIAR – Consultative Group for International Agriculture Research. Available online at: https://wle.cgiar.org/thrive/2017/03/20/precision-agriculture-bigger-yields-smaller-farms.

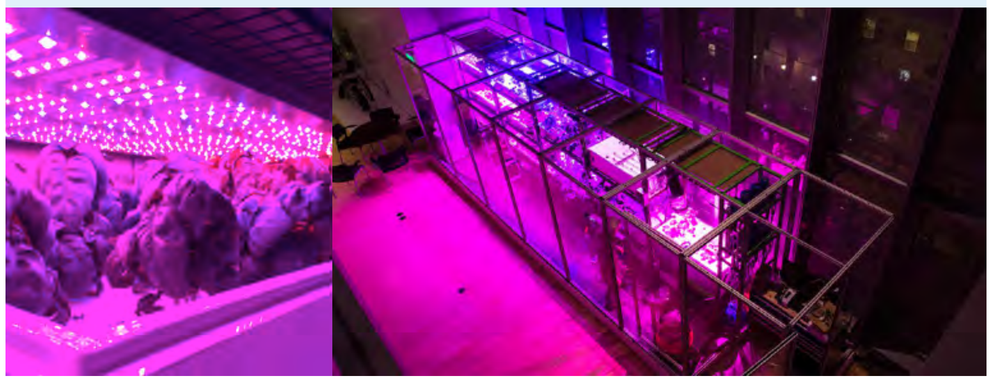
(i.e., Toyota Production System [TPS]). Value-added work is any activity that produces goods or services that customers will pay for, whereas "muda" is any limitation that causes waste. Waste reduction is an effective way to increase profitability as well as efficiency. The "eight deadly lean wastes" are defects, overproduction, waiting, not utilizing talent, transportation, inventory excess, motion waste and excess processing. The best agricultural production companies and actors along the UFEs use such lean process thinking for their businesses.

Local urban and peri-urban food production, including vertical farms, is being enhanced by open-source, "off the shelf," technologies that have been developed for greater transparency, networked experimentation and education across multiple users and countries. One effort is the MIT Open-Agriculture Initiative (OpenAg) to develop a healthier, sustainable and more inventive food system of the future (Figure 12).

According to founder Caleb Harper, OpenAg was created "in an effort to drive a paradigm shift from the industrial to the networked age of agricultural production, giving rise to a computationally-based food systems revolution that will account for the ecological, environmental, economic and societal implications of producing food." OpenAg's computer vision and machine learning is attempting to bridge the gaps in controlled

Figure 12. MIT Open Agriculture Initiative – CEA, Using a Modified, Reefer Trailer System for Lettuce Production

Credit: MIT Media Lab



environment agriculture by employing computer vision and robotics. OpenAg also provides an open-source toolkit for crowdsourcing plant analysis to measure and quantify plant growth and development, which is needed for crop production in reefer-trailer-size smart farms and vertical farms (Figure 12).

OpenAg is seeking to develop "climate recipes" for growing specific crops in controlled environments. Harper notes that "plants respond to every input with unique phenotypic expressions of their hard-wired genomes, and each change to the input may affect the plant's final output on a physical and chemical level. Plants are factories for the chemicals and nutrients we need in our own bodies, so by controlling what we put in, we can better control what they give out."

New desalination technologies could enable desert areas with seawater resources to become new agricultural CEA production areas for selected vegetables and table greens. Some 97 percent of the earth's water is saline and unfit for crop production. Current desalination processes are energy-intensive and limited by membrane technology. However, commercial prototype projects are underway in Australia, Saudi Arabia and other desert areas, adjacent to seawater, to use concentrated solar thermal power for desalination and cooling greenhouses for CEA production of vegetables (Figure 13).

Figure 13. Sundrop Farms

Credit: Sundrop Farms

Sundrop Farms operations (South Australia) is powered by a concentrated solar thermal power plant (arrow-tower); seawater is withdrawn from Spencer Gulf and desalinated for producing truss tomatoes to supply the Australian supermarket operator Coles under a 10-year contract.

Blockchain Technology

ICT technology can enable access to credit and executing financial transactions, which has been an especially persistent constraint for smallholder producers. The Gates Foundation has released an open source platform, Mojaloop, to allow software producers, banks and financial service providers to build secure digital payment platforms at scale. Mojaloop software uses more secure blockchain technology to enable urban food system players in the developing world to conduct business and trade.[24] The free software reduces complexity and cost in building payment platforms to connect smallholders with customers, merchants, banks and mobile money providers. These digital financial services allow smallholder producers in the developing world to conduct business without a brick-and-mortar bank (Figure 14).

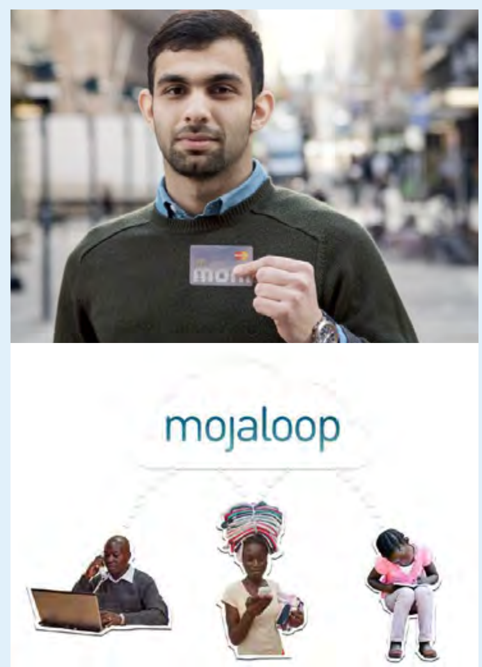
Consumers want to know that their food is safe to eat. Blockchain is also important for traceability and transparency to meet food regulatory requirements during the production, post-harvest, shipping, processing and distribution to consumers.[25] Urban consumers and regulators are expected to require more

Figure 14. Blockchain Technology

Credits: MIT Technology Review; Gates Foundation

Blockchain technology is being used for traceability, identification and digital payment platforms; also important for food safety and quality control from production to consumer.

- New electronic public ledger – identification, traceability, food safety with RFIDs
- MONI Card: Finland's digital money system for asylum seekers
- MojaLoop: Blockchain-powered mobile payment system
- Open-source software for financial services companies, government regulators – build digital payment platforms
- The Central Directory Service routes each payment to the correct service/provider in the ecosystem



24 Tapscott, D. and Tapscott, A. (2016). Blockchain Revolution: *How the Technology Behind Bitcoin Is Changing Money, Business, and the World*. New York: Penguin Random House.

25 Helmstetter, M. (2018). The five biggest startup opportunities in agtech today. *Forbes*. Available online at: https://www.forbes.com/sites/michaelhelmstetter/2018/06/26/the-five-biggest-startup-opportunities-in-agtech-today/#11aa69e534a6.

product information and labeling from listing the sustainable production system utilized, chemical applications, GMO status, handling and transportation. For example, blockchain could be used in recording inputs (procedures, chemical usage, environmental conditions from sensors, etc.) during production of strawberries. When the strawberries are harvested and shipped in a refrigerated reefer, RFIDs monitor temperature, relative humidity and other parameters, and are connected to the cloud/blockchain for record keeping. The blockchain inputs can continue up until the point of consumption. Combining blockchain with RFID technologies and other sensor systems will enhance food safety.[26]

Another impediment for small producers is often that lack of a legal ID, which impedes some 1.5 billion people. The UN is using blockchain to create IDs, which will enhance the ability of these people to buy/sell/get loans and to potentially develop businesses along nodes in UFEs.

26 For example, Walmart is using blockchain to improve food safety.

High Quality, Enhanced Seed

It is common for African and many other developing world farmers to habitually harvest, save and plant low-quality, low-yielding "land-race" seed. Many public breeding programs are ineffective, underfunded and have few incentives for encouraging increased productivity. Weak public breeding programs and poor enforcement of intellectual property rights, in West Africa for example, impede hybrid patent development and incentivization of greater participation by industry – thus reinforcing low agricultural productivity. New business models based on private-public partnerships can speed development of hybrid and improved seed (patents, royalties) and their adoption. Private-public partnerships to produce high value seed can create sustainable ecosystems for entrepreneurs to develop and implement use of climate-resistant, disease-resistant, higher-yielding crops (Figure 15).

Figure 15. Developing High-Value Seed

Credit: R.L. Geneve

Public-private partnerships developing high value seed, including vegetable seed, that is developed as breeder seed through public (national) breeding programs, then multiplied through the private sector as certified seed and later sold to producers/farmers.

Enhanced Genetics, Biotechnology and Nanotechnology for Sustainable Intensification of UFEs

CRISPR is a promising gene editing technology that can be used to enhance crop productivity while avoiding societal concerns of GMOs. The technology allows genes to be added and deleted, much like using word-processing software, but does not incorporate "foreign" genes (utilized in GMO-produced plants and animals). CRISPR can accelerate traditional breeding and selection programs for developing new climate and disease-resistant, higher-yielding, nutritious crops and animals. It provides a pathway for plant and animal breeding that is more reliable, cheaper and faster than traditional methods.

Nanotechnology can be used to reduce postharvest losses of perishable fruits and vegetables during harvest, transportation, and delivery to consumers, which can be as high as 50 percent in the developing world. Plant derived coating materials developed with nanotechnology can reduce waste; enhance freshness and nutrition; and extend shelf-life and transportability of fruits and vegetables (Figure 16). Nanotechnology coating could significantly reduce post-harvest crop loss in developing countries that lack adequate cold-chains (refrigeration).

Figure 16. Nanotechnology and Advanced Materials

Credit: Apeel Sciences

Edipeel: A little more peel is added, but it is invisible and edible.

- Protects and extends shelf-life and transportability
- Reduces waste
- Enables better flavor and nutrition

Nanotechnology is also used in polymers to coat seeds[27] to increase their shelf-life and increase their germination success and production for niche, high-value crops.

Just as humans have a gut microbiome, plants have a root microbiome that offers much potential in integrated pest management (IPM) systems for increased plant resistance to environmental and pathogen stress (Figure 17). These rhizosphere microorganisms (bacteria, beneficial fungi) can enhance plant nutrient uptake, drought resistance and chemical signaling important to plant development. The Earth Microbiome Project is just beginning to address how to better utilize these rhizosphere organisms. This could lead to a new, environmentally friendly, naturally produced, biological fertilizers, herbicides, fungicides and pesticides.

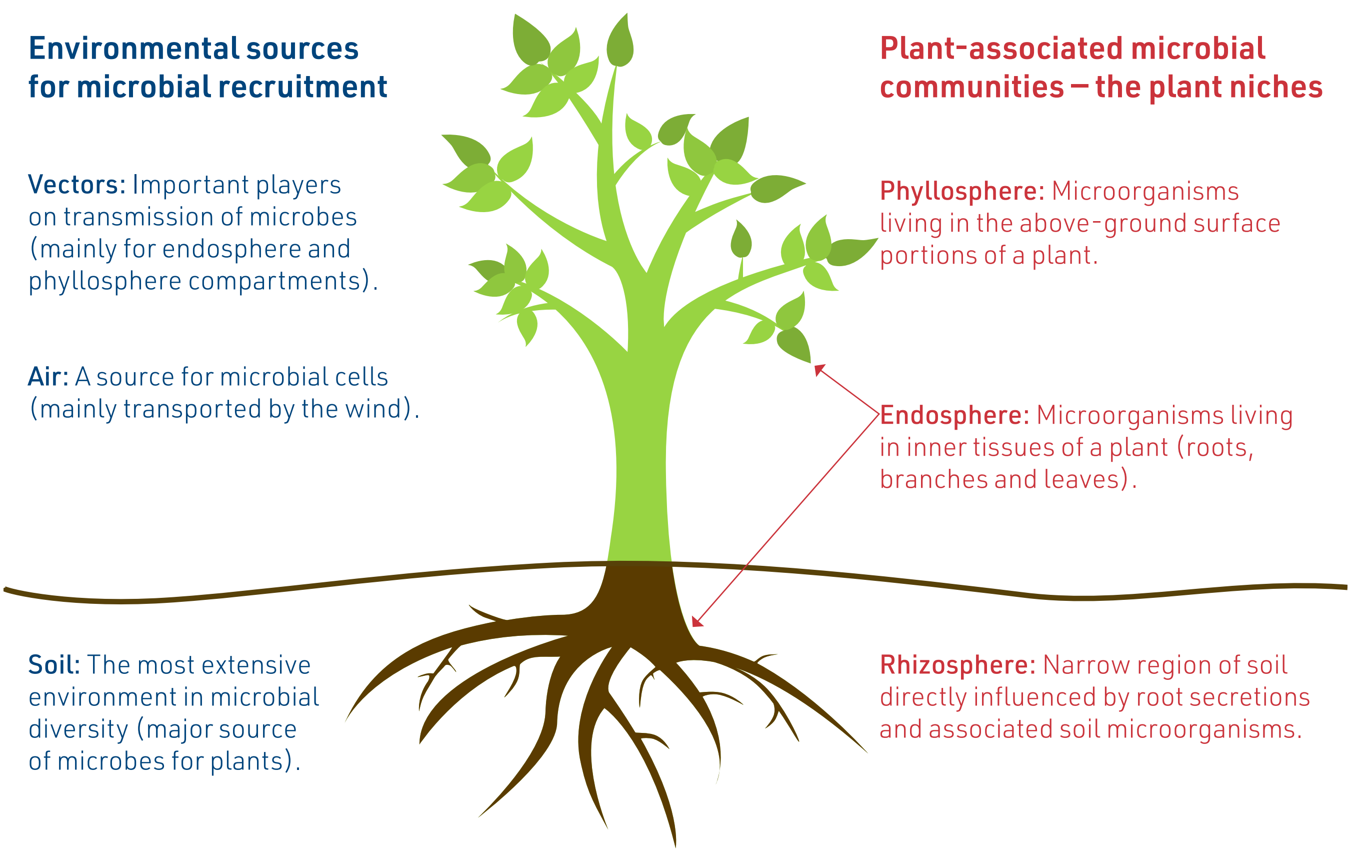
IPM can also increase vegetable and fruit yield while reducing chemical usage. Furthermore, the use of IPM can be enhanced by portable, handheld, genomic sequencing technology, available in Africa and other developing regions, to identify in the field beneficial root microbiome organisms, plant pathogens or food contaminants (Figure 18). For example, there are portable sequencing devices such as Nanopore's MinION, the size of USB sticks that are

27 Davies, F.T. , Geneve, R.L. and Wilson, S.B. (2018). *Hartmann and Kester's Plant Propagation: Principles and Practices*. 9th ed. Englewood Cliffs, New Jersey: Pearson. ISBN-13: 978-0134480893.

Figure 17. The Plant Microbiome

Schematic of the plant microbiome composed of the rhizosphere, endosphere and phyllosphere – as part of plant-microbe associated communities. Environmental sources of microbes include vectors, air and soil.

Credit: Redrawn for F.D. Andreote, et al. (2014). Exploring interactions of plant microbiomes. Sci. Agric. (Piracicaba, Braz.) 71(6). http://dx.doi.org/10.1590/0103-9016-2014-0195. Corresponding author: fdandreo@gmail.com.



connected to a smart-phone that is in turn connected to the cloud to stream data in real time. It enables cost-effective, "lab-in-the-hand" genomic sequencing, without requiring a physical lab and elaborate equipment to be located in the developing country, where the devices are used.

"Sustainable intensification" of agriculture is smart agriculture that uses agro-ecology, inorganic and organic farming, and IPM with judicious use of chemicals – including fertilizers and pesticides. Because yields are lower, organic agriculture requires more land and ends up leaving a larger carbon footprint than conventional agriculture production. Organic agriculture alone is insufficient to feed the world. While organic agriculture has an important niche in the matrix of different agricultural production systems, organic products are not necessarily safer nor more nutritious. On the other hand, many of the newest synthetic pesticides are not harmful to the ecosystem and are very targeted to affect specific pests, enabling beneficial predatory insects to thrive. Good agricultural practices (GAPs) imply smart use of chemicals, pesticides and fossil fuels that are environmentally and economically sustainable. A world without inorganic, chemical usage is neither "greener" nor sustainable.

Figure 18. Democratization of DNA and RNA Sequencing Tech

Credit: Oxford Nanopore Technologies

NanoporeTech Portable, lab-in-your-hand technology, streaming genomic data to ID beneficial root microorganisms, plant pathogens or new Ebola virus strains

- MinION portable real-time device: DNA and RNA sequencing
- Portable genomic sequencers, size of USB stick – connected to smart-phone, connected to the cloud, streaming data in real time
- MinION portable DNA sequencer: Lab-in-your-hand technology; democratize genomic sequencing
- ID: Root microbiome organisms, plant pathogens, food contaminants, mutations of deadly viruses, ie. Ebola strains

Technology for City Production of Plant-based Foods

Cellular Agriculture, Lab-Grown Meat and 3D-Printed Food

Lab grown meat, plant-based meat substitutes, and the technology for 3D printing food may radically change where and how protein and food are produced, including the cities where it is consumed. There are a wide range of innovative food alternatives to traditional meats that can supplement the need for livestock, farms and butchers.

The history of innovation is about getting rid of the bottleneck in the system, and with meat, the bottleneck is the animal. Rather than giving up the experience of eating red meat, technology is enabling marketable, attractive, plant-based meat substitutes and lab-grown meat that can potentially drastically reduce world per capita consumption of animal-produced red meat. Transition to such products could have a huge impact on global carbon emissions since current agricultural production systems for “red meat” have a far greater detrimental impact on the environment than automobiles (Figure 19).

Figure 19. What We Eat (Red Meat) Has a Bigger Impact on the Environment than the Car We Drive

Credit: Weber, C. and Matthews, H. (2008). Food-miles and the relative climate impacts of food choices in the United States. *Environ. Sci. Technol.*, 42 (10), 3508-3513. DOI: 10.1021/es702969f.

Tons of CO_2 Equivalent Per Year

8.1 Production of all foods consumed per average U.S. household

4.4 Auto driven (19,300 km/ 12,000 miles) per year

0.4 Food transportation (1,000 km/600 miles) – all U.S. foods from production to consumer

Red Meat

Production of red meat is **150 percent more greenhouse gas (GHG) intenstive** than chicken or fish.

Reducing red meat consumption for chicken, fish, eggs and/or vegetable-based diets achieves more GHG reduction than buying all locally-sourced food.

Cultured and printed meat could substantially reduce environmental costs

There have been significant advances in plant-based foods, like the “Impossible Burger” and “Beyond Meat,” that can satisfy the consumer’s experience and perception of meat (Figure 20).

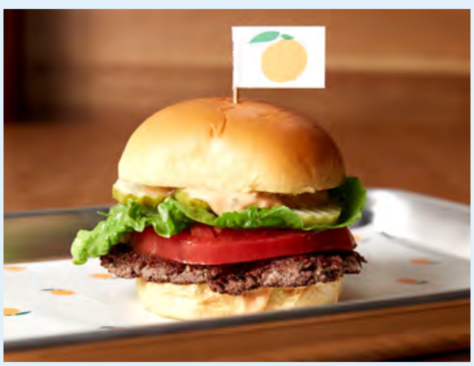
Other nutritious food products are also being made from plants. Three-year old startup Ripple Foods, for example, produces “milk” made from peas that has the same protein as 2 percent milk, but less sugar and saturated fat – and more calcium and vitamin D (Figure 20). No cows required.

To eliminate the inefficiency in raising animals for slaughter, scientific teams and startups are also developing laboratory produced meat for animal-free burgers, chicken, turkey and fish to create new sustainable, commercial industries. There have also been major advances in “growing” real meat in a lab based on actual animal cells. In the future, “clean meat” can be produced starting with muscle stem cells from live cattle, what is called “cellular agriculture.” [28] Several startups, including Memphis Meats, are pioneering “clean meat” or cultured meat, ranging from beef to chicken (Figure 20). Finless Foods is one such a new company trying to reduce the use of fish by replicating

28 Shapiro, P. (2018). *Clean Meat: How Growing Meat Without Animals Will Revolutionize Dinner and the World*, New York: Gallery Books.

Figure 20. Rethinking Meat and the Future of Protein

- For thousands of years, we've relied on animals to turn plants into meat
- Steaks, burgers and chicken are staples of the American/world diet
- The sustainable food movement –plant-based, mass-market solutions to replace animal protein
- Are these new protein sources poised to transform the global food system?
- Ripple Foods: Non-dairy milk made from pea protein; high protein; low sugar; smooth taste



Credit: Impossible Foods.

The Impossible Burger is made from natural, plant products.

Credit: Ripple Foods.

Ripple Foods produces milk made from peas.

Credit: Memphis Meats.

Memphis Meats cultures chicken from the cells of live chickens.

fish filets. Cells of live animals can be cultured in urban "breweries" that subsequently reduce use of land and water, as well as greenhouse gas emissions by more than 90 percent, while producing significant health benefits compared with consumption of farm-raised animals. These meat-producing breweries could become nodes in UFEs throughout the world.

3D printing or additive manufacturing is a "general purpose technology" used for making plastic toys, human tissues and aircraft parts; and 3D printing of satellites in space and buildings. 3D printing also can be used to convert alternative ingredients such as proteins from algae, beet leaves or insects into tasty and healthy products that can be produced by small, inexpensive printers in home kitchens. The food can be customized for individual health needs as well as preferences. In addition, 3D printing can contribute to UFEs by producing on-demand replacement parts, which are badly needed in the developing world for tractors, pumps and other equipment. Catapult Design 3D prints tractor replacement parts as well as corn shellers, cart designs, prosthetic limbs and rolling water barrels for the Indian market.

"Foodini" is a 3D food printer for commercial kitchens and enterprises that the company's co-founder, Lynette Kucsma, has likened to "a food factory shrunk down to the size of a box that sits on your food counter" or "a mini manufacturing plant in your kitchen" (Figure 23). 3D printing could also reduce food waste, as it enables production with 'ugly' food." Matís, an Icelandic food and biotech institute, is working with Foodini to produce 3D-printed, nutritious cuts of fish from portions that would otherwise be discarded during mass manufacturing." Kucsma noted that "there's a concept of 'ugly' fruits and vegetables, meats and fish that people don't want to eat because they look unconventional. This means that they often don't pass quality control and are thrown away, despite being perfectly good produce." This 3D food-printing technology may become common place in home kitchens in the developed world in the next several decades, and in commercial kitchens and food processing for the developing world.

Figure 23. 3D Printing of a Wide Variety of Foods with Kitchen Appliance Printers, Such as "Foodini"(left).

Credit: Foodini

- Healthy and good for the environment – help convert alternative ingredients such as proteins from algae, beet leave or insects into tasty products
- Opens the door to food customization and therefore tune up with individual dietary needs and preferences

Acceptance of these plant-based, lab-grown and 3D printed foods will require changing diet choices through education, marketing and developing attractive, affordable, tasty plant-based substitutes through technology. Adopting these new technologies is not only critical for environmental sustainability and human nutrition – but also offers opportunities for new businesses and services.

Next Generation Urban and Rural Food Producers

The key to advancing UFEs will be educating, developing and mentoring a new generation of urban producers and value chain players. They will not necessarily have grown up on a farm but rather learned their trades within the growing UFE. They will be part of the collaborative economy connected to digital platforms, artificial intelligence, the cloud and the Internet of Things. The new UFEs will connect producers, horticulturists, agronomists, plant biologists, distributers, traders, marketers, urban planners, nutritionists, chefs, educators, food processors, computer programmers, engineers (chemical, mechanical, electrical, environmental) and behavior scientists. MIT's OpenAg is committed to developing a new generation of farmers by targeting schools. "I want kids to see agriculture as an exciting field where they can innovate, explore and make a real impact on their communities and on the world," OpenAg founder Harpers says. "Creating an exciting technology platform that inspires students to innovate and explore is our best bet towards a better future of food."

Technology can be a great platform for recruiting the next generation of tech-savvy producers and off-farm food ecosystem actors who can just as easily come from urban as rural backgrounds. Young people want to use technology, be connected to the cloud, have meaningful jobs, businesses, careers that can support a family and make a difference in the world.

Traditionally, most middle-class parents, in the developing or developed world, do not want their children studying and working in agriculture. But these views are based on huge misconceptions about the modern food ecosystem and the career opportunities using ICT, IoT, precision agriculture, AI, CEA, blockchain, solar, enhanced genetics, biotechnology, nanotechnology and all the ubersized services that still need to be developed. With technology, for example, profitable businesses can be built by growing plants vertically in warehouses, without soil – utilizing hydropic and aeroponic CEA systems, enhanced by robotics and AI.

Technology is crucial for unlocking Africa's agricultural potential to create wealth. And much of that technology is already available. As A. Adesina, President of the African Development Bank, notes, "technologies to achieve Africa's green revolution exist. For the most part, they are all just sitting on the shelves." For example, Africa desperately needs to employ more reliable, efficient irrigation systems. There are existing, low-cost, drip irrigation systems, off-the-shelf soil moisture sensors and solar and wind power systems to run irrigation pumps. There are people-powered treadle pumps and other irrigation systems that can be powered by small, 2-wheel tractors. Uber business opportunities exist for adapting and using these technologies.

Modern UFE technologies can help smallholder farmers create viable businesses. This includes developing business-to-business (B-to-B) downstream opportunities, linked to markets. For instance, custom seed propagators of high value vegetable and floriculture crops can raise seedlings to the "plug stage" in seedling tray systems and sell them to producers/farmers. While it is more expensive for farmers to buy the "plugs" rather than propagate their crops, the seedling plugs assure farmers they will have successful crops that will be of high quality and will be produced more quickly to meet market demands. There are also custom propagators of grafted vegetable seedling plugs with greater yields and pest resistance in Vietnam and Thailand. This is another B-to-B technology, selling directly to farmers to transplant in their fields and using CEA hoop-house tunnels to grow and "finish off" marketable vegetable crops.

Amiran, a commercial greenhouse supplier in Kenya, developed a program targeting young producers and technology-savy entrepreneurs (both from on- and off-farm) who are 35-years-old or younger. Amiran has developed "farmer kits" as a micro-niche, "packaging technology" approach using appropriate technology for producing high-value horticulture crops with smallholders linked to markets (Figure 24). The vegetable production system utilizes low-cost, insect-screened greenhouse structures, outdoor drip irrigation and high quality (hybrid) seed. There is access to trainers, pest-certification and assistance to forge direct links to markets. These technologies are appropriate for urban, peri-urban and rural producers in the developing world for servicing urban markets with high-value, horticultural product. Ensuring they have "skin in the game," the young farmers in the Amiran program are required to contribute 10 percent collateral.

There is further support for these startup farmers, from the Kenyan government and commercial banks in Kenya, in the form of low-interest loans and reinsurance that is used for micro-insurance of production inputs (e.g., high-value horticulture seed, greenhouse materials, drip irrigation, chemicals, etc.). The $4,000 micro-loan packages are to be paid off over a period of several seasons, based on the high-value vegetable crop cash flow.

Figure 24. "Package Approach"

Credit: Amiran Kenya Ltd

The Amiran package approach to enable young Kenyan entrepreneurs to service urban and peri-urban markets with high-value vegetable crops – linked to markets.

- Farmers greehouse; drip irrigation system; water tank; farmers sprayer
- Gold medal seeds; nursery set; organic plant inputs; bioorganic plant protection; health and safety; training; agro support package
- Amiran Farmers Kit Insurance

Way Forward: Building Tomorrow's Integrated UFEs

For Africa and much of the developing world, food security and economic mobility will be dependent on a second Green Revolution (see Appendix I). But this new Green Revolution will be different that the first, which was focused on increased grain yield (increased calories, alleviating hunger). Instead, it will entail sustainable intensification, biodiversity, biotechnology/molecular biology, development of climate-resistant high-yielding crops, nutrient-dense crops, better adaption of current and future technologies that enable GAPs, uberization and a platform-connected "internet-of-food-things."[29] This will require a diverse-group of entrepreneurs along the value chain from production to servicing consumers. Providing urban and peri-urban markets with high-value niche crops and services offers great opportunities for smallholder entrepreneurs and for meeting world food security and nutritional requirements. Technology offers the platform to better connect the nexus of food, water, energy, nutrition, human health, sustainability (environmental, economic, societal) and smart policy – and to do so in a way that is scalable, affordable and sustainable.

Technology alone will not solve the developing world's challenge of creating the next generation sustainable UFEs. The "elephant in the room" hindering progress is development and enforcement of smart policies on land use, land ownership, trade, entrepreneurship, credit and market access, cooperatives, transparency in government, rule of law and education, and country-wide investment in agriculture, all-weather roads and reliable electricity. There also needs to be local capacity building and mentorship for scaling up technology deployment. Successful UFEs cannot rely on a "top-down," master-plan approach. Rather, it is critical to encourage and support development of a "bottom-up" collaboration that integrates local knowledge and ideas with technology that is linked to value-chains (markets). The interconnectivity of UFE technologies will better enable local entrepreneurs to adapt and grow their businesses.

For scaling-up and commercially utilizing technology in UFEs, there needs to be an efficient and effective deployment ecosystem that empowers all the actors in the deployment process to find each other and join forces to get the job done.[30] This includes a well-functioning ecosystem of local partners, financiers, suppliers, sales personnel and others to implement that business model.

For technology deployment business models for the UN's Sustainable Development Goals (UNSDGs), a two-pronged strategy is recommended that includes: 1) developing a platform so that all the disparate elements of the ecosystem, ranging from technology vendors to local supply chain candidates to financiers to potential local entrepreneurs to other diaspora representatives, can find each other and join forces more easily; and 2) building the capacity of local organizations, institutions and individuals to participate more actively and fully in the deployment process.

A holistic, comprehensive approach is needed that utilizes the powerful new tools and innovative business models to build UFEs that connect rural, peri-urban and urban food production, processing, distribution and consumption. They must be economically, environmentally and socially sustainable, and supported by government policies and civil society. This will

29 Rajiv Shah, the former administrator of USAID and current head of the Rockefeller Foundation, observed that some of the greatest leaps in human progress have not come from just new technologies – but by applying those technologies locally. There are underutilized technologies, which if digitally connected, could have a dramatic impact on the food ecosystem.

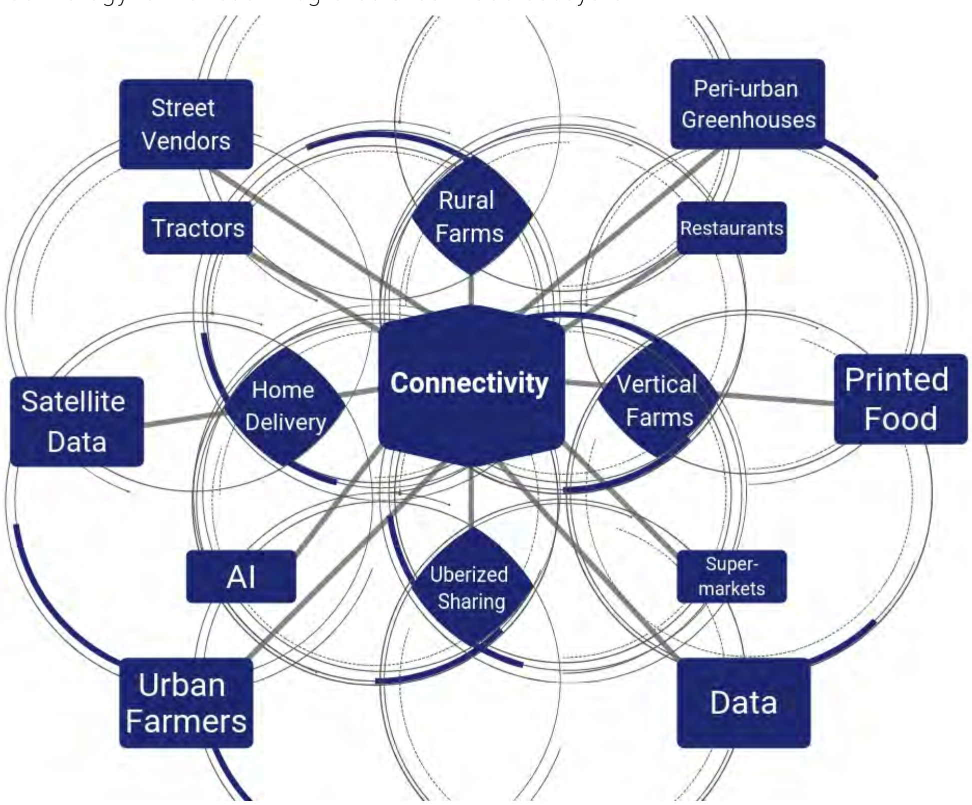
30 Watkins, A. (2018). Takeaways and Policy Recommendations Global Solutions Summit 2018. *From the Lab to the Last Mile: Technology Deployment Business Models for the SDGs*. 4 June 2018. United Nations Headquarters. New York. Available on line at: http://www.globalsolutionssummit.com/uploads/3/1/5/5/31554571/takeaways_and_policy_recommendations_--_final.pdf.

require a multi-discipline path linked to value-chains and dependent on sound policy and transparency (trade, land-ownership, access to finance, markets), information delivery and GAPs. In short, a "package approach" that leads to entrepreneurship and new opportunities. Increasingly, UFEs will be enhanced by use of artificial intelligence, growing data streams, blockchain, Internet of Things, drones and robotics. The capabilities of these and other exponential technologies are rapidly improving while their cost is also falling, often exponentially, which will increase their availability in the developing world. This is making possible a "better, cheaper, faster, scalable" approach to development, including development of UFEs.

New UFEs will also be critical elements of and contribute development of a circular economy. "Looking beyond the current 'take, make and dispose' extractive industrial model," according to the Ellen MacArthur Foundation, "the circular economy is restorative and regenerative by design. Relying on system-wide innovation, it aims to redefine products and services to design waste out, while minimizing negative impacts. Underpinned by a transition to renewable energy sources, the circular model builds economic, natural and social capital." The future is shifting towards such a circular economy. Rather than a traditional production, throw-away and waste model, the circular economy will include producing parts and services on demand as needed with greater local production with 3D printing and other advanced manufacturing processes and increasing use of recycled materials for feedstock. The circular economy will require reliable road systems, infrastructure, electricity and broadband internet. Leap-frogging technology will help shore-up infrastructure, banking, governmental policy making and implementation, and enhance production, marketing, processing and delivery systems (Figure 25).

Figure 25. Complex Connectivity

This chart is intended only to suggest the complexity and interconnectivity of the technology-enhanced integrated urban food ecosystem



Recommendations to Promote Development of Technology-Enhanced UFEs

Development of environmentally and economically sustainable and increasingly productive UFEs will require a comprehensive effort by business, government, NGOs and other organizations. This will involve both "bottom-up" and "top-down" approaches with the private sector the primary engine of growth supported by enabling government policies and investments. Technology is not a "silver bullet" but just a tool to be innovatively utilized when appropriate and supported by effective business models. The following is an initial list of goals, approaches and policy recommendations to promote technologically-enhanced urban food ecosystems, connecting farm and city.

Goals and Approaches

- **Learn from the locals:** Locals know where the bottlenecks in the food ecosystem are and how they might be overcome, and their knowledge can be combined with available and affordable technologies to create new businesses in the food ecosystem.
- **Build resilience:** The UFEs must be integrative from multi-crop to multi-source protein production (livestock, poultry, fish, insect, etc.) to build resilience to climate and economic shocks.
- **Encourage diversity in the food ecosystem:** Agricultural practices will vary in a world of niches from small to large producers, offering different products and services, all linked to the market place and value-chain.
- **Link multinational supermarkets to the rural/urban food ecosystem:** Developed world supermarkets/ hypermarkets like Walmart and Carrefour are expanding into developing world cities and are looking for quality local produce to service middle-class markets.
- **Expand and maintain enabling infrastructure:** Accessible and affordable broadband for all citizens is a critical foundation for technology dissemination and connectivity, along with all-weather road networks, reliable electricity, water, sanitation, and other basic infrastructure.
- **Support producers' cooperatives:** Cooperatives and business associations can be critical local-level aggregations, providing producers with training and mentoring, enhanced production knowledge and techniques, reduced crop/animal losses, micro loans, warehouse storage, potential cold-chain usage, transportation, and market information. There can be member-owned "cooperatives" and business associations all along the "food ecosystem value-chain" from production, processing, and storage, to processing and delivery to end-customers. Cooperatives enable better aggregation at the local level: buying and marketing power, self-finance, info delivery, value-chain driven, training,— and adapting new technologies. These networks enable knowledge transfer and timely assistance to producers.
- **Support private sector innovations through mentoring:** Mentorship and business coaches (private-public) are needed throughout the UFEs from production, processing, storage and to delivery to end-customers. This will also help identify, empower, and support early adapters of new technologies and business models. Such support systems are crucial for innovators to survive and scale-up. Farmers empowered by know-how and data can make better informed choices about technologies, techniques, and business models.
- **Encourage life-long learning and training:** Adapting and utilizing technology and innovative techniques requires life-long learning and continually retooling. Potential providers of life-long learning include private-public "extension services," such as those pioneered in the US, and Digital Green in Asia

and Africa, that can help adapt new technologies (mobile phone, internet connectivity, sensors, big data, etc.). It is essential to develop networks that enable information transfer to stake-holders throughout the food ecosystem, such as Digital Green's low-cost videos of successful local producers, in languages/dialects that are applicable, understandable and inclusive.

Collaborative Projects and Government Policies

City and regional governments, in collaboration with businesses, incubators and accelerators, civic organizations, and universities, could engage in a wide range of activities and collaborations to support development of technology-enhanced urban food ecosystems, including:

- **Gather data to map the existing food ecosystem** to discover how food moves from farm to table in the region. GIS generated maps could provide a baseline for understanding the current system with its strengths, weaknesses, food deserts, and bottlenecks to help identify opportunities to enhance efficiencies and build new businesses.
- **Educate the senior leadership** of the city and regional governments, businesses, and key non-government stakeholders, on the opportunities and challenges for developing UFEs. This is likely to be an on-going process and will involve outreach to experts in technology, rural and urban agriculture, businesses and entrepreneurs, and civic groups. Developing strong understanding and support for UFEs as well as local leadership will be critical to success.
- **Seek to build a consensus on a vision** of a desirable and realistic future UFE for the city and region to develop specific goals, timelines, and strategies for achieving that vision. This vision should be integrated with an overall strategic vision of the city so that it builds on, and contributes to, achieving other goals for jobs, education, mobility systems, inequality and poverty reduction, health care, and overall civic "wellbeing."
- **Develop a working UFE plan with stakeholders** based on this vision and set of goals and strategies for development of the UFEs that integrates rural and peri-urban agriculture with urban food production, distribution and consumption systems. This planning process should examine the potential of current and future technologies to enhance efficiency, quality, and quantity of food production and distribution of the entire food ecosystem encompassing surrounding rural agriculture. The plan should also be fully integrated into a "smart cities" plan for the city and region.
- **Develop and implement "smart" policies** on land use and ownership, entrepreneurship, credit and market access, cooperatives, government transparence and rule of law, and investment in agriculture, all-weather roads, and reliable electricity.
- **Establish strong public outreach**, including through social media, to communicate and encourage feedback on the UFE vision, goals, strategies, and plans.
- **Strengthen ties with cities and urbanization organizations globally** to share experiences and learn from each other. This includes a wide range of organizations, including those focused on climate change and sustainability. Work with local business, civic groups, and universities to organize delegations to visit other cities to learn from their experiences with UFEs and to host visiting delegations.

- **Build out the connectivity infrastructure** which undergirds UFEs, soon to be upgraded to ubiquitous 5G wireless networks, with the goal of bringing affordable and accessible broadband internet to all citizens.
- **Build capacity within the government** to exploit the opportunities and meet the challenges in building UFEs. This includes understanding the potential of a wide range of technologies and how they can be employed by entrepreneurs to build the pieces of an integrated system - and how the government can advance these developments through public-private partnerships.
- **Promote the development of "Food Valleys"**[31] composed of incubator systems with universities that attract industry as well as smaller, more flexible, innovative start-ups.
- **Create regular symposia and UFEs business/technology shows** to educate the public and bring together established companies and startups to network and to promote their businesses and technologies. These activities could be held in parallel or integrated with "smart cities" conferences.
- **Stimulate innovation by establishing contests and "prizes"** for innovations to aid advancing the UFEs plan. These contests and prizes could be sponsored with local businesses and civic organizations.
- **Champion development of a new generation of "urban food producers"** as good, well-paying jobs and careers. This could range from establishing new courses and "hands on" training in city schools, including local community colleges and universities, to working with businesses for apprenticeships and other innovative education programs. Online courses and social media could also be harnessed to educate and encourage young people to pursue urban food production. More generally, promote life-long learners with technology, people-skills, and entrepreneurial skills. This would include "mentoring," encouraging collaboration, and a multi-disciplinary approach to solving "wicked problems" — and more specifically demonstrating career opportunities in the UFEs nodes of production, processing, distribution, design, and marketing.

31 Terazono, E. (2018). Future of food: Inside Agritech's Silicon Valley. *Financial Times*, 14 Oct. 2018. Available online at: https://www.ft.com/content/199cae4c-cbc6-11e8-b276-b9069bde0956.

Acronyms

AI	Artificial Intelligence
B-to-B	Business-to-business
BMPs	Best Management Practices
BRINE	Cluster of biotechnology, robotics, information, nanotechnology/nanoscience, computer/cloud technology and energy
CAADP	Comprehensive Africa Agriculture Development Program
CEA	Controlled Environment Agriculture
CGIAR	Formerly the Consultative Group for International Agricultural Research; it is a global partnership that unites organizations engaged in research for a food-secured future.
CIP	International Potato Center
CRISPR	A genetic engineering tool that uses a CRISPR sequence of DNA and its associated protein to edit the base pairs of a gene.
CSA	Community Supported Agriculture
EPA	Environmental Protection Agency
FAO	Food & Agriculture Organization of the United Nations
FWENH	Nexus of Food, Water, Energy, Nutrition and Human Health
GAPAD	Global action plan for agricultural diversification
GAPs	Good Agricultural Practices; part of "smart" agricultural practices
GDP	Gross Domestic Product
GHPs	Good Handling Practices
GIS	Geographical Information Systems
GMO	Genetically Modified Organism
GPS	Global Positioning System
ICT	Information Communications Technology
IFAD	International Fund for Agricultural Development
IoT	Internet of Things
IPM	Integrated Pest Management
IT	Information Technology
LEDs	Light Emitting Diodes
NBIC	Nanotechnology, biotechnology, information technology, and cognitive science are a set of technologies or converging technologies for improving human performance

NGOs Non-government organizations

PUA Peri-urban agriculture; transition between rural and urban

RFID Radio Frequency Identification

SMS Short message service is a text messaging service.

SMEs Small and medium-sized enterprises

UA Urban Agriculture

UFEs Urban Food Ecosystems

UH Urban Horticulture

UN United Nations

UNCTAD United Nations Conference on Trade and Development

UNDP United Nations Development Program

UN-Habitat United Nations Human Settlements Program

USDA United States Department of Agriculture

USDA-NRCS United States Department of Agriculture, Natural Resources Conservation

UNSDGs United Nations Sustainable Development Goals — 17 Global Goals

UPA Urban and peri-urban agriculture

WFP World Food Program

3D 3D printing or additive manufacturing

Appendix I: Technology and the Four Agricultural Revolutions

Agriculture Revolution 1.0 (AR 1.0) occurred 10,000-plus years ago with the domestication of plants and animals, enabling the development of the first cities. AR 1.0 included development of farm tools, use of farm animals, development of irrigation and canal systems (Egyptians, Mesopotamia, pre-Incas), and division of labor from production to processing to transportation. It was highly labor intensive, utilizing a majority of the population.

Agriculture Revolution 2.0 (AR 2.0), from the 1800s through the mid-1900s, coincided in the developed world with the industrial revolution, mechanization and commercial farming. Technology innovations during AR 2.0 included seed drills, ginning mills, combustion engines, electricity, machinery, tractors, chemical inputs, later refrigeration, long-distance transport, industrial processing, improved breeding and selection programs for plants and animals. *In much of the developing world, AR 2.0 never fully arrived as mechanization and adaptation of modern agricultural technologies were limited.* AR 2.0 also coincided with a second urban revolution that led to a massive expansion of cities and urban societies that relied on enhanced food production through use of technology, which also led to a sharp decline in farm-labor jobs. In 1900, 40 percent of the U.S. population was still employed in agriculture but a century later, only 2 percent of the population worked directly in farming and agriculture contributed around 1 percent of GDP. In Africa today, however, more than 65 percent of the population still works in agriculture, which contributes around 35 percent of GDP.

AR 2.0 also created serious problems. These include degradation of soil, improper use of fertilizers and pesticides, depletion of underground water aquifers, pollution, inefficient use of resources, lack of adaption of good agricultural practices (GAPs), urban encroachment consuming prime farm land, and growing consumer demand for the consumption of meat, particularly beef. Agriculture became a primary source of greenhouse gas emission and primary user of land and water.

Agriculture Revolution 3.0 (AR 3.0) started in the 1970-80's with more advanced technologies, including Borlaug's "Green Revolution" that more than doubled yields in grain and rice production. AR 3.0 included higher-yielding seed and hybrids adapted to environmental change, increased fertilizer, pesticide and water usage, greater mechanization, automation, assembly line production and processing. Integrated pest management (IPM) utilizing "smart agriculture" GAPs became widely used, including better cultural techniques, more judicious chemical usage and a greater reliance on natural biological systems from insect-pest control, utilizing naturally occurring insect-predators, soil microbes to enhance plant resistance to stress and disease resistance. Computerization, simple digitization and electronic information technology (EIT), and web-based intranet and internet information and applications, helped transform and enhance the food ecosystem. While much of the developing world lagged behind in adapting these new technologies, India utilized green revolution technologies to become more self-sufficient in food production.

AR 3.0 included use of modern molecular techniques to develop genetically modified organisms (GMOs) that contain genes from other organisms. The GMO, Flavr Savr tomato could ripen on the vine without becoming overly soft, thus increasing its flavor and shelf-life, was developed in 1987 and commercially released in 1994. GMO development also led to "greener" crop production of cotton, corn, soybean, egg-plants, and other crops that required less chemical, pesticide and petroleum usage during their production. While use of GMOs are sometimes inappropriate, they are an important tool in the toolbox. The U.S. National Academy of Sciences, USDA, FDA have not found GMO crops any less safe than conventionally produced crops. Nevertheless, environmental groups have been largely successful in blocking their adaption in the developing world, which needs GMOs for self-sufficiency, human-health and long-term environmental sustainability in producing food crops.

Many of the problems of AR 2.0 have persisted with AR 3.0. Crop yields have been plateauing. There has been inefficient and wasteful use of land and water; over-use of and improper use of chemicals; and pollution and over-farming of unproductive land, especially in the developing world. Nearly 1/3 of the world's arable land has been lost in the past 40-years to erosion, pollution and urban encroachment. High levels of food-loss continue to occur "from farm to fork," including food spoilage, waste and unequal food distribution.

In the developing world, major barriers still exist for agricultural modernization. These include: insecure land-tenure and ownership, inadequate finance (micro- and macro), lack of transparency, weak enforcement of the rule of law, and lack of smart government policy to ensure sustainable ecosystems (environment, production, trade). To end hunger, achieve food security, improve nutrition, and promote sustainable agriculture, developing countries need to invest more in agriculture. These requirements have been spelled out in the Comprehensive Africa Agriculture Development Program (CAADP) and the UN Sustainable Development Goals 2030. Such investment in agriculture by developing country governments is critical to economic growth and long-term sustainability. Moreover, growth in the agricultural sector is four times more effective in raising the income of the poorest people than growth in other sectors.

Agriculture Revolution 4.0 (AR 4.0). Fast forward to the 21st century. It has become the information age of connectivity, the cloud, complexity, big data, precision agriculture, drones, GPS-driven tractors, controlled environment agriculture (CEA), vertical farming, 3D printing of food, the tasty Impossible Burger made of non-meat components, Tyson's foods line of plant-based protein alternatives to meat, Ripple plant-based milk, greater refinement of good agricultural practices (GAPs), and new advances in biotechnology (i.e. CRISPR), which can leap-frog previous restraints towards using GMOs. AR 4.0 is sometimes referred to as the era of BRINE or the NBIC Cluster: Biotechnology, robotics, information, nanotechnology/nanoscience, computer/cloud technology and energy. There is a fusion of technologies that blur the lines between the physical, digital and biological spheres (2016 World Economic Forum). AR 4.0 has the potential to accelerate development of urban food ecosystems by connecting and integrating these systems with rural, peri-urban and urban agriculture.

Appendix II: Technologies for Urban Food Ecosystems (UFEs) in the Developing World – Current, Near-Term and Future

Currently available, soon-to-be-available, and prospective commercialized technology is making possible increasingly efficient and integrated urban food ecosystems. The chart below utilizes a "McKinsey approach" for classifying technologies that can advance UFEs in the developing world. These technologies can be sorted into three categories: 1) currently available, but underutilized technology, 2) technology that will be available in the near term (within five years); and 3) technology that is on the horizon but has yet to be commercialized and scaled. Examples are given below. There is some overlap between current and near-term technologies. **The technology platforms are listed in the order of Figure 2**.

TECHNOLOGY PLATFORMS	TECHNOLOGY STATUS	DESCRIPTION & REFERENCES
1. Connectivity Info delivery and digital technology platforms: ICT, IOT, mobile money, finance	***Current but underutilized technologies***	CocoaLink in Ghana uses text and voice SMS with cocoa industry experts and smallholder producers. Digital Green uses low-cost, technology-enabled communication. MFarm is a mobile app that connects Kenyan farmers with urban markets via SMS. AgroSpaces is a web and mobile platform in Cameroon that connects smallholder farmers in the value chain with buyers. In Africa, Farmerline and AgroCentra use mobile and web platforms as part of their business plan connecting farmers with the services they need. This includes weather forecasts, market prices and GAPs. In East Africa, Shamba Shapeup is a "make-over" reality show that both informs and entertains farmers with on-site, demonstrated solutions to improve their plant and animal production practices. Less than 1 percent of commercial lending in Africa goes into agriculture (generally to smallholder farmers) so smallholders have little capital for equipment. EcoCash is an innovative mobile payment solution that enables customers to complete financial transactions directly from their mobile phone. Customers can also buy airtime, pay for goods and services, etc.

TECHNOLOGY PLATFORMS	TECHNOLOGY STATUS	DESCRIPTION & REFERENCES
	Near-term technologies (within five years)	RFIDs (radio frequency identification) are tiny ID tags with internet linked sensors and actuators embedded in machines and agricultural products that can track packages and products, record temps and relative humidity (important in shipping), be used for inventory control, etc. More precision agricultural irrigation, pesticide application, autonomous tractors, robotics and mechanization for agriculture production; robotics to inspect lettuce on conveyor belt. Internet of Things (IoT), ICT, RFIDs are becoming cheaper, more off-the-shelf and applicable for urban food ecosystems. In the near future, the use of water and fertilizer will be measured and monitored in detail, sometimes on a plant-by-plant basis. Higher yields and less waste will be achieved with better information for production systems, weather, soil conditions and market demand for specific crops – all delivered via cellphone/ internet. With IoT will be a greater reliance on systems like IBM's question-answering cloud service Watson.
	On-the-horizon technologies (beyond five years)	Enhancements continue.
2. Uberized services Producers to consumers	***Current but underutilized technologies***	Hello Tractor is the Uber of small, 2-wheel tractors. EM3 AgriServices in India are facilitators who work with farmers owning tractors, harvesters and other mechanical implements to "rent" their equipment to smallholder producers. Trotro Tractor of Ghana uses the same sharing economy model as Hello Tractor. It links farmers with tractor owners in Ghana via mobile phone codes. Farmers dial a code to request the use of a tractor, which they pay for with mobile money. Africa has a number of local, indigenous, online delivery services, from SoupDirect and EasyAppetite in Nigeria to FoodCourt in Rwanda. In India, food delivery apps are competing to gain market share – including Google's Aero, UberEATS and Indian startups such as Swiggy and Zomato; hybrids of Peapod food delivery in the developing world can enable entrepreneurship and youth employment in the service industry. Wildkale app is the Uber for Farmers Markets – offering small and medium farms a platform to create virtual farm stands to connect consumers directly to farmers. Farmigo – is a CSA and food hub management software to give small farms the tools to manage their CSA. Ugly foods or Imperfect Produce is a model for reducing food waste, which distributes produce to consumers.
	Near-term technologies (within five years)	"Uber" mechanization will play an important role in commercializing smallholder farmers; 75 percent of world food comes from small farms.
	On-the-horizon technologies (beyond five years)	Enhancements continue.

TECHNOLOGY PLATFORMS	TECHNOLOGY STATUS	DESCRIPTION & REFERENCES
3. Precision agriculture GPS, IOT, AI, sensing tech	***Current but underutilized technologies***	Use of sensors (moisture, temp, nutrition – connected to the cloud); Big data – collecting data points in real-time – aerial imaging – developing machine-learning algorithms for production; sensing water in plants; GPS-guided tractors for precise planting, fertilization, irrigation and harvesting – more realistic near-term and far-term in the developing world. Digital soil maps (African Soil Information Service) – essential for reliable fertilization recommendations. Use of drones for enhanced urban/ peri-urban land mapping, management and policy – for agricultural land-use, land-tenure and ownership categorizing. Zenvus (Nigerian precision farming startup) using electronics and analytics to measure and analyze soil data(temperature, nutrients, water) – for fertilization and irrigation recommendations. Ujuzikilmo is a Kenyan startup, uses soil sensors and analytics to make farm production recommendations.
	Near-term technologies (within five years)	Greater reliance on sensors (moisture, temp, nutrition – connected to the Cloud); Big data – collecting data points in real time – aerial imaging – developing machine-learning algorithms for production; sensing water in plants; GPS-guided tractors for precise planting, fertilization, irrigation and harvesting is near-term and far-term.
	On-the-horizon technologies (beyond five years)	AI – artificial intelligence advancements in UFEs. IoT: the Cloud, Watson and farming. Advanced robotics, autonomous vehicles, on and off farm.
4. Controlled Environment Agriculture (CEA) Protected culture, vertical farming	***Current but underutilized technologies***	From field production with mineral soil (geoponics) to hydroponics to aeroponics to raised beds to sack gardens to green walls; high-hoop poly houses to appropriate greenhouse production to high-end, vertical farming using climate-controlled CEA, LEDs and CO_2 injection. Sustainable intensification: advanced inputs (high yielding varieties) with improved inputs of fertilizer, efficient irrigation; utilization of resource-conserving practices – mixed cropping, zero tillage (agroecology) where appropriate. Business to Business (B-to-B): Custom seedling plug producers to supply greenhouse vegetable producers, i.e. Plantech. In Vietnam and other countries, there are custom propagators of grafted vegetable seedlings to supply farmers with disease-resistant, higher yield crops to plant and produce.

TECHNOLOGY PLATFORMS	TECHNOLOGY STATUS	DESCRIPTION & REFERENCES
	Near-term technologies (within five years)	The CEA systems range from passive, poly hoop houses to sophisticated greenhouse production will become more efficient and cost-effective in the future as businesses – serving urban and peri-urban markets. Vertical farming (appropriate for green crop production of selected vegetables & other crops; but inappropriate for grain crops, many fruit crops); roof-top gardens; successful serving urban markets: consumers, restaurants, super markets. Aerofarms, Vertical Farming – Singapore, Vertical Farming – Holland, MIT Open Agriculture Initiative
	On-the-horizon technologies (beyond five years)	Enhancements continue.
5. Blockchain Traceability, food safety (postharvest), personal identification	***Current but underutilized technologies***	Blockchain – financial opportunities, i.e. Moni card (Finland) – works as "Master Card debit card" for immigrants. Mojaloop allows software producers, banks and financial service providers to build secure digital payment platforms at scale (Forbes Oct2017). Blockchain can also offer greater traceability for food safety. Also, for personal identification (ID), over a billion people do not have a legal ID.
	Near-term technologies (within five years)	Enhancements continue. Greatest opportunity with this technology is near-term and far-term in the developing world.
	On-the-horizon technologies (beyond five years)	Enhancements continue.
6. Solar electric Energy, micro-grids and storage	***Current but underutilized technologies***	Opportunities to use solar, enhanced battery storage, wind power. Technology exists and continues to improve. Opportunities for more efficient microgrids, rather than more costly large utilities construction.
	Near-term technologies (within five years)	Greatest opportunity with this technology is near-term and far-term in the developing world. Sundrop Farms (South Australia) is powered by a concentrated solar thermal power plant to generate energy to cool greenhouses and for desalination of irrigation water for producing truss tomatoes to supply the Australian supermarket Coles. Solar energy and desalination can be appropriate for high-value crop production in high-sun areas with access to saline water. This sophisticated level of technology is far-term for the developing world.
	On-the-horizon technologies (beyond five years)	Enhancements continue.

TECHNOLOGY PLATFORMS	TECHNOLOGY STATUS	DESCRIPTION & REFERENCES
7. High-quality enhanced seed Hybrids, climate and pest resilience	***Current but underutilized technologies***	Technology utilizing high value seed and hybrid seed – rather than low-yielding, farmer-collected "land-race" seed – (USAID, WASP Mid-Term Evaluation). Inclusion of appropriate inputs of fertilizer, chemicals, irrigation and integrated pest management systems (IPM) – using beneficial rhizosphere organisms (microbiome) – biostimulants, mycorrhizal fungi for biocontrol and environmental stress resistance, etc. High value seed will dramatically improve in the near-term and far-term as molecular biology (CRISPR) is integrated into traditional breeding and selection programs.
	Near-term technologies (within five years)	Conducive changes in government policy, trade and enforcement of intellectual property rights for greater adaption of hybrid and high-value seed are needed. Greater adaption of this technology is critical.
	On-the-horizon technologies (beyond five years)	Enhancements continue.
8. Enhanced genetics Gene editing, synthetic biology, cloud biology	***Current but underutilized technologies***	Technology recently developed and is being integrated with traditional breeding and selection to speed up advancement of new cultivars. Great potential in the near-term and far-term. Use of CRISPR gene-editing systems to create non-GMO products using modern molecular biology – combined with traditional breeding and selection systems. Synthetic Biology – design of new biological parts & redesign of existing parts; e.g., plants engineered to produce artemisinin (malaria), biofortified micro-nutrients and antioxidants; greater crop resistance – drought, disease, etc. Greatest potential near-term and future.
	Near-term technologies (within five years)	Enhancements continue. Greatest opportunity with this technology is near-term and far-term in the developing world.
	On-the-horizon technologies (beyond five years)	Enhancements continue.

TECHNOLOGY PLATFORMS	TECHNOLOGY STATUS	DESCRIPTION & REFERENCES
9. Biotechnology Microbiome editing, soil biologicals, alternative proteins, plants as factories for drugs, meat substitution	***Current but underutilized technologies***	Greatest potential for adaptation and commercialization is near-term and far-term. Includes use of beneficial rhizosphere organisms (microbiome) – biostimulants, mycorrhizal fungi for biocontrol, and naturally produced, biological fertilizers, herbicides, fungicides and pesticides. These rhizosphere microorganisms (bacteria, beneficial fungi) can enhance plant nutrient uptake, drought resistance – and signaling important to plant development. Earth Microbiome Project, will enhance commercial usage in the future. There have been great advances in plant-based foods, like the "Impossible Burger" and Beyond Meat. Finless Foods is a new company trying to replicate fish filets. Scientific teams and startups are developing laboratory produced meat for animal-free burgers, chicken, turkey and fish to create new sustainable, commercial industries. In the future, "clean meat" can be produced starting with muscle stem cells from live cattle, what is called "cellular agriculture." Several startups, including Memphis Meats, are pioneering "clean meat" or cultured meat, ranging from beef to chicken.
	Near-term technologies (within five years)	Enhancements continue. Development is more near-term and far-term.
	On-the-horizon technologies (beyond five years)	Enhancements continue.

TECHNOLOGY PLATFORMS	TECHNOLOGY STATUS	DESCRIPTION & REFERENCES
10. Nanotechnology and advanced materials Seed coating, disease control, postharvest, etc.	***Current but underutilized technologies***	Nanomaterials in agriculture – greater reactivity, electrical properties (better adhesion with less chemical usage of target pesticides to leaves); greater strength per unit; coating of food products – enhance shelf-life, disease resistance, etc. There are edible barriers made of plant extracts to apply to fruits and vegetables during postharvest. These natural products help retain moisture, reduce respiration and keep microorganisms from fruits and vegetables, i.e. delay spoilage and make cold-chain storage less of an issue. Very important for the developing world servicing urban markets. They can be used for either organic or conventional production systems. Less pesticide usage is required. Greatest opportunity for the technology is near-term and future. DNA assembly – creating novel materials on the nanoscale. Seed coating for enhanced germination and seedling establishment with nanotechnology materials being used in developed world, but has more potential near-term and far-term in the developing world.
	Near-term technologies (within five years)	Enhancements continue. Greatest opportunity with this technology is near-term and far-term in the developing world.
	On-the-horizon technologies (beyond five years)	Enhancements continue.
11. 3D printing/ additive manufacturing Food, parts production, machinery, structures	***Current but underutilized technologies***	3D printing or additive manufacturing is a "general purpose technology" that is being used for making everything from plastic toys and human tissues to aircraft parts, buildings and on-demand replacement parts, which are badly needed in the developing world for tractors, pumps and other equipment. Catapult Design 3D prints tractor replacement parts as well as corn shellers, cart designs, prosthetic limbs, and rolling water barrels for the Indian market. 3D printing also can be used to convert alternative ingredients such as proteins from algae, beet leaves, or insects into tasty and healthy products that can produced by small, inexpensive printers in home kitchens.
	Near-term technologies (within five years)	Enhancements continue. Greatest opportunity with this technology is near-term and far-term in the developing world.
	On-the-horizon technologies (beyond five years)	Enhancements continue.

TECHNOLOGY PLATFORMS	TECHNOLOGY STATUS	DESCRIPTION & REFERENCES
12. Intervention of new tech with underutilized tech "On-" and "off-grid" usage, i.e. precision soil sensors and solar pumps integrated with efficient drip irrigation, "packaging technologies"	***Current but underutilized technologies***	IDE – low cost drip irrigation systems and pumps for developing world, buried clay pot irrigation, solar drip systems, pedal-powered low-pressure system. Kickstart Treadle foot pumps. SunCulture supplies drip-irrigation kits using solar energy to pump water. Water delivery and recycling (10 percent of urban waste/gray water in Accra is recycled for local food production); surface and sub-surface drip irrigation. "Package Approach" – high value seed, hybrids, grafting, fertilizer, chemical and drip-irrigation inputs, including appropriate CEA; poly, insect-screened hoop houses; technical information and expertise; micro-loans and market linkages; connected to the web and telecommunications, i.e. Amiran. Coolbot refrigeration control systems are being adapted for fresh produce storage by farmers, as well as by independent butchers and small fishing and shrimp boats, and produce value-chain players in the developing world. Solar electric for small refrigeration units. Technology current, near-term and future needed to offset deficiencies of developing countries; need to invest in road systems and leverage via the African Development Bank and World Bank, etc. Examples of road systems for UFEs, e.g., in rural Texas, farm-to-market (FM) roads begun during the depression were signed into law in 1949; connected farmers and ranchers to urban centers and distribution centers; revolutionized local and regional economies; FM road development in Texas was with 50/50 state and federal government support. Increase broadband: 7 billion mobile phone subscriptions (2013), 40 percent world has computer access – but 2.3 billion lack access to improved sanitation.
	Near-term technologies (within five years)	Enhancements continue. Greatest opportunity with this technology is near-term and far-term in developing world.
	On-the-horizon technologies (beyond five years)	Enhancements continue.

About the Authors

Dr. Fred Davies is a Regents Professor emeritus, faculty of Molecular and Environmental Plant Sciences, and AgriLife Research Faculty Fellow at Texas A&M University. He is a Senior Borlaug Fellow in Horticulture at the TAMU Borlaug Institute of International Agriculture. Davies is a Senior Fellow, Global Federation of Competitiveness Councils. He was a former Senior Science Advisor (Jefferson Science Fellow) at USAID, Bureau of Food Security. He continues to advise USAID on food security, agriculture and horticulture – serving as the team lead, evaluating USAID plant seed programs in West Africa. He has over 40 years experience in research, evaluation, teaching, industry outreach and consultancies in horticulture, agriculture, plant propagation and seed programs in more than 25 countries.

He received a B.A. and M.S. from Rutgers University, and a Ph.D. in Horticultural Sciences, Plant Physiology and Tropical Agriculture from the University of Florida. He has been a Visiting Scientist at the USDA Horticultural Crops Laboratory (Oregon), CINVESTAV Plant Biology Institute (Mexico) and International Potato Center (Peru). He has also been a Visiting Professor at Oregon State University, Monterrey Tech. Univ. (Mexico), National Agrarian University of Peru, and Bogor Agricultural University [IPB (Indonesia)]. As an expert in international horticulture, agriculture and food security – he has been a Guggenheim Fellow and Senior Fulbright Fellow to Peru, Mexico, and Indonesia. He is past-president of American Society for Horticultural Sciences (ASHS) and International Plant Propagators Society (IPPS). His research has been supported by NASA, National Science Foundation, U.S. Dept. of Agriculture and industry.

Banning Garrett is a Washington-based strategic thinker, writer, keynote speaker and entrepreneur with more than four decades of experience in national security, U.S.-China relations, and global trends. He currently focuses on exponential technologies and their impact on the economy and intersection with long-term global trends, urbanization, development, and geopolitics. Garrett has consulted to the World Bank, the United Nations, and the U.S. government, and has written for more than two dozen journals and media outlets and has been interviewed by numerous international broadcast and print media. Garrett is on the faculty of Singularity University, a Senior Fellow at the Global Federation of Competitiveness Councils, a Senior Fellow at Global Urban Development and a consultant to the Institute for Defense Analysis. Garrett has made presentations to think tanks, business groups, international conferences, UN organizations and governments in Asia, Africa, Latin America, Europe and North America.

Garrett was founding director of the Atlantic Council's Strategic Foresight Initiative and created and led the Council program on the implications of emerging technologies and its Urban World 2030 program. He was Director of the Council's Asia Program (2003-2012) and in 2006 established and subsequently led the Council's cooperation with the National Intelligence Council (NIC) in production of the NIC unclassified, quadrennial long-term global trends assessments. Garrett has also worked on U.S.-China relations since the 1970s. Besides writing and speaking about U.S.-China relations, he consulted to the U.S. Government and conducted an informal strategic dialogue between China and the U.S. from 1981-2002 before joining the Atlantic Council. Garrett has a BA from Stanford and a Ph.D. from Brandeis University.

Global Federation of Competitiveness Councils Membership

SUSTAINING AND GENERAL MEMBERS

Argentina
Business Foundation for Quality and Excellence – FUNDECE

Australia
Department of Industry, Innovation and Science

Brazil
National Confederation of Industry – CNI/SENAI/SESI/IEL

Brazilian Innovation Agency – Finep

Canada
GO Productivity

Western Economic Diversification Canada

Ecuador
Quito Council on Competitiveness

Greece
Delphi Economic Forum

Japan
Japan Innovation Network

Japan Science and Technology Agency – JST

Kazakhstan
Kazakhstan Competitiveness Council

Malaysia
National Council of Professors – MPN

Malaysian Industry-Government Group for High Technology – MIGHT

Qatar
Qatar Foundation R&D

Russia
Eurasia Competitiveness Institute

Saudi Arabia
Saudi Arabian General Investment Authority – SAGIA

United Arab Emirates
Competitiveness Office of Abu Dhabi

United Kingdom
Centre for Competitiveness

United States of America
Council on Competitiveness

UNIVERSITY AND RESEARCH MEMBERS

Australia
Aikenhead Centre for Medical Discovery

Bond University

Monash University

Swinburne University

Canada
Western University

Finland
University of Helsinki

Germany
Ludwig-Maximilian University Munich

Greece
American College of Greece

Hong Kong
University of Hong Kong

Malaysia
Universiti Teknologi Petronas

University of Malaya

Mexico
Monterrey Institute of Technology and Higher Education

New Zealand
University of Auckland

Portugal
Catholic University of Portugal

University of Minho

Qatar
Qatar University

Weill Cornell Medicine – Qatar

Switzerland
University of Zurich

United Kingdom
Imperial College London

King's College London

Queen Mary University of London

Ulster University

University of Southampton

United States of America
Arizona State University

Georgetown University

Michigan State University

Northeastern University

Ohio State University

Purdue University

University of California San Diego

University of Chicago

University of North Carolina at Chapel Hill

University of South Carolina

Webster University

CORPORATE AND INDIVIDUAL MEMBERS

Al Dabbagh Group

Anson Chan

Athens Exchange Group – ATHEX

BlueSpace

Center for Research and Consulting

Consolidated Contractors Company

Justitia Advisory

Lockheed Martin

Nadim Industries

Piraeus Bank

Stratega

Xinova

GFCC FELLOWS

About our fellows
The GFCC fellows are vital assets to our growing international community of leaders in innovation, academia, and industry. Invited to join on the basis of their contributions to solve competitiveness challenges on a global scale, they advance the GFCC network's ability to get things done. GFCC fellows are thought leaders and professionals with proven and impactful track records in business, government, and research or civil society organizations. Moreover, they are interested in competitiveness, economic development, and prosperity, showing a commitment to creating a better world and improving the lives of their fellow citizens—locally and globally. With the GFCC as the conduit, the fellows engage with peers from across the world, promote mutual learning, share their experiences and ideas, learn from others, and spread competitiveness ideas.

Distinguished Fellows
Zakri Abdul Hamid

Ahmad Tajuddin Ali

Edward D. Agne

Nathalie Cely

Lee Yee Cheong

Luciano Galvão Coutinho

Amr Al-Dabbagh

Petros G. Doukas

Luis Fernandes

Nika Gilauri

Yanos Gramatidis

Karen A. Holbrook

Jerry M. Hultin

Carole Hyatt

João A. H. Da Jornada

Charles Kiefel, OAM

Stephen Kingon

Tae-shin Kwon

Joan MacNaughton, CB Hon FEI

Christos Megalou

Peter Meyers

Michiharu Nakamura

Liam Nellis

Lucas Papademos

Richard Parker, CBE, FREng

Frank-Jürgen Richter

Laura Sandys

Jack Sim

Rogerio Studart

Manuel Trajtenberg

Gregory F. Treverton

Simon Peter "Pete" Worden

Kandeh K. Yumkella

Senior Fellows
Rehan N. Chaudri

Fred T. Davies

Mark Esposito

Dionisio Garcia

Banning Garrett

Kwanza Hall

Kathryn Hauser

Greg Horowitt

Elisa Jagerson

Nkem Khumbah

Susan McCalmont

Mark D. Minevich

Michael Nelson

GFCC TEAM

Charles O. Holliday Jr.
Chairman

Deborah L. Wince-Smith
President

Roberto dos Reis Alvarez
Executive Director and Secretary to the Board

Chad Evans
Treasurer

Yasmin M. Hilpert
Senior Director of Policy and Engagement

Please check out our other publications at thegfcc.org.

GFCC
Global Federation of Competitiveness Councils

**Global Federation of
Competitiveness Councils**
900 17th Street, NW, Suite 700
Washington, DC 20006
USA
T +1 202 969 3382
www.thegfcc.org