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 5 years); and 3) technology that is on the horizon but has yet to be commercialized and scaled. Examples are given below. There is some over-lap between current and near-term technologies. The technology platforms are listed in the order of *Figure 2*. Hyperlinks to selected references are included.

Technology Status	**Technology Platforms**	**Description & References**
Current but underutilized technologies		
1	ICT – Information Delivery	Digital technology platforms – ICT, GPS – Telecommunications, merchandizing, mobile money. CocoaLink in Ghana uses SMS text and voice messages with cocoa industry experts and small-holder producers. Digital Green uses low-cost, technology-enabled communication. MFarm is a mobile app that connects Kenyan farmers with urban markets via SMS messaging. AgroSpaces is a similar web and mobile platform in Cameroon that connects smallholder farmers in the value chain with buyers. In Africa, Farmerline and AgroCentra use mobile and the web 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 TV show that both informs and entertains farmers with on-site demonstrated solutions to improve their plant and animal production practice.
	IT-Microfinance	Less 1% commercial lending in Africa goes into agriculture (generally to smallholder farmers) so smallholders have little capital for equipment. EcoCash Zimbabwe microfinance, banking by cell, circumventing traditional banks; 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.
2	Uberization of Equipment: Production, Cold Storage, Transportation, Delivery	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.

	Uberization of Urban Food Transportation & Delivery Systems Farm Markets & Community Supported Agriculture (CSA) to Connect Producers & Consumers	Africa has a number of local, indigenous, on-line-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.
3	Precision Agriculture	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-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. Simple, off-the-shelf sensors of water, fertilization, nutrition, plant health. 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.
4	Production Systems Using Good Agricultural Practices (GAPs): from Field-Production Using Mineral Soil to Controlled Environment Agriculture (CEA)	From field production with mineral soil (geoponics) to hydroponics, 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. In urban and peri-urban production, technology driven businesses can bypass traditional field production (vegetables, selected fruit crops and flowering plants) with passive hoop houses, hydroponics, aeroponics to vertical walls, sack/container, roof top gardens; vertical farming more realistic near-term in the developing world with selected greens, herbs and vegetables to service urban markets.
5	Blockchain; Traceability, Food Safety (Postharvest); Personal Identification	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. Block chain can also offer greater traceability for food safety. Also for personal identification (ID) – over billion people do not have a legal ID.
6	Infrastructure: Electricity	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.

7	High Value Seed, Irrigation, Fertilizer (Slow-Release, Controlled-Release, Stabilized) & Chemical Inputs	These inputs needed for climate-smart, agricultural intensification. Technology utilizing high value seed & 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. Government policy needs to change in West Africa to encourage use and commercialization of high-value and hybrid seeds. High value seed will dramatically improve in the near and far term as molecular biology (CRISPR) is integrated into traditional breeding and selection programs.
8	Enhanced Genetics: Gene Editing, Synthetic Biology, Cloud Biology	Technology recently developed and is being integrated with traditional breeding and selection to speed up advancement of new cultivars. Great potential in the near 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.
9	Biotechnology: Microbiome Editing, Alternative Proteins, Plant factories – Meat Substitution, Drugs	Greatest potential for adaptation and commercialization is near 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.
10	Nanotechnology & Advanced Materials	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 post-harvest. 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 and far term in the developing world.
11	3D Printing/ Additive Manufacturing	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.
12	More Efficient Irrigation & Fertitgation Systems	IDE – low cost drip irrigation systems & pumps for developing world; buried clay pot irrigation; drip irrigation; solar drip systems; pedal-powered low-pressure system. Kickstart Treadle foot pumps. Sunculture Kenya offers solar pumps for drip irrigation; Sunculture supplies drip-irrigation kits using solar energy to pump water sunculture.com/products. Water delivery & recycling (10% of urban waste/ gray water in Accra recycled for local food production); surface and sub-surface drip irrigation.
	Package Approach: Inputs, Information, Finance, Market Linkages	"Package Approach" – high value seed, hybrids, grafting, fertilizer, chemical and drip-irrigation inputs, including appropriate CEA- controlled environment agriculture –poly, insect-screened hoop houses, technical information & expertise, micro-loans and market linkages – connected to the web and telecommunications, i.e. Amiran
	Modified Cold-Chain, Cooling	Coolbot refrigeration control systems are being adapted for fresh produce storage by farmers and produce value-chain players in the developing world - as well as by independent butchers and small fishing, shrimp boats. Solar electric for small refrigeration units.
	Infrastructure: Paved, all-weather roads; basic sanitation	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 & ranchers to urban centers & distribution centers; revolutionized local & regional economies; FM road development in Texas was with 50/50 state & federal government support. Increase broadband: 7 billion mobile phone subscriptions (2013), 40% world has computer access – but 2.3 billion lack access to improved sanitation .
Near-Term technologies (within 5 years)		
1	The Internet of Things; the Cloud, AI for Farming	Internet of Things IoT– RFIDs – (Radio-frequency IDs) - tiny ID tags with internet linked sensors and actuators embedded in machines & agricultural products; RFIDs can track packages, products, record temp, RH – relative humidity (important in shipping), inventory control, etc. More precision agricultural irrigation, pesticide application, autonomous tractors, robotics and mechanization for agriculture production; processing- robotics to inspect lettuce on conveyor belt. The internet of things, ICT, RFIDs are becoming cheaper, more off-the-shelf and applicable for urban food ecosystems. This involves exploiting data from many sources — sensors on farm equipment, plants and animals, satellite images and weather tracking. In the near future, the use of water and fertilizer will be measured and monitored in detail, sometimes on a plant-by-plant basis. There is also rising demand for transparency in farming. Consumers want to know where their food comes from, how much water and chemicals were used, does it meet sustainability standards, and when and how it was harvested. Transparency is critical to a company's survival: data collection is a critical component. American cereal farms are both highly capital-intensive and large scale. Average U.S. farm size is 450 acres (81 ha), while African farms average is about 2 acres (0.8 ha).

		[West Africa has a large productivity gap to bridge – achievable through GAPs, better seed, fertilization, reliable & efficient irrigation (less 5% irrigated), markets, technology & market data/info/internet connectivity]. Sensors will continue to get cheaper and more available, as will increasingly sophisticated and inexpensive remote imaging from satellites. Big data and GAPs are important for the developing world to get the needed productivity gains. 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.
2	Uberized Services	Adaptation and Enhancements continue. Most of the developing world cannot afford capital-intensive heavy machinery. There will be fewer big farms – and a larger matrix of small and medium-sized producers. "Uber" mechanization will play an important role in commercializing smallholder farmers; 75% of world food comes from small farms.
3	Precision Agriculture	Enhancements continue. Greatest opportunity with this technology is near-term and far term in developing world. 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 and far term.
4	CEA systems	Enhancements continue. Greatest opportunity with this technology is near and far term in developing world. 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	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 Enhancements continue. Greatest opportunity with this technology is near and far term in developing world.
5	Blockchain	Enhancements continue. Greatest opportunity with this technology is near-term and far term in developing world..
6	Sustainable Technology Using Renewable Solar Energy and Desalination of Sea Water for Growing Vegetables and Fruits	Enhancements continue. Greatest opportunity with this technology is near and far term in 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.
7	High Quality Seed	Enhancements continue. 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.
8	Enhanced Genetics	Enhancements continue. Greatest opportunity with this technology is near-term and far term in developing world.
9	Biotechnology: Microbiome Editing, Alternative Proteins, Plant factories – meat substitution,	Enhancements continue. Development is more near and far-term.

	drugs	
10	Nanotechnology	Enhancements continue. Greatest opportunity with this technology is near-term and far term in developing world.
11	3-D Printing	Enhancements continue. Greatest opportunity with this technology is near-term and far term in developing world.
12	Intervention of New Technology with Underutilized Technology	Enhancements continue. Greatest opportunity with this technology is near-term and far term in developing world.
On the horizon technologies (beyond 5 years)		
1	Connectivity: ICT, IOT, Finance	Enhancements continue
2	Uberized Services	Enhancements continue
3	Precision Agriculture	Enhancements continue; AI – artificial intelligence advancements in UFEs. IoT: the Cloud, Watson & Farming. Advanced robotics, autonomous vehicles – on- and off-farm. Off-the-shelf technology becomes cheaper and more available.
4	CEA – Controlled Environment Agriculture	Enhancements continue
5	Blockchain	Enhancements continue
6	Solar Electric, Microgrids, Storage	Enhancements continue
7	High Quality Enhanced Seed	Enhancements continue
8	Enhanced Genetics: Gene Editing, Synthetic Biology, Cloud Biology	Enhancements continue
9	Biotechnology: Microbiome Editing, Alternative Proteins, Plant factories – Meat Substitution, Drug production	Enhancements continue
10	Nanotechnology & Advanced Materials	Enhancements continue
11	3D Printing/ Additive Manufacturing	Enhancements continue
12	Intervention of New Technology with Underutilized Technology	Enhancements continue
	Growth of Bioeconomy &	Closed loop systems (more efficient use and re-use of water, chemical inputs); avoids linear ‘make-use-dispose’ model of production.

	Circular Economy	Fab City (Global Fabrication Labs) – non-linear, spiral innovation ecosystem – materials flow inside cities & information circulates globally – reduced waste, transportation, less off-shoring of jobs; increased sustainability, job creation, knowledge flow, citizen cohesion/ civil stability; job creation – producing locally where applicable, distribution, new services;