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% of the U.S. population was still employed in agriculture but a century later, only 2% of the population worked directly in farming and agriculture contributed only 1% of GDP. In Africa even today, however, more than 65% of the population still works in agriculture, which contributes around 35% 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 wheat 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 stainability 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, 3-D 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 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; Silberglitt 2015). AR 4.0 has the potential to accelerate development of urban food ecosystems - connecting and integrating these systems with rural, peri-urban and urban agriculture.

- *Hyperlinks to selected references are included.*