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32 Agricultural Systems: Co-producing Knowledge and Food

Alastair Iles, Garrett Graddy-Lovelace, Maywa Montenegro, and Ryan Galt

Introduction

Food is both a material out of which human cultures get made and a product of them. From ancient Egyptian grains to the bread riots of eighteenth century England to the fast-food worker strikes of 2015, food has long been the stuff of subsistence and social transformation. More recently, it has also been a central focus of science: making chemicals to kill crop pests and fertilize soil, creating plants through breeding and biotechnology, pasteurizing and testing samples of raw milk. The fields of agronomy, animal science, and horticulture on which early agricultural science was based are now witnessing the rise of gene chipping, climate modeling, and databases with terabytes of soil, temperature, and agrobiodiversity data. Yet food is supremely democratic and knowable. Particularly when it comes to food, humans from many cultures are opinionated and willingly proffer advice on eating and nutrition. Growing and eating food is also culturally symbolic, reflecting larger imaginaries and patterns of social meaning formation. The sorts of food that people consume speak not only to their preferences but also to the agricultures their cultures have developed or adopted and to their traditions and changing identities in a world of highly mobile capital, science, and trade. Food is thus a window into the many incredibly complex sociotechnological systems that span the globe, and on which humans depend.

For over 12,000 years, many generations of farmers have experimented with crops, animals, and processing methods, learning how to manage complex ecological and social conditions. Their early scientific trials gave birth to a remarkable variety of indigenous foods, exemplified in the hundreds of potato types found in the Peruvian and Bolivian Andes. Starting in Western Europe from the 1700s on, and accelerating across the twentieth century in particular, agricultural systems have undergone dramatic changes (Mazoyer and Roudart 2006). Farms have increased in their sizes, yields, and degrees of ecological simplification; they have become integrated into industrial production networks and markets that turn mass-produced crops and animals (often designed for higher yields) into processed foods. We argue that such productivist forms of agriculture need to be understood as the co-production of forms of agricultural knowledge, technology, organization, landscapes, politics, markets, consumers, eaters, and species. Understanding how all of these facets have been co-produced together—interweaving changes in agricultural science and technology with broader social, economic, and political changes—and how these transformations have made productivist agriculture so powerful vis-à-vis other forms of agriculture has been a particularly important site for research in the field of science and technology studies (STS).

Science and technology studies provides a suite of concepts, methods, and cases that reveal the ways in which productivist systems have arisen, acquired power and authority, and ultimately transformed agriculture (and its knowledges, systems, organization, and people) through encounters with science and technology. STS scholars have built a deep foundation of research that critically unpacks science, expertise, and other ways of knowing, such as local knowledge. They have investigated how scientists and industry have engaged in boundary work to make productivist agricultures more legitimate and powerful vis-à-vis "traditional" agricultures. These scholars have also learned about how the vast infrastructures of growing, processing, and distributing food have taken material shape in the everyday work needed to supply food to billions of people. STS has revealed the commonly shared epistemologies and ontologies hidden in seemingly disparate arenas of farming methods, food processing, and eating practices. STS has made visible, in other words, the politics and processes by which agriculture and food have been co-produced over the past century with material infrastructures, ecological landscapes, and social imaginaries, values, and institutions.[1]

At the same time, STS research on agriculture also looks toward the future of agriculture. Over the next few decades, ongoing processes of agricultural transformation will configure our collective human futures. Productivist trajectories in agricultural systems continue to develop new kinds of science and technology—such as flex crops for fuels, chemicals, and food, or artificial meat—that will shape the types of foods that humans eat and the kinds of bodies and diseases they develop. This knowledge may further lock human societies into highly intensive and environmentally damaging agricultural forms, despite pretensions to being sustainable. Yet, even as productivist forms of agriculture evolve, new modalities of knowledge and practice are emerging, such as agroecology and organic farming, to challenge them and offer alternatives to the world's farmers and eaters. In exploring these alternatives, the powerful critical methods of STS expose not just the limitations of productivist agriculture but how political struggles over epistemologies in growing vegetables open up new spaces for experimentation in other parts of the food system. Nonetheless, the work of advocates of change will be long and hard because they too must co-produce all the different facets of alternative agricultures.

We first discuss how taking a co-production approach can help make visible the mutual constitution of agricultural systems and technoscientific development. We then review STS research on the rise of productivist systems, followed by the challenges and transformations to such systems—underlining how this work has become more diverse in its geography, topics, methods, and participants. We conclude by arguing for the reconceptualization of food systems around diversity, not homogeneity. Many more insights are ready to be revealed through the work of new generations of researchers excited by the possibilities of doing STS work on agriculture.

Navigating Agricultural Systems through a Co-production Idiom

Agricultural systems are complicated forms of life. Unsurprisingly the "global food system" is a catchall for countless food systems that exist at and across local, subnational, national, and global levels. It consists of the metabolic processes and organisms that turn sunlight into plant sugars, the co-evolution of farmer knowledge and physical landscapes, and the millennia of seed selection that turned wild plants into edible food.[2] It comprises farm systems, processing systems, transportation systems, and marketing systems; it is trade and investment, public policy, research and development, and finance. These enfold knowledge and labor in each process and relationship. Industrialized agriculture dominates in some regions, while traditional and indigenous farming thrives in others. Much more commonly, agri-food systems feature farms and landscapes employing mixed conventional and traditional practices.

Nonetheless, industrialized variants of agriculture are imbued with particular political, economic—and *epistemic*—power in contemporary societies; over the course of the twentieth century, they have encroached on, destabilized, and displaced preexisting systems with less power, and they continue to do so in many parts of the world. The roots of productivism lie in Malthusian theory and the fear that population would outstrip world food supply. Contemporary productivist systems embed this logic, emphasizing the production of cheap, abundant food to meet projected population growth and caloric demand. This goal is achieved by continually boosting crop and animal yields, increasing scales of economy, and reducing production costs (Busch 2005). Starting in the Industrial Revolution in Europe and the United States, agricultural scientists and engineers, wealthy farmers, companies, and government agencies developed numerous technologies to allow farmers to intensify their production, reduce labor, and control nature (Mazoyer and Roudart 2006). Over the twentieth century, successive generations of new technologies, from barbed wire and tractors, pesticides and fertilizers, to hybrid seeds and genetically modified crops, served the goal of expanding food surpluses. Particularly in the United States and Europe, government policies, agricultural research systems, farming landscapes, and industrial food chains co-evolved around providing these surpluses. Supermarkets, food-processing firms, and distribution networks displaced farmer markets, local mills and abattoirs, and village stores. Such "productivist" forms of agriculture spread globally, to the point that China, Brazil, and other developing countries are now copying the meat and grain production practices of the United States (e.g., Schneider and Sharma 2014).

The dominance of productivist agricultural systems raises fundamental questions. Why does industrial farming hold greater legitimacy than traditional systems or alternatives such as organic agriculture? Why do companies and governments turn to technological solutions to repair agriculture's sustainability problems? How do scientists come to wield greater power than peasant farmers?

Since the late 1970s, agri-food studies and the social studies of agriculture have matured as an interdisciplinary field that connects agriculture and food to social structures and dynamics. These studies have arisen as a response to growing interest in the problems of industrial agriculture and international trade in food. Scholars have written on topics spanning food histories, producer-consumer relations, commodity chains research, and land politics. They have dealt with agrarian identities, farmer knowledge and practices, and (re)production of food as livelihood, political economy, worldview, and memory.[3] Many scholars have used STS concepts and methods—from boundary work and epistemic politics to actor-network theory and controversy studies—to enrich their agri-food analyses. As a consequence, scholars have gained new facility in unpacking how seemingly natural agricultural landscapes and seemingly inevitable technological innovations reflect human agency and politics. They are better able to trace how changes in knowledge underlie changes in industrial practices and supply chains. Reciprocally, studies of genetically modified (GM) crops and food-related regulatory science have proven especially important as core domains of STS research, generating significant insights into the politics of expertise, public understanding of science, and cross-comparative differences in regulation and politics of risk that are now widely applied across the field (see e.g., Jasanoff 2005; Kinchy 2012; Levidow and Carr 2009; Wynne 2001). Table 32.1 summarizes the major themes, ideas, and sites in STS scholarship on agriculture.

Table 32.1
Overview of Agricultural STS Themes, Sites, and Ideas*

	Established	Emerging
Major STS themes	Green revolution technologies Governance of food safety risks (e.g., BSE; more recently, leafy greens) Pesticide regulation The changing nature of public science in the biotechnology era Public understanding of GMOs, especially on a cross-national basis Standards for use in making foods and setting eco-labels Development of industrial agriculture technologies and organisms	Agrobiodiversity Seeds and IP Farmer knowledge politics Science in policy making aimed at markets and eaters
Key sites of STS work	Regulatory agencies Governments Agricultural departments Universities (especially land-grant universities in the United States) International S&T networks and institutions (e.g., CGIAR)	Food supply chains Food companies Farms Extension field days Social movements (e.g., the MST in Brazil)
Key ideas in STS		
	Trust and deference to expertise Constructions of risk and risk society Lay/expert knowledge Boundary work around S&T Credibility of knowledge used in regulatory processes	Technological determinism Standardization and classification Local/indigenous knowledge Disciplining of actors through surveillance Embodied knowledge Community-based agrobiodiversity activities

*We composed the table based on our collective reviews and knowledge of the STS and agri-food literatures. By "emerging," we mean that a small but substantial amount of STS work has already been done.

Nonetheless, STS scholarship has not necessarily developed a synthesis of the human, cognitive, material, and structural patterns that agricultural systems contain. In this light, we suggest that using "co-production" as a storytelling idiom can help clarify how contemporary societies build agricultural systems through processes of knowledge-making and material work (Jasanoff and Wynne 1998). Many strands of co-production exist in the STS literature on agriculture, reflecting the field's diverse constructivisms. For example, "envirotech" scholars bridging environmental history and history of technology reject traditional views of technology driving deterministic impacts on plants and animals (e.g., Gorman and Mendelsohn 2011; Russell 2001; Vileisis 2011). Instead, these scholars trace (1) how agricultural technologies co-evolve with spatial landscapes and industrial systems and (2) how numerous organisms form interdependent relations with productive systems to the extent they can be seen as technologies in their own right. Russell et al. (2011) contend that the Industrial Revolution in Britain depended on workers fed by imported U.S. wheat, thereby co-producing agrarian transformation via more intensive farming and new shipping infrastructure.

We are particularly interested in how and why knowledge-making is incorporated into *institutions and practices of political economy making and governance*, and in reverse the influence of these practices on the making and use of knowledge (Jasanoff 2004). Scientific knowledge and political/legal/economic order are co-produced at multiple stages in their joint evolution, from legitimating findings in agricultural stations, to developing technologies based on this science, to creating legal and bureaucratic regimes to manage the technological applications. Ideas and practices, then, can reshape physical landscapes and living forms, as much as they can remold social norms and legal and political institutions. Simultaneously, these changes can loop back to change the terms in which people think about themselves and their place in the world (Jasanoff 2004).

The modern chicken exemplifies how agricultural organisms have been remodeled to suit the demands of mass production and consumption (Boyd 2001; Galusky 2010; Squier 2010). Chicken meat was once marginal in the U.S. diet. In 1948, a supermarket pioneer, A&P, and the USDA began running a recurrent competition to create the "Chicken of Tomorrow." They enlisted thousands of farmers to compete to breed "superior meat-type chickens," with the goals of achieving high feed-to-weight conversion and attracting consumers. Over the next fifty years, breeding programs supported by land-grant institutions across the United States created larger birds with more white, breast meat. The discovery of vitamin D enabled confinement rearing, while breakthroughs in antibiotics and hormones brought animal nutrition science and the pharmaceutical industry into a network of public and private broiler production interests. Increasingly consolidated "integrators," whose contract farming systems took hold around confinement chicken rearing in the rural South, formed a lynchpin of this network. Reengineering the modern bird, in sum, transformed labor organization, research and development, government policies, and consumer markets, not only for chicken but also for livestock agriculture more generally. In turn, the reciprocal pressures of consumer demand, favorable laws, and further science produced the modern bird: in 1957 broiler chickens weighed 900 grams when they were 56 days old; by 2005 they had swelled to 4.2 kilograms.[4]

Unpacking Industrial Agriculture

As the story of the chicken transformed suggests, STS scholars are particularly interested in exploring the relationships between agriculture and technoscience. How, for example, does scientific and technological knowledge influence the emergence of industrial agriculture? Why and how, in turn, does the legitimacy of industrial agriculture depend on science? One way to begin answering these questions is to examine how parts of industrial food systems developed. Much of this history pertains to the United States: it was in the U.S. South and Midwest, as well as in California, that many innovations first appeared and matured. These innovations were progressively exported to other regions in the United States, to other industrial countries, and across the world via the green revolution. Historians such as Mintz (1985), Cronon (1991), Stoll (1998), and Fitzgerald (2003) have sketched the broad historical patterns of industrializing agriculture. STS scholars have built on such histories to do their own tracing of technologies and sciences. These collective works suggest several key co-production pathways (Jasanoff 2004). For example, many farmers gained new social status as technologically advanced growers (identity making). Government officials subsidized industrial farming or passed laws to regulate food safety (institution making). Agricultural managers and extension scientists used scientific efficiency and economic cheapness to justify growth (discourse making). These pathways joined people, organisms, technologies, and supply chains into stable forms that now appear indispensable. Yet many people, ecosystems, and organisms lost as a result: workers and animals were exploited; consumers began eating unhealthy diets with higher levels of carbohydrates, sugars, and fats; and small farmers and wild bees faced extinction pressures.

In this section, we trace the emergence of productivism in three key arenas: the transformation of the farm into a factory, the rise of agricultural research institutions as core players in making industrial farms and foods (from an era in which agricultural research was not particularly significant), and the wider industrialization of agricultural food systems through the growth of manufacturing chains, processed foods, and supermarkets.

Conceiving the Factory Farm

Colonial sugarcane plantations in the U.S. South, the Caribbean, and Latin America pioneered many industrial techniques, such as monoculture crops and large-scale processing (Mintz 1985). Banana, cotton, rubber, coffee, and cacao plantations spawned some early multinational enterprises. Yet it was in the Midwest and California that industrialization penetrated more deeply into biological cycles. Cronon (1991) narrated the genesis of many industrial food practices in Chicago's metropolis from the 1850s onward. Initially, settlers turned the Midwest prairie into grain and livestock farms but remained small-scale producers for local towns. As the meat and grain industries used the railway to source and distribute foods across larger territories and adopted mass production techniques, growers were integrated into new supply chains. With the advent of more powerful grain traders, standards for measuring foods in storage and processing systems were needed to enable exchange. Physical wheat in sacks metamorphosed into abstract commodities in grain elevators. New discourses of efficiency and scales of economy were co-produced with technological innovations such as machines for dissecting cattle (the "disassembly line") and refrigerating meat in railway carriages.

It took decades before many farmers came to reimagine their farms as industrial factories instead of ecologically diverse landscapes. Fitzgerald (2003) explores how the industrial farm became more material during the 1920s, when machinery and electrical technologies were increasingly reliable and affordable. Many farmers converted to industrial methods because of cultural, economic, and sociotechnical pressures. While some small farmers preserved their traditional practices, others expanded their holdings to repay debt and survive in the capitalist political economy. Larger farms could only be managed more readily (and economically) by using tractors, harvesters, and other technologies that reduced labor. These technologies encouraged monoculture cropping to facilitate planting, weeding, and harvesting. Fitzgerald describes the efforts of some farmers to escape their "ignorant" social status by acquiring the identity of profitable business managers. As new agricultural sciences entered land-grant universities, the U.S. Department of Agriculture, and agribusiness firms, farmers often deferred to extension scientists and marketing agents, whose "superior" knowledge was articulated in scientific language. Discourses of "factory farms," in turn, were reflective of larger political economies: They began circulating in the hinterland just at a time when Fordism flourished. While mass production and assembly lines transformed the culture and organization of manufacturing, rural systems followed suit. Farm managers were coaxed into cultures of bookkeeping and quantifying yield/revenue. Equally important, early agribusiness companies nurtured cultures of using industrial inputs and specializing in high-yield crops and livestock, sending out armies of marketing agents to do demonstrations.

Nonetheless, as Fitzgerald (2003), Henke (2008), Busch (2005), and others show, productivism encountered many resistances. Many American farmers defied new-fangled machines for decades, stirred by their conservative philosophies and agrarian identities. Kline (2000) discusses how farmers selectively used technologies such as electricity, automobiles, and telephones—and developed their own conventions of use, reflecting

their traditions of local experimentation. They used telephones communally, not individually. Car engines were used to drive farm equipment. Henke (2008) highlights ongoing debates in land-grant universities and cooperative extension systems about their role in advancing agriculture. Who were the farmers they were serving? What outcomes should they pursue? Even now, productivist regimes must be "constantly remade in innumerable, localized engagements" (Jasanoff 2004, 43) as disparate participants perform their social roles.

Creating the Agricultural Knowledge State

In the early twentieth century, land-grant universities established cooperative extension programs as a particularly important site in which agriculture knowledge and material systems were co-produced (Busch and Lacy 1983; Henke 2008). Progressive Era progenitors of extension drew on a study of rural America commissioned by President Theodore Roosevelt, which contended that small farmers were obsolete. To improve rural lives, they suggested, technical advisers should aid growers in making their farms larger and more technologically sophisticated. Following the Lever-Smith Act in 1914, the University of California built a large network of extension agents to translate agricultural science knowledge into practical forms that farmers could quickly adopt. Extension agents worked assiduously to spread productivist practices and assumptions. Henke (2008) traces how advisers helped develop discourses of efficiency and expertise that not only reinforced their identity as experts but remolded farmer identities. One crucial mode of knowledge-making was the "field trial." Farmers rejected new techniques as unsuitable for their local soil, water, and climate conditions. Accordingly, advisers developed a procedure of conducting field trials that simultaneously served as scientific experiments and as processes for enlisting farmers into new practices they were wary of. Such trials raised familiar STS questions of how to verify and represent the resulting experimental knowledge (Henke 2008).

Government agencies, such as departments of agriculture, regulatory bodies, and legislatures, also helped expand productivism through their discourses and institution building. As repositories of knowledge and power, they recognized knowledge as authoritative, conferred identities on people, and perpetuated tacit models of human agency through their bureaucratic procedures (Jasanoff 2004). Following—and reinforcing—discourses of rural improvement and poverty, Congress was instrumental in creating land-grant universities, cooperative extension, and agricultural research programs. In response to Dust Bowl and Depression era crises, the Roosevelt administration invented policies ranging from food stamps and food reserves to soil conservation programs and short-lived support for farmer-led learning networks. It also invested sizably in public agricultural science at land-grant universities and the U.S. Department of Agriculture (Kloppenburg 1988). Research within these facilities had far-reaching consequences for remaking the structure and function of agri-food systems. Seed hybridization, introduced in the 1930s, separated farmers from reproduction of their own planting material, permitting private corporations to benefit from marketing seed. The advent of hybrid corn also induced a pivotal agrarian identity shift. The process of creating hybrid corn was simple, but the number of crosses and the record keeping required to keep track of them excluded most farmers from the process (Fitzgerald 1993). Seeds were only the proverbial tip of the agri-food iceberg, as they fostered changes to machinery, chemical inputs, and feed-meat complexes that transformed agriculture.

Following World War II, the federal government endorsed large-scale industrial production through its research directions and policies (especially through the "farm bill"). Congress enacted laws that (1) created a federal research funding mechanism, (2) developed an international food aid program, and (3) established the basis of price floors and countercyclical payments to support commodity crops like corn and wheat. Farmers were encouraged to grow more food, reducing its cost and creating a surplus that could be exported overseas as well as used in animal feed and processed foods. Commodity subsidies were made contingent on farmers expressing specific identities—large-scale, monoculture, technologically advanced. USDA evolved into a particularly powerful government institution, whose leaders influenced imaginaries of American agriculture for decades (Busch and Lacy 1983; Busch et al. 1991). As Hamilton (2014) shows, USDA officials conflated technological progress with the growth of "agribusiness," a term first coined in 1955. Ezra Benson, Secretary of Agriculture, avowed: "Inefficiency should not be subsidized in agriculture or any other segment of our economy" (cited in Hamilton 2014, 565). Carbohydrates and sugars therefore became available in unprecedented quantities for companies to use in then-novel processed products.

The productivist worldview spread widely around the planet when U.S. institutions and their international counterparts—including the U.S. government, the Rockefeller Foundation, the World Bank, and many developing country governments—forged a network of research institutes that later became the Consultative Group for International Agricultural Research (CGIAR). As the first generation of agriculture-focused STS scholars noted, central to these alliances was a process of circulating scientific discourses through institutions and actor networks, particularly in developing countries, although this circulation was largely hidden behind a more public discourse of fostering a "green revolution" around the world. Educational institutions trained bureaucrats and technical extension experts in productivist tenets; government departments

then designed favorable policies, which foundations reinforced through their project funding (Fitzgerald 1986; Jennings 1988). Visible evidence of the green revolution included the growth and diffusion of high-yielding varieties, harvesting machines, pesticides, chemical fertilizers, and irrigation technologies. Yet, it was the transmission of knowledge, from the 1940s through the 1980s, that helped change the character of agri-food systems throughout the world, such as Mexico, Brazil, India, the Philippines, and the Peruvian Andes (e.g., Shepherd 2005). Within programs built around the needs of larger-scale, wealthier farmers, cadres of technical experts extended the theory, practice, and input commodities of industrial agriculture. These experts, in turn, persuaded farmers to adopt intensification techniques. Smith (2009) notes that the process was hardly linear; rice research varied across time according to how the Rockefeller Foundation, CGIAR's International Rice Research Institute, and other actors framed agricultural and development problems.

Building Food Infrastructures

Downstream from the farm, an array of supply chains, processing plants, food science laboratories, and supermarkets have co-evolved as a vast system that now reliably delivers food to many millions of people. Largely invisible to consumers, this infrastructure transforms crops and animals, mass-grown in industrial farms, into standardized packaged products designed to travel worldwide and to appeal to human palates. "Foods produced on larger scales must be predictable in quality, quantity, content, safety, cost, flavor, texture and return on investment" (Jauho et al. 2014). To achieve this stability, food infrastructures produce and use S&T knowledge in the many steps between farm and dinner table. They are beneficiaries and advocates of the industrial farming model; they also influence the preferences of consumers toward favoring high-calorie, high-fat and high-carbohydrate diets (Otter 2015).

Over the decades, supply chain actors have changed markedly in their structural power and ability to mobilize S&T to produce foods. From the 1920s to 1960s, U.S. and European companies like Bayer and Dow gained ascendancy by manufacturing essential inputs into farming: Using a postwar surplus of chemicals, they remade norms of input use, entrenching fossil fuels at the heart of modern agriculture. United Fruit Company and Dole—the first multinational food firms—helped popularize the concept of monoculture cropping in the 1920s in the form of banana and other tropical fruits. Despite growing public and scientific awareness of pesticide problems, new pesticides entered the market and spraying rates escalated (e.g., Russell 2001). Agrarian sociologists noted that farmers became captive to the technological treadmill, forced to invest in costly technologies such as machinery, hybrid seeds, and fertilizer to keep up with the ever-growing demands for larger scales of economy (Cochrane 1979).

By the 1960s and 1970s, food processors such as Unilever, Nestle, Heinz, and General Foods were more commanding. A plethora of processed foods appeared, creating new demand for cheap, abundant crops and livestock. Food science was widely used to manufacture these foods: ingredients and process conditions were quantified precisely to enable more uniform outputs (Otter 2015). Ready-made or frozen meals gained popularity during the 1950s as eating identities and discourses began to favor "time-poor" convenience and "modern" diets featuring foods from packages, not in fresh form. In the United States, Cold War mentalities and atomic-age science were instrumental in these developments, engendering Jell-O molds and foods that were "bound" in mayonnaise or "imprisoned" in pepper rings (Adler 2015).

Simultaneously, branded product differentiation intensified, as companies pursued more specific, lucrative markets (Hamilton 2003). This explosion of processed products called for delicate manufacturer tinkering with package design, ingredients, preparation techniques, and compositions to work reliably and provide consistent, palatable tastes (Moss 2013; Otter 2015). Processing changes the nutrients, textures, and flavors of vegetables. Consequently, sugars, salts, fats, and additives such as colors, preservatives, and stabilizers were added to foods to manipulate consumer desires and increase durability. Fractionation technologies borrowed from the chemical industry brought about another sea change, enabling whole foods to be broken down into interchangeable food parts (Goodman, Sorj, and Wilkinson 1987). Agrarian products such as milk transformed into casein, lecithin, whey, and milk protein isolate, while corn and soy brought high-fructose corn syrup and partly hydrogenated oils into the constitution of "fabricated foods." As a result, anonymous food science laboratories quietly obtained more authority within agribusiness, since their specifications could profoundly reshape farming or processing practices. Mass media and advertising using consumer research enabled the remaking of eater identities around particular food discourses (e.g., Mudry 2009). Such branding has since undergone a pendulum swing, away from Jell-O molds and toward all things "natural." Nonetheless, convenience foods have continued to multiply in their seeming diversity and attractions.

In the 1980s and 1990s, food companies began restructuring supply chains to meet low-cost business models (Belasco and Horowitz 2011). Two supply-chain types grew dominant: supermarket chains and fast-food chains, which both benefited from scientific and technological innovations to grease flows of food from farm to dinner table (or car seat). Supermarkets first appeared in Britain around 1912, and fast-food chains such as McDonald's proliferated from the 1950s onward. STS scholars are fruitfully

examining uses of S&T knowledge in aiding companies to design outlets, regulate supply chains, and sell food. One example is Hamilton's (2008) history of how trucking facilitated the growth of regional and nationwide retail distribution networks. Fast-food chains pioneered many distribution techniques and means of controlling agricultural production practices (Hockenberry 2014). Early consumer psychology enabled supermarkets to plan their stores to steer consumers toward buying processed foods through layout concepts such as the "central store" or the shelves that showcase such foods (Powell 2014). The advent of universal product codes (UPC), barcodes, and electronic data interchange protocols between 1973 and 1980 eventually enabled retailers like Walmart and Safeway to "industrialize" their logistics and intensify "lowest-cost" discourses aimed at consumers (Hockenberry 2014). Advanced electronics and logistics have since empowered retailers to take much greater control over supply chains.

Underlying these developments is the making and use of standards in food systems. Historically, standardization has enabled industrialization: it permits things to be interchanged and reduces variable human judgment. Standard cropping practices enable mechanized harvesting, standardized factories churn out identically packaged foods, and standard nutrition labels enable consumers to see if milk is low-fat. But standards also entail setting expectations and norms for actors along supply chains. What should a food look and taste like? What foods can be sold on the market? What counts as better-quality food? How should food be produced? STS scholars have pondered these questions at length (e.g., Busch 2011; Busch and Bingen 2006; Callon, Méadel, and Rabeharisoa 2002).

Standards only appeared in food systems during the 1930s. Now, every part of food production and consumption is subject to numerous standards from private, nongovernmental, and state authorities. Busch (2011) explores how different types of standards can "design" food. For example, filters are used to decide whether food has passed safety requirements; they serve as rejections of the unacceptable. Multitiered filters can decide whether a grain is wheat and further sort it into soft, hard, or durum, determining its use for processing into specific products. Standards have the power to reconstruct nature to make it conform to human expectations—for example, by pressuring wheat breeders to change crop biology according to grain classifications. Standards are commonly based on scientific knowledge and coupled with technologies to measure compliance. Standards are not immutable or static: they are continually renegotiated as politics, knowledge, behavior, and ecological conditions change.

Busch et al. (2006) further suggest that standards convey shared knowledge and assumptions among disparate actor groups who may be widely distributed worldwide in modern supply chains: "Standards permit persons with little knowledge of each other's practices, and even less of each other's thoughts, to coordinate their action" (ibid., 138). Crucially, as Busch and Tanaka (1996) found for canola oil in Canada, actors in each part of the supply chain have diverging opinions about ideal oil characteristics. Other STS studies have looked at the actor-network underlying the development of standards for soybeans in Brazil (De Sousa and Busch 1998). Standards, then, are a means to discipline these disparate, competing interpretations into agreements that ensure product consistency. Even so, actors can still construe standards differently, thus calling for external monitoring and verification through audits. Shrimp farmers in Indonesia understood "sustainable" practices very differently than a certifying body in Europe (Konefal and Hatanaka 2011). Credibility in these negotiations is key. Like other facets of industrial agriculture, agri-food standards gain authority through appearing technically objective and neutral; they gain legitimacy through being represented as scientific. Nonetheless, as Busch (2011) demonstrates, standards embody corporate, technical expert, or government choices, thus reinforcing pervasive power asymmetries across modern food systems. Who makes standards, and with what procedures? These remain important questions.

Evolving Challenges and Transformations to Productivist Systems

Productivist agricultural systems remain dominant in many parts of the world. Yet, new forms of agricultural knowledge and production are also increasingly prevalent. Over the past decade, new generations of STS researchers studying agriculture have diversified their topics, sites, geography, and methods considerably, bringing these new countercurrents to productivism into focus. This development reflects the broader attention of the field not only to how dominant sociotechnical systems come to be but also to how they are challenged. In particular, scholars are investigating (1) the (re)emergence of alternative systems such as organic agriculture, agroecology, and agrobiodiversity, and (2) how agricultural industries are responding to sustainability challenges by modifying productivist systems. Co-production helps scholars and practitioners understand the ways in which productivist agriculture systems transform sustainability into technological solutions. Co-production also suggests that developing alternative forms of science, policy, and practice could eventually change the epistemic underpinnings of agriculture with the outcome of marginalizing productivism.

Participatory Expertise and Legitimating Sustainable Alternatives

Exciting STS research shows that not only are alternative systems emerging, agriculture across the planet has an historical foundation of diverse agrarian practices and

foodway traditions on which to build. The meanings of technology and science are not predetermined by industrial agricultural norms (Kloppenburg 1991). Anthropologists and agricultural historians have investigated knowledge production through the use of indigenous (or local scale) technologies including fiber baskets, living fences, livestock breeding, fishing traps, stone mills, storage cisterns, and pasture formation practices such as burning (e.g., Shah 2008). Such technologies predated industrialization and have continued to evolve with experimentation and learning. These technologies are co-produced with social institutions such as village irrigation cooperatives and with agricultural identities like *campesinos* or yeomen.

The fundamental place of farmer-made knowledge in agriculture is also garnering more recognition. Researchers have consistently shown that farmers, gardeners, and artisan food processors throughout the planet hold extensive practical skill and tacit knowledge as part of their cultural heritages. Indeed, ancient farmers were the first scientists as they built techniques based on empirical observations of weather and pest incidence and identified particular plants they wanted to retain (Busch et al. 1991). Such knowledge underlies the mutually constitutive relationships between ecologies and agriculture. Graddy-Lovelace (2013, 2014), Montenegro (2015), Carney (2009), and other political ecology/STS scholars are extending the work of earlier scholars in geography (e.g., Carl Sauer) in showing that farmers co-produce natural and cultural landscapes through their agroecological/traditional practices. In systems from vertical archipelagos in the Peruvian Andes to the rice/fish agriculture of China, farmers continue to devise clever technologies and management institutions that amount to biocultural knowledge systems. They have bred plants, livestock, and fish to live in agrobiodiverse complexes that provide life-sustaining ecological resources from soil fertility to pollination. Seeds are a particularly significant component; farming communities have developed many in situ seed conservation, saving, and sharing practices. In this, farmer knowledge and science exceeds modernist agricultural expertise in allowing this diversity to unfold and continuously adapt.

Within institutional contexts for agriculture research and education, however, farmer and local knowledges remain largely black-boxed. Warner (2007, 2008) critiques much conventional agricultural extension for imposing a divide between technical experts and laypeople and for relying on a transfer model in which farmers are passive, willing recipients of information rather than knowledge generators. This model has structured agricultural science institutions and defined the social roles that farmers play. By contrast, sustainable food movements worldwide increasingly emphasize participatory knowledge-making in a new politics of agricultural expertise. Instead of ceding scientific and technical capacity to those who are professionally trained and certified, organic food activists, biodynamic vintners, worm-composting gardeners, lentil growers, and artisanal fermented-food makers are claiming authority and legitimacy to make knowledge on an equal epistemic footing with agricultural scientists. Their activism and communities of practice pose new (yet familiar) STS questions: Who are experts in sustainable food? What criteria and processes are used to recognize and verify expertise? How do experts relate to those who are considered less expert?

Organic agriculture has blossomed since the 1980s. STS scholars have helped us understand why organic food has gradually grown more authoritative vis-à-vis industrial food. Gieryn (1999) explores the early struggles of organic farming. Much composting theory came from a developing world region: Indore, India, where soil scientist Albert Howard ran a field station for twenty years. There he blended indigenous knowledge and scientific tests. British agricultural scientists and government officials, by contrast, rejected such fluidity; they drew cognitive boundaries between "scientific" industrial and "unscientific" alternative practices. Accordingly, they disdained organic methods as primitive farming. Through early international networks of scientific expertise, such attitudes percolated throughout the world, affecting colonial and then postcolonial authorities' views of indigenous practices. They also entered U.S. agricultural culture. Carolan (2006b) notes that in 1951 politicians and scientists characterized J. I. Rodale—an American organic pioneer—as irrational during a congressional hearing on agriculture's future. In 1971 the U.S. Secretary of Agriculture Earl Butz said, "We can go back to organic farming if we must—we know how to do it. However, before we move in that direction, someone must decide which 50 million of our people will starve" (in Obach 2015, 35). Such boundary work had the effect of stifling research and government support in organic farming for decades.

Since the 1980s, however, organic agriculture has become more broadly accepted in industrial and developing countries. Much of its legitimacy stems from communities of practice coopting the prestige and power of science. As Obach (2015) notes, in the U.S. context, scientists and universities devoted more attention to organic agriculture in the mid-1980s as USDA and Congress inserted research-funding clauses into the farm bill in response to lobbying pressures from organic farmers. The Rodale Institute commissioned the first scientific appraisals and built its own long-term research station. This is an example of how co-production processes can "ratchet up" the legitimacy of alternative agricultures. Warner (2007, 2008) argues that organic farming has gained greater credibility because many proponents are embracing the language, experimental practices, and standards of proof prevalent in conventional agricultural science. Adopting quantification and scientific imagery confers authority on alternatives to conventional practice. Studying agroecological partnerships in California, Warner discusses how growers and scientists can be convinced that "organic farming works" through quantifying the amount of pesticides reduced. Similarly, Carolan (2006a, 2008) argues that organic agriculture benefits from protagonists aligning with like-minded university-based institutes and researchers and thereby acquiring scientific standing. Ingram (2007) notes that U.S. alternative agricultural movements rely on "immutable mobiles" such as reports, newsletters, and research findings, as well as on expert communities, to circulate knowledge in what Latour calls a capillary societal network (Latour 1999). The organic movement in particular has successfully created a discourse of "healthy soils leads to healthy bodies" over seventy years. With growing scientific, policy, and market support, Chinese, Indian, and Latin American scientists and governments are treating organic food with greater respect.

One of the core elements of many alternative agricultural movements is the argument that communities of living organisms—and the communities of agricultural knowledge and practice that work with them—lie at the heart of all agriculture. Brice (2014a) examines the practices of winemakers in South Australia in deciding when to harvest grapes. Using ethnographic analysis, he demonstrates that vintners build and use a sophisticated practical sense that drives the coordination of labor, trucks, and processing plants around the unpredictable ripening of grapes. A critical period of harvesting grapes exists: it must be done at the right time and must be finished quickly. Technical biochemical tests of grape sugar content helps vintners determine when to harvest, but they also rely on their field observations of weather and season conditions and of grape state (taste, color, sound). Brice underscores the agency of plants in shaping the behavior of farmers, who learn to monitor phenomena like soil texture, rainfall, and pest activity. Similarly, Grasseni (2005) studies the "skilled vision" of dairy cow farmers in northern Italy when they learn to identify their own cattle and choose promising individuals to breed. Expert breeder-farmers integrate sight, touch, and smell in appraising cattle, while referring to an ensemble of materials such as blueprints of the ideal cow and cattle registers. The ability to envisage human-plant/animal cohabitation is often stigmatized by modern technical experts as "preindustrial awareness of time," properly replaced by technological and calendar time. Yet this ability reveals the persistence of other ways of time reckoning that rely on farmer knowledge and observations that no mechanization can provide.

Particularly intriguing in this regard is scholarship exploring the persistence of life within apparently industrialized processes—and pointing to the unsuspected (by scholars and policy makers) importance of interspecies relations in growing food. Far from human agents controlling the process, farmers must work with diverse species (Carlisle 2015), from cows to fungi and from lentil plants to insects. Brice (2014b) ponders an example of wine that vintners reluctantly pasteurize to remove an enzyme remaining inside grapes from fungal infection but that destroys ongoing microbial community interactions that give wine its aroma and taste, which diminishes the wine's economic value. Similarly, as Paxson (2008) notes, many cheese makers and drinkers of raw milk complain that pasteurization results in "dead" milk where "healthy" microbes no longer can join the human microbiome. Innovative work on vermicomposting also suggests that urban gardeners are generating their own knowledge and expertise around soil amendments (Abrahamsson and Bertoni 2014). Many environmental conditions affect worm colonies in compost bins, so the success of vermicomposting depends on developing attunement to worm needs, namely, "learning to speak worm" (ibid., 134). Gardeners work with worms and microbes to create metabolic communities that transform food waste into fertilizer. Compost politics exist as well: "The worlds of earthworms, their external and internal digestive processes, the mites, the nematodes, the decomposing kitchen waste, [and] the vermicomposter" (ibid., 143) must be brought together. The idea of metabolic communities inside foods, soil-replenishing methods, and processing technologies shows different co-production processes at play that offer ways to think about agriculture differently.

STS researchers studying agroecology in Latin America take this scholarship a crucial step further, highlighting the political, institutional, and civic dimensions of agricultural communities of practice by showing how social movements can be co-produced with new forms of science and technology. Agroecology is "the application of ecological concepts and principles to the design and management of sustainable food systems" (Gliessman 2015, 18). For example, farmers can benefit from cultivating interactions between plants and insects so that pests are dispelled; they can intercrop plants to provide pollinator habitat, nitrogen fixation, and overyielding effects. Unique among alternative movements that challenge productivism, agroecology proponents assert that science, movement, and practice are already entwined in a more advanced form of agriculture (Méndez, Bacon, and Cohen 2013). Although organic agriculture has begun to gain credibility in scientific institutions, it remains the case that organic has succeeded more in marketing/retail and certification/labeling than in achieving a coherent set of scientific principles and practices (Obach 2015). Agroecology, by contrast, is an advanced science in its own right, based heavily on complex systems science and ecology. These forms of agricultural science pivot sharply away from technoscientific, reductionist approaches, characterizing agricultural systems in terms of nonlinear environmental change, complex biotic and abiotic interactions, and diversity across ecological, spatial, and temporal scales (e.g., Gliessman 2015). Importantly for STS, agroecologists approach this research with a step change in scientific praxis: for

many proponents, agroecology is transdisciplinary work that challenges the epistemic boundaries of what science is and who participates. Vandermeer and Perfecto (2013) have described the synergies of Western science and indigenous knowledge in agroecology. The former is broad but shallow knowledge, the latter is deep, but narrow; both are complex traditions of equal, though differentiated, legitimacy.

In studying the *Campesino a Campesino* and Landless Workers movements in countries such as Cuba, Brazil, and Mexico, agroecology has much to offer STS in the way of emerging trends in the remaking of scientific communities and practices. These movements not only create space in which farmers can question industrial methods but make science explicitly political and civic. They are new sites for co-producing agrarian citizenship (Wittman 2009), educational processes, and agricultural science. Holt-Giménez (2006) details agroecological pedagogy in depth: he shows that farmer schools constitute sites of science-in-the-field. In these contexts, farmers are more likely to trust in, and learn from, their cultural peers than from technical advisers. Farmer schools devise their own experiments, make tools for visualizing problems, and test conventions. Participating in their own experiments can demonstrate to farmers that agroecology works. In effect, they are turned into witnesses who can attest to the merits of sustainable farming. Knowledge is treated as always politically and socially embedded—intuiting the constructivist moorings of STS.

Studying agroecology, however, underscores the significant tensions that exist regarding "experts" in social movements, particularly in developing countries. Delgado (2008, 2010) investigates knowledge production inside social movements, using the case of the Movimento Sem Terra (MST) in Brazil. She criticizes the Western-centric biases built into STS notions of expertise, such as assuming a sharp demarcation between laypeople and technical experts. Movimento dos Trabalhadores Sem Terra began in the 1970s as a landless laborer struggle for land access and grew into a large, dispersed movement with many communities across the country. Years of internal debate led to the movement endorsing agroecology. Delgado shows that agroecology has differing meanings and politics inside the Movimento dos Trabalhadores Sem Terra. The movement has built its own network of agricultural technicians and farming schools in rivalry with a state-sponsored system. Thus, it has gained the power to co-produce knowledge and institutions. For older technicians, agroecology is revolutionary politics to liberate farmers from Cartesian thought. For younger technicians, agroecology rethinks human-nature relations, through valuing indigenous wisdom, and creating a *dialogo de saberes* (dialogue of knowledges). Many MST farmers use conventional farming methods including pesticides and monocultures. Technicians must wrestle with how to persuade these laypeople to change their ways. Some technicians retain an information-deficit model and assume that farmers are ignorant and must be dissuaded from productivism. In many cases, technicians reproduce expert-lay distinctions, categorizing farmers without their say. Nonetheless, many farmers reject their categorization and insist on having their indigenous knowledge recognized.

Making Productivism More Sustainable?

Starting in the 1970s civil society actors, scientists, farmers, and governments increasingly questioned industrial agriculture's ecological and social costs, ranging from feedlot pollution and fertilizer runoff to animal suffering and worker abuses (e.g., Thompson 1995). In Europe, more stringent regulations and agri-conservation policies materialized, while in the United States, market pressures prevailed due to weak government intervention. Civil society opposition to industrial food, however, is appearing worldwide. Concerns about exposure to pesticide residues and nutrient deficiencies motivated growing consumer demand for organic food in industrialized countries from Italy to Japan. In China, many consumers now fear contaminated domestic milk and meat and seek safer imports from Australia, New Zealand, and Europe (Tracy 2010). In many countries of Africa, farmers and eaters are reluctant to embrace GM crops, which they see as being foisted on them by powerful companies and their own governments (e.g., Mwale 2006). In response, the agricultural industry has experimented with different ways to capture value from "sustainability."

For decades, STS scholars have helped to analyze disputes, at once ontological and epistemic, over what is and is not sustainable agriculture. Recently, for example, some scholars have taken interest in the processes and politics of measuring sustainability in supply chains. Wal-Mart, Unilever, and most multinational firms now buttress their sustainability claims by establishing new institutions such as sustainability consortia and standards and metrics to push their suppliers into adopting greener practices. For example, Freidberg (2014, 2015) considers how life cycle assessments are now acquiring power to govern globally sourced foods. Life cycle assessment quantifies the environmental impacts of producing food, often sidelining salient political and social debates. Freidberg finds that corporations continue to be powerful producers of (selective) knowledge along supply chains. In their embryonic development, agri-food life cycle assessments are gaining greater authority through being objective and comprehensive. Yet they also embody negotiations within companies and across industry communities over what will count as sustainable food. Agri-food evaluations often exclude worker health and other labor impacts, thus discounting their importance. Inside large multinational corporations, workforces are typically distributed across many countries and different national cultures; they may vary in their views of what sustainability means

and whether it matters. Much political and cognitive work, therefore, must be done to make life cycle audits credible to these diverse audiences.

Other scholars are tracking new international calls for a "doubly green revolution"—a sustainable version of agricultural transformation in poor parts of the world that will better aid farmers in regions that ostensibly were previously untouched, such as Africa (Conway 1997). In 2009 the Royal Society in Britain published a prominent report that defined sustainable intensification as "agriculture in which yields are increased without adverse environmental impact and without the cultivation of more land." Sustainable intensification has quickly acquired cachet in guiding scientific research, philanthropy, and policy programs at national and global levels. Sustainable intensification is pointedly catholic in scope: genetically modified crops will be considered alongside agroecology. STS-inflected scholars (e.g., Kerr 2012) and environmental NGOs, however, criticize sustainable intensification as another salvo in industry's subtle efforts to disguise further intensification as sustainable. Sustainable intensification is discursively imbued with authority by being linked to what its proponents argue is the imperative of increasing global food production 70 percent to 100 percent by 2050 to feed a population of 9 billion people. However, Tomlinson (2013) has critically deconstructed this "feeding the world" claim by demonstrating its improvised origins in Food and Agricultural Organization policy statements and showing how numerous government and scientific actors have repeated it as though it were objective truth. Critics have also shown that investments in sustainable intensification appear to be geared toward biotechnology and industrial technologies. Sustainable intensification is being associated with climate-smart, precision, and eco-efficient agriculture practices. In precision agriculture, for example, industry is beginning to use drones, sensors, and GPS to economize irrigation, fertilizer, and planting strategies. Reflecting this new trend, in 2014 Monsanto bought a little-known company, Climate Corporation, to take control of its extensive database of U.S. field locations and climate conditions. Data-intensive forms of knowledge-making, in other words, are entering agriculture in gene banks and farm fields alike.

Food companies and researchers are also engaging in promissory, even evangelical, discourses surrounding envisioned technoscientific food futures: artificial meat, superfoods like açaí berry and einkorn grain, soylent meal replacements, probiotics, and other so-called functional foods. STS asks, Why is food such a key site for (especially American) experimentations with fantasies of the future? In large part, this is because industrial crops and livestock have become highly fungible—seen as capable of being manipulated into endless forms. Artificial meat is viewed as a solution to the many ethical, social, and environmental damages of meat production (Galusky 2014; Marcu et al. 2014). Researchers in Maastricht have worked for ten years to culture muscle cells in a scaffold and direct their growth into tissue through electrical stimulation and physical vibrations (Specter 2011). In October 2013 the first synthetic hamburger was eaten in London. Growing meat in vitro promises to alleviate the suffering of livestock as they are raced through feedlots to the slaughterhouse. Growing only muscle tissue obviates the energy squandered on growing other tissues such as bones and avoids the complications of tending livestock (Galusky 2014). Yet synthetic meat faces many challenges from high price to philosophical and aesthetic acceptance. Galusky argues that if humans start growing meat in vitro, they must provide biological inputs through technological interventions, thus becoming more dependent on machines. Artificial meat would uproot food production from its geographical, ecological, and social contexts. Producing meat in vitro, for example, ignores the role of animals in fertilizing diversified farms. In addition, artificial meat must succeed in winning consent from many reluctant participants across food systems. Such experiments are still nascent but indicate an important juncture. Will future food be sourced technologically or organically?

Still another industrial agriculture development is the beginning of a biobased economy. Goodman, Sorj, and Wilkinson (1987) forecast the "bioindustrialization" of agriculture: agribusiness would join chemical companies, biotechnology businesses, oil firms, and financial institutions to create new joint ventures crossing previously clearly bounded industry sectors. This prophecy has come true. Crops are increasingly being used not just for food and animal feed but also to make energy, fibers, and chemicals. As Borras et al. (2015) note, certain crops are now treated as fungible "flex crops." Since the early 2000s, biofuel production has grown in the United States and in developing countries from Brazil to Indonesia, partly because of government incentives to mitigate climate change (Levidow and Paul 2010). Similarly, biobased chemicals are materializing as a new agricultural output. Numerous companies—both giants and start-ups—are using corn, sugarcane, and cellulosic matter to produce chemicals. They are experimenting with fermentation and genetically modified organisms that can process raw materials or make the desired chemical. The biorefinery is developing as a factory that can transform crops into whatever outputs are desired or most profitable. Yet the multiple meanings of flexible crops are hardly settled (Borras et al. 2015). Farmed plants and trees often have multiple, though discrete, uses in traditional and indigenous agricultures. These specific uses are being erased as biotechnology models promise new fungible ones. Moreover, the future directions of flex crops are still malleable, as seen in switchgrass in the United States. In principle, switchgrass can be grown as part of diversified farms. In practice, researchers and companies are already trying to industrialize switchgrass by designing plantations, developing machines to plant and harvest the grass, devising agri-chemical protocols, and genetically modifying plants. In sum, the agricultural industry continues to devise technological adaptations but these are appearing at a time when societal scrutiny is more intense.

Toward Agriculture STS

We show that co-production idioms can help elucidate the often-obscure processes and pathways that have collectively built agricultural and food systems. The making of productivist regimes is founded on 150 years of the co-production of knowledges, technologies, institutions, cultures, organisms, humans, and markets. Paradoxically, the strength of the industrial system stems, in part, from its own heterogeneity. Industrial food is not one single beast but develops in multidirectional, locally and spatially variable ways while following an underlying, recurrent logic of productivism. Co-production processes have imbued industrial food with a strong legitimacy grounded in science and technology. Industrial food is credible because it appears efficient and inevitable. Yet the system depends on the massive day-to-day labor of workers across different sectors of the agri-food system. Much of the power of industrial food is due to its technological momentum and deeply entrenched structures and processes that reinforce one another, thereby locking human societies into productivist methods. We see this tendency in the attempts of productivist agricultures to become more sustainable, using technological fixes such as artificial meat, flex crops, and sustainable intensification. STS scholars can continue critically unpacking how and why productivist systems have been assembled, what they mean for human health and human rights, and the politics of how people authorize these systems with their beliefs and behavior.

We also want to highlight agri-food systems not merely as productive but as reproductive. Regenerating and renewing diversity can be helpfully illuminated in terms of co-productive ecological and social processes. As STS scholars are helping to reveal, agricultural systems worldwide still harbor substantial diversity—often in the forms of agrobiodiversity, heterogeneous landscapes, farmer and food-maker knowledge, customary laws, and inherited foodways. Alternative agricultures that promote diversity are appearing, or making a comeback, often with the aid of scientific authority as in organic food, and often through social movements as with agroecology. STS scholars can do much to interrogate the epistemic and political conditions for reconceptualizing food as diverse—not homogenous—systems. They can foster a dialogue of knowledges among different disciplines, ecologies, cultures, and sociotechnical worlds. We have provided some glimpses of the diverse texts and voices that can be brought to bear on this important work. Indigenous farmer-activists like to say, "*Se hace el camino al andar*" (We make our path as we walk it). STS scholars, then, have a responsibility to enable peoples worldwide to walk the paths they want.

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Notes

1. In this chapter we focus in depth more on the STS literature that emphasizes agricultural systems (and in particular industrial agricultural systems) than on the literature on food, nutrition, and health. Obesity, nutrition, culinary methods, and foodways are all deeply intertwined with productivist systems. But for reasons of coherence and brevity, we cannot adequately synthesize the entire food system.

2. By farmers, we also mean ranchers, pastoralists, livestock operators, fish farmers, and farmworkers.

3. Useful overviews of the complicated agri-food area can be found in Buttel (2001) and Goodman and Watts (1997). STS studies of food and agriculture offer important bridges to many other scholarly communities: business history, geography, economic sociology, history of medicine, medical anthropology, environmental studies, food studies, culinary histories, and so forth.

4. See https://www.washingtonpost.com/news/wonk/wp/2015/03/12/our-insatiable-appetite-for-cheap-white-meat-is-making-chickens-unrecognizable/.

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33 Knowledge and Security

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For the past hundred years, the pursuit of national and international security has been largely synonymous with the use of science and technology to design and deploy powerful weapons. From the battleships and chemical weapons of World War I to the radar systems and atomic bombs of World War II to the intercontinental ballistic missiles and nuclear arsenals of the Cold War, scientists and engineers transformed the nature of warfare during the twentieth century. Not surprisingly, given their focus on the social and political contexts and dynamics of science and technology, researchers in science and technology studies (STS) have made extensive contributions to analyzing this transformation and understanding its complex consequences for the organization and funding of science, technology, and the military, as well as the relationships between national security and the social, economic, and political dynamics of modern societies. Today, science and technology remain central to contemporary national and international security. STS scholars, working within and outside of security establishments, are making important contributions regarding how to think about and respond to current global security challenges.

Security landscapes have fundamentally changed in the twenty-first century and with them STS contributions to security studies. Science and technology are no less integral to national and international security today, but their influence is changing. New weapons, such as drones and computer viruses, remain important, but increasingly the focus of security is shifting into the realms of knowledge and information. Just as the national security states of the Soviet Union and Eastern Europe built massive information architectures to serve their needs, so, too, the rise of information societies is reconfiguring the power of states across the world to gather information as they pursue expanded security.

The processes of knowledge making have been identified as crucial to both the making of security and the broader implications of security mechanisms (such as regimes, frameworks, technologies, practices, and materialities). Although the topics