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Entrepreneurial Talent Building for 21st Century Agricultural Innovation

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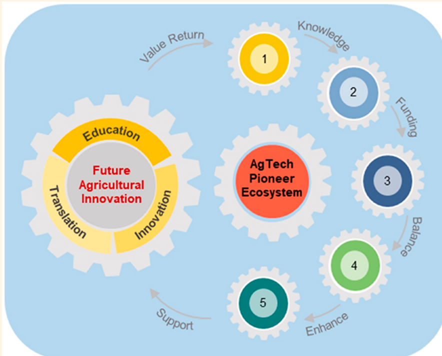
ABSTRACT: **Agricultural innovation is a key component of the global economy and enhances food security, health, and nutrition. Current innovation efforts focus mainly on supporting the transition to sustainable food systems, which is expected to harness technological advances across a range of fields. In this Nano Focus, we discuss how such efforts would benefit from not only supporting farmer participation in deciding transition pathways but also in fostering the interdisciplinary training and development of entrepreneurial-minded farmers, whom we term "AgTech Pioneers", to participate in cross-sector agricultural innovation ecosystems as cocreators and informed users of developing and future technologies. Toward this goal, we discuss possible strategies based on talent development, cross-disciplinary educational and training programs, and innovation clusters to build an AgTech Pioneer ecosystem, which can help to reinvigorate interest in farming careers and to identify and address challenges and opportunities in agriculture by accelerating and applying advances in nanoscience, nanotechnology, and related fields.**



Agriculture has catalyzed the emergence of human civilization and is one of the most important sectors of the modern global economy.[1,2] Food and agriculture are integral to human health, well-being, and nutrition, and food access is a critical factor in human development.[3,4] However, the agricultural sector faces numerous and mounting challenges: It consumes a significant portion of resources (*e.g.*, land area, water),[5] carries a high environmental footprint,[6] and has vulnerabilities to anticipated climate change and socio-economic changes.[7] Urgent action is needed to build more resilient systems of food production.[8−11]

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The crux of the problem lies in an agricultural paradox. Current projections estimate that the world's population will reach nearly 10 billion people by 2050.[12] To meet rising food demands, a combination of increases in food production[13] and decreases in waste throughout the food chain[14] is needed to improve resource efficiency.[15] Such changes, however, will be geographically localized. It is also anticipated that farmers in the developing world, where production is lower than the global average and postharvest losses are high, will need to produce a sizable proportion of this extra food, despite a rather limited amount of arable land along with environmental challenges such as extreme droughts.[16,17] Unfortunately, farmers in the developing world suffer from some of the highest levels of poverty, food insecurity, and malnutrition.[18,19] In both the developed and developing world, farming is often a high risk or losing proposition economically, which has been discussed within the food regime concept framework and is attributed to factors such as trade liberalization and corporate privatization of agricultural knowledge and resources.[20,21] The income gap between urban and rural communities continues to widen and is drawing people away from farming, while urbanization further reduces the amount of arable land.[22]

The developed world faces similar challenges. The average age of farmers is rising,[23−25] and it is increasingly difficult to capitalize small farms.[26] As a result, there are fewer, larger farms operated by fewer and older farmers. For example, in the United States, the median farm size doubled during 1982−2007,[27] and the median farmer age increased from 50.3 years

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in 1978 to 57.5 in 2017.[28] Although technological innovations have helped to strengthen agricultural productivity in some cases and there is growing interest among farmers to utilize innovative technologies,[29] greater productivity does not necessarily translate into higher farmer profits. The development and implementation pathways of new technologies must, therefore, be carefully considered. Indeed, the agricultural treadmill concept developed by Cochrane describes how farmers must increasingly invest in new technologies to boost productivity in order to stay competitive even while crop prices fall due to greater supply that blunts farm income.[30]

To overcome this long-established treadmill effect, recent initiatives such as the European Union (EU) Common Agriculture Policy (CAP) have begun making direct payments to farms,[31] which have both increased average farmer income and economic disparities among farmers.[32] Although payment subsidies can potentially provide short-term alleviation of the challenges facing farmers, there is growing recognition that many aspects of global agriculture, such as specialization, export orientation, compartmentalized thinking, and power concentration, are locked in, which has spurred discussion about the need for a paradigm shift from highly intensive, industrial agriculture to a more diversified set of sustainable agroecological systems.[33] The ongoing COVID-19 pandemic has further exacerbated the situation and caused tremendous economic damage to many farmers and also exposed vulnerabilities that highlight the need for system-level changes related to socioeconomic sustainability, data security, rural broadband, and water.[34−36]

Toward this goal, a variety of agricultural innovation systems and ecosystems have been developed to facilitate transitions toward more sustainable food production in terms of economic and environmental outcomes.[37,38] These efforts increasingly call for building cross-sector innovation across multiple stakeholders and adopting mission-oriented perspectives focused on addressing specific challenges such as ensuring biodiversity and dealing with climate-related environmental changes.[39] It has also been recognized that agricultural innovation will play critical roles in achieving the United Nations Sustainable Development Goals of improving health and education, reducing inequality, spurring economic growth, and supporting environmental protection.[40−42]

Within this scope, there have been ongoing efforts to empower farmers as agents in innovation systems through communities of practice[43] and by involving farmers within project innovation teams to tackle specific problems.[44] There are also growing calls to foster agricultural entrepreneurship and to support related educational and training programs for farmers at different career stages or entering from different fields.[45] This emphasis on agricultural entrepreneurship and partnerships comes at a time of fast-paced changes in the food system landscape as a wide range of future-oriented technologies (often described as Agriculture 4.0/5.0; see refs 46 and 47) are needed to accelerate the transition to sustainable practices[48] along with the growth of emerging fields such as indoor vertical farming and urban agriculture.[49−51] Although cutting-edge technologies have the potential to enable sustainable agriculture, past experience also shows that technological innovations can concentrate power, and it is therefore critical that farmers, along with a diverse range of stakeholders, are involved in steering food system transition pathways toward sustainability.[52]

Moreover, new technologies are needed to meet challenges specific to agriculture, in particular, issues of price, reliability, and regulatory practice. The technologies need to be cost constrained. For example, typical revenues in corn and soybean farms in the United States Midwest are ∼$700 per acre, and profit margins over the past few years have been near zero or even negative.[53] Technologies must also be highly reliable in the face of seasonal fluctuations, climate change, and regulatory protection. As these transformations take place, it is important to consider how to support the adaptation of different types of farmers, including exploring options such as exiting agriculture or skills retraining.[54]

In this Nano Focus, we propose that agricultural innovation efforts would benefit from not only facilitating the adoption or enhancement of sustainable practices as research and extension work but also strategically building future human capital resources in the agricultural sector. In particular, we believe there is strong potential in supporting the education and training of entrepreneurial-minded farmers who are positioned to harness the latest technological advances of Agriculture 4.0/5.0 and will help support the transition to and enhancement of sustainable food systems. Innovations in nanoscience and nanotechnology are at the heart of many high-opportunity technological areas,[55] and we term this group of farmers "AgTech Pioneers" in recognition of the Technology Pioneers concept put forth by the World Economic Forum, which views innovation as critical to the future well-being of society and to spurring economic growth.[56] Our viewpoint also considers one of the greatest long-term challenges to the agricultural sector in many parts of the world, which is the current dearth of young people, especially those with science and engineering backgrounds and entrepreneurial interests, pursuing careers in agriculture as farmers. The development of strategic initiatives to foster human capital building and talent management through a combination of educational, cultural, economic, and social avenues will help to reinvigorate the agricultural sector and to ensure that future farmers live in a world where they are active participants in agricultural innovation and recognized as cocreators who have aligned interests with technological progress. Agricultural innovation and entrepreneurship have been widely discussed from the viewpoints of the United States and EU; we cover relevant examples from around the world and discuss pertinent examples from the Asia-Pacific region where we feel that such initiatives would be especially timely and beneficial.

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AGRICULTURAL INDUSTRIALIZATION STRATEGIES

Although the conceptual development of mission-oriented agricultural innovation ecosystems continues to evolve,[37,39] ideas such as cross-sector collaborations and multifunctionality have played important roles in the agricultural policy initiatives

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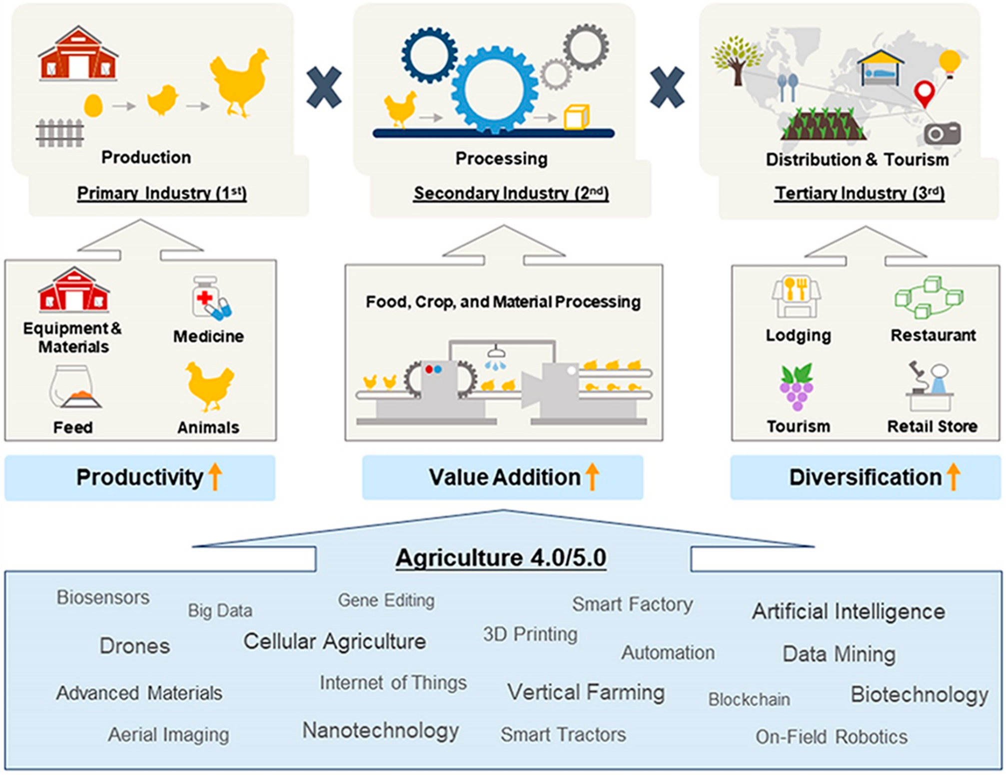

Figure 1. Example of Sixth Industrialization Plan and potential for incorporating Agriculture 4.0/5.0 technologies. The coordination of agricultural production together with other industries can lead to greater productivity, value addition, and diversification, especially when combined with new technological innovations.

of various countries worldwide. One of the most active regions of the world is the EU, which developed the CAP to support farm production and farmer income along with a more recent focus on sustainability and environmental considerations.[57] The EU has also spearheaded development of the Innovation Partnership network on "Agricultural Productivity and Sustainability", which is composed of multiparty, collaborative initiatives designed to fast-track innovations into market solutions while supporting rapid modernization of relevant sectors and markets.[58,59]

Another example of a national-level initiative to spur agricultural innovation and economic growth is the Sixth Industrialization Plan that has been implemented in Japan[60] and South Korea.[61] Although farmers typically focus on agricultural production as the primary (first) industry, this initiative seeks to help farmers become involved in food processing and distribution as a secondary (second) industry along with agricultural well-being and tourism experiences as tertiary (third) industries among various opportunities. The term "Sixth Industrialization" comes from multiplying 1 × 2 × 3 in reference to coordinated action across three industries (1 × 2 × 3 = 6) and was designed to integrate agricultural production efforts together with higher-value processing and distribution efforts in order to amplify potential economic benefits created by collaborations between farmers and actors involved in downstream business activities, as shown in Figure 1. However, the Sixth Industrialization Plan has proven difficult to implement widely because cross-sector integration requires broad skill sets and capabilities as well as basic awareness among actors of the potential for cooperation to enhance productivity and profitability. Most farmers are specialists and have traditionally focused on maximizing agricultural production;[62] the economic conditions of the region in which a farm has operated can also affect the degree of entrepreneurial behavior (*i.e.*, the recognition and pursuit of new, nonfarming business activities).[63]

As technological advances associated with Agriculture 4.0/5.0 gain firmer footing globally, the importance of educating and empowering farmers to work together effectively with technology-focused actors from different sectors in mutually beneficial relationships will become increasingly critical to achieve the objectives of policy initiatives such as the EU Innovation Partnership network and the Sixth Industrialization Plan.

At the same time, we note that incorporating potentially disruptive technologies from different fields such as artificial intelligence (AI), smart factories, network technologies, automation, gene editing, and nanoenabled Internet of Things (IoT) devices for sensing, communication, and power into agricultural practice[64,65] requires careful consideration of how their adoption is useful for farmers or, even better, developing those technologies based on addressing core needs or problems faced by farmers. Developing professional courses and training exercises may not be sufficient by themselves. In the United States, community colleges and agricultural extensions[66] play key roles in agriculture, and, thus, partnerships will be important in education, dissemination, and feedback. For example, developing data-intensive AI-based techniques for agricultural applications may have limited value until rural broadband backhaul availability (through fiber or microwave links for instance) and local network distribution can be introduced widely in agricultural regions.[67]

In general, farmers are open-minded about incorporating new technologies that can improve agricultural productivity.

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However, unless technologies are developed to answer core problems from the ground up, farmers generally remain consumers of these technologies, which can further entrench industrial agricultural practices *via* the treadmill effect and technology lock-in. Somewhat counterintuitively, technologies that increase productivity may hinder future profitability by locking in the use of practices *du jour*, as was recognized for United States cotton production nearly half a century ago[68] or as is a topic of discussion today in France with respect to crop diversification.[69] In addition to financing the initial purchases of new technologies, farmers are often forced to enter contractual relationships regarding technology maintenance and support along with data collection/data rights, sharing, and ownership.[70] Some inexpensive solutions can benefit immediate farming needs, but may require taxpayer subsidy and/or are done at externalized cost to the environment and society. Examples include the practice of wheat stubble burning in the farmlands surrounding Delhi, India, which contributes dramatically to Delhi's air pollution problem,[71] and reactive N losses impacting water quality in the United States Corn Belt[72] and air quality in the California Central Valley.[73] Solutions for complex problems such as these require technological advances in conjunction with policy considerations, regulatory practices, and incentivization. This strategy was successfully demonstrated in California, in moving to nonburn solutions for rice stubble by combining technology development and state regulatory mandates (between 1990 and 2000).[74,75]

Such issues may leave one to ask: How can technology be made environmentally sustainable and maximally beneficial for farmers? This question is relevant not only for today's farmers but also among prospective farmers, who are often turned away due to the rising costs of entering farming, uncertain economic prospects, and the gap between the practice of farming—including a certain level of perceived autonomy[76] that farmers hope to have—and the actual dependence on technology innovation driven by industrial agriculture. Although there are ongoing efforts to support farmers' rights to repair equipment along with a growing hacktivist culture to promote open-source tools and resources to build, to modify, and to fix farming equipment,[77] the scale of technological advances arising from Agriculture 4.0/5.0 may be so significant and complex that such pushbacks may be insufficient to address the fundamental issues if farmers want to make the transition to sustainable food systems and gain more control over technology resources. Considering these points, we believe that an important part of harnessing technological advances to realize sustainable food systems in the long term will be encouraging the development of entrepreneurial-minded farmers with distinct sets of skills and experiences, who can actively and equally partner in technology-focused innovation projects together with other engineers, scientists, and actors from various sectors, including nanoscience and nanotechnology.

INSPIRING YOUNG FARMERS

One of the greatest long-term challenges to the agricultural industry is the low number of young people becoming farmers,[78] which will have long-term ramifications for supporting and enhancing agricultural innovation and sustainable food systems. For example, research has shown that young farmers often have fresh perspectives on agricultural innovation compared to more experienced farmers[79] and display high levels of entrepreneurship.[80−83] To address this demographic challenge, governments have developed policy initiatives to attract farmers such as the NEWBIE network in the EU, which helps new farmers build sustainable farm businesses in Europe.[84] Globally, there have also been increases in entrepreneurial activities related to topics such as alternative (nonanimal) proteins, cellular agriculture, and urban farming,[49−51,85,86] and start-ups should be included as actors in mission-oriented agricultural innovation systems.[39] Furthermore, demonstrated niches of technological innovation can compete with mainstream approaches and eventually facilitate transitions to sustainable practices.[87] The ongoing COVID-19 pandemic has brought renewed investor attention to agricultural technology and its importance for food safety and security, especially since food production and agriculture are essential services.[88]

Even so, there remains a significant gap in how most people view the roles of innovation in the agricultural sector *versus* other technology-driven industrial sectors. This gap is striking because innovation arguably plays at least as important of a role in agriculture as it does in information technology (IT) or nanobiotechnology, for example, but the culture of human capital building is markedly different across these sectors.[89] The IT and nanobiotechnology sectors conjure images of start-up billionaires and entrepreneurial success stories that inspire technologically savvy youth to pursue careers in these fields and to strive to create the next innovation that might change the world. Such possibilities are not only a dream but are physically embodied in places like Silicon Valley, where innovation is considered cool and there are high local concentrations of like-minded budding innovators and entrepreneurs with social cohesion.[90] By comparison, real-life examples of these concepts, especially success stories and the "cool" aspect of innovation, are relatively less disseminated in agriculture.[91] Hence, a renewed focus on inspiring young people to become engaged in agricultural innovation would be beneficial because the potential for talent recruitment and development[92] along with the need for human capital building[93] is there, especially given the critical importance of transitioning to sustainable food systems and the impact of food systems on health, nutrition, and the environment.

A recent example is the work of technology entrepreneur Kimbal Musk who created an indoor urban farming company and has given public talks and media presentations highlighting the importance of future farming and healthy food.[51] Notably, his company created the 12-months-long "Next-Gen Farmer" training program to help young people acquire the skills and experience that are needed for urban farming. There has also been discussion about how to stimulate agricultural innovation by adopting a venture science model consisting of private and public investment within collaborative multistakeholder partnerships, which would reduce some of the traditional collaboration challenges of working with major corporations in the sector.[94] Although urban agriculture globally has context-specific benefits[95] that vary in magnitude for caloric security (generally low) *versus* nutritional security (generally high),[96] it also has strong potential as a "gateway" endeavor for youth, particularly in urban regions, for the production side of the agricultural sector.[97]

Within this context, we consider lessons from other high-tech sectors (and what might not apply due to the specifics of different sectors) and how education and training programs can increase the numbers of farmers who participate in

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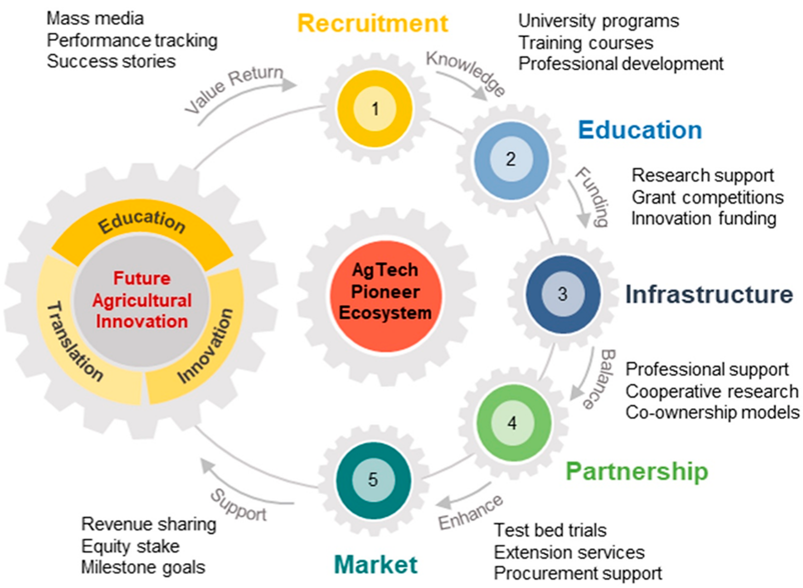

Figure 2. Agricultural innovation ecosystem for AgTech Pioneer development. The ecosystem encompasses five stages and is focused on supporting the development of young, entrepreneurial-minded farmers who can be cocreators and active participants in agricultural innovation.

translating the latest technological advances of Agriculture 4.0/5.0 into viable agricultural innovations. These efforts would complement existing programs designed to help current farmers and would concentrate on nurturing the development of AgTech Pioneers—entrepreneurial-minded farmers who have strong science and engineering backgrounds combined with cross-disciplinary education and training experiences to participate actively in technology-focused agricultural innovation as cocreators and can help to realize the transition to sustainable food systems globally. These educational efforts, which could potentially be hosted in university communities in partnership with private and public partners, would expand on the wide range of advisory services, training programs, accelerators, venture capital groups, and innovator networks that have been created in recent years. They would provide a mission-oriented agricultural innovation system[39] to support the training of future farmers with strong foundations in both technology and agriculture domains along with practical training to translate Agriculture 4.0/5.0 technologies into tools and resources for real-world applications.

While examining what a possible AgTech Pioneer ecosystem might look like, we anticipate that a plurality of transition pathways will be required to build sustainable food systems; we do not envision the AgTech Pioneer as a one-size-fits-all "good farmer" who can address all of society's needs.[98] Rather, we believe that AgTech Pioneers would add diversity to the farming community and provide avenues to increase the numbers of new farmers while simultaneously empowering farmers to gain control over and to direct technology development and resources. Such activities could also help to reinvigorate the public view of agricultural innovation, especially by increasing awareness among youth from diverse backgrounds, and play critical roles in supporting the transition to sustainable food systems.

AGTECH PIONEER ECOSYSTEM

Figure 2 presents an overview of the proposed AgTech Pioneer ecosystem, which is intended to educate and to train entrepreneurial-minded farmers who can harness the technological progress of Agriculture 4.0/5.0 and beyond to participate actively in transition pathways toward building sustainable food systems. As mentioned above, the AgTech Pioneer ecosystem fits within the mold of a mission-oriented agricultural innovation system.[39] The mission, in this case, is focused on cultivating the recruitment and development of farmers working at the interfaces of technology domains, agricultural practice, and entrepreneurship. We draw upon the concept of innovation ecosystems, which can support the growth of knowledge hubs that fuel creativity and innovation[99] and bring in actors from different sectors.[37]

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The basic educational philosophy of the AgTech Pioneer ecosystem draws inspiration from cross-disciplinary educational efforts such as those found in translational medicine (*e.g.*, the Harvard-MIT Division of Health Sciences and Technology, which trains scientific researchers and doctors to have strong foundations across science, engineering, and medicine along with clinical training experience).[100] This educational approach is based on the idea that translating scientific discoveries into clinical practice requires extensive training across the relevant domains, and the training environment closely integrates fundamental science and engineering together with medicine to fuel innovation and entrepreneurship.[101] The Dutch Agri-Food Network of Entrepreneurship (DAFNE) education program is another

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useful example that is coordinated and led by Wageningen University & Research and provides several interesting learning design aspects, including invited lectures from successful agri-food entrepreneurs, case studies, business plan competitions, entrepreneurial route planning, and intellectual property courses.[102] Recent discussions of research agendas for advisory services highlight how disruptive technologies will impact farming and the importance of providing value-added activities for technological capabilities,[103] a topic that can be incorporated into formal education and training as well. Compared to past efforts, a key point of expansion will be greater emphasis on fundamental education in science and engineering, which will enable individuals to access Agriculture 4.0/5.0 technology concepts more deeply and to find opportunities to apply them. A recent, focused example of such efforts is The Internet of Things for Precision Agriculture, which is an Engineering Research Center supported by the United States National Science Foundation that seeks to develop IoT technologies for precision agriculture while building a diverse workforce.[104]

The ecosystem consists of five main stages that begin with recruiting future AgTech Pioneers and involve a series of education and training steps to help these future farmers gain critical skills and experiences to reach the point of developing and deploying market-ready solutions. Although there are many possible career development pathways of an individual AgTech Pioneer, the five stages reflect the anticipated direction of career progress. The direction is intended to indicate that successful market commercialization of innovative products and services developed by the AgTech Pioneer community would yield funding support and successful career examples that would contribute to supporting the first stages of recruitment in future cycles. The first two stages contain novel ingredients directed at talent recruitment and learning design, whereas the latter stages focus more on supporting the transition from student to entrepreneur and will connect AgTech Pioneers with the wide range of emerging entrepreneurial training opportunities and business development models described above.

The first stage involves attracting and recruiting individuals who demonstrate strong interests and/or potential in science and engineering, *and* in pursuing entrepreneurial careers in the agricultural sector. This cohort will target students already enrolled in agricultural science degree programs as well as students from other disciplines with overlapping technologies and interests. Part of the effort at this stage needs to be placed not only on talent identification and selection but also on inspiring engagement in the agriculture sector.[89] This imperative is especially important for attracting young people (*e.g.*, high school and undergraduate students) and encouraging them to break away from the idea that farming has relatively low levels of innovation opportunity and occurs only in rural areas and to pursue farming careers.

Such efforts should also focus on identifying individuals from diverse and underrepresented backgrounds in the agricultural sciences, which has also been discussed within the context of building a sustainable agricultural career pipeline.[105] Although agricultural innovation can take place in rural communities, and such areas will remain an area of high importance, it is increasingly also occurring in (peri-)urban areas[106,107] in certain parts of the world, and farming careers of various kinds are becoming possible in essentially all geographical regions. Singapore[108] and Shanghai[109] have been cited as examples of urban agricultural innovation in the Asia-Pacific region.

The second stage will focus on developing and implementing educational programs that support individuals to acquire strong backgrounds in fundamental science and engineering, which is oriented toward agricultural applications. For example, one might teach chemical engineering principles from the perspective of edible insect processing to isolate and to purify protein and lipid components.[110] Such curricula will be linked together with Agriculture 4.0/5.0 technology advances and incorporate case study examples, team-based exercises, and experiential learning to see how technology fundamentals are connected with agricultural applications. The United States Department of Agriculture's National Institute of Food and Agriculture recently launched the AI Institute for Next Generation Food Systems and the AI Institute for Future Agricultural Resilience, Management, and Sustainability, which also merit attention as innovation platforms to stimulate interdisciplinary solutions.[111]

By grounding curricula in fundamental science and engineering and helping students to develop critical thinking and problem-solving skills to apply such knowledge to the agricultural sector, students will be prepared to participate actively in addressing future technology needs. These educational activities can enhance existing agricultural education practices and be designed in the form of associate, undergraduate, and graduate school degree programs, certificates, or courses. Although the AgTech Pioneer ecosystem mainly focuses on training new farmers, professional development and community awareness programs will also be developed for existing farmers who are interested in enhancing skills and knowledge and could be delivered through various industry avenues, such as commodity producer boards, agricultural consultants, farm cooperatives, and extension agents. It is especially important that AgTech Pioneer educational and training programs encourage interdisciplinary thinking and cross-sector collaboration because technology will continue to progress, and working together with and providing feedback to other actors who have higher level skills across relevant domains will help accelerate innovation and lead to technology-enabled solutions for real-world projects. Additional training support in relevant business domains (*e.g.*, management, financing, accounting, and intellectual property) will also be useful and will be incorporated into practical learning exercises and research projects.

The third stage involves the agricultural equivalent of the "Valley of Death" that is commonly found in the translational medicine sector[112] and deals with how to help AgTech Pioneers build agricultural projects and business ideas in academic and incubator environments and transition them into fledging commercial enterprises. In this respect, agriculture shares certain commonalities with the biomedical sector: Both are capital intensive and require significant investment to translate research and development findings[113] into commercially viable products and services. At the same time, innovation within the agriculture industry has unique challenges that necessitate creative, new business models. For example, technological solutions in farming can leverage the advantages of scale, but they also need to be highly reliable and robust in the face of unpredictable operating conditions (such as weather), and tight profit margins that compromise bandwidth for risk-taking. A recent example of developing a viable technological solution is the class of natural plant

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biostimulants that can support plant growth and improve tolerance against abiotic stressors while reducing the use of synthetic chemicals such as pesticides and fertilizers.[114] The exploding United States and EU markets for biostimulants speak to farmer interest in reducing nutrient and pesticide inputs and/or increasing use efficiency.[115]

Government initiatives to support entrepreneurial and innovation activities in this space, such as DAFNE (described above), are promising models and should be expanded to other parts of the world and enhanced with more direct commercialization aims. Public–private partnerships can play important roles at this early development stage by stimulating network building and directing the pathway of technology innovation.[116] Industry and academic consortia, such as the Good Food Institute and One Planet,[117,118] can help to recruit and to inspire students to enter the field as well as to identify and to address shared technological challenges. Shared research and production facilities (*e.g.*, the Innovator360 food incubator[119] and the planned Agri-Food Innovation Park in Singapore[108]) and shared ownership along with government support for farmer unions seeking to support agricultural innovation would further enhance AgTech Pioneer activities at this stage and also facilitate collaboration with additional types of farmers and actors from other domains.

Later stages in the ecosystem will help promising new AgTech Pioneer entrepreneurial ventures survive the initial stages of commercialization by providing government-backed and private funding in return for equity or a percentage of future profits among different types of possible financing models. Although a variety of nondilutive and dilutive funding models are used by governments worldwide to support research innovation and commercialization, we believe that some form of payback is important to generate return on investment for the public good, which can support circular mapping of the ecosystem. Accordingly, through strategic funding programs that support later-stage AgTech Pioneer ventures and incorporate payback-type mandates in successful cases, we envision that successful projects will both inspire and partially financially support the recruitment and training of future AgTech Pioneers in a virtuous cycle. Government-supported test beds and procurement schemes to support the early adoption of new agricultural innovations will further aid project commercialization.

Although the AgTech Pioneer ecosystem could be implemented globally, we believe that building regional innovation clusters first would be an attractive way to gain initial momentum and to attract future farmers from a wide range of backgrounds. Such clusters could fit well in United States university towns where some of the nation's top universities in the agriculture field are found and have strong connections to surrounding rural communities as well as in peri-urban areas globally, such as in high-population density areas. Indeed, the United States land grant universities were founded during and after the Civil War in the heart of agrarian regions to ensure innovation and dissemination for farmers,[120] providing an infrastructure for updating research and education to meet the agricultural challenges of the next 150 years.[121] The Food Valley of The Netherlands also offers an inspiring vision of a cluster for promoting agricultural education, training, entrepreneurship, and translation in a coordinated manner;[122,123] implementing the AgTech Pioneer ecosystem will expand on this success and support the development of future entrepreneurial farmers committed to agricultural innovation. Active and focused engagement with communities in urban areas should also be considered in order to expand and to diversify AgTech Pioneer recruitment and participation.

We anticipate that national governments will play leading roles in initiating and supporting national-level planning of the AgTech Pioneer ecosystem, while management would likely involve a coalition of government agencies related to agricultural, scientific innovation, educational, and labor issues, along with universities, private companies, and nongovernmental organizations. Such possibilities are especially attractive to consider in geographic regions where science and technology education and research—boosted by government strategy and support—have catalyzed the growth of other industrial sectors such as IT and nanobiotechnology. Achieving similar degrees of success with the agricultural sector will help direct and manage the transition to sustainable food systems.

CONCLUSIONS AND OUTLOOK

The growing need to transition to more sustainable food systems demands that a wide range of actors from different sectors work together in teams[124] to translate promising Agriculture 4.0/5.0 technologies into next-generation agricultural practices and resources. To achieve this goal, a diversity of transition pathways will likely be needed,[52] and we must consider how agricultural innovation impacts farmer livelihoods in an inclusive manner. Given declines in the proportion of society that derives its livelihood directly from farming, we must support current and future farmers as they adapt to the evolving food system landscape while also rethinking how we advance and nurture the entrepreneurial potential of farmers in the age of Agriculture 4.0/5.0. As one step in this direction, the proposed AgTech Pioneer ecosystem will support the education and training of entrepreneurial-minded farmers with strong science and engineering backgrounds who can actively collaborate with other farmers and cross-sector actors to harness technological progress and to cocreate agricultural innovations that will help to realize the potential of sustainable food systems. In addition to creating AgTech Pioneers, we envision that these efforts could help to reinvigorate public interest in the agriculture and food sectors and potentially increase the number of young people who pursue different types of farming and food technology careers. These efforts can also support translating advances in nanoscience and nanotechnology into future-oriented agricultural innovations.

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Notes

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