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Agriculture Technology Policies and Practices for the Future of Canadian Agriculture.

Dawn Trautman

April 2024

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ACKNOWLEDGMENTS

Thank you to everyone who contributed to my Nuffield project. It is my sincere hope that I've done the topic and organization justice. The Nuffield Agricultural Scholarships are a lifelong commitment and I look forward to further contributions over the years, to this topic of study and the program overall.

I'd also like to thank my family and friends for their support along the way, as well as my work colleagues and others in my professional network, with an extra special thanks to the Nuffield Canada Reports Committee for their support throughout the process.

I'm so grateful for all the individuals who've been so welcoming in hosting, providing insights, and offering support throughout my journey. I am humbled by your generosity and kindness.

SPONSORSHIP

My Nuffield Scholarship is courtesy of the Alberta Wheat Commission and I'm extremely grateful to represent the organization with this scholarship opportunity.

EXECUTIVE SUMMARY

Globally, we're at a pivotal moment where challenges in resource sustainability are sparking an unprecedented wave of innovation in the agri-food sector, offering a unique opportunity for leadership in driving productivity, resilience, emission reduction, and equitable profits. Emerging technologies show promising solutions to these challenges, but we are also seeing shifting regulations, supply chain stressors, and international agreements impacting agricultural production.

At the centre of this shift is the potential for innovation to power the Canadian agriculture industry's journey towards heightened productivity and sustainability. This research aims to cast a global net, examining a diverse array of agricultural technology (agtech) stakeholders worldwide. The goal is to uncover the challenges and opportunities that will shape Canada's agri-food innovation policy, bolstering the commitment to fostering a dynamic and robust agtech ecosystem.

Agri-food innovation policy should focus on facilitating the adoption of technology and practices that enhance sustainability and productivity. To do so, there are several considerations gleaned from this research:

1. People are at the centre of agtech innovation: human-centred design principles ensure the focus is on the correct stakeholders while accounting for the fact that they are not all the same. For effective policy, think globally for impact, but locally for action and outcomes.
2. Policy, technology, and processes should be co-developed with relevant stakeholders: synergistic models between government and the private sector combine mandates and ability to enable capacity building and effective distribution platforms.
3. An open and collaborative approach is needed: to be successful, agri-innovation policy must leverage knowledge within and external to the agri-food sector. Multiple voices and perspectives will drive a process based on co-learning and mutual responsibility and ultimately ensure improved system resilience.
4. Take a systems-based approach: Through systems thinking we consider the interconnectedness of various elements, involving relevant stakeholders, and fostering a culture of collaboration and openness. Utilizing this approach enables policymakers to design policies that not only address immediate challenges but also build capacity for long-term sustainability and innovation within the agri-food sector.

The goals of agri-innovation policy should be proactive to address global challenges related to environmental impacts and socio-economic instability. Stakeholders from innovators to farmers need policies to address equity of access, systems that avoid solutions seeking problems, and platforms to overcome knowledge and infrastructure barriers. Further, whole-system, integrated management is needed for assessing progress, and this includes productivity, environmental services, and sustainable intensification. To effect change and to implement it at scale, we need partnerships for action at local and especially global scales. We must ensure solutions recognize and engage with the voice of the farmer.

It is important to note that we do not need to wait on policy to solve problems; all stakeholders in the agri-food industry can make changes on their own or in a larger effort. And while grassroots efforts can initiate systems change, well-designed agri-food innovation policy helps ensure equitable and consistent access to platforms and technologies that enhance agri-food production. This is a responsibility for our policymakers as improved resiliency in agri-food systems impacts the health, education, community development, and equality of individuals, as well as trade, and transportation on a larger scale.

DISCLAIMER

This report has been prepared in good faith but is not intended to be a scientific study or an academic paper. It is a collection of my current thoughts and findings on discussions, research and visits undertaken during my Nuffield Farming Scholarship.

It illustrates my thought process and my quest for improvements to my knowledge base. It is not a manual with step-by-step instructions to implement procedures.

Neither The Nuffield Farming Scholarships Trust, nor my sponsor, nor any other sponsoring body guarantees or warrants the accuracy, reliability, completeness, or currency of the information in this publication or its usefulness in achieving any purpose.

Readers are responsible for assessing the relevance and accuracy of the content of this publication.

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1.0 INTRODUCTION

Agriculture stands at a critical juncture, facing the urgent task of feeding an expanding global population with finite resources, navigating the complexities of climate change, societal shifts, and unpredictable market dynamics. Yet, amidst these challenges lies a golden opportunity for Canada to lead the way in cultivating a future of sustainable, healthy, and safe food through strategic investments in agri-food innovation. This field spans a vast terrain, touching on macroeconomic policies to grassroots innovation, including critical topics like soil and water conservation, biotechnology, and the development of new, value-added products and services.

The research presented in this paper zeroes in on the policy landscape surrounding agri-innovation, underscoring the need for policies that not only incentivize but also build capacity for breakthroughs in agricultural technology (agtech). There's a pressing need for solutions that boost productivity, foster resilience, minimize emissions, and ensure fair profits. It's a collective effort, requiring the engagement of stakeholders across the spectrum to sculpt the food systems of tomorrow. While roles within this ecosystem may overlap, each entity primarily contributes to research, business development, or serves as a crucial bridge in the innovation chain.

1.1 CONTEXT OF STUDY

Beyond impacts on the farm, agri-food policy plays an important role in food security, which in turn impacts the health, education, and equality of individuals, as well as international trade and transportation on a larger scale. Effective policies can lead to economic growth, social development, and political stability, which foster enhanced quality of life at individual, national, and global scales. The continuous development and adoption of innovative technologies for the advancement of the agriculture industry in Canada is essential to the well-being of Canadians in providing safe, smart, and sustainable food. The industry is also a critical component of Canada's diversification strategy, particularly given Canada's advantages in natural resources (i.e., arable land, abundant water, clean air), historical know-how, and entrepreneurial mindset in agricultural production.

This project aims to better understand the opportunities and partnerships between the private and public sectors as it relates to agri-food innovation and smart agriculture adoption. Stakeholder interactions are impacted by policies, which ultimately impact the actions of each group, such as the ability of technology companies to develop made-in-Canada solutions; how they access appropriate channels to reach their end customer, the farmer; who are in turn impacted by various barriers or opportunities to adopt new solutions, such as policy incentives, and technology transfer efforts (e.g., media, national/regional agencies, public R&D). While all stakeholders have a critical role to play, this research leans into discovering policy implications that may reduce the friction of on-farm adoption of new agtech. The interactions between various stakeholders are dynamic and case specific; a general list of stakeholders and influences in an agtech ecosystem is provided in Figure 1.

Farmers Tech / solution end users	**Start-ups** Entrepreneurs, Inventors, Owners	**Media** Inform on new trends, tech, etc.	**Corporates** For-profit organizations	**Public R&D** Academia, public research institutes
Industry Assoc. R&D, marketing, training, education	**Mentors** Guide start-ups in value prop.	**Accelerators** Programs to help startups succeed	**Investors** VC, private finance, banks	**Government** Sets policy; provide support
Consumer Upstream demand pull	**Service Providers** Legal, HR, etc.	**Agencies** Companies or NFP providing support	**Private R&D** Aligned with company strategy	**Inf. behaviour** Culture, mindsets, attitudes, etc.

Figure 1. Various stakeholders in an agri-tech ecosystem.

1.2 OBJECTIVES

The objective for this research is to summarize a selection of global agtech stakeholders to measure challenges and opportunities that are transferable to agri-food policy considerations in Canada, as we continue to develop a robust agtech ecosystem and agriculture innovation strategy, regionally and nationally. Agricultural innovation systems[1] are the policy areas of interest for this work, which flow into innovation as a growth driver, with the end goal to achieve improved productivity and sustainability of the Canadian agriculture industry (i.e., see shaded boxes within Figure 2).

It should be noted that this focused approach of examining a single policy area and growth driver does not comprehensively ascertain all barriers or opportunities for achieving a more productive and sustainable agricultural industry; rather this approach includes a spotlight on agtech innovations as a fast-moving area of technology convergence, which will continue to disrupt the industry as we know it. Policy areas and growth drivers do not act in isolation; for instance, automation-based innovations may lead to labour savings, resulting in productivity growth, where the driving force may be from any combination of innovation, economic forces, and natural resource constraints. All other growth drivers are of general interest to this research but are inferred in an informal manner. For instance, it is well understood that structural changes (e.g., technology, financial/economic forces, human capital, value chain forces) impact the capacity to adopt innovations, many of which have resulted from public and private investments in agricultural research and development (R&D), which are often attributed to positive productivity growth and used as an indicator of research or innovation impact (OECD, 2019). Similarly, climate change has led to the adoption of environmentally resilient practices and products (e.g., seed selection and/or genetic modification), another innovation driver that increases both productivity and sustainability.

[1] An agricultural innovation system consists of a collaborative network of individuals, organizations, and businesses, along with supporting institutions and policies, within the agricultural sector to existing or new products, processes, and organizational structures into practical use.

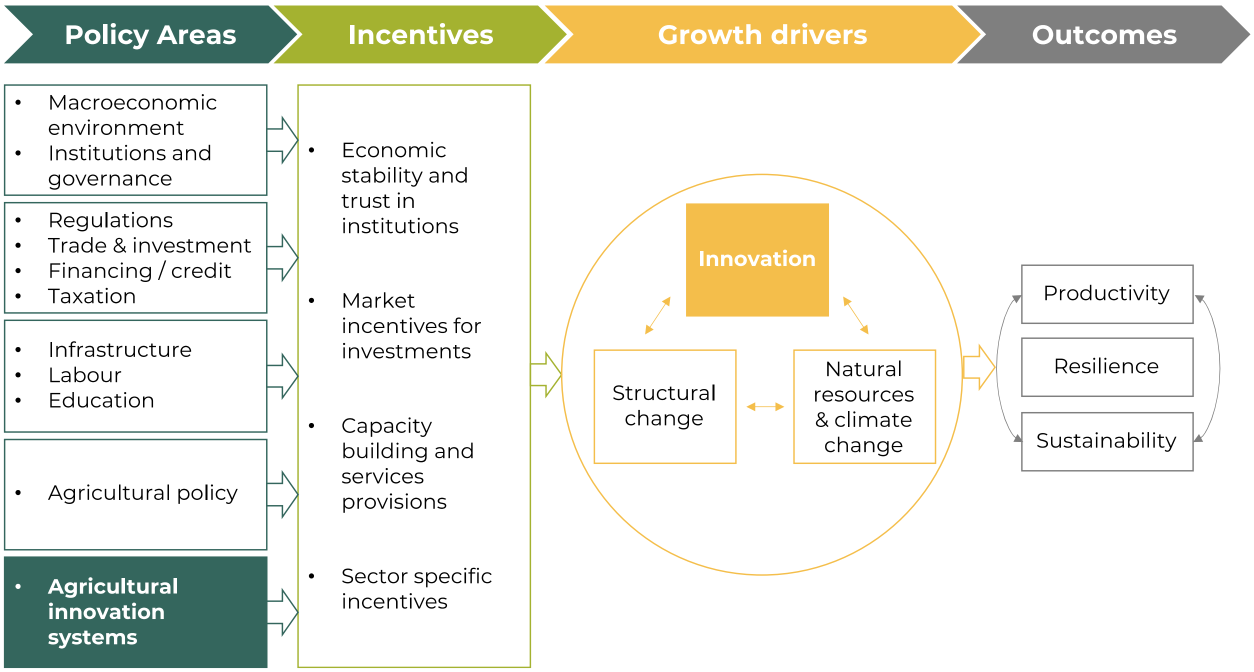

Figure 2. Policies to outcomes in agriculture (adapted from OECD, 2019).

1.3 METHODOLOGY

I travelled to eleven different countries[2] on three continents to study my topic. Unfortunately, two of my planned visits to additional countries were cancelled last minute due to tightening Covid-19 restrictions and another trip did not get planned due to travel visa and geopolitical issues. To compensate for some of these unavoidable disruptions, I attended online sessions, including the United Nations Food Systems Summit, to broaden my perspectives in lieu of traveling in person.

Additionally, I've been fortunate to be part of the broader agtech ecosystem in professional and personal networks, and I've gathered information and inspiration from several organizations in this capacity. A list of interviews and discussions and a list of organizations consulted during my research are provided in Section 6.1.

The above-mentioned travel, conferences, and discussions were supplemented with additional online research from academic journals, media releases, industry briefings, corporate reports, and public sector research. This resulted in a blend of micro- and macro-level findings, where micro-level results were obtained directly from interviews, discussions, and events attended, while macro-level results were discovered when analysing various reports detailing sector trends and perspectives. The travel and online small group meetings (a necessity due to Covid-19 restrictions) allowed direct observation of the attitudes, behaviours, interactions, events, and social processes of the various individuals working within various agtech ecosystems. Qualitative research helps understand the 'why' behind trends exposed by quantitative research, but the challenge is effectively interpreting the findings. This was done by studying existing literature, including surveys conducted, on the topic, and was also included with the

[2] Australia, Brazil, Canada, France, Italy, Netherlands, Portugal, Spain, Switzerland, UK, USA.

aim to reduce any bias in the research due to uncontrollable conditions (i.e., travel restrictions). The goal of the mixed method approach is to reveal the impact of policy decisions related to agtech practices, in various locations, to date.

1.4 BACKGROUND

The global food system has been through significant shocks since the start of my Nuffield research in Winter 2020. Covid-19 restrictions severely impacted labour availability and food accessibility. Commodity prices rose in Spring 2020; this coupled with continued shutdowns of various stakeholders in the food value chain increased prices paid by consumers. Add in geopolitical disruptions with the Russian invasion of Ukraine, and it's been a turbulent three years, with peaks of food (and general) inflation in Canada throughout 2022.

Prior to recent global events, there were significant challenges within the Canadian agri-food industry. Resources for agricultural production are increasingly constrained with land-use competition, climate change, evolving regulatory environments and social expectations. Yet, the global population is expected to increase to approximately 10 billion by 2050, resulting in total global food demand to increase by an estimated 35% to 56% from 2010 levels (van Dijk, 2021). Added complexity comes with the fact that the largest projected population growth is to occur in regions where there is little to no capacity to expand on agricultural production.

There is additional urgency around climate and environmental targets to slow the impacts of climate change. Many governments, corporations, and NGOs have committed to the 2030 United Nations Sustainable Development goals for peace and prosperity for people and the planet, now and into the future. These groups have agreed to ambitious and necessary goals related to ensuring a healthy future; many of these goals are related directly or indirectly to agriculture, and we only have a handful of more growing seasons to meet the 2030 targets.

Consumer demand and preferences are also of importance. There is increasing interest in how food is produced, but at the same time record food inflation, at least for North American consumers. Consumers are increasingly disconnected from their food sources, yet preferences are shifting and there is increasing interest in food attributes related to health, sustainability, and transparency. The profile of food and farming is growing, yet the sector is facing unprecedented uncertainty, new regulations, and geopolitical tensions. Profitability also depends on satisfying regulations and consumer demands.

Massive technological advancements have occurred, and technology convergence indicates more disruption within the agriculture industry is on the way. Smart technologies[3] provide benefits in digital thinking, effectively bridging the gap in agriculture potential and reality across the value chain. While there are risks with disruption, there are also opportunities as we evaluate solutions to minimize the uncertainties in our ability to produce and distribute food. We live in a globalized world where international agreements, regulations, and geopolitics impact how we produce food and farm. Technology is another tool in the toolbox to alleviate some of the tensions in sustainably producing enough healthy food to feed the growing global population.

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[3] There are numerous examples of smart technologies in agriculture; an example might be connected field sensors to provide real time monitoring of irrigation with built-in decision tools to manage appropriate actions based on the data collected.

Technology advancements in turn are impacted by a complex set of factors. Societal values, beliefs, and concerns can impact the development of technologies that rely on the collection and sharing of personal data. Public opinion and acceptance of new technologies can also impact adoption and diffusion. International trade agreements, political relationships between countries, and cultural differences can impact the global diffusion of new technologies, while cultural differences in attitudes towards technology can impact adoption rates. Government policies, regulations, and funding can drive the development of green technologies and policies that support research and development can encourage innovation. The availability of funding and the cost of capital can impact the pace of innovation and the ability of early-stage companies to bring new technologies to market. Over the past ten years, venture capital investments in agtech have grown five times in terms of number of deals and approximately eight times in terms of deal value (i.e., from an estimated 200 deals valued at $1.3bn in 2013 to 988 deals valued at $10.6bn in 2022) (Pitchbook, 2023).

Regarding technology capabilities, we are at an inflection (and convergence) point with the capability and maturity of many of the technologies, meaning we have more computing power, better algorithms, and it's more affordable to harness information. Specifically, advances in sensors, GPS, and data analytics are being used to optimize production by collecting data on soil conditions, weather, crop growth, and more. This data is used to develop more accurate predictive models, which helps farmers make better informed decisions. IoT (Internet of Things) devices such as drones, smart sensors, and robotic machinery can be used to automate production practices and improve efficiency and reduce labour costs. As more data are collected from sensors, drones, and other IoT devices, they provide increasingly accurate insights into production parameters, which can be used to optimize management (see Figure 3). All these advances have been made possible by a combination of policies, technology development initiatives and investments, industry competition, consumer demand and acceptance, and collaborative research. Additionally, the integration of traditional farming knowledge with modern technology is an important consideration as local producers have knowledge of crop rotation and soil management practices that can be combined with data analytics. **The need for sustainable agriculture practices is driving the development of technologies that reduce the use of water, fertilizers, and pesticides, while also protecting soil health and biodiversity.**

Figure 3. Global megatrends and disruptions in the global agri-food sector (adapted from Deloitte, 2020).

While the advancements to date have been incredible, it's been noted that much more needs to be done, and urgently. Challenges in advancements in agtech include difficulty of both start-ups and farmers accessing capital for investing in development and adoption of new solutions. There's also a critical lack of digital infrastructure in many areas of the world, Canada included, that limits the effective use of digital solutions in rural areas. Regulatory and legal issues, such as intellectual property (IP) rights and data privacy, can make it difficult for agtech companies to operate and innovate. And, the agri-food sector can be notoriously fragmented, with a lack of collaboration and information sharing between various stakeholders, including farmers, researchers, agtech companies, and the consumers/public. Addressing these challenges and capitalizing on opportunities will require collaboration and cooperation between governments, private sector, and greater society to create an enabling environment for the agtech ecosystem to thrive.

1.4.1. TERMINOLOGY

The distinction of 'smart agriculture' from other advancements in agtech over the years has raised some questions of what makes a technology 'smart'. The distinction was highlighted during a presentation at the 3rd Annual World Intelligent Farming Summit in in Barcelona in June 2022 (Bell, 2022):

> *Smart machines are the foundation to facilitating data use and moving to improved connectivity and machine synchronization. Smart features within a platform allow machines to observe, measure, respond and precision farming is a farming management concept based on observing, measuring, and responding to inter and intra field variability in a crop, targeting an optimized, task-based outcome. Intelligent farming is the application of information and data technologies for optimizing complex farming systems. Unlike with precision farming, the focus of intelligent, or 'smart' farming is not on precise measurement or determining differences within the field or between individual animals, but rather on the access to data and the application of these data*

(i.e., how the collected information can be used in an intelligent way, known as decision-based farming). Intelligent solutions are a combination of intelligent and precision farming applied together to obtain maximized outcomes for different producer needs.

There are many definitions of 'smart agriculture', with the general idea being that it is more than just precision agriculture – it is the application of connectivity (e.g., IoT) where sensors and software are used to collect and analyse data to optimize production decisions in real or near real time (e.g., via mobile platforms). It effectively makes farm operations more predictable and efficient, using a more holistic view compared to precision agriculture and positioning technologies alone, and encompasses fields shown in Figure 4. At the industry level, and beyond the farm gate, smart technologies in agriculture also include agricultural e-commerce, food traceability anti-counterfeiting, agricultural leisure tourism, agricultural information services and other aspects. This research focuses on smart agriculture beyond the strictly technological components involved at the production stage and will use 'agtech' to refer to technological advancements designed for the entire agriculture sector.

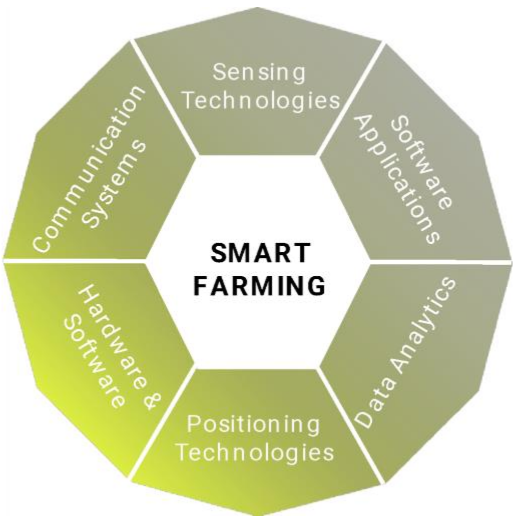

Figure 4. Types of technologies involved in smart farming (adapted from Katiyar and Farhana, 2021).

2.0 OBSERVATIONS & INTERPRETATIONS IN AGTECH ADOPTION

The rate of change in technology advancement and adoption of agtech during the relatively short period from the start to conclusion of my research has been quite remarkable. Some of the reasons for this include rapid advancements in key technologies such as robotics, artificial intelligence, and IoT; increased investment from the private sector, which has allowed for increased commercialization of agtech; and increased government support from early-stage R&D to solutions aimed at alleviating supply chain woes and food shortages during the Covid-19 pandemic.

Technology, practices, and people are all connected, and even a simple practice change may cause ripples or waves of change upstream or downstream in the value chain. For instance, the technology behind cultured (fermented) foods has advanced to a stage where the claimed quality is on or near par with the naturally sourced food it's replacing. With cost parity potentially not far away, one consideration is the communities and farmers likely to be disrupted by this new supply source. On the one hand it can be argued that the environment may be better off, but on the other hand at least one generation has had their income reduced and there will be local communities impacted by such a disruption. While these types of disruptions are not the focus of this paper, the point of interconnection is critical for developing effective policy within and external to agricultural innovation.

Specific to Canada, I heard several times that our producers are less interested in precision because resources are comparatively cheap and/or abundant. This distorts producer targets to be overly focused on yields when they should be focused on profits. And on a related note, I heard that there was a general feeling that, in Canada both producers and government are overall less aware and concerned with sustainability and the UN SDG goals as compared to European counterparts. Whether these comments resonate or are refutable is less the point than the fact that meaningful improvements will require coordination at numerous levels and scales, from early R&D to agri-innovation adoption to consumer acceptance, at local, regional, national, and international levels.

A general theme I picked up was an overemphasis on the need to 'educate the farmer' or conversely 'educate the consumer'. However, it is also easy to observe that there are not many farmers in attendance or engaged in the process when at government or academic events; and when at producer-led events while there are typically only a few researchers, academics, and policy makers, and very few urban-only consumers[4]. This dynamic is creating an 'us vs. them' mentality, creating mistrust and irrationally dividing the ecosystem. This makes it more difficult to bring the best solutions forward. 'Othering', when we view or treat a person or group of people as intrinsically different, is generally uncooperative, as we become more concerned with group belonging than recognizing an opportunity to use technology–whether it be one that has been developed or one to be developed for stakeholders who are seeking a solution–to serve as a connector and bridge the gap between social systems.

2.1 THE FARMER EXPERIENCE

'Sometimes innovation is just doing it.'

Farmer cooperative representative, Job (The Netherlands)

From numerous perspectives, farming is becoming more difficult. There is increased pest resistance, climate challenges, economic uncertainty, and more. This leaves a big opportunity for innovative technologies and practices to address productivity and profitability. I spoke with farmers and farmer associations in Canada, US, Europe, and South America. In all regions, it became clear that there is often a disconnect between what farmers say and what they do. Many farmers say, from a rational perspective, that if it "makes me money, I'll use it", and for many this is certainly the case. But there are other constraints at play – available resources and costs, relevance, user-friendliness, and risk aversion – that contribute to how and by whom innovations are adopted (Figure 5). Additionally, there are balances to consider in terms of culture and information availability and information overload.

Cost	Relevance	User-friendliness	Risk & Trust
• Up-front investments • Recurring costs (e.g., subscriptions) • Switching costs	• Farm size • Lack of trial research / data in context of environment • Accuracy	• Skills • Producer age • Human capital • Farmer-centric innovation	• Accuracy • Data governance • Perceived benefits • Technology preferences

Figure 5. Constraints to on-farm adoption of digital technology (adapted from McFadden et al., 2022).

The biggest takeaway is that while some differences (e.g., operation size and scale, producer education and age, geographical location, etc.) can be strongly correlated with technology adoption, overall, farmers often have similar concerns, and the most important factor is to work together not only as producers but also in the greater innovation ecosystem.

[4] Generally, the private sector has done a reasonable job of representation at producer-led events, which is not surprising as they need to be aware of the needs of their customers.

2.1.1 INNOVATORS AND EARLY ADOPTERS

Innovators and early adopters make up just 16% of the general population, according to Rogers (2010; Figure 6). And while there are valid criticisms of the theory, it is a useful and often-used framework to help understand adoption of new technologies. According to Rogers (2010) innovators are often risk-takers who more easily cope with uncertainty and failure. They play an important role in introducing innovations and may also play a gatekeeper role in the flow of information (AgriFutures Australia, 2022). Early adopters are comfortable adopting new ideas; they are generally considered respected opinion leaders who provide advice and information on the innovation to others. In this way they are enablers of critical mass adoption.

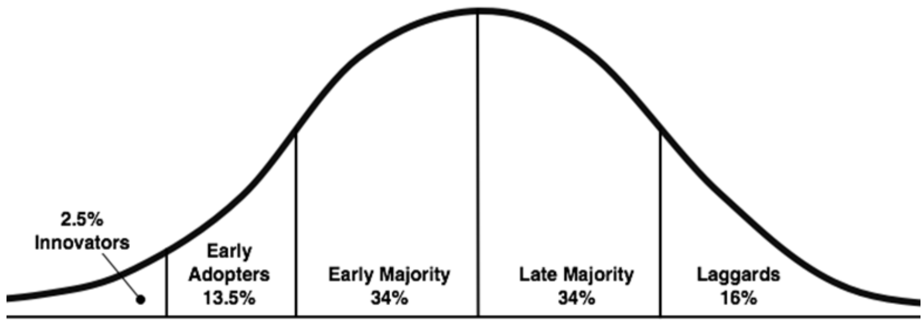

Figure 6. Diffusion of innovations according to Rogers (2010).

On-farm technology adoption has been studied extensively to tease out the major contributing factors. I spoke with a researcher exploring the drivers and barriers of smart farming technology adoption in Europe across cereal, dairy, beef, and specialty crop operations (Dilleen, 2022; Demeter, 2022). For the technology adoption model, the study considered useability, technology benefit, overall attitude and behaviour towards use, method of technology provision, and the role of trust. Overall, many farmers are curious about technology and will take some time to learn about it. Regarding those who are considered early adopters, noted influencing factors included (Dilleen, 2022):

- Improved work-life balance (e.g., virtual fencing and tracking collars on cows in Ireland);
- Interest in how technology might help with sustainability;
- Technology ease of use and integration;
- Farm size due to need for efficiency from automation (e.g., at seeding) and resource availability (e.g., 4000-hectare farm in Romania hired a statistician to analyse trends; it was determined a drought was coming and the producer adjusted management);
- Access to regional development funds (e.g., capital access to technology for women farmers in Northern Italy for autonomous tractors).

Attitudes, information sources, and technology providers were also important determinants. In general, the respondents had a positive attitude toward smart farming technologies with most current users agreeing that the technology helps to reduce costs and connect with other farmers (Demeter, 2022). Many social influences were related to trust and culture. In some areas there was a noted lower desire to automate menial tasks as it is a point of pride (e.g., driving tractors). There were noted concerns of data being used ‘against us’ (e.g., for regulatory purposes, price predation, etc.) and a general wariness of where the information will end up. Perceived barriers to adoption were higher for current non-users vs. users (Figure 7), meaning that farmers are not recognizing the proposed benefits from technology providers or peer farmers but rather focus on possible downsides (Demeter, 2022).

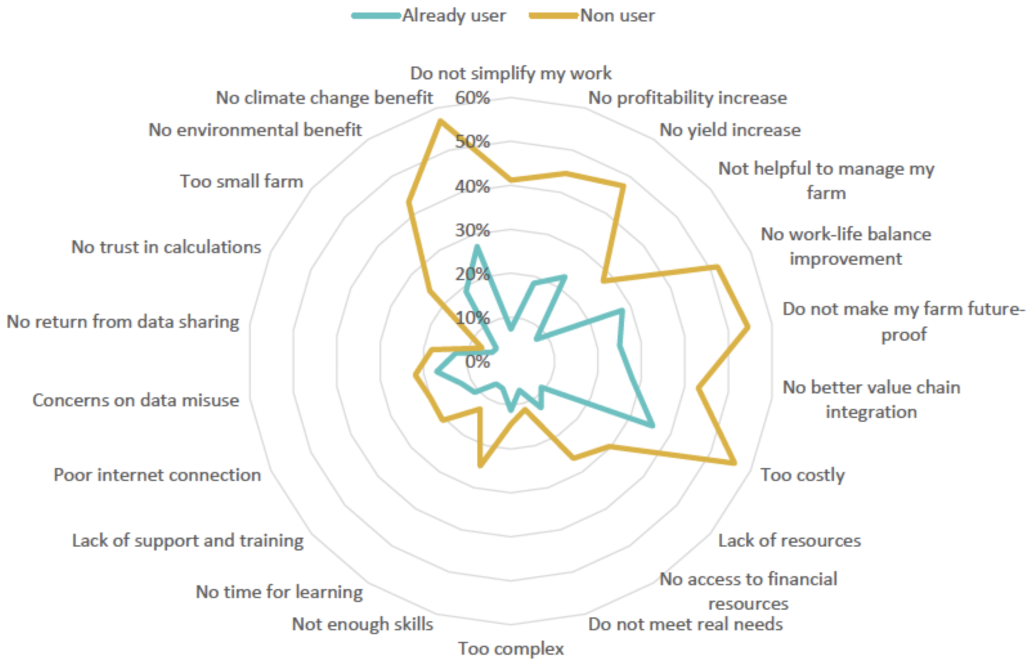

Figure 7. Barrier profiles of users and non-users to smart farming technology adoption (Source: Demeter, 2022).

I also spoke with several leading-edge producers and producer groups. Pathways to technology adoption varied, but the overall motivation was related to productivity and sustainability outcomes for their operations.

Willem[5], an organic, climate-neutral dairy farmer near Utrecht, was primarily seeking market differentiation and competitiveness when he became an early adopter of genetic selection of cows producing A2 (low lactose) milk. The discovery of A1 and A2 proteins in milk impacting people with lactose sensitivity became apparent in 2002; however, the research to commercially identify cows that naturally produce A2 milk took another decade. Willem collaborated with Wageningen University to confirm the genetic type and started adopting the practice of selecting for cows producing A2 milk in 2013 as a higher value product to export to Asian markets where a higher proportion of the population cannot digest lactose. Besides genetic selection, Willem has also adopted biometric collars, advanced milking technologies, cross-breeding, and climate technologies to enhance competitiveness and stay ahead of expected regulatory changes. He noted that some of the technologies have not only improved cow welfare, but also his own in terms of work-life balance and profitability (e.g., the cows are producing more as a correlation with health). Regarding trust with technology providers, Willem takes the practical view that if the data can be used to solve his problem, they can have the data.

Liam[6] Cronin, a young and entrepreneurial Canadian producer, is targeting farm diversification by starting a custom drone business. There are still numerous restrictions to drone use on-farm and Liam is targeting various avenues to be an innovator in the space, including lobbying provincial representatives

[5] My thanks to fellow Nuffield Scholars Judith (2020) and Rick (2018) De Vor for hosting and introductions.

[6] My thanks to fellow Nuffield Scholar Amy Cronin (2020) for hosting and introductions.

to update regulations. In the meantime, he's working within the constraints to bring value-add by targeting bio-based, natural stimulants for enhanced productivity.

Kees and Sjors[7] are dairy producers in the Netherlands with a highly successful on-site cheesery. Kees began working with the major feed automation technology developer, Lely Industries N.V., more than 10 years ago. They took a collaborative approach where Lely would use the on-farm data to make improvements that would work for the farm. Kees and Sjor's dairy became the second in the world to incorporate a fully automated feeding system, helping Lely test and improve the process from 2011 to 2013; these systems are on over 1000 farms around the world today. A big advantage at the time was that Lely paid for the data, which helped offset some risk of adopting new technologies. While Lely no longer pays for the data, the system has proved to be highly valuable to the operation as there is always feed available, resulting in labour savings and improved efficiencies from real-time data feedback.

I heard from Catalyst Farming[8] in the UK, where a group of farmers is using a collaborative approach to bring together data, technology, and people to improve their farming operations. For this group of farmers, they wanted increased yields, increased quality (grain protein, oil, and sugar content), decreased inputs, and reduced environmental impact (e.g., nutrient leaching). In less than two years of working together and leveraging shared resources (e.g., analyst and agronomist), the team has effectively utilized the information, made improvements, and has started influencing change and creating farm policies. For them, it all comes down to the data. By using their own data, they have improved decision assessments, made marginal gains (no silver bullet), and stayed competitive. Data does not have to be complicated—some of the most impactful results were from measuring yields, drilling dates, fuel use, and machinery hours. While the ideal system differs from farm to farm, based on soil type, weather, crop rotation, and more, by working together these producers discovered a low cost, flexible system that has improved soil health, reduced cultivation, and increased resilience, consistency, and yields. Collaboration and sharing require a lot of trust and effort between the groups, but by sharing data and information, the staff and farmers are incentivized to improve.

Most early adopters are self-selecting. They are engaged within their networks to access learnings from academia, influence legislation, and participate in technology co-development. The level of engagement has given these producers market advantage and further expanded their networks. In terms of lasting advantage, some cautioned that eventually today's best or most advanced practices will be tomorrow's standard; for lasting advantage there is a continual need to innovate and seek change. Equally important will be to ensure that later adopters have awareness of new innovations and the opportunity to evaluate and trial new solutions. As a note of caution, it was pointed out during this research, that the same early adopters are being offered too many options and some are starting to see fatigue in trialling new innovations. Innovators and early adopters should be thought of as partners in the technology development process. And for this to be effective, other stakeholders from R&D to commercialization of technologies must consider the farmer's business plan and build the solution together.

2.1.2 DELIVERY GAP

In the past, technologies available to farmers were related to the need to increase production, profits and productivity with the main constraints being availability of capital, knowledge and useability of the technology, and market risks (OECD, 2001). Now, as we move to solve challenges beyond productivity to

[7] My thanks to fellow Nuffield Scholars Judith (2020) and Rick (2018) De Vor for hosting and introductions.

[8] https://catalystfarming.co.uk/

meet sustainability targets, abide by various local to international regulations, and meet consumer demands, there is an abundance of technology options and information sources. While more choice is generally a good thing, it also means there is often more uncertainty. Adopting new technologies and practices is an investment, and if information on technology access and the payoff is not clear, uptake will be stunted. The gap is not in the science, technology, quantification of benefits, or the data, it's in the delivery, implementation, and accessibility of pushing many solutions up the pipeline, often with no delivery mechanism attached, which makes them difficult to implement on a large scale.

For example, smart agriculture technologies can help farmers optimize their use of inputs like fertilizers, pesticides, and water in real-time. This technology has been shown to increase yields and reduce environmental impacts (Balafoutis, 2017), but it requires a significant investment in hardware, software, and training. There are many data points, and now there is increased information complexity in on-farm decision making. Time and complexity costs must be accounted for as barriers and reduced. One way to do so is to ensure provided information is concise, highly accurate, and relevant. PhenoRob Autonomous Weeding Robot in Germany is an example of the challenges faced by agtech due to the technology not being ready as a producer tried the robot for a year, but ultimately returned it because it was still too much of a prototype to be used effectively at scale (Storm, 2021).

To reduce the 'delivery gap', multiple stakeholders must be engaged and working towards this common goal. Governments must invest in clear and easy regulations, engage farmers in technology, address connectivity challenges, and demonstrate benefits through repetitive showcases. It is crucial to determine farmers' pain points and work together to co-develop solutions using an outside-in approach. Distributors and farmer associations must have a role in helping farmers decide and adopt technology. Cash is not the only incentive; profitability and training should be the focus.

To increase uptake, focus should be on simplicity and trust. Intermediaries like agronomists can coach farmers in using new tools, and the agronomy field must look to enhance their knowledge on agtech and their ability to use new data sets. Advisors need to know how to optimize an operation and advise growers properly, which can be achieved through training. Trust in technology providers is essential, and companies should help farmers trust them by integrating and bridging the gap of trust. Mitigating the risk of adoption for producers, financial incentives, improving the accuracy and relevance of data, and showing farmers how to implement decisions, and connect with machines and people on-farm can help.

The challenge of delivering agtech solutions extends beyond hardware and software. It also includes the need for better supply chains, financing, and policy support. For example, digital marketplaces can help farmers sell their crops at fair prices, but many small-scale farmers lack access to these platforms. Similarly, financing mechanisms, including operating loans can help farmers invest in agtech solutions, but they may not be available in all regions.

The accessibility of agtech solutions is also influenced by factors like education and infrastructure. Farmers in remote areas may not have access to the internet, which limits their ability to use digital tools like weather forecasting and market information services. Additionally, many farmers may lack the education and training needed to fully understand and utilize agtech solutions. Farmers are also B2B companies; new technologies are being pushed into their hands as though they have dedicated IT and HR teams, when it is most often a family run enterprise with individuals responsible for multiple roles from finance to agronomy.

An example is the use of drones in agriculture. Drones can be used to monitor crop health, detect pests and diseases, and even spray crops with pesticides. However, the cost of drones and usage regulatory barriers can be a challenge for farmers. Additionally, many small-scale farmers may not have the technical skills to operate drones, which limits the potential benefits of this technology.

The gap in agtech adoption is not due to a lack of science, technology, quantification of benefits, or data. Instead, the challenge lies in the delivery, implementation, and accessibility of these solutions. Interconnectedness of everything means that changing one thing disrupts other areas. Many solutions are developed in silos and when they are implemented in real environments unexpected feedback loops often occur. It is necessary to co-develop effective delivery mechanisms, support the development of infrastructure and supply chains, provide financing and policy support, and invest in education and training programs for farmers to help bridge this delivery gap.

2.1.3 PROFIT DRIVERS

While agtech solutions are already driving improved on-farm productivity largely through efficiency gains, some doubt remains regarding the return on investment (ROI) on agtech solutions. Major adoption barriers may include overall cost and willingness to pay for subscription-based solutions (Fiocco et al., 2023; Demeter, 2022). To overcome this skepticism, it’s critical for producers and technology and service providers to be very clear on the value proposition as it relates to the profit drivers for the *individualized* farm. The best path toward improved profitability may vary among producers, even in the same region and with similar structures.

Farmers must see a clear financial benefit in adopting new agtech solutions, whether it's through direct or indirect methods. For example, in Brazil, farmers can benefit from financial incentives by using bio-inputs like pesticides and herbicides, or by converting manure into biogas by investing in small biodigesters (World Agri-Tech South America Summit, 2022). Similarly, a Dutch dairy farmer I spoke with noticed improved profitability after installing advanced milking robots that both clean the udder, legs, and hooves and monitor the cows' health and milk quality. Data ownership and use is also an important conversation and negotiation; many farmers I spoke with are very willing to share data if it helps solve on-farm problems, such as detecting morbidity or monitoring feed quality.

Other profit drivers include proactive consideration of environmental regulations, such as using solar collectors to power cheese-making operations or separating manure into components, observed on two different Dutch dairy operations. The use of new technologies like advanced milking automation can reduce electricity use and drive profits, as observed in Europe where on-farm electricity costs can become prohibitive. In Canada agronomists are advising crop farmers to focus on profits rather than yields alone, as obsessing over yields can not only lead to information fatigue but also result in poor environmental consequences and add unnecessary costs.

Farmers often reach out for advice only when they have a big problem to solve, which slows adoption progress. However, proactive farmers who ask the right questions related to continual improvements toward their profitability, rather than waiting to fix a problem after it’s occurred, can benefit from the full potential of agtech solutions. I spoke with a data scientist at Deveron and during the early stages of the technology development where calibration and validation were primary objectives, there were some cases of over promising and under delivering. However, with improvements in delivery (i.e., as related to the previous section), farmer feedback on what delivers value is critical to ensuring agtech delivers on promises of improved profitability (Sinclair, 2022).

2.1.4 RISK MANAGEMENT

There are five well-established types of risk in agricultural production: production, market, institutional, personal, and financial (Komarek et al., 2020). Agtech primarily aims to reduce production (i.e., reducing uncertainty related to climate, environment, pests, and diseases) and market risks (i.e., reducing information asymmetry of commodity and input prices; and improving market access), but there are also considerations within institutional (i.e., policy changes and social norms), personal (i.e., labour saving technologies to reduce risk of injury) and financial risk (i.e., agri-fintech alternatives to traditional farm financing).

While agtech aims to reduce certain risks in agricultural production, adoption of new technologies and practices can present its own risks as it can be costly in time and capital. Many farmers prefer bolt-on or add-on solutions to mitigate the risks of new, large, and costly purchases, such as an adaptation kit for an existing tractor. Labour has been the driving force in adoption in many regions as it improves the quality of life and increases productivity. Timing for seeding and harvest is critical, and producers and farm labourers often work hours beyond the window of safety; machinery size, autosteer and GPS technologies have mitigated some of these risks.

In Germany, and elsewhere, the current use of traditional herbicides is cheap and effective for broadacre farming, making it less desirable to take on the risk associated with new practices unless there are policies implemented to discourage these status quo methods (Storm, 2021). Similarly, in North America, many farmers use more nitrogen than necessary as a risk reduction strategy to ensure higher yields, leading to nitrogen pollution and increased costs. Willingness to adopt new practices is also highly correlated with land and environment; in regions where the status quo is 'good enough' (i.e., many farms in North America) there is risk associated with any change, even positive change.

From a psychological safety perspective, farmers generally have a hard time switching to new technologies, and this is even more prevalent if the solution comes from non-agriculture people. Some farmers are not as trusting of suppliers and other service providers if the level of support isn't there; and in any case of new technologies, the providers are often learning as they go, and support may not yet be standardized. As such, there is a time risk associated with adopting new technology and working with new service providers (Dilleen, 2022). A related risk is the failure of the technology, and it's been observed that producers may mitigate this risk by renewing technologies prior to their end-of-use lifetime. For instance, some early innovators in the livestock sector in the Netherlands are relying on biometrics to detect estrus; to minimize the impact of failure, they are replacing components within five years, rather than the technology standard of ten years.

To mitigate the risks of adoption, producers need financial incentives and accurate, relevant data that help them make informed decisions and connect with machines and people on the farm. De-risking the farmer may include unlocking new finance streams to enable and speed up technology diffusion. Agri-fintech[9] platforms, while relatively new, aim to lower the costs of borrowing money from institutions by sharing risks among the value chain players, and providing improved clarity and transparency on investment ROI.

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[9] Agri-fintech can be thought of as using technology to fill gaps between financial institutions and value chain operators, accounting for farm inputs, climate conditions, yields, and market prices and conditions within agri-food production and supply.

2.2 GOVERNMENT, NGO, ACADEMIA & PUBLIC SECTOR R&D

'Funding bodies push small projects to mitigate risk, but it only delays real progress'.

- Greg, robotics engineer

From a policy perspective, governments and other organizations have promoted, and continue to promote, the development of innovative technologies by encouraging R&D, collaboration, and knowledge transfer through a variety of initiatives, including:

- Government funding to help to support ecosystem development, timely legislation development, cross-disciplinary research, facilitation of knowledge sharing, and providing resources for early-stage technology companies (Rawat, 2020).
- Education, training, and incentive programs to help support technology development and convergence, leading to technical improvements, reduced technology costs, and improved technology transfer.
- Public-private partnerships to bring together government agencies, private companies, and academic institutions to support technology advancement. These partnerships can provide funding, expertise, and resources to support cross-disciplinary research, innovation, and the development of new technologies and help balance low-risk demonstration projects with higher risk but more impactful projects.
- Development and enforcement of IP laws to incentivize innovation by providing legal protections for the creators of new technologies.
- Regulations around data privacy and security to facilitate the sharing of data between different technologies and regulations around interoperability to promote collaboration and the development of new technologies.

During my research, I spoke with several individuals and visited public institutions – from academia, public R&D, and I have worked with government agencies on building agtech ecosystems. These groups deliver tremendous value in doing the work behind the scenes as well as the critical basic research in proving and improving on the viability of the technology.

2.2.1 PUBLIC R&D: TECHNOLOGY IMPROVEMENT

Public sector R&D plays a significant role in supporting technology development and improvement in agtech both through funding support of initiatives at public and private institutions and directly with government and public sector R&D facilities. This is an important group who conduct the basic research required to reduce costs and optimize or reengineer existing technologies.

The first focus of such investments should be on meeting the most basic conditions, such as social-economic infrastructure, roads, education, and information and communication technology (ICT), before moving on to more advanced areas. Particularly in developing regions, non-governmental organizations (NGOs) often play a critical role in encouraging governments to invest in the necessary infrastructure. Speed and scale are critical in this process, and digital infrastructure is one of the various methods that can be employed to achieve these objectives. Brazil has been focusing on providing necessary infrastructure for full digital enablement and connectivity (World Agri-Tech South America Summit, 2022). Public funding of agricultural R&D is critical to provide stable funds for knowledge infrastructure, strengthen research with public interests, and complement private research efforts (OECD, 2019).

Harper Adams University in the UK is conducting research and innovation in sustainable farming, with a focus on creating farm-innovation hubs (i.e., the first autonomous farm, the Hands-Free Hectare, now the Hands-Free Farm[10]; Lowenberg-DeBoer, 2021). Just six years ago the technology was still in full demonstration mode, but researchers, inspired by open-source drone systems, engineered an existing tractor to include GPS and lasers (for safety), and programmed the machine using a root-plan so that it learns when to perform each task, by field location. While much is still in the proof-of-concept stage, this was a big step forward in showing what is possible in a test environment at a public institution.

One challenge in developing agtech is that there are big differences between countries and the inherent uniqueness of agriculture, including local climate, culture, history of the landscape, legal rights of landowners, and so on. For automated technologies to be successful, they must have zero error; so currently it's still a question of human supervision of the machines, which is not supportive of the full efficiency claims. With increased public sector R&D support some of these challenges can be alleviated from improvements reducing build costs and getting to the zero-error target. At the Lincoln Institute of Agri-Food Technologies[11] (LIAT) in the UK, I spoke with one of their lead robotics engineers who shared that even with significant advances and the price of technology dropping, half the cost of the robots may be for sensors to ensure safety of the autonomous machine. Algorithms from vision cameras are being trained to help offset this cost and partially replace the need for all the sensors.

Overall, there are still many challenges to overcome before autonomous agriculture becomes a reality, and the sentiment from individuals involved in public sector R&D is that we are in a transition period. First, we had Roombas as the enabling technology where they map their environment; next we have autonomous cars; and over the next ten years we will move towards autonomous agriculture. Part of the challenge is also that many small actors don't have the resources needed to tackle the problems and several companies end up all focusing on similar innovations, with little appetite to take the risk and develop solutions that address the full problem, possibly due to inability to monetize on the solutions in a commercial setting within a reasonable timeframe. We often end up with many small demonstration projects that often lack tangible industry solutions; and similarly, industry funding bodies push small projects to mitigate risk, but this may only be delaying real progress (Cielniak, 2021). Collaboration and a bigger-picture mindset are required to overcome these obstacles and create a sustainable and efficient agtech ecosystem.

2.2.2 REGULATIONS, LEGISLATION, AND INCENTIVE MECHANISMS

One important role of governments, NGOs, academia, and public sector R&D stakeholders is to update regulations and legislation, particularly for emerging technologies (e.g., autonomous agricultural vehicles), either directly (e.g., government) or via participation in working groups informing on policy and legislation (e.g., academia, NGOs). Improving policy soundness and transparency is crucial to increasing policy effectiveness, trust, and efficiency in the agri-food sector. Overall, the governance of national agricultural innovation systems requires improvements. Policies that keep farmers in uncompetitive and low-income activities, harm the environment, stifle innovation, slow structural and generational change, and weaken resilience should be rolled-back, and revised policy should focus on measures to improve the sector's long-term productivity and sustainability (OECD, 2019). Stakeholder-consulted strategies capable of incorporating real-time improvements should be developed, with clarity on stakeholder roles to improve collaboration and coordination among these groups. The industry must

[10] https://www.handsfree.farm/
[11] https://www.lincoln.ac.uk/liat/

innovate and improve productivity and environmental performance along the entire value chain; an effective policy environment is key to harnessing evolving market opportunities (OECD, 2019) to maintain the competitiveness and sustainability of the sector.

Legislation and regulations can also be a major hurdle in the adoption of agtech. For example, the UK's "right to roam" law and safety concerns make it difficult to implement autonomy in agriculture. There are also strict codes of practice for using autonomous machines, and there are hundreds of standards to consult when designing autonomous vehicles. Despite engineering and technical progress in machinery automation, the lack of clear and easy regulations can slow down adoption. The professor I spoke with at Harper Adams University is working with the British Standards Institute[12] for Autonomous Crop Robots where they are using success with the Hands-Free Farm as the catalyst to inform legislation. However, farmer specific standards are also needed for meaningful producer involvement to avoid similar pitfalls to drone legislation where sight and height restrictions ultimately eliminated the full benefits of using drones in many parts of the world, and at this time, Canada included.

Policies informed by science are more robust and can be translated into something achievable at the farmer level. Decision support systems and applied systems approaches can help with this. Additionally, stakeholders need to focus on responsible use and potentially adopt the standard into law rather than leaving it to non-industry bureaucrats to decide. For instance, Australia has had a code of practice for farm autonomous vehicles since 2008.

Incentives are also crucial in agtech adoption. Social science researchers aim to understand why people respond to incentives to craft policies that can favourably shape the system and understand how to influence lasting change in agtech adoption. For instance, the World Wildlife Fund recommends rewarding farmers with payments such as carbon credits for improving soil health and integrating livestock (CSC, 2020). Public sector stakeholders work to engage farmers in technology and co-develop policy solutions, which is critical to ensuring that agtech is not just "cool" in the lab setting but also feasible and valuable in real-world applications.

In terms of incentivizing startups and agri-tech entrepreneurship, this support could be targeted towards regional incubators and accelerators to educate and support company growth. Regional incentives may also attract foreign interest from startups; for example, I met Saga Robotics[13] at LIAT in the UK, even though they are originally a Norwegian company. They have opened R&D operations in the UK and are growing part of their business there as the UK public sector offers tax incentives for technology development.

Regardless of the mechanism and target, clear and transparent policy requires government investment to engage producers, technology experts, and develop solutions from the outside-in, while considering implications throughout the agri-food value chain, to be most effective.

2.2.3 ACADEMIA, EDUCATION, AND KNOWLEDGE/TECHNOLOGY TRANSFER

Academia, education, and knowledge transfer play a crucial role in the adoption of agtech. One way they do this is by paying attention to how to work with farmers and early adopters. For instance, Harper Adams University consulted with community legislators and considered public perception when

[12] https://www.bsigroup.com/en-CA/
[13] https://sagarobotics.com/

introducing autonomous practices in their fields. They also made sure to provide bolt-on solutions for farmers who prefer something they are familiar and comfortable with.

Another way academia and education help to increase agtech adoption is by studying determinants of adoption, such as the influence of neighbour behaviour. The PhenoRob[14] (Robotics and Phenotyping for Sustainable Crop Production) research Cluster of Excellence at the University of Bonn includes over 100 interdisciplinary researchers in computer science, geodesy, robotics, plant science, soil science, economics, and environmental science, all working to transform crop production by optimizing breeding and farming management through developing and deploying new technologies. I spoke with an economist there, who is investigating various determinants of adoption to identify the most critical factors influencing agtech adoption for extension specialists to be better equipped to transfer knowledge (Storm, 2021). The research at PhenoRob can be used to inform policy design around information sharing with industry and improved communication to foster acceptance of innovation.

In addition to academia and education, innovative programs such as France's Hectar[15], an ecosystem for agtech entrepreneurship and education, have emerged to encourage adoption. I spoke with a researcher and veterinarian at Hectar[16], who explained that the school takes an entrepreneurial approach, inviting partners to join their ecosystem with projects and providing an adapted program for people without any agriculture background (Renoux, 2022). The campus includes an accelerator program, a farm lab, and a corporate training program, among others. The farm lab brings together students from business school, agriculture, and technology to work with corporates to discover solutions to pain points. The students are mentored and coached by business and agtech experts at Hectar over one to two months from project brainstorming to kick-off. The goal of this approach is to bring fresh ideas from young researchers and entrepreneurs, using a collective intelligence approach to find solutions. Hectar was created to balance work and personal life with an entrepreneurial/economical blend to ensure production is stable while respecting tradition and the environment. It was conceived by former agricultural policy advisors, entrepreneurs, educators, and industry, with a watchful eye on expected industry changes (i.e., it's anticipated that up to one-third of all French farms will change ownership by 2025).

When built with flexibility and focused on results for producers and industry, academia, education, and knowledge and technology transfer programs have become key to advancing agtech adoption[17]. Their efforts to work with farmers and early adopters, investigate determinants of adoption, and provide educational programs that incorporate innovative approaches can help increase the adoption of agtech and ultimately improve agricultural productivity and sustainability. Public sector involvement and willingness to take risks are crucial to developing large-scale, high-impact projects that could bring about significant changes to the agricultural industry.

[14] https://www.phenorob.de/

[15] https://en.hectar.co/

[16] My thanks to Nuffield France (Stéphanie Chanfreau) and Florie-Anne Wiel for arranging the connection.

[17] There are many examples of academic-public sector partnerships not quite getting the focus on outcomes right and as a result these partnerships often result in frustration and are cumbersome to navigate. For the purposes of brevity this research did not focus on programs where improvements in execution would be beneficial.

2.3 PRIVATE SECTOR

"We need an Elon Musk [for agtech]"
- Prof. James

Regarding agtech R&D, commercialization, and distribution within the private sector I considered three main groups: startups, investors, and corporates (i.e., including input suppliers, equipment manufacturers, retailers, etc.). Producer collaborations between these groups can accelerate adoption in several ways. For example, large corporations often have access to thousands of acres through their customers which can be leveraged for data and information sharing; startups may require industry consultation to trial and validate technologies in working environment settings. A collaborative effort among these groups and with other stakeholders within the agtech ecosystem may create the opportunity to better evaluate new solutions and target producer value propositions, while assessing the agronomic and general validity of new practices and technologies.

2.3.1 START-UPS

Some of the opportunities for startups in the agriculture industry include a growing demand for food due to population growth, increasing pressure to innovate to improve sustainability and reduce waste, and a need for more efficient and cost-effective farming practices. However, there are several challenges that startups face, including a lack of funding, difficulty in gaining access to customers and distribution networks, and the need to navigate often complex regulatory environments. Additionally, the agriculture industry can be slow to adopt new technologies, so startups may need to be patient and persistent in their growth.

I heard from a panel of producers from Brazil who discussed how startups can be most effective in engaging and working with farmers. There was a lot of focus on the need to ask questions and listen to ensure there is an appropriate problem-solution fit; and to focus on offering the solution that is requested (i.e., don't try to upsell), while understanding the customer (e.g., "you're giving me an airplane, when what I need is a bicycle"). This was interesting advice and entrepreneurs engaging with producers would be wise to focus on the solution-ask.

However, in early stages of technology development, there are opportunities to build novel solutions if there are significant gaps and white space to explore. In this case, once there is an idea to be iterated and a minimum viable product (MVP) is developed, then the process can be iterated using feedback from the end users–the producers. Innovation alone is not a business, and the solution must be sold in the market under the appropriate business model. As such, startups should focus on developing products that are intuitive, easy to use, and are solving a legitimate problem for their target customers.

Business models that are newer to agriculture are making progress, such as subscription-based and 'farming-as-a-service' (FaaS), where services are offered as a suite of management solutions, giving farmers access to services such as precision farming tools, analytics, labour services, equipment rentals, and market access, and more. It can include a combination of software and hardware, or one or the other. The Small Robot Company[18] in the UK is using a FaaS business model to ease technology switching costs for producers as they use small and light robots to collect data to analyse, much like an agronomist would do, but with improved accuracy to bring intelligence to the level of the individual plant. They are

[18] https://www.smallrobotcompany.com/

continually iterating their technology to be lighter, more accurate, and with a longer battery life. While it would not work in all cases, as it was often noted that farmers prefer to purchase their own equipment, with early-stage solutions the FaaS business model can be less risky for farmers to engage these services as they won't be left with an early, and likely quickly outdated, version of a technology as they iterate and improve.

As generally smaller players in the private sector, startups are looking to partnerships to reduce risk and grow. In France, Hectar pairs startups with farmers for field trials in their accelerator program. While the participating farmers initially start off as advisors, they also have skin in the game with this collaboration. Eventually the teams get to a peer-to-peer network collaboration, which results in the most valuable feedback for what is working and what isn't. In Canada, it was noted that a successful model for adoption might be to utilize a non-direct method, where startups begin working with industry by first engaging existing and trusted service providers, such as agronomists, as the initial entry point for technology transfer to industry (Sinclair, 2022).

Startups require significant capital and resources for market access, as well as training to support product development. And while the need for capital is not unique to small or early companies, an interesting observation in Brazil is in the biologicals market where smaller and newer companies are making progress and gaining market access more readily when compared to other global regions[19]. New ventures in the agtech space will likely need five or more years to really get to distribution. During this time, they need alignment with customers to continuously improve their product, gain traction to gain investment, and develop their distribution and support network to gain critical mass (Redick, 2022).

The most impactful takeaway might also be the simplest, to communicate solutions and progress to the world as effectively as possible to get the solution through the noise and into the hands of the producers who can most benefit from the innovation. Startups can host workshops, provide training materials, or partner with agricultural extension services to promote their solutions. At the end of the day, farmers are also entrepreneurs, and they are looking for solutions to ensure their operation profitability.

2.3.2 CORPORATES

Corporates within the private sector are playing a significant role in driving the adoption of agtech, as they recognize the potential for transformative change in agriculture and focus on adding value to farmers, driving business goals with utilization of technology, and creating funnels of engagement. Companies such as Bayer Crop Science[20] are leveraging technologies such as e-commerce solutions, satellites, and an open innovation model[21] to drive innovation. They are incorporating satellite technology to predict yields and are investing in training individuals to understand the value of technology and consider the cost of implementing and adopting (CSC, 2020).

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[19] There are numerous and interacting hypotheses around this observation, including government support, knowledge transfer, cost-effectiveness of bio-inputs for manufacturers and producers, diversity of crop production, and tropical climate considerations.

[20] https://www.bayer.com/en/agriculture

[21] Open innovation is a collaborative approach that involves sharing knowledge, resources, and technologies across traditional boundaries to accelerate the creation and application of innovative solutions.

Digital farming has great potential, but companies such as Yara International[22] (global headquarters in Norway) are wary of creating more data for data's sake. Yara's Atfarm tool is using satellite data to create a regenerative index, driven by agronomists, to create accessible tools regardless of farm size (Campuzano, 2022). Companies must focus on creating actionable insights for informed decisions and using risk-sharing and value-based pricing to address fears and share the risk. Similarly, PepsiCo[23] is using digital tools to collect and structure data on potato crops, with 35 dashboards for KPI benchmarking and supplier/grower/variety performance analysis to communicate results to growers and facilitate adoption of sustainable practices under their Pep+ initiative (Cerezo Rebe, 2022). Growers are finding value in the single-entry method for the platform (i.e., structured data from planting, chemical use, inputs, irrigation, and crop development) as well as the sustainability metrics. Barilla[24] is demonstrating the technology benefits to their contract growers with a digital platform to provide insights on optimized crop rotation, tillage, pest control, seed variety, sowing timing, and nitrogen management (Silvestri, 2022). Many of these corporates are not charging for the platforms, which can often be used on acreage not under contract with the company[25]; rather they are provided to the growers to facilitate adoption of improved practices, and the corporates are able to use the data to inform their own processes, whether they be related to yield forecasting or performance benchmarking.

The challenge for companies such as Philip Morris International[26] is selecting appropriate technology to address a compelling business need, gaining senior management support, and ensuring that technology meets ESG and legal requirements. It employs an Innovation Funnel process that leverages collective experience and prioritizes ideas based on strategic fit, business value, feasibility, and desirability (Roberts, 2022). Quick implementation is also essential to prevent duplication and repeating mistakes. While large, high-impact innovation ideas are often favoured, incremental innovation can be more successful and requires less development time and budget.

In terms of investing in R&D, large for-profit firms generally factor in market size, technological opportunity, ability to generate economic benefits of research, and the costs of R&D inputs (Fuglie et al., 2012). Private sector R&D investment has been increasing since the 1980s with advances in biotechnology research, while public sector investment has slowed during the same time (Fuglie et al., 2012), with U.S. public agricultural R&D falling by approximately one-third over the past two decades (Nelson and Fuglie, 2022). While investment may appear to be a positive outcome for the agriculture industry, it must be noted that this private R&D investment is concentrated among only a few firms, which may be concerning for encouraging new entrants (i.e., startups) and agriculture diversity (i.e., expand crop type focus).

The private sector is playing a significant role in driving the adoption of agtech, and companies are using various technologies and strategies to transform the agricultural industry. However, challenges such as changing industry standards and regulations, creating actionable insights, and selecting appropriate technology must be overcome. The industry must also focus on training individuals to understand the value of technology and provide cost-effective solutions.

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[22] https://www.yara.com/

[23] https://www.pepsico.com/who-we-are/our-commitments/pepsico-positive

[24] https://www.barillagroup.com/en/sustainability/sustainable-sourcing/

[25] Some corporates indicated that there may be a charge at some point. This is like the Lely automated feeding system where the partnering producer did not pay for the information while the concept was being developed.

[26] https://www.pmi.com/

2.3.3 INVESTORS

Private investors, such as private equity (PE) and venture capital (VC)[27], are crucial in contributing to the adoption of agtech. The investments provided by PE and VCs help early-stage technology companies to receive funding, expertise, and resources, which accelerates the pace of innovation and brings new technologies to market more quickly. VC firms encourage cross-disciplinary research and often invest in companies working at the intersection of different fields, such as biotech and software. This investment helps to bring about technology convergence and develop new solutions to complex problems. Additionally, VC firms have extensive networks and resources that help portfolio companies grow and succeed, including access to specialized expertise, mentorship, and other resources to support venture success. Over the past decade private sector investment in agtech for on-farm solutions has grown from about US$0.8bn in 2013 to US$10.2bn in 2022 (AgFunder, 2023; Figure 8). In 2022 this represented 847 deals[28] (AgFunder, 2023; Figure 9).

Accelerators, venture studios, and incubators also play a significant role in agtech adoption by providing startups with resources and mentorship to help overcome challenges, such as a lack of funding, talent, or expertise. Agtech requires a fundamental new way of doing business, and accelerators and related stakeholders can help bridge the gap between traditional agriculture and the technology industry.

At an investor panel I attended in Brazil, investors were asked what entrepreneurs need to get right to attract investors (World Agri-Tech South America Summit, 2022). Top 'needs' for investors included:

- Existing customers and market relevance.
- Good team with passion and commitment.
- Proprietary technology.
- Demonstrated sales and growth (revenue vs. capital expenditure).
- Consistent unit economics business model and scalability.
- Sustainability impact.
- Go to market agility (i.e., within 1-2 years).
- Certainty and clarity on profitability and flexibility to stretch the runway if needed.
- Controlled growth as the most important factor.

There are several challenges that need to be overcome for agtech adoption to continue to thrive. In Latin America (LATAM), it's generally thought that there is more caution around getting cash, and as a result companies who can raise funds are generally more resilient (World Agri-Tech South America Summit, 2022). Recently, access to equity is getting more difficult everywhere, due to high volatility and interest rates. This is impacting the way deals are structured today, with co-investment more frequently coming from institutional investors via specialized funds and extended hold periods, which is expected to throw off the entire investment cycle, including the PE/VC firms' ability to raise additional capital in future periods (Verdant Partners, 2022).

Private investment provides startups with the resources and expertise needed to bring new technologies to market quickly. However, challenges need to be overcome, such as access to equity, rising interest rates, and hold periods / raise cycles. Overall, the trends in the private investment sector are positive for bringing innovative solutions to the industry as investment tends to lead to more nimble

[27] Private equity is capital invested in a company that is not publicly listed or traded. Venture capital is funding given to startups or other young ventures that show potential for long-term growth.
[28] There were 1,362 total upstream deals and 2,606 deals in all agri-food tech in 2022 (AgFunder, 2023).

companies that are less dependent upon financial engineering and more focused on fundamental business activities to achieve growth.

Various indicators (e.g., resource and climate constraints, population growth, etc.) have established the need for agtech solutions, and as a result farm technology investment has grown on average 34% each year for the past ten years (AgFunder, 2023). However, investment is generally occurring at earlier stages, Seed and Series A, leaving funding diluted and startups struggling to scale (Fiocco et al., 2023) and build the required customer base. This gap is of concern, and more needs to be done to help startups grow to the scaleup stage; this is often known as the scaleup gap, and some regional public programs are beginning to provide support through public and VC-run accelerators and related programming (Alberta Innovates, 2022).

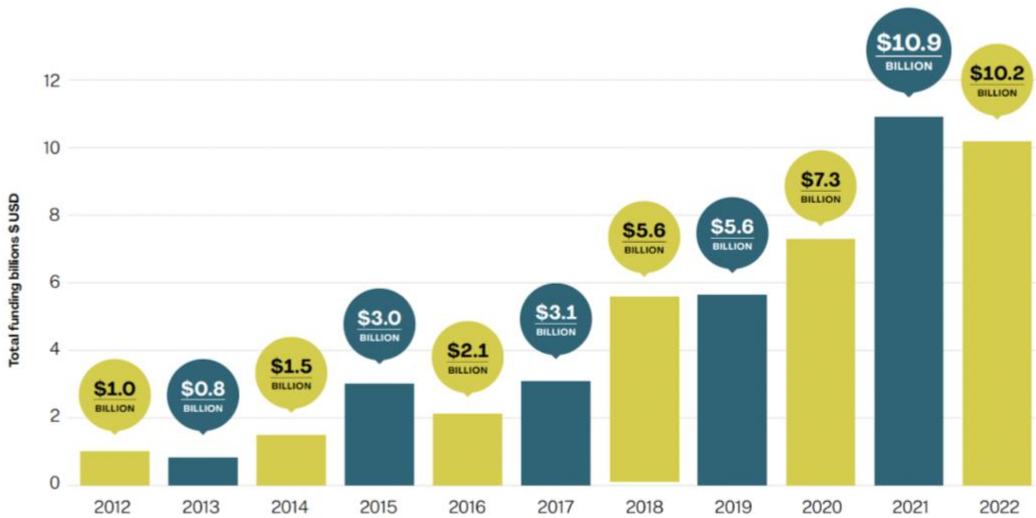

Figure 8. Agtech (on-farm solutions) funding by year (Source: AgFunder, 2023).

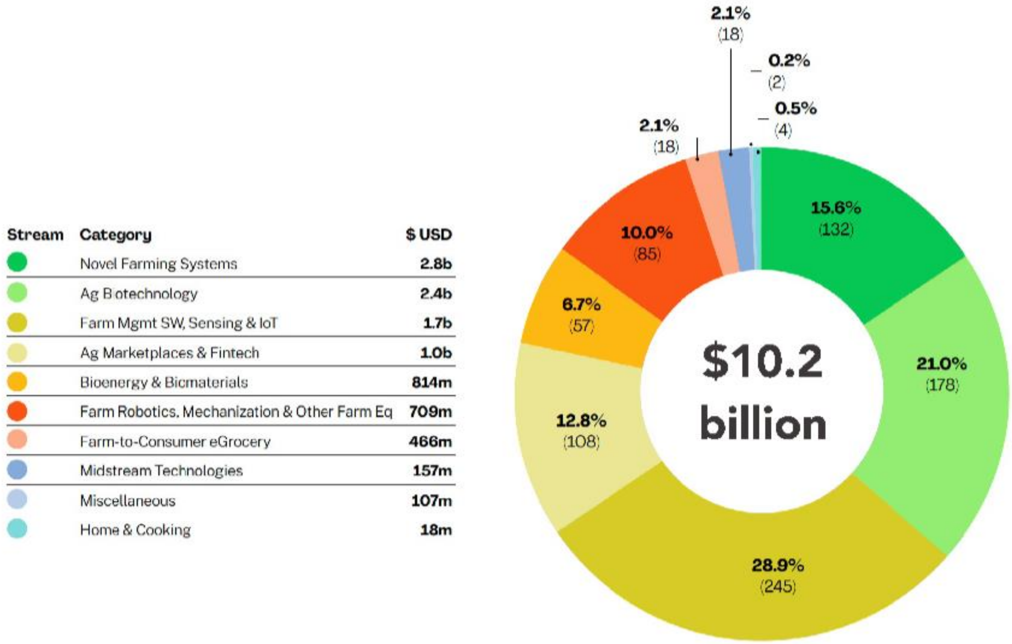

Figure 9. Agtech (on-farm solutions) investment by category, 2022 (Source: Agfunder, 2023).

Overall, adequate capital and support is necessary for companies of varying maturities, but particularly at scaling and commercialization stages (Macdonald et al., 2022). Future opportunities for investment are expected for solutions that help farmers and agribusinesses increase efficiency and navigate an increasingly complex regulatory environment, all while improving food security and reducing our impact on the environment, such as agri-fintech, controlled environment agriculture, soil health and carbon tech, novel crop nutrition solutions, and alternative proteins (Macdonald et al. 2022).

2.4 INTERCONNECTED THEMES AND TOPICS

"Innovation without social justice will not work."
- UNFSS, 2021

With more advancements, the reach of agtech becomes broader as the opportunities for problem solving extends to themes beyond the immediate stakeholders. Related themes that surfaced throughout my research include awareness of consumer acceptance, sustainability, climate change, regenerative agriculture, new market opportunities, and the need for diversity, equity, and inclusion when designing policy and technology solutions. All these considerations eventually connect in some direct or indirect way with the stakeholders discussed in previous sections. This deep interconnectedness becomes more apparent when considering downstream stakeholders and themes indirectly impacted, but impacted nonetheless, by agtech and its related policy, market disruptions, and environmental considerations.

2.4.1 CONSUMER ACCEPTANCE

There are often conflicting demands at the point of the consumer. There are indications of consumers wanting both high quality, flexitarian, sustainably sourced food, but with inflation at an all-time high there is also increasing focus on affordable and healthy food and improved food access.

The world's food system faces numerous imminent threats, including population growth, climate change, and food supply shocks due to crises such as pandemics. Disruptive[29] food technologies are considered critical for the transition towards a more resilient food system. It is crucial to consider the factors influencing consumers' perceptions of novel technologies in food production during the early stage of development and introduction to ensure greater acceptance (Siegrist and Hartmann, 2020). Given the limited number of disruptive innovations in the food system (i.e., see Figure 10), there is a clear need for new technologies to address the various challenges related to food production and supply.

Siegrist and Hartmann (2020) discuss consumer acceptance of four different novel[30] food technologies: gene technology (GT, i.e., genetically modified, GM), nanotechnology, cultured meat, and food irradiation. In the case of GT foods, there is some perceived dread translating to hazard around the perception of GM foods. It is noted that people generally lack knowledge on GM foods and so they are evaluating the foods attributes on heuristics related to trust and naturalness. Engineered nanoparticles are used in food additives but in the future may expand this to new crop breeding methods to enhance plant growth and disease resistance. Most consumers are unaware of nanotechnology used for preservation techniques, and they are generally unable to assess risk or benefits of this technology. Cultured meat is grown with fermentation technologies from stem cells as an alternative to livestock production. Cultured meat is only available for public consumption in Singapore to date (Yu, 2023), so true consumer acceptance is still uncertain, but it's expected to be some balance of risk/disgust over the unnatural heuristic versus the animal welfare benefit; and of course, cost will be a critical consideration for acceptance. Finally, food irradiation generally evokes negative associations with consumers and the treated products are often perceived as lower quality. Regarding agtech, GM foods are the main interest; however, understanding how consumers view other disruptive technologies is relevant for understanding best practices in communicating with the end consumer, and to better understand the demands of consumers.

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[29] Disruptive innovation describes a process where a product or service initially takes root in simple applications at the bottom of a market—typically by being less expensive and more accessible—eventually displacing established competitors.

[30] The term 'novel' does not necessarily refer to the invention of a technology, but rather to its introduction into the market.

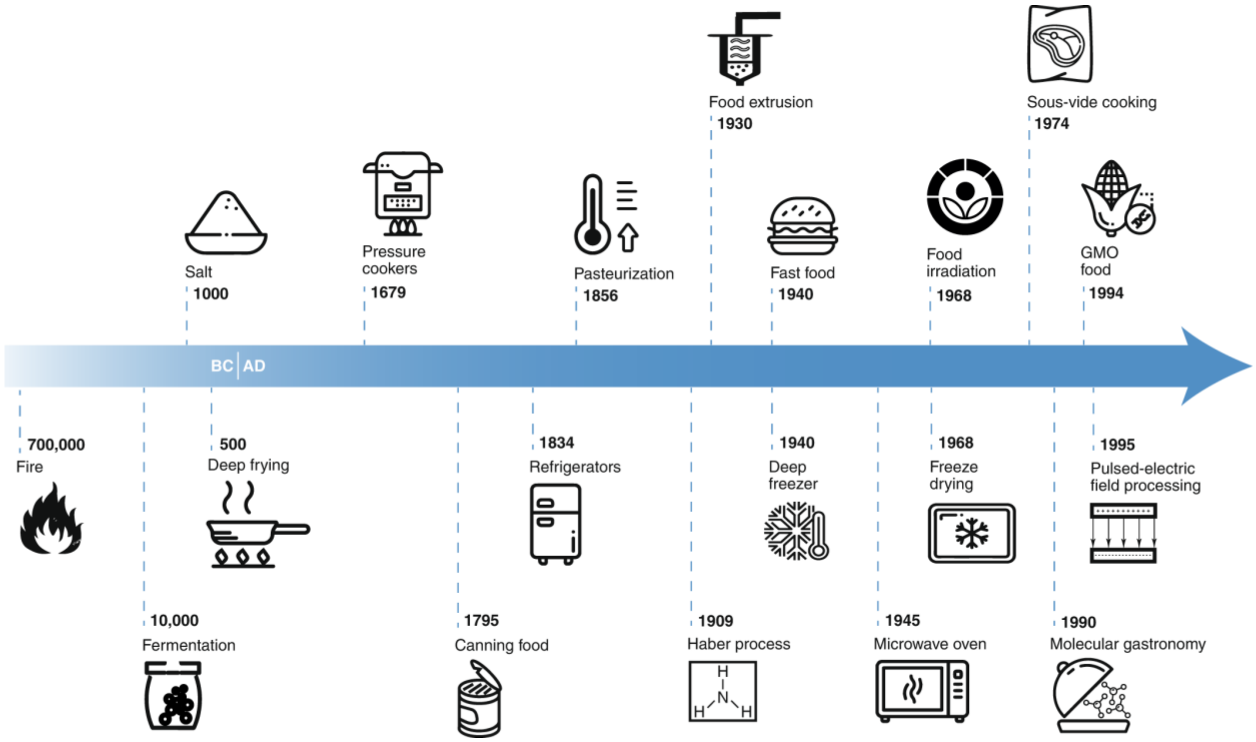

Figure 10. Timeline of historical food technologies (Source: Siegrist and Hartmann, 2020).

The need for a sustainable, secure, and safe food system necessitates the use of novel food technologies. However, general skepticism regarding technologies in the food domain remains a challenge (Siegrist and Hartmann, 2020). The food industry needs to become more in tune with changing consumer behaviour, which is increasingly influenced by government education and incentives. Labelling has an impact, as when regulatory bodies determine a technology should be labelled if used in/for food production, consumers may interpret this as a warning and feel an associated risk with consuming labelled products. Most companies acknowledge that market trends associated with the future of food have a significant impact on their business, and therefore, aligning business models with future-of-food trends is vital to keeping businesses future-proof, attracting new customers, and increasing sales (Deloitte, 2022).

There are several considerations from a consumer acceptance perspective when it comes to the adoption of agtech, including:

- Consumers need to be educated about the benefits of agtech and how it can improve the quality and safety of the food they eat. Producers, processors, and retailers can help by explaining the benefits of new technologies and providing information about how they work.
- Consumers need to trust that the food produced using agtech is safe and healthy. Farmers and agtech companies can build trust by being transparent about their practices and by following best practices for food safety.
- Consumers are increasingly concerned about the environmental impact of agriculture. Agtech can help to improve sustainability by conserving resources and reducing the use of pesticides and other chemicals.

2.4.2 CLIMATE CHANGE, SUSTAINABILITY, AND REGENERATIVE AGRICULTURE

Agtech solutions that are developed and adopted must be mindful of other factors to ensure that they contribute to the development of sustainable, resilient, and equitable agri-food systems. Climate change, sustainability, regenerative agriculture, and related topics are considerations that arose during my research as themes necessary for consideration when adopting agtech solutions. These factors are closely intertwined and interdependent, and addressing one without the others may not result in the desired outcomes of improving productivity and sustainability.

In the past several years we have seen some of the warmest temperatures on record, along with megadroughts and floods. Climate change is one of the most pressing issues facing the world today, and its impacts are already being felt across the globe. Agtech solutions to help mitigate and adapt to climate change are becoming increasingly important. This includes technologies that can help reduce greenhouse gas emissions, improve water management and soil health, and promote climate-smart agriculture. During my research I heard from a producer in the UK who is tackling soil degradation with the intent to reduce his climate impact by incorporating agroforestry to sequester more carbon in his soils. He is using a mixed approach, with traditional orchards with livestock, established tree stands for timber and fuel, and mixed nut and deciduous trees with cropping strips (Norfolk Agri Association, 2021).

In the above case study, the producer is using some principles from syntropic agriculture, which moves innovation beyond technology to include a focus on the human-nature relationship, with the aim to balance social, economic, and environmental goals. It successfully achieves productivity targets, while promoting succession and regeneration of native ecosystems via the combination of scientific and traditional knowledge, a practice that resorts to no-impact or low-impact technologies, and a philosophy that perceives humankind and nature as integrated and interdependent (Andrade et al., 2020).

Environmental sustainability is another important consideration for agtech adoption. Agtech solutions must be designed and implemented with the goal of reducing negative environmental impacts, such as land degradation, soil erosion, and water pollution. This can be achieved by using precision agriculture technologies to reduce inputs and optimize resource use, as well as promoting sustainable practices such as conservation agriculture and agroforestry. Not all advancements necessarily directly use agtech; I heard from a (different from above) UK producer who is combining biodiversity and carbon sequestration by taking 500 hectares of marginal land out of production. The result is saving him £45,000 per year in diesel, reducing the equivalent emissions, and has reduced the need for herbicides by incorporating beets in his crop rotation. Biodiversity is de-risked due to reduced compaction, fertilizers, and chemicals from cultivation, and it has also saved him these input costs (Norfolk Agri Association, 2021).

Regenerative agriculture practices have been lauded for decades, but more attention is on the space due to the urgency to improve soils and for the search for input alternatives (i.e., due to supply, costs, regulations). Regenerative agriculture is an approach that aims to restore and enhance the ecological health of farming systems. Agtech solutions that promote regenerative agriculture can help improve soil health, increase biodiversity, and enhance ecosystem services. This can be achieved using technologies that support diversified cropping systems, reduce tillage, and promote the use of cover crops and green manures. To many producers, including a multispecies producer in the UK, livestock and net zero go together, with this producer focusing on forage-mixes to balance her soils (i.e., including alfalfa, chicory, sainfoin, birdsfoot trefoil, plantain), and subsequently seeing improvements in lamb liveweight gains

(Norfolk Agri Association, 2021). While there is no agreed-on definition for regenerative agriculture, it is inextricably tied to soil health and soil management, and as such it's critical to work at field level to improve carbon storage via practices such as no till and cover crops (World Agri-Tech South America Summit, 2022), in addition to livestock integration.

Agtech has an important role to play in transitioning towards a more circular economy in agriculture. A circular economy aims to minimize waste and maximize resource use efficiency by promoting closed-loop systems that reduce the need for new inputs and minimize waste outputs. In agriculture, this means finding ways to reuse and recycle agricultural waste and by-products and reducing reliance on synthetic inputs. Agtech can facilitate this transition by providing tools for precision agriculture, which can help farmers optimize crop yields while minimizing inputs such as water, fertilizers, and pesticides. Additionally, agtech can provide solutions for the recycling and repurposing of agricultural waste, such as using crop residues for feed or bioenergy production. By adopting circular economy principles, agtech can help reduce environmental impact and create a more sustainable and resilient agricultural system.

In agriculture, sustainability generally means 'nature positive food production' and it is regenerative and non-depletive. Sustainable agriculture delivers healthy and nutritious food while respecting planetary boundaries and protecting the natural environment. As sustainability is a driver of growth, we cannot demonize the farmers as they are the conduit to sustainability (World Agri-Tech South America Summit, 2022). In general, other stakeholders who may be providing some of the tools and technologies to producers need to better understand on-farm practices by spending more time on-farm. This includes policymakers to ensure the correct incentives are in place and technologies reach the farmers. Today, we get approximately 75% of our calories from twelve plants and five animals; there is a need to diversify for human and planetary health (World Agri-Tech South America Summit, 2022). Knowledge and technology transfer is an important consideration for sustainability when considering agri-innovation adoption, including but not limited to agtech.

Another consideration that came up during my research include ESG (environmental, social, governance) implications. Typically, this framework is related to investing, but it's also applicable to technology development, when we consider the greater ecosystem requiring interaction from various stakeholders including large corporations, investors, and startups. Agriculture can be both detrimental and beneficial to the environment and the environmental and social factors of ESG and agriculture can often be intertwined, and often impacted by policy. Major corporations and non-profits within the agri-food sector have committed to initiatives to promote soil health and environmentally friendly agriculture. ESG is the triple bottom line for industry sustainability and identifying these impacts is the first step towards mitigation, which must be considered in designing policy and technology to produce safe, smart, sustainable food[31].

Agtech solutions that are designed and implemented with these factors in mind can contribute to the development of sustainable and resilient agri-food systems that benefit both farmers and consumers. By taking a holistic approach that considers the interdependence of these factors, agtech can play a vital role in addressing the challenges facing the agriculture sector today. There is an urgency for transformative action as we are only a handful of seasons to 2030, the year many organizations have

[31] The types of ESG impacts most often considered in agriculture and food sector reporting and target setting include energy consumption, biodiversity, GHG emissions, climate resilience and adaptation, water management, gender balance, food safety and security, Indigenous partnerships and relationships, and fair labour practices (Chell et al., 2022).

committed to change; but more importantly, we are worryingly close to triggering a climate tipping point (Armstrong McKay et al., 2022). We must be able to measure impact to deliver results, and this will require more ambitious and transformative leadership to embrace systems thinking.

2.4.3 NEW MARKETS

Agtech is opening new market mechanisms related to sustainability and environmental impact. One such mechanism is carbon markets, which allow for the trade of carbon credits to incentivize carbon sequestration and emission reductions. Farmers and ranchers can participate in carbon markets by implementing regenerative and sustainable agriculture practices that sequester carbon in the soil or by reducing their greenhouse gas emissions using various agriculture technologies and techniques.

Carbon markets are in a transition stage, where there is much discussion around avoidance vs. capture and voluntary vs. mandatory. Co-development with new Measurement, Reporting, and Verification (MRV) techniques to determine lasting impact of these markets will be critical. In Brazil the most significant impact to carbon footprint is land use change (World Agri-Tech South America Summit, 2022). And while there is a need to stop land conversion and create incentives to reforest the land, the pull must come from the entire value chain, including consumers (e.g., carbon markets to create the incentives and compensate farmers). It is also an incredibly complex issue that goes far beyond the agriculture sector into forestry, infrastructure development for transportation (i.e., roads creating landscape fragmentation), and policy around economic development.

While it's not the focus of this work, new techniques in MRV are helping establish both voluntary and compliance carbon markets in Canada and globally. As agriculture can be both a source and sink of GHG, carbon can be removed in two ways, offsets or insets, where insets reduce emissions on the farm based on production practices, while offsets compensate for emissions elsewhere either on the farm or within the supply chain. There are various methods agtech might contribute to these markets; for example, a producer in the UK is growing hemp and developing the associated industrial value chain (e.g., hempcrete as a carbon sink) as a carbon capture tool but incorporating carbon trading with Dark Green Carbon[32] which uses blockchain technology[33] to ensure transparency in its end-to-end carbon offsetting solution (Norfolk Agri Association, 2021).

In Canada many farmers are cautious about carbon markets as the contracts, out of necessity, extend over a long period. As carbon markets extend beyond agriculture, there are issues with timing and 'permanent' carbon storage, where verifiers are normally looking for 100 years, but have loosened to 5-20 years for agriculture carbon markets (Sinclair, 2022). Baseline sampling is very costly and returns within five years are still uncertain. Add to that, the additionality and the 'neighbours' clause, which makes some good producers ineligible due to current use of good practices (i.e., in some carbon markets, if regenerative is already being used, the baseline measurement precludes them from benefiting from the market mechanism). In comparison to cropping agriculture, there is significantly better potential for carbon storage in pastureland and livestock production as it can be difficult to permanently sequester carbon in row crops.

[32] https://darkgreencarbon.org/

[33] Blockchain technology is digital system that keeps records of transactions across many computers in a way that ensures security and immutability of the data.

For improved success, there needs to be a cultural and technological shift. Carbon markets require good data to ensure the models are accurate (i.e., including soil and management). Protocols must work for the grower (i.e., ground truth the models) and be created with capacity to scale. To date, many groups are tackling the education component by developing tools to show the farmers the impact of their carbon decisions. They are working with universities to validate the technologies to measure soil carbon and land change to validate the scientific baselines and determine the real needs of the market. It goes beyond creating incentives for producers in terms of payments and improved land health; countries with aggressive carbon pledges, such as China are a key buyer of agricultural products worldwide, and regions who deliver on improved carbon sequestration and storage may become preferred suppliers (World Agri-Tech South America Summit, 2022).

Besides carbon markets, other market mechanisms include sustainability certification programs that provide premium prices for sustainably produced food and fibre products. These programs can incentivize farmers and ranchers to adopt sustainable practices and provide consumers with more transparency and assurance that their food and fibre purchases are contributing to a more sustainable future. Additionally, there is potential for agtech to facilitate new markets for alternative proteins, such as plant-based and lab-grown meat, which may provide more sustainable and efficient alternatives to traditional animal protein production under certain conditions. Other markets could include diversification strategies such as agrotourism, agroforestry, and more.

2.4.4 REPRESENTATION: DIVERSITY, EQUITY, INCLUSION

In recent years, there has been an increasing recognition of the importance of equity, diversity, and inclusion (EDI) in various fields, including agtech research, commercialization, and adoption. EDI is a conceptual framework that promotes fair treatment and full participation of all people, especially those who have historically been underrepresented or subject to discrimination.

Drawing insights from other knowledge systems, including Indigenous Peoples, small-scale producers, and other under-represented groups can contribute to informing policy for more efficient, inclusive, resilient, and sustainable agri-food systems. In Brazil, it is necessary to bring more women to the table for making decisions on agtech implementation. There, women make 62% of the purchasing decisions, highlighting the importance of including their perspectives in agtech development and commercialization. In other regions, women act as knowledge translators in the rural economy as part of the gig economy. They are paid for working with farmers and getting them to transition their practices (digital transition as well); by incorporating social integration and inclusion within the local ecosystems, there is a more sustainable adoption model for agtech (World Agri-Tech South America Summit, 2022).

The FAO's first-ever Science and Innovation Strategy was designed through an inclusive, transparent, and consultative process[34]. The strategy indicates that FAO will strengthen its contribution to science-policy interfaces at national, regional, and global levels to support organized dialogue between all relevant stakeholders in support of inclusive science-based policy making for greater policy coherence, shared ownership, and collective action (FAO, 2022).

[34] The "accelerators" of the FAO Strategic Framework 2022–31 include technology, innovation, data and complements (governance, human capital, and institutions), as well as cross-cutting themes of gender, youth, and inclusion.

By promoting diversity, equity, and inclusion, we can create more innovative and sustainable solutions that benefit everyone in the agri-food industry. However, in practice the integration of science and evidence into effective agri-food sector decision-making processes remains a significant challenge. Policymakers may not inform scientists and other knowledge holders about their needs, while scientists and other knowledge holders may not actively engage in the policy-making process. Additionally, many obstacles may compromise this participation. Therefore, it is crucial to promote diversity, equity, and inclusion in the agricultural sector to ensure that all voices are heard, and decision-making is inclusive and informed.

2.5 OBSERVATIONS AND INTERPRETATIONS SUMMARY: ROLES OF STAKEHOLDERS

> *"I believe in the deep interconnectedness of everything, in the benefits of our codependency, and in the opportunity of today when we believe in a tomorrow. […] I believe that we have done well, but I think we can do better. I believe we can do much, much better."*
>
> — Frank Chimero, The Shape of Design

The agri-food sector is unique from an innovation perspective due to the fragmented and high-risk nature of primary production, variability across different geographies and crop types, impact of climate, natural processes, and seasonality, and high entry costs (Macdonald et al., 2022). Despite these numerous challenges, there is a general optimism of being in this 'transition' period in agtech's evolution from its costly and tenuous beta version to a robust and ubiquitous gold version. The numerous stakeholders within the agtech ecosystem are inextricably linked and dependent on each other to attain a sustainable future for the agriculture industry. Overall, stakeholders need to collaborate and move away from the 'us vs. them' mentality for this to be achievable.

The biggest challenge to overcome is change; whether that be from informal practices related to tradition or attitudes or formal legislation and regulations. To bring about agri-food innovation, change will be required, and this will require small change catalysts. These include any stakeholder, so long as they are willing to propose the new ideas that become the basis for change by bridging the gap in a credible and trusted way, including researchers, academics, NGOs, producers, entrepreneurs, and the media.

In many cases, specific changes require efforts from specific stakeholders. For instance, governments can establish policy built on sound science, and they can support healthy competition in the private sector. Policies can be developed to strengthen IP, streamline regulatory procedures, and offer favourable tax scenarios for R&D investment to encourage private investment in agricultural innovation (Fuglie et al., 2012). Almost 25% of companies perceive the government as the most important stakeholder to foster ecosystem collaboration in the agri-food sector (Deloitte, 2022).

Farmers can look for low-risk opportunities to trial new technologies. Industry conveners can help integrate learnings from other sectors, bringing stakeholders together, and accelerating the go-to-market and overall value. Along with innovators, we need sufficient investment capital and other catalysts, including tech accelerators, incubators, and strategic policy efforts, to scale and commercialize technologies (Macdonald et al., 2022). Food companies can collaborate with those in the supply chain to understand the opportunities and impacts of any new technologies. Communicators play a critical role because words are powerful and knowledge transfer is critical. Activism and knowledge sharing can help create a bigger social movement for policy change and ensure that governments are held accountable.

With various global challenges facing the industry today, it's more important than ever to understand and strengthen Canada's agri-food innovation ecosystem. It's not always about what we can do, but also what we should do, what we can do today, and how we can do better tomorrow. There are many exciting developments including recent focus on regenerative agriculture, alternative proteins, and new markets, but the scale-up that is required for system-level change is still lacking. To transition to system-wide transformation we need financial certainty for farmers and innovators, policymakers, and governments to set the stage, pull from well-informed consumers, and all stakeholders to work together to initiate change now, when and where they are.

3.0 RECOMMENDATIONS

With expected increased resource constraints and food demand, agriculture needs to become more sustainable and resilient. This will require increased investment and adoption of productivity-boosting and sustainability-enhancing technology and participation from all ecosystem stakeholders. A wide range of policies directly or indirectly impact innovation, productivity, and sustainability in the agriculture sector. Policy design should focus on measures that facilitate the adoption of technology and practices that enhance sustainability and efficiency. To do so, there are several considerations gleaned from this research:

1) People are at the centre of agtech innovation: human-centred design principles ensure the focus is on the correct stakeholders while accounting for the fact that they are not all the same. For effective policy, think globally for impact, but locally for action and outcomes.
2) Policy, technology, and process should be co-developed with relevant stakeholders: synergistic models between government and the private sector combine mandates and ability to enable capacity building and effective distribution platforms.
3) An open and collaborative approach is needed: to be successful, agri-innovation policy must leverage learnings within and external to the agri-food sector. Multiple voices and perspectives will drive a process based on co-learning and mutual responsibility and ultimately ensure improved system resilience.
4) Through systems thinking we consider the interconnectedness of various elements, involving relevant stakeholders, and fostering a culture of collaboration and openness. Utilizing this approach enables policymakers to design policies that not only address immediate challenges but also build capacity for long-term sustainability and innovation within the agri-food sector.

The goals of agri-innovation policy should be to get ahead of global challenges related to environmental impact and on-farm socio-economic instability. To do so, innovative solutions must fit with the needs of the production system. Stakeholders from innovators to farmers need policies to address equity of access, systems that avoid solutions seeking problems, and platforms to overcome knowledge and infrastructure barriers. Further, whole-system, integrated management is needed for assessing progress, and this includes productivity, environmental services, and sustainable intensification.

In the agri-innovation system we must ensure that we are valuing the right things and taking responsibility as we introduce new technologies, practices, and processes. Effective policy should focus on effective governance linking outcomes from local to global scales, use a collaborative approach that takes responsibility, and use a long-term, open view to provide dynamism and cohesion in the agri-ecosystem. These recommendations are discussed in-depth below.

3.1 APPLY HUMAN CENTRED DESIGN PRINCIPLES

Human-centered design can be a valuable approach for creating both agri-food products and services and agri-innovation policy. The main goal of human centred design (HCD) is to ensure an understanding of how to address end-users' pain points and preferences throughout the entire design/development process to ultimately make the product, service, or policy more likely to be adopted and used. By considering the perspectives and needs of the people who will be using the product or service, HCD can lead to designs that are more effective and user-friendly. This approach encourages designers to look beyond traditional solutions and come up with new and creative ideas. And perhaps most importantly, HCD can create effective feedback channels from designers to users, which may result in a more efficient design process and a better end product, service, or policy.

If the benefits are so clear and tangible, it might seem obvious and easy to implement HCD. However, it can be a time-consuming and resource-intensive process, particularly if it includes extensive user research and testing. This is typically a critical step in designing tech-enabled solutions, and an added challenge may be balancing competing priorities and trade-offs between different design elements or balancing difficult and costly changes to the end product or service.

To overcome these challenges, user involvement is key, and involving users early in the design process through user research, interviews, and testing can help. Other stakeholders should include a multidisciplinary development team such as designers, developers, and agri-food experts. Balancing competing priorities and trade-offs is a common challenge in HCD. Prioritizing the most important design elements and managing trade-offs effectively can help to ensure that the final design meets the needs of users.

A component of HCD is to use outcome-focused or results-oriented decisions that are made with the end goal in mind and are focused on achieving specific outcomes, based on evidence, data, and facts to ensure that decisions are well-informed. Decisions are customer-centric, focused on meeting the needs and desires of the customer to ensure that the customer is at the centre of the decision-making process. To get to needs and desires, collaboration and partnerships involving stakeholders from different areas of the value chain should be involved. Outcome-focused decisions are adaptable and flexible and can be adjusted as new information and circumstances arise in order to fully incorporate ongoing improvement and progress.

Iterative design is an approach that involves repeating the design process multiple times, with each iteration building on the feedback and insights from the previous one. Figure 11, shows a understand-explore-materialize (i.e., designing the right things, designing things right, and refining the designs) design process based on Google design sprints that can be used from the ideation stage of a product or policy solution for iterative improvement with feedback from all stakeholders. A design-build-test-learn cycle can be borrowed from biological systems for this continuous, iterative approach, to expand on this framework as the design process is never truly finished, and being flexible and adaptable to changes and new information can help to ensure that the final design is the best possible solution (i.e., from 'learn' to re-start the iterations). Resilience is developed by staying persistent about solving the problem at hand; however, there must be flexibility in the solution—how it's developed, delivered, and more. A willingness to evolve methods for designing solutions is key to rapid iteration and creating new solutions.

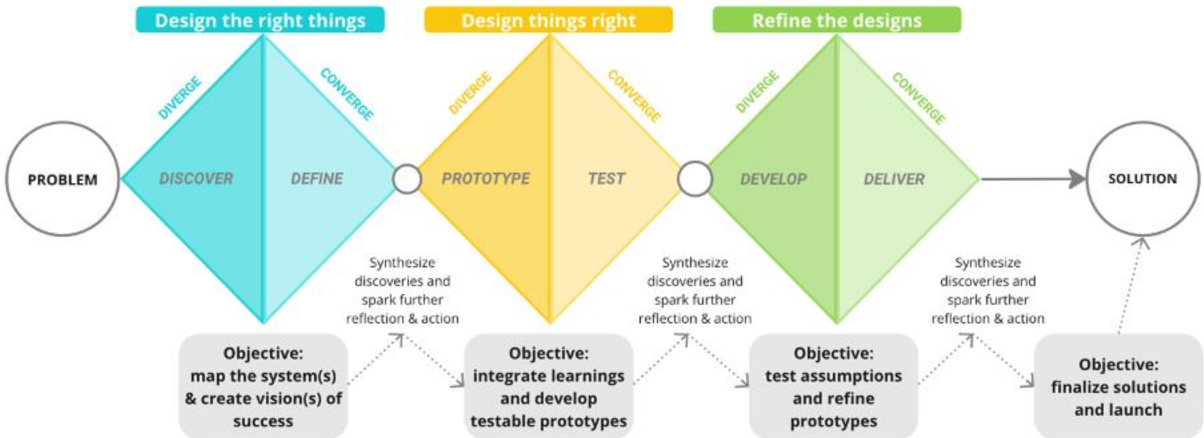

Figure 11. Design sprint process for solving problems and testing new ideas.

While an iterative process for continual improvement of technology is a factor, I heard several times during my research that it's not the technique or technology that is that issue; it's the implementation and accessibility of information which ultimately impact updates and advancements of technologies within the agri-food sector. An effective approach outlined by a farmer and agtech entrepreneur I spoke with suggests starting with an accessible platform (i.e., user design) and working with industry standards and groups external to agriculture, as these are the groups who often hold and update the standards (Nijkamp, 2021).

One method to improve implementation is participatory design, a framework that has been used in wide-ranging approaches and applications since the 1970s (Jackson-Smith and Veisi, 2023), including in agriculture. When applied effectively, these methods can improve understanding of agtech development and adoption by managing expectations and engaging all stakeholders early and often in the product development process. Early engagement, particularly with end users, results in better design outcomes and opportunity to develop responsiveness to shifting conditions impacting agtech adoption, including policy (Stitzlein, 2020). Linking product design with continuous end-user feedback can enable developers and farmers to connect and align desired outcomes to enhance the overall impact of the technology solution (Stitzlein, 2020).

Policy can have a significant impact on HCD and outcome-focused principles by creating an environment that supports and incentivizes decision-making based on measurable outcomes related to end-users needs. Policies can support research and development in human-centered design, which can help to improve the effectiveness and applicability of these principles. Beyond regulation and direct support, policies can foster collaboration between stakeholders, including customers, suppliers, employees, and other partners, to ensure that products and services are developed with a focus on user needs and desires. This can be achieved through programs that require collaboration between stakeholders and initiatives to promote collaboration within industry and academic sectors, and might include funding for academic research, on-farm trials or proof of concepts, business and innovation grants, partnerships between industry and academic institutions, and support for public-private partnerships. While there are several examples already mentioned where participatory design is included early on, another example that I came across during the travel component of my research was the PepsiCo Positive (pep+) initiative (Cerezo Rebe, 2022) in sustainable farming, where groups such as the International Center for Tropical Agriculture (CIAT), German Agency for International Cooperation (GIZ), Foundation for Food and Agriculture Research, U.S. Farmers and Ranchers Alliance, World Farmers' Organization, and AgroScout partnered to develop demonstration farms to support farmers in a transition to best practices to yield beneficial outcomes for producers and the environment[35].

In terms of who to engage, policy should encourage the engagement of farmers, food processors, rural communities, and other stakeholders to contribute to the design and development of agricultural technology. Policies that support and promote the co-creation of solutions can ensure that the technology developed is user-centric and responds to the needs of the agriculture sector. Governments can invest in creating an innovation-friendly ecosystem by supporting research and development, facilitating access to finance, and promoting public-private partnerships. This can include targeted support for incubators, accelerators, and innovation hubs.

Regulations should be designed to promote the use of innovative technologies in the agriculture sector while ensuring safety, security, and environmental protection. Governments should work with stakeholders to develop policies and regulations that encourage experimentation and innovation while minimizing risks. The development of open standards, data interoperability, and common platforms can promote the development of sustainable and efficient agriculture systems. Governments can promote open standards and data sharing practices to support the development of interoperable technologies.

Training and capacity building can help farmers, rural communities, and other stakeholders to understand the benefits of technology, adopt new innovations, and provide feedback on their effectiveness. Governments can play a role in developing training programs and providing incentives for capacity building. Policy should encourage the development and adoption of technology solutions that promote sustainability, such as precision agriculture, digital soil mapping, and regenerative or conservation agriculture practices. For example, the Government of British Columbia has developed a Sustainable Agriculture Strategic Framework, built on the integration of agtech with regenerative principles based on advisory from farmers, academics, industry associations, private sector representatives and special advisors (Government of British Columbia, 2023).

Governments can provide incentives for the adoption of sustainable practices and support the development of new sustainable technologies. OECD (2022) evaluates agricultural policies in 54 countries, categorizing training and capacity building initiatives under support to general services as 'agricultural knowledge and innovation system'. Canada compares relatively well with other OECD countries in supporting initiatives in this category, averaging over 5% more support as a percent of the total support estimate (Figure 12). Current strategic initiatives falling under this category include the *AgriScience programme*, *Science, research, and innovation*, *Environmental sustainability and climate change, Environmental Farm Plans (EFP)* programmes and the *Environmental Stewardship Incentive* programmes accounting for the bulk of current initiatives. While there was a recent reduction in support for these initiatives in Canada (Figure 12, 2021p), the 2023-2028 framework[36] focused on sustainable

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[35] https://www.pepsico.com/our-impact/sustainability/esg-summary/pepsico-positive-pillars/positive-agriculture

[36] The new Sustainable CAP strategy focuses on sustainable agriculture and tackling the climate crisis, the emergence of new threats, and the development of new technologies. Details here:

agriculture is expected to support the industry with continued industry-led research and development, adoption of innovation, and inspection and control systems (OECD, 2022)[37].

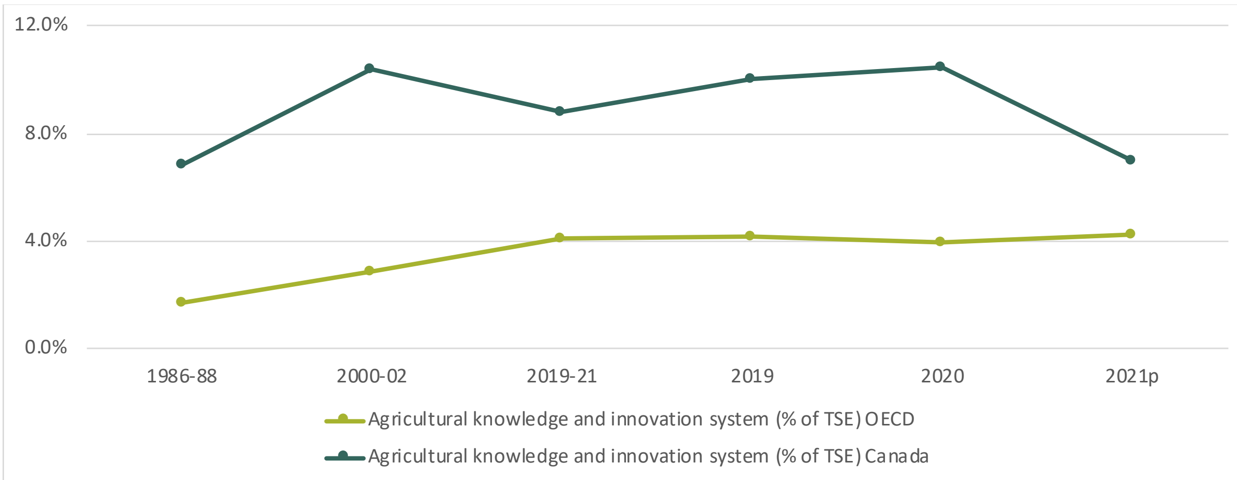

Figure 12. Trends in contributions to agricultural knowledge and innovation systems as a percent of total support estimate (TSE), OECD vs. Canada (data from OECD, 2022).

3.2 UTILIZE CO-DEVELOPMENT PRACTICES

Co-development is a collaborative approach to product or service development that enables multiple stakeholders to work together to jointly develop products or services that better meet the needs and desires of end-users. To effectively adopt a co-development approach, it is important for organizations to understand the concepts behind co-development practices, including collaborative partnerships, customer-centricity, iterative development, open communication, and shared ownership. Many of these concepts overlap with the previous recommendation of HCD.

Effective policy can create an environment that supports and incentivizes collaboration between different stakeholders with diverse perspectives and resources. This might include policies that provide funding and support for co-development initiatives such as research and development, innovation grants, and support for public-private partnerships (PPP). PPPs are a key policy instrument as they create strong innovation hubs, which enhance connections and alignment between stakeholders within innovation systems. Hermans et al. (2019) finds that PPPs are particularly useful for stimulating early innovation in agricultural systems, including knowledge development, network building, and technology diffusion, but are less effective at stimulating later stage innovation including final market development and end-user demand, and note that additional policy instruments may be required at this stage.

Smaller players in the private sector, including startups, are often looking to public-private partnerships to reduce risk and grow at earlier R&D stages. PPPs bring together government agencies, private companies, and academic institutions to support technology convergence. These partnerships can

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https://agriculture.canada.ca/en/department/transparency/departmental-plan/2023-2024-departmental-plan#a2-2

[37] The report also notes the Canadian agriculture sector is lagging in meeting GHG reduction emissions compared to other countries, in part due to the sector's exclusion from certain regulations, as well as the need for clear and specific targets, monitoring and impact assessments to fully realize the various policy ambitions (OECD, 2023).

provide funding, expertise, and resources to support cross-disciplinary research, innovation, and the development of new technologies. I visited and spoke with several successful PPPs, including at Harper Adams University, LIAT, Swiss Future Farm (SFF) and Swiss Food and Nutrition Valley (SFNV). Harper Adams University, for example, works closely with Innovate UK and numerous corporations such as CNH, AGCO, Syngenta, and Cargill to stimulate early innovation and build networks and develop knowledge.

The Swiss Future Farm (SFF) is a collaboration between the regional government, renting land from the federal government, and acting as a hub for equipment manufacturer AGCO. The SFF focuses on sustainability, abiding by new environmental regulations, creating an ecosystem to work in a connected farm for best data management, and sharing as much information as possible for knowledge and technology transfer (KTT). Local operating teams work directly with local farmers to showcase and trial new technologies and validate ease of adoption as uncertainty and risk aversion among farmers in implementing new technologies and practices remain a key concern.

Hermans et al. (2019) consider seven innovation system functions that interact and develop as a direct and cumulative cause of each other through three possible innovation motors that increase momentum of activity with PPPs. This relationship is shown in Figure 13, where the three innovation motors include:

i. Government identifies a problem (i.e., dark green arrow, starting with Technology Search Expectations), provides funds to solve, diffuses the knowledge to farmers and entrepreneurs, which leads to more interest and resources to solving the problem;
ii. Technologies or solutions are controversial or require some regulatory or other change to be competitive, and as such supporting coalitions initiate this shift in attitudes (i.e., dotted light green arrow, starting with Supporting Coalitions), resulting in a feedback loop starting with early trials or pilots, to more information dissemination, additional development, and early adopters; and
iii. When the market begins to develop (yellow arrows starting with Entrepreneurial Activities), where early entrepreneurs begin initiatives to persuade governments or other regulatory or other standards organizations for favourable market conditions for improved development and implementation environment (Hermans et al., 2019).

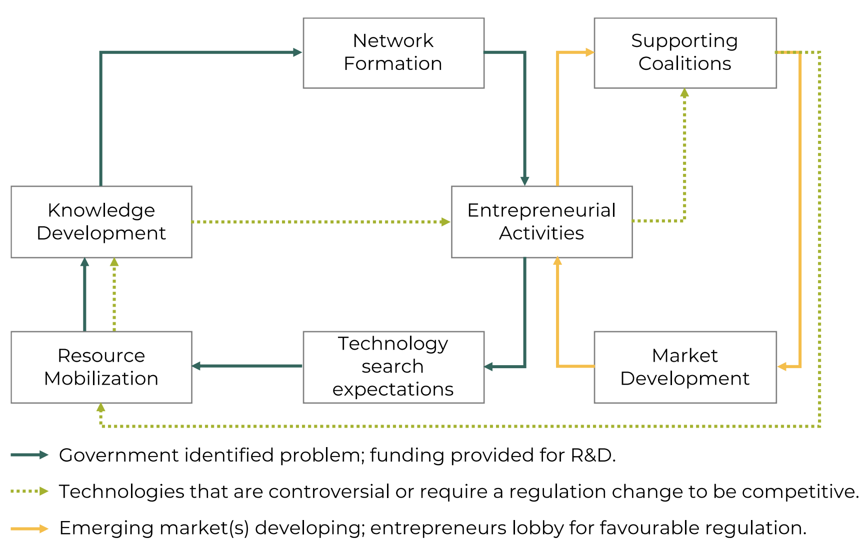

Figure 13. Innovation system functions and the three innovation motors (adapted from Hermans et al., 2019).

Policies play a crucial role in creating an environment that supports and incentivizes collaboration between different stakeholders in the agri-food industry. By providing funding and support, regulating IP, establishing standards and regulations, providing education and training, and encouraging effective partnerships, policies can facilitate co-development practices that lead to improved innovation for agri-food system transformation. While there are exceptions, some co-development policies are better suited for earlier stages of innovation, within the knowledge development, network building, and diffusion type activities. The estimated Canadian and Global benefit-cost ratio of agricultural research is estimated at 10:1 to 20:1, largely related to significant productivity improvements (AIC, 2017) from extension activities and basic and applied research. Stimulating later stage innovation and final market development, including end-user demand and acceptability of new innovations and technologies may require additional policy instruments, such as those focused on open innovation.

3.3. HARNESS OPEN INNOVATION

With open innovation an organization or group looks outward, beyond their internal capabilities and resources, and considers multiple sources for driving innovation. These sources might include external R&D from research institutions, translating solutions from different industry verticals, competitors, and the startup ecosystem. "Open innovation has the potential to widen the space for value creation: It allows for many more ways to create value, be it through new partners with complementary skills or by unlocking hidden potential in long-lasting relationships" (Dahlander and Wallin, 2020). With open innovation, an open and collaborative approach is utilized to access a wider pool of ideas, knowledge, and resources. For private and public organizations, this can improve competitiveness and drive faster, more profitable, and more actionable results than internal innovation alone. Open innovation collaborations bring new, nimble solutions for larger corporations and improved traction and market accessibility for startups and smaller organizations.

The implementation of open innovation can be challenging. Traditional organizational cultures often resist the shift towards openness, collaboration, and knowledge-sharing with external partners. Overcoming this cultural resistance and fostering an environment that values external input and collaboration is crucial. Relatedly, IP concerns can impede open innovation efforts due to protectionist attitudes as organizations may be hesitant to share proprietary information to protect their competitive edge. Stakeholders engaged in open innovation must ensure they are aligned in their commitment to the initiative, including alignment on timelines, outcomes, and overall goals. Effective communication is critical for success, particularly as the number of groups involved increases. Open innovation requires agility and flexibility; proactive and supportive organizational cultures are necessary for success, as are communication, adequate resourcing, and IP strategy to build the trust required for open innovation to be most effective.

More and more organizations are looking to open innovation for impact. We heard from Bayer at the Nuffield CSC where the company is leveraging an open innovation model for incremental and disruptive innovation. Numerous other groups are leveraging this strategy as well, from John Deere, Corteva, BASF, and Kubota[38]. When these groups engage in open innovation, they are often working with other

[38] John Deere: Collaborator program (https://www.futurefarming.com/smart-farming/tools-data/john-deere-connects-to-start-ups/); Corteva Open Innovation initiative (https://www.openinnovation.corteva.com/); BASF Open Innovation Platform Agro (https://agriculture.basf.com/global/en/innovations-for-agriculture/open-innovation.html); Kubota Open Innovation (https://www.kubota.com/innovation/open-innovation/index.html).

industry enablers and ecosystem conveners as well. For example, many of the previously mentioned corporations are working with the investment and innovation platform, THRIVE | SVG Ventures[39] to extend the reach and impact of their goals by plugging in to THRIVE's global ecosystem of startups, scaleups, cooperatives, research organizations, government stakeholders, academia, and potentially traditional 'competitor' organizations. Collaboration with groups such as Accelerators and venture investors can help harness knowledge into action and impact, speeding up the innovation cycle within agriculture and food.

Policy for promoting and improving open innovation in the agriculture industry might include IP and data sharing protection or regulation, funding support, and education and training initiatives. Clear and enforceable IP rights can help to create an environment that encourages innovation and protects the interests of stakeholders. Open innovation often involves the sharing of data and information between different stakeholders. Clear regulations around data sharing and privacy can help to facilitate collaboration while protecting sensitive information. Standards and benchmarks can help to ensure that open innovation initiatives are effective and produce meaningful results to further incentivize the practice through ease of knowledge transfer when standards are readily in place. Funding for research and development, innovation grants, and support for public-private partnerships encourage open innovation as a direct approach. Policies that provide education and training opportunities for stakeholders can help to build the necessary skills and knowledge required for effective open innovation, and might include training in collaboration, communication, and project management.

Several groups I spoke with were working on initiatives related to improving the ease of engaging in open innovation, including Harper Adams University in working with transport standards for autonomous machinery, the Swiss Future Farm with their partnership with multiple levels of government, and in Canada, various support for accelerator and incubation programs, linked to corporate and non-corporate interests (e.g., THRIVE | SVG Ventures with federal and provincial support).

3.4. CONNECTING THE DOTS WITH SYSTEMS THINKING

Systems thinking is a crucial approach in understanding and addressing complex challenges, such as those related to agtech innovation and policy design. It involves considering the interconnectedness and interdependence of various components within a system to identify effective solutions. By connecting the dots of the three main recommendations into systems thinking to address the existing volatility, uncertainty, complexity, and ambiguity of our environment and society today, we can enhance innovation efforts by understanding the interconnectedness of policy and production, ultimately leading to more transformative impact.

In a systems thinking framework, people are considered key elements within the agtech innovation system. Their needs, motivations, and behaviours are critical factors that influence the success or failure of any policy intervention. Human-centered design principles help policymakers and stakeholders understand the diverse needs and perspectives of different individuals and groups in the agri-food sector. This approach acknowledges that stakeholders are not homogenous and that one-size-fits-all policies may not be effective. Thinking globally for impact means considering the broader context of agtech innovation, such as global food security challenges, climate change, and technological advancements. Understanding these larger global dynamics can help identify potential risks and

[39] https://thriveagrifood.com/

opportunities. However, local action and outcomes are equally important. Systems thinking recognizes that what works in one region might not be suitable for another due to varying socio-economic, cultural, and environmental factors. Therefore, effective policies should be tailored to the specific needs and capabilities of local communities, ensuring practical and relevant implementation.

Systems thinking emphasizes the importance of collaboration and co-creation between various stakeholders, including governments, private sector entities, farmers, researchers, and consumers (e.g., public-private partnerships). Each of these stakeholders plays a role in the agtech innovation system, and their involvement in policy design ensures a comprehensive understanding of the challenges and potential solutions. By adopting a synergistic approach between government and the private sector, policymakers can leverage the strengths and resources of both to drive agtech innovation effectively. Governments can provide regulatory frameworks, financial incentives, and public goods, while the private sector can contribute technical expertise, innovation, and investment. Co-developing policies with relevant stakeholders also fosters a sense of ownership and responsibility, increasing the likelihood of successful implementation.

Systems thinking acknowledges that innovation and policy design do not occur in isolation. An open and collaborative approach encourages the sharing of knowledge, experiences, and best practices within and beyond the agri-food sector. This exchange of ideas helps policymakers and stakeholders learn from each other and adapt successful strategies to specific contexts. By leveraging external learnings, policymakers can draw from other industries or domains that have faced similar challenges and identify relevant solutions. This cross-pollination of ideas and experiences fosters a process of co-learning, where stakeholders collectively build knowledge and understanding of the complex agtech innovation system.

Moreover, an inclusive approach that considers multiple voices and perspectives leads to more comprehensive policy solutions. Different stakeholders bring unique insights to the table, and their involvement ensures that policies address a broad range of issues and potential impacts. Mutual responsibility is fostered when all stakeholders have a role to play in the co-development and implementation of policies, creating a sense of shared ownership and commitment to the success of the system.

Ultimately, applying systems thinking to policy design for agtech innovation helps create more resilient and adaptive systems. By considering the interconnectedness of various elements, involving relevant stakeholders, and fostering a culture of collaboration and openness, policymakers can design policies that not only address immediate challenges but also build capacity for long-term sustainability and innovation within the agri-food sector.

4.0 CONCLUSION

Agri-food has one of the greatest urgencies and potential for innovation, and numerous stakeholders are contributing towards a sustainable future. The focus of this research is on agri-innovation policy and its ability to provide incentives and capacity building for agtech innovation. We need increased productivity, enhanced resilience, reduced emissions, and equitable profit models in agriculture. For this, all stakeholders have a role to play in building tomorrow's food system. The stakeholders from Figure 1 are categorized within an agri-innovation system in Figure 14, below. While there is undoubtedly overlap of actors within various capacities, in a generalized view each primarily supports research and education, business and enterprise, and plays a bridging or enabling role.

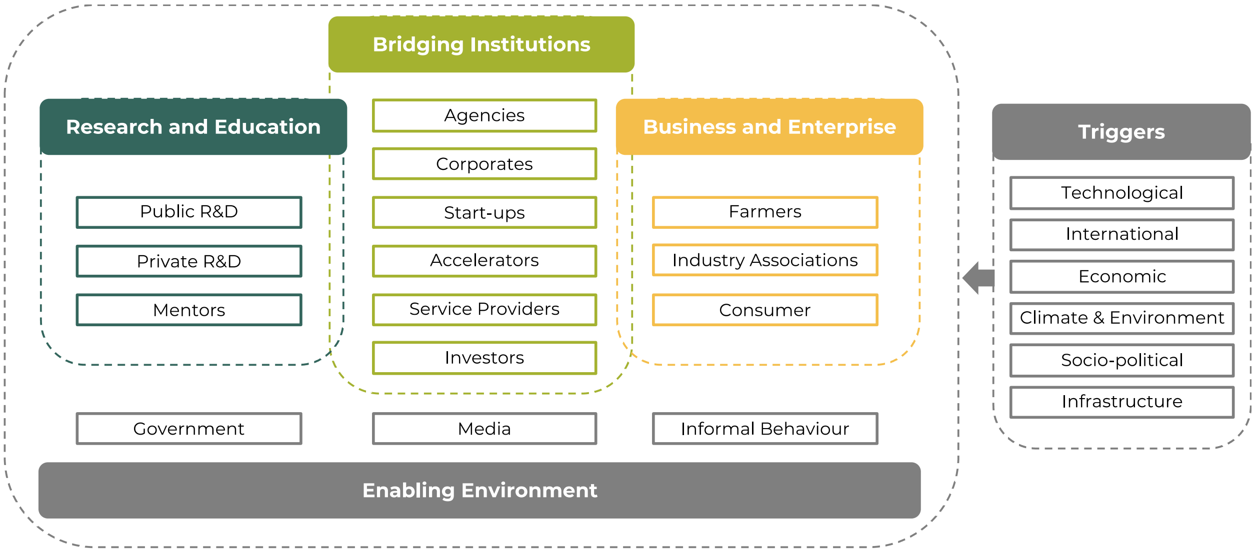

Figure 14. Categorization of stakeholders within an agri-innovation system (adapted from Chuluunbaatar and LeGrand, 2015 and Anandajayasekeram, 2011).

During this research I came across many examples of triggers impacting local and regional agri-food systems, from socio-political, infrastructure, technological, to climate and environment. This is all to say that developments do not occur in isolation and each stakeholder is co-dependent on other groups, institutions, and environments.

The ecosystem of stakeholders in Figure 14 are influenced in their interactions via policies, institutions, informal behaviour (i.e., culture, attitude, beliefs), which determines how knowledge is generated, shared, and used. Together, these players bring innovations in their various forms into use; in this research the use of interest relates to on-farm agtech adoption.

One of the main policy gaps in agricultural innovation systems in North America is the lack of coordination and collaboration between different actors in the innovation ecosystem. While there are many stakeholders involved in agricultural innovation, including farmers, researchers, government agencies, and industry organizations, there is often a lack of coordination and communication between these groups. Or there may also be regulatory or policy barriers that limit the ability of different actors to work together effectively. This can lead to inefficiencies in the innovation process, duplication of efforts, and missed opportunities for collaboration and knowledge sharing.

To address these gaps, there is a need for policies and programs that promote collaboration and coordination between stakeholders in the agricultural innovation ecosystem. This can include funding for public-private partnerships, support for industry associations and networks, and policies that incentivize collaboration and knowledge sharing. In addition, there is a need for policies that address regulatory barriers and promote the adoption of new technologies and practices in the agriculture industry. This can include policies that provide incentives for the adoption of sustainable practices, regulations that enable the use of new technologies, and support for research and development of new agricultural technologies.

With recent advancements we are seeing a fundamental new way of doing business and investing in the agri-food industry. Overall, we are moving towards a leaner, faster, more agile system, across the value chain. With all the various stakeholders, we need to leverage collaborative models to harness the momentum and start moving the industry towards beneficial innovation, through incremental and disruptive mechanisms. Collaborative models must put people and community at the centre of agtech innovation, be outcome-focused, and leverage open innovation processes.

There is a lot of opportunity for all stakeholders to work together and contribute to building and sustaining the momentum. This will include identifying existing barriers and opportunities, encouraging smart agriculture investments (public and private) in businesses (SMEs, MNEs, and start-ups) and research, introducing easy to apply technologies on-farm, and assessing the potential policy changes necessary to optimize Canadian agricultural production to provide safe and nutritious food for Canadians and the World.

Globally we have stressed resources and higher, disproportionate demand. Emerging technologies show promising solutions in many cases. We are also seeing shifting regulations, supply chain stressors, and international agreements all impacting agricultural production. We need more sustainable stakes in the ground, and agtech is one conduit to reducing environmental impact.

To effect this change and to implement it at scale, we need partnerships for action at local and especially global scales. We must ensure solutions are farmer-focused first, and to do so policies need to recognize and engage with the voice of the farmer. In other words, policies and partnerships must exist at the farm. There is a dual culture shift of adopting new technologies: organizations (i.e., startups, corporates, researchers) need a culture shift to fit with farmers, and farmers need a culture shift in working with new technologies and non-agri-stakeholders.

We need to use partnerships as pathways to adoption and impact. We need trust and transparency, education (on all fronts), collaborative work (especially more on-farm interactions). We must use global thought for impact, but with local execution. We need clarity and standardization on impacts and/or benefits from neutral third parties. And we need well-placed incentives and policy to support adoption and market development.

With coordinated efforts across all policy levels, policymakers have the resources and capacity to address many of these needs, but full industry coordination and collaboration effort from all stakeholders will be needed to advance agtech innovations and ensure a sustainable and competitive future for the Canadian agri-food industry.

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6.0 APPENDICES

6.1 LIST OF INTERVIEWS, DISCUSSIONS, AND ORGANIZATIONS

These organizations provided valuable information for this report in a variety of ways, including providing interviews, thought leadership, hosting tours, lectures provided to the public, hosting events, and more.

- Alberta Innovates (Canada)
- THRIVE by SVG Ventures (Global)
- AgSmart Olds (Canada)
- Nuffield International (Global)
- Rural Routes to Climate Solutions (Canada)
- Livestock Gentec, University of Alberta
- Food Systems Summit 2021: Dialogues Gateway (Global)
- Jilin Agricultural University (China)
- Agri-TechE (UK)
- National Institute of Agricultural Botany (UK)
- Harper Adams University (UK)
- Small Robot Company (UK)
- Lincoln Tech (UK)
- Saga Robotics (Norway / UK)
- Swiss Future Farm (Switzerland)
- Beleefboerderij De Elihoeve (Netherlands)
- Willem High Tech Dairy (Netherlands)
- Kees & Sjors Dairy and Cheesery (Netherlands)
- Nijkamp Dairy (Netherlands)
- Swiss Food and Nutrition Valley (Switzerland)
- Universität Bonn, Phenorob (Germany)
- Cronin Family Farms (Canada)
- Deveron (Canada)
- Delta Power (Canada)
- 3rd Annual World Intelligent Farming Summit (Spain)
- World Agri-Tech South America Summit (Brazil)
- Demeter (UK)
- Hectar (France)

6.2 ABBREVIATIONS

AI: artificial intelligence

API: application processing interface

B2B: business to business

B2C: business to consumer

CSC: Contemporary Scholars Conference

DEI: diversity, equity, inclusion

ESG: environmental, social, governance

FaaS: Farming-as-a-Service

GHG: greenhouse gas

GT: gene technology

GM: genetically modified

ICT: information and communication technology

IP: intellectual property

IoT: Internet of Things

KTT: knowledge and technology transfer

LATAM: Latin America

MNE: multinational enterprises

MRV: measuring, reporting, validation

MVP: minimum viable product

PE: private equity

PPP: public-private partnerships

R&D: research and development

ROI: return on investment

SME: small and medium sized enterprises

VC: venture Capital