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NITI Aayog

NITI Frontier Tech Hub

Reimagining Agriculture: A Roadmap for Frontier Technology Led Transformation

November 2025

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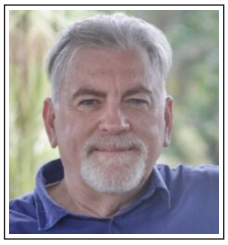

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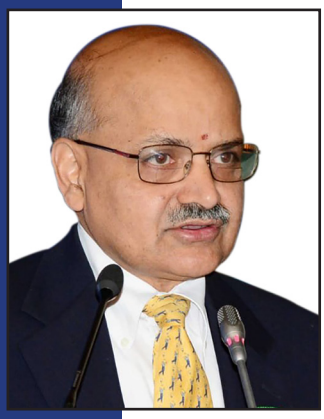
Foreword



The dream of **Viksit Bharat** rests firmly on the strength and sustainability of our foundational sectors. At the heart of this ambition lies agriculture, a sector that feeds the nation and secures the livelihoods of a majority of our population. Over the last seven decades, India's farmers have achieved remarkable food security through grit and ingenuity. However, as we stand at the cusp of the Amrit Kaal, we must acknowledge that incremental improvements are no longer sufficient to meet the challenges of the 21st century: climate volatility, resource depletion, and the critical need to maximise income for our small and marginal farmers. A paradigm shift is necessary, and this shift must be powered by technology.

This strategic roadmap, **"Reimagining Agriculture: A Roadmap for Frontier Technology Led Transformation,"** represents NITI Aayog's vision for navigating this crucial transformation. It is a blueprint for integrating the most advanced technological capabilities- from **Arti icial Intelligence** and **Machine Learning** to **IoT-enabled Precision Agriculture, Drones,** and **Satellite Imaging-** directly into the hands and fields of our farmers. These technologies are not merely tools; they are the engines of productivity, the guardians of sustainability, and the catalysts for economic equity. They promise a future where every drop of water, every ounce of fertiliser, and every hour of labour is optimised, leading to higher yields and, crucially, higher incomes.

Our approach is holistic and systemic. The roadmap proposes a Digital Agriculture Mission 2.0 and outlines key recommendations across three pillars: Enhance, Reimagine, and Converge.

Enhance: Agriculture's foundational systems by focusing on a 360-degree data ecosystem, digital enablement of the last-mile interventions and upgrading the AgriTech startup accelerator ecosystem.

Reimagine: Future-ready, globally competitive talent & innovation ecosystems, focusing on a shift to translational R&D, interdisciplinary indus-try-aligned talent and revamping the institutional architecture for innovation

Converge: Build instruments for public-private dialogue to align industry and government efforts for agile policy making and accelerated transformation

The journey ahead requires unprecedented collaboration. NITI Aayog is committed to championing the policy and governance frameworks required to unlock this potential. I call upon all our partners -State Governments, research institutions, private enterprises, technology developers, and, most importantly, the millions of farmers who are the primary stakeholders- to embrace this vision. Let us translate this strategic intent into decisive action, ensuring that India's agricultural sector makes a transformative leap, becoming a global benchmark for resilience, productivity, and prosperity.

The time for transformation is now. Together, we will sow the seeds of a high-tech, high-impact agricultural future for India.

B.V.R. Subrahmanyam
Chief Executive Officer, NITI Aayog

Foreword

Agriculture stands on the brink of a profound **technological renaissance.** For decades, our progress in this sector has been measured in hectares and yields; the next revolution will be measured in **data, intelligence, and design.** This is the new norm, and success will not be defined by whether we transform, but by **how fast** we do.

The **NITI Frontier Tech Hub's Roadmap** brings together what I believe is the most critical insight of our time: that India's leadership in agriculture will not be determined by how much technology we adopt, but by how intelligently we integrate and scale it.

The shift ahead will be defined by four major transitions: from **data scarcity to sovereign agri data systems**; from **fragmented advisory to AI-powered, real-time decision networks;** from **isolated lab research to mission-driven, translational R&D;** and from **fragmented funding to patient, long-term capital** that supports deep innovation.

The roadmap reminds us that **data is the new soil, AI the nervous system,** and **biotechnology the new seed infrastructure** of Indian agriculture. Yet, its most important message is that these technologies will mean little unless we reimagine the **institutions, incentives, and talent systems** that bring them to life, building a generation of **AI-literate, tech-enabled farmers and agri-entrepreneurs** who can lead India's next great transformation.

Our goal must be clear: to make agriculture not just more productive, but more **predictive, resilient, and equitable,** to move from fragmented interventions to a connected ecosystem that learns, adapts, and scales.

If the Green Revolution fed India, this **Intelligent Revolution must empower it,** ensuring that every farmer becomes not just a user of technology, but a **co-creator of the future of food.**

Debjani Ghosh
Distinguished Fellow, NITI Aayog
Chief Architect, NITI Frontier Tech Hub

Executive Summary

Agricultural transformation lies at the heart of India's vision to become a developed nation by 2047. Recognising agriculture's critical role in ensuring economic resilience, rural prosperity, and food security, frontier technologies such as seed technologies, verticalised farming, digital twins, precision agriculture and smart sensors, agentic AI, predictive analytics, and advanced mechanisation offer unprecedented possibilities to significantly **enhance productivity, sustainability, and farmer incomes.**

As India embarks on this transformative journey, it is important to recognise the diversity of the country's agricultural and farming landscape - from rain-dependent smallholders to commercial-scale cultivators, farmers face diverse challenges and demand tailored solutions. To keep the insights real and recommendations actionable, we have segmented the farming community into three primary archetypes - **'Aspiring farmers** (70–80%)', **'Transitioning farmers** (15–20%)', and **'Advanced farmers** (1–2%)'. Throughout this roadmap, our findings and suggestions are **contextualised to these farmer archetypes.** While the holistic agriculture and allied ecosystem includes dairy, poultry, fisheries and livestock, in this phase of our work, we have focused exclusively on crop production.

Through our detailed analysis, we identify **six systemic barriers** that are currently limiting technology scale-up and impeding the transformation of Indian agriculture. These include siloed agricultural **data** systems**, trust** deficits among farmers, a persistent **'phygital divide'** between digital innovations and physical infrastructure, ecosystem **fragmentation** restricting scalable solutions, **talent** gaps affecting technology implementation, and constrained **capital** flows, especially for early-stage agri-tech enterprises. The roadmap recommends an actionable three-pillar framework for a **Digital Agriculture Mission 2.0** to address prevailing barriers and advance agricultural transformation:

1. **Enhance foundational systems** which can take the benefits of the digital infrastructure being built to the farm via robust last-mile advisory services and dynamic agri-tech innovation ecosystems.

2. Proactively **reimagine research and talent systems** by fostering interdisciplinary, mission-oriented research, adaptive regulatory environments, and targeted skills development.

3. Institutionalise centres of excellence and policy foresight units to **converge public-private efforts,** aligning policymaking and regulatory framework with national priorities, market needs, research agendas, and inclusive grassroots dissemination strategies to accelerate transformation.

Primarily articulated for **policymakers and government bodies,** this strategic framework serves as a vital resource to shape enabling environments and coherent interventions. Equally, it supports agribusinesses, innovators, academia, and development organisations, helping align their strategic investments and innovations with national priorities. Importantly, this is a living document, intended to continuously evolve as new insights, technologies, and threats emerge, ensuring that India's strategic response remains **relevant, resilient,** and **future-ready.**

Through **decisive action and collaborative engagement,** India can realise an optimistic future, transforming agriculture into a dynamic, globally competitive sector and securing inclusive rural prosperity aligned with the nation's vision for 2047.

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1. INTRODUCTION: AGRICULTURAL TRANSFORMATION FOR A VIKSIT BHARAT

1.1 The Imperative: Transform Farmer Livelihoods

> **India's agriculture must become a cornerstone of a developed India**
> - The Hon'ble PM of India at Viksit Krishi Sankalp Abhiyan

Agriculture and Food Systems will be a key driver of Viksit Bharat, shaping several critical national imperatives: food and nutritional security, rural livelihoods, climate adaptation, and global trade competitiveness. Employing 45.8% of the national workforce[1] and producing nearly 1 billion tons[2] of food annually, the sector underpins employment generation, national health outcomes, and inclusive economic growth. For India to achieve the status of a developed nation by 2047, its per capita Gross National Income (GNI) must rise fivefold[3], a goal inseparable from achieving a commensurate increase in agrarian incomes and productivity.

Over the last decade, agriculture and allied sectors have witnessed a steady 3-5% CAGR, fuelled by extensive government efforts, private innovations, and sizeable domestic demand. It is estimated that by 2047, the sector could potentially triple in size, powering India's growth.

Despite measured success, persistent challenges such as fragmented landholdings, low productivity, limited downstream linkages, and the rising impact of climate change continue to constrain overall sectoral growth. Over 86% of Indian farmers are smallholders, with an average landholding size of 0.74 hectares[4]. Reliance on resource-intensive practices, compounded by limited irrigation and mechanisation, exacerbates the farmers' vulnerability to extreme weather shocks, rapid soil degradation and groundwater depletion. Substantial post-harvest losses, exceeding USD 18 billion in 2022 alone[5], inequitable value chains, and asymmetric bargaining power further depress farmer incomes. Further, systemic gaps in access to finance, insurance buffers, and entrenched digital divides leave millions of farmers unable to benefit from existing solutions.

To unlock the next economic leap for the country and boost farmer incomes, a paradigm shift is needed. Structural reforms, last-mile enablement, and deep technological innovations will be critical to improving agricultural productivity, minimising post-harvest losses, accelerating the export footprint, and increasing the sustainability and climate resilience of food systems.

1.2 Frontier Technologies as a Lever for Transformation

Frontier technologies offer a transformative opportunity for Indian agriculture to overcome these structural challenges, especially as mounting complexities render conventional interventions inadequate. These technologies act both as standalone end solutions and as enablers to critical solutions across the agricultural value chain, as demonstrated in Exhibit 1.1. Globally, cutting-edge technologies like CRISPR seeds, biostimulants, biofertilizers and biochar are improving yields sustainably, increasing soil health and mitigating climate rishks, while precision irrigation systems, predictive analytics, modified atmosphere packaging, etc., are minimising input costs and wastage.

At the forefront of this are seed technologies. Advances in this domain can directly and decisively address India's most pressing agricultural challenges to unlock transformation. High-yielding varieties substantially boost productivity per land parcel, pest-resistant plants improve crop quality

1 The Periodic Labour Force Survey (PLFS) for 2023
2 Business as usual estimations of total food production from crops and animal products by NITI Aayog's Working Group Report on Crop Husbandry, Agriculture Inputs, Demand & Supply (2024)
3 16th Finance Commission Chairman highlighted 7.3% growth in dollar terms required over next 24 years
4 NABARD All India Rural Financial Inclusion Survey (NAFIS) conducted for the year 2021-22
5 Study to determine post-harvest losses of Agri produces in India by MoFPI and NABCONS

at reduced costs and pesticide use, while climate-resilient and drought-tolerant varieties safeguard yields against unpredictable environmental shocks, and biofortified seeds enhance nutritional profiles without additional strain on natural resources, serving critical nutrition security goals. On the other hand, AI has emerged as a powerful enabler. Pilots such as Telangana's AI-enabled advisory have delivered promising results with 21% yield increases, 11% price gains, and 9% reduction in input use in a single season[6]. AI-enabled precision advisory, coupled with a digitally enabled last-mile network, can amplify the reach and timeliness of technology diffusion while AI-powered underwriting using alternate data can unlock credit for underbanked populations, increasing their capacity to adopt new solutions. Drone and satellite-based field intelligence, cell-based solutions, meanwhile, provide solutions tailored to remote geographies and small landholdings.

Initiatives like the Digital Agricultural Mission, National Mission on Agriculture & Technology, Kisan Drone Scheme, and National Mission for Sustainable Agriculture have made strides in enhancing agricultural outcomes and improving the on-farm effectiveness of technologies in India. Achieving sustained, inclusive transformation requires accelerating the integration and scaling of frontier technologies, bridging current implementation gaps, and fostering an enabling environment for continuous innovation.

6 Saagu Baagu pilot in Telangana delivered AI-based advisory, quality-testing and e-commerce services to 7000+ chili farmers in phase 1

From Seed to Sale: Frontier Tech can unlock value across the farmer lifecycle

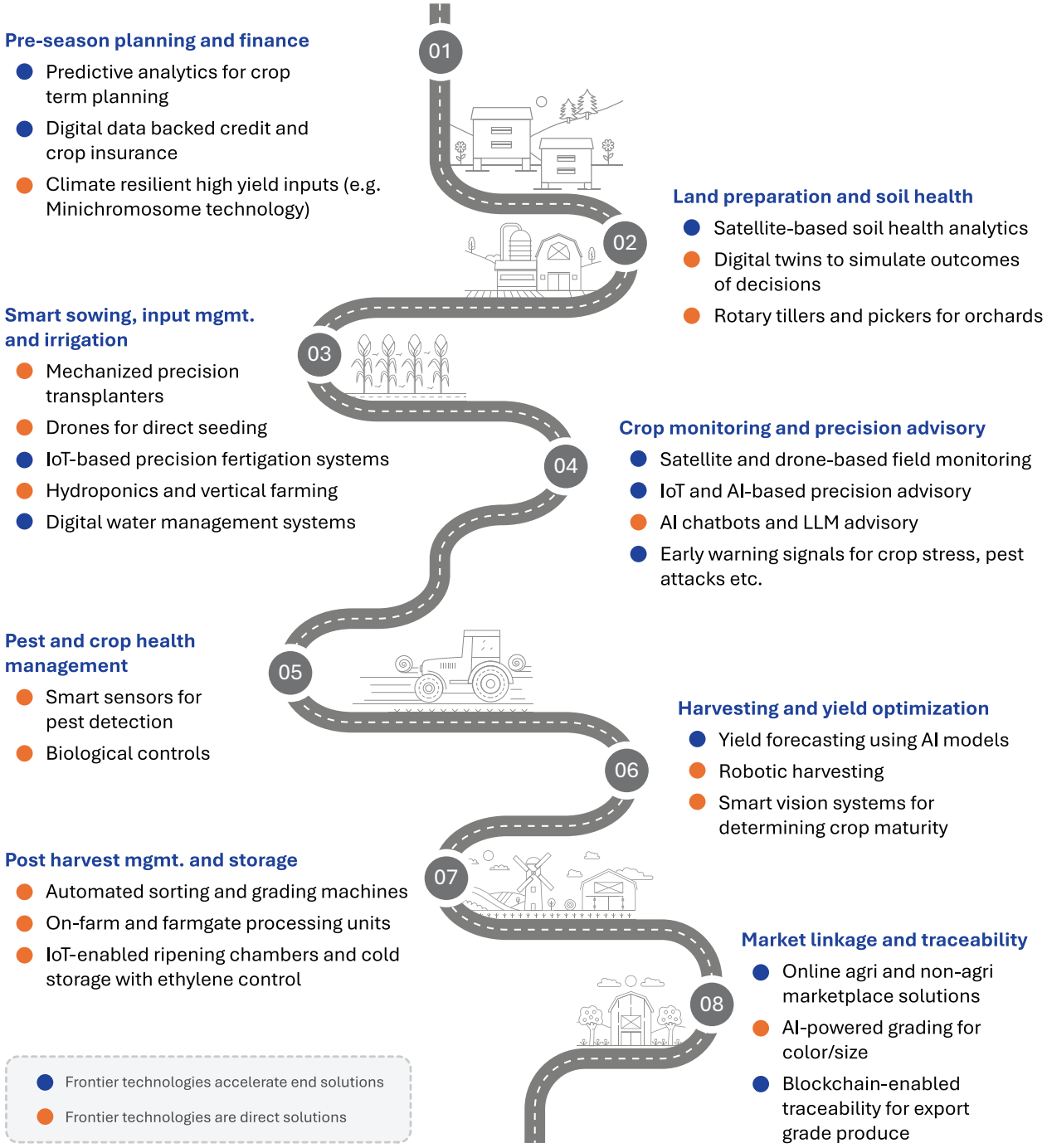


Exhibit 1.1: From Seed to Sale: Frontier technologies unlock value across the farmer lifecycle

2. INDIA'S AGRICULTURAL LANDSCAPE: CHALLENGES & THE ROLE OF FRONTIER TECHNOLOGY

2.1 Farms & Farmers: The Current Landscape

Frontier technologies, in the context of Indian agriculture, need to be tailored to account for the heterogeneity of the country's farmers. From rainfed, subsistence smallholders to progressive, commercial-grade cultivators, each farmer faces a unique set of challenges and seeks curated solutions. Hence, this section segments farmers into three distinct, yet broad, archetypes based on their incomes (detailed calculations in Appendix 1), landholding size, irrigation, cropping pattern, tech adoption and needs, along with corresponding illustrative examples.

	01 Aspiring (70-80%)	02 Transitioning (15-20%)	03 Advanced (1-2%)
Agricultural Income (INR/year)[4]	17,000 - 60,000	1,00,000 – 2,00,000	> 4,00,000
Landholding (Ha)	<2 Marginal and small	2-10 Small & medium	>10 Large
Irrigation	Predominantly rainfed (~60%)[1/3], 20-30% irrigate via borewells, canals[2/3]	Micro-irrigation via sprinklers, drip irrigation (~10%)[2/3]	Advanced irrigation techniques with automation
Crop Mix	Single or dual cropping; predominantly food grains	Dual cropping, gradual shift to horticulture and cash crops	Multi-cropping (3 cycles), export-grade crops
Level of tech adoption	Low adoption, need to build access & confidence in technology	Early stages of adoption, seeking relevant solutions	High rates of adoption, experimenting at the frontier
Indicative Examples	Wheat farmers in North India cultivating <1 Ha of rain-fed plots	Cotton & soya farmers in Central India cultivating 2-6 Ha of well irrigated lands	Export-quality grape farmer in West India cultivating 10-12 Ha of fully irrigated lands

1.Net income (Revenue from sale of crops – Cost of inputs, irrigation and labor) per hectare per year. E.g., – For rainfed farmer growing Lok-1 variety of wheat, Revenue of INR 90k per hectare (3000kg @ INR30/kg); Costs of INR 50k/hectare for seeds, irrigation, fertilizers, machinery rentals etc
2. National Rainfed Area Authority, Ministry of Agriculture & Farmers' Welfare (2022) 3. Agricultural Statistics (2022) 4. Situation Assessment Survey of Agricultural Households 2018-19 (detailed calculations in Appendix 1)

Exhibit 2.1: Three key farmer archetypes in Indian agriculture

Aspiring Farmers:

Small-holder, rain-dependent, subsistence-oriented, under-mechanised, high-risk–low-margin

70–80% OF FARMERS

Age: 55 years

Land size: 0.5 Ha

Irrigation: Rainfed

Crops: Single (wheat)

Mechanisation: None; own labour

Consider Rajat, a **marginal** wheat farmer, cultivating half a hectare of rainfed land. **Lack of timely and reliable advisory, resource constraints** and **working capital shortages** prevent the adoption of high-yielding seeds, mechanised tools and micro-irrigation solutions. Thus, he is entirely **dependent on monsoons** and droughts, and even a few weeks of delayed rains can damage his crop. Without a tractor or power tiller, he and his family prepare the field **manually.** During seasons with adequate rainfall, he plants vegetables on small patches of land. **Lacking proper storage** and **direct market linkages,** this year most of his crop spoiled, and he was forced to sell at a d**istress price**, earning barely INR 30,000 from farming. This makes farming a **high-risk, low-margin** endeavour, necessitating supplemental income through casual labour.

Transitioning Farmers:

Medium-holder, irrigated, multi-crop, tech curious, entrepreneurial yet market-constrained

15–20% OF FARMERS

Age: 32 years

Land size: 3 Ha

Irrigation: Borewell & Canal

Crops: Paddy & vegetables

Mechanisation: Rented tractor and power tiller

Meet Bindu, a farmer cultivating three hectares with access to canal and borewell irrigation. This permits **multi-cropping,** growing paddy during the kharif season and **diversifying to higher-value** vegetables and pulses during the rabi season. Due to the high costs of labour and mechanisation, she and neighbouring farmers jointly hire a tractor for ploughing. Keen to adopt **cost-effective, proven technologies,** Bindu uses her smartphone for weather updates, price information, and generalised advisory through social media, but actively seeks **personalised support.** Some of the latest technologies are also **not suited to the scale of her farm.** Last year, she tested a new hybrid tomato seed, yielding higher returns but also grappled with pest outbreaks. Post-harvest she struggles to fetch fair prices: Local agents rarely offer optimal rates, but she **lacks access to better markets.** She considered transporting to city markets, but her yields lacked the scale to be feasible for independent transportation. **Lack of storage and processing facilities** also prevents her from fetching optimal prices. With the right support, entrepreneurial farmers like Bindu can become **engines of growth** for Indian agriculture, investing in their practice for higher returns.

Advanced Farmers

Large-scale, capital-intensive export-oriented, innovation-seeking, but ecosystem-constrained

1–2% OF FARMERS

Age: 50 years

Land size: 12 Ha

Irrigation: Sensor-based fertigation

Crops: Export-grade grapes, tomatoes

Mechanisation: Canopy mgmt. system, fertigation units

Consider Aman, an **agri-entrepreneur** and **large-scale farmer** operating 12 hectares of **export-grade** grape vineyards and tomato crops. He has installed an automated sensor-based drip fertigation system complemented by precision tools for canopy management. He **imports** grape pruning tools and was the **first to experiment** with a high-Brix variety to maximise quality and comply with stringent export standards. Despite his **commercial savvy** and **influential market position,** he struggles to navigate the complex regulatory **requirements** and extensive paperwork. His yields have plateaued recently; thus, he is seeking disease-resistant & high-yielding vines. **Shortage of technically trained labour** & rising costs also push Aman to explore automated harvesters. However, neither technologies are **not yet available in India**. Aman's situation underscores that even India's most advanced farmers need a supportive ecosystem for cutting-edge innovation and global competitiveness.

Across archetypes, farmers are contending with deeply **interlinked, structural pain points,** albeit with differing degrees. These challenges can lock in a vicious cycle of volatile incomes, limited investment capacity, and under-realised agricultural growth potential:

Rising cost of cultivation

↑ 20 - 40%

Increase in cost of cultivation, including cost of labour during Kharif and Rabi seasons since 2021[1]

Lower farm productivity

3.52 T/Ha

3.52 T/Ha India's wheat yields compared to China (5.8 T/Ha) and Egypt (7 T/Ha)[2]

Low price realization

30-40%

Value of end consumer price captured by farmers due to low bargaining power & market access[3]

Credit & Risk Vulnerability

52%

Of Indian Farmers in debt, with most marginal farmers spending more than they earn[4]

Post-Harvest Losses & Wastage

15-20%

Of produce (~Rs.1.5 Trillion) is lost annually due to inadequate storage and transport infrastructure[5]

Climate Risk & Resource Degradation

10-50%

Estimated decline in key crop yields by 2080 due to climate change and soil nutrient depletion

1. Cost of cultivation estimates from the Annual Price Policy Reports 2021, 2025 (Commision of Agricultural Costs & Prices) 2. Estimates from the Food and Agriculture Organization, United States (2023, 2025), Government of the United States of America 3. Working Paper Series by RBI's Department of Economy & Policy Research, (October 2024) 4. Press Information Bureau, 2020 5. Study to determine post-harvest losses of agri-produce in India by NABCONS and Ministry of Food Processing Industries, Government of India (2022) 6. Estimates by National Innovations in Climate Resilient Agriculture (NICRA)

Exhibit 2.2. Structural challenges in Indian agriculture

A **holistic approach** with structured pathways is needed to transition farmers from aspiring to advancing, one that simultaneously improves productivity, lowers losses, links farmers to markets, and de-risks agriculture. As we define the role of technology in realising this vision, it is useful to outline the specific outcomes we seek for farmers by 2035 (a mid-term milestone) and 2047 (the centenary of Independence). Broadly, to achieve an increase in farmer incomes, the agricultural sector must prioritise improving farm productivity and diversification, strengthening post-harvest management and value chain addition, enhancing market linkages, and promoting sustainable, climate-resilient practices.

Key Viksit Bharat Indicators

	2025	2030 Target	2047 Target
Improve productivity (Annual yield in MT)	316	>380	>550
Optimize overall N:P:K ratio ($N:P_2O_5:K_2O$)	7.7:3.1:1	4:2:1	4:2:1
Expand area under irrigation	~46%	>50%	>60%
Improve farm level mechanization	40-45%	>50%	>75%
Reduce post harvest losses incurred (in % GDP)	~15%	<12%	<5%
Increase share of Horticulture (% Agriculture GVA)	~33%	~33%	~35%
Increase processing level	Foodgrain (%)		
	>66%	>75%	>90%
	Horticulture (%)		
	>3%	>7%	>20%
Restore degraded land (in Mha)	N/A	>26	>49

Prioritised areas

- Improving farm productivity and diversification
- Strengthening post-harvest management and value addition
- Enhancing market linkages (domestic and export)
- Promoting sustainable, climate-resilient practices

Exhibit 2.3: Key indicators for achieving Viksit Bharat 2047

These priorities for 2035 and beyond represent the actions required to boost farmer incomes and sector growth. In the next section, we assess the current status and delve into how frontier technologies can be leveraged to mitigate prevailing challenges and address 2035 priorities.

2.2 Frontier Technologies in Indian Agriculture: Opportunities

Frontier technologies have immense potential to catalyse agricultural growth in India. To illustrate this potential, envision a fully tech-integrated **farm of the future** in India in 2047

Exhibit 2.4: Resilient Farming Practices in a tech-enabled, mechanised, and digitally monitored farm with multi-cropping in 2047

2.3 Gaps and Breakdowns in Technology Application

While the benefits of integrating frontier technology are well-known, it is important to recognise and address barriers across different farmer segments, stalling at one of three stages: adoption (market to farm), commercialisation (lab to market), and innovation (lab). These challenges to scaling frontier technologies are summarised by archetypes in the table below:

Three-pronged approach to drive agri transformation: Increase ADOPTION, Drive COMMERCIALIZATION, Support INNOVATION

	Aspiring	Transitioning	Advanced
What farmers need	• Micro irrigation solutions • Individualized credit and insurance • Adaptive SOPs, localized advisory • Market linkages with higher price realization • Access to high quality seeds and inputs	• Access to farm machinery (tractors, robotics etc.) • Direct buyer linkage and price discovery • Precision advisory & AI/ML based SOPs • Farmgate/on-demand storage & processing	• Blockchain enabled traceability & certification for exports • Advanced seed varieties • Controlled Farming technologies (e.g. hydroponics) • Autonomous robotics as a service
Key barriers to Frontier tech	• Solutions exist • Solutions accessible • Low adoption • Low farmer confidence in tech solutions • High upfront costs for adoption • Lack of peer-to-peer advisory and handholding support for adoption of new practices	• Solutions exist • Low contextualization of solutions • Low diffusion • Low applicability of solutions to needs across geographies • On ground infrastructure needed to scale • Lack of talent e.g. drone operators, sensor technicians, agri-data engineers	• Solutions to be innovated • Then focus on commercialization & adoption • Frontier tech is still under development • Limited approvals, lack of trials to verify on ground application
Key requirement	Increase ADOPTION MARKET to FARM	Drive COMMERCIALIZATION LAB to MARKET	Support INNOVATION LAB (invent)

Exhibit 2.5: Key barriers to frontier technology by different farmer archetypes

In short, an aspiring smallholder's barriers (e.g., trust and affordability, last-mile support to explain, enable and operate technology) differ greatly from those of a transitioning farmer (e.g., low contextualisation of solutions to agro-climatic zones and farm scale, lack of enabling phygital infrastructure) and an advanced large farmer (e.g., regulatory or innovation hurdles). Accordingly, scaling frontier technologies in agriculture requires a tailored approach for each segment, boosting **last-mile adoption** for aspiring farmers, enabling widespread **commercialisation** for transitioning farmers, and supporting ongoing **innovation** for advanced farmers. For instance, consider the following examples of frontier technologies and the **structural barriers they face:**

Example 1 | Low adoption of micro-irrigation by aspiring farmers owing to economic viability and low last-mile support

Farmer needs

- **Efficient water use** to sustain yields in water-scarce conditions
- **Affordable and reliable irrigation solutions** that maximize productivity
- **Tools for monitoring** soil moisture and automating irrigation

Status of solutions existing

- Drip and sprinkler systems exist and are available, dramatically improving water-use efficiency
- IoT-based soil moisture sensors and automated irrigation triggers
- Digital monitoring and remote irrigation management tools

Barriers to adoption

- **Fragmentation** reduces the economic viability and cost effectiveness
- **Low trust** - Concerns over maintenance, durability, and risk of breakdowns; skepticism about digital scheduling tools
- **Limited last mile** advisory and implementation support
- **Lack of customized** solutions (e.g. – bundled offerings

Example 2 | Low contextualisation and commercialisation of automatic sorting and grading for transitioning farmers reduces viability

Farmer needs

- **Higher price realization** through standardized grading
- **Fast & consistent sorting,** reducing manual labor
- Accommodate **local crop varieties** and quality criteria

Status of solutions existing

- AI-driven machines sort produce by size, shape, color, surface defects
- New sorting machines are **modular and crop-agnostic** and can grade multiple crops by uploading appropriate AI models
- Automatic grading enables traceability & quality records

Barriers to commercialization

- **Limited local data** makes it hard to train models for crop varieties
- **Lack of phygital infrastructure** like collection centers, coupled with electricity/ internet connectivity limit adoption
- **Lack of guidelines** for sorting/ grading specifications result in low standardization and price realization, limiting value proposition of tech

Example 3 | Low innovation of frontier technology solutions, like digital twins, limits reach to advanced farmers

Farmer needs

- **Data-driven decision making** with validated outcomes
- **Sustainable farming models,** highlighting sensitivities
- **High predictability** of yield and disease control

Status of solutions existing

- AI-powered farm modeling platforms that create virtual replicas of fields and crops
- Real-time data integration from IoT-based soil, crop, and climate sensors

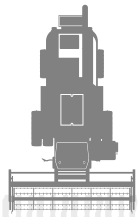
Barriers to innovation

- **Limited data** to feed into extensive models for farm simulation
- **Fragmentation and low affordability** restrict economic viability
- **Lack of skilled talent** for deploying and training models, and **low farmer trust** and awareness on utilization of twins for optimum results

3. UNLOCKING AGRICULTURAL TRANSFORMATION FOR INDIA WITH FRONTIER TECH

3.1 Systemic Roadblocks Hindering Agricultural Transformation

As illustrated in the previous section, though frontier technologies can transform the sector, they are often stalled due to systemic roadblocks. This section identifies six key roadblocks viz. Data, Trust, Phygital Divide, Talent, Fragmentation, and Capital that act as key impediments to a thriving AgriTech ecosystem.



6 Key roadblocks to frontier tech revolution in agriculture Identified

01 Data
- **Why it matters:** Data powers personalization, AI tools, new service delivery models etc.
- **Barrier:** Siloed data, no single-source of truth, lack of localized, high-quality AI-ready datasets

02 Trust
- **Why it matters:** Without trust, even great tech sees no traction
- **Barrier:** Low credibility and high risk of adopting new solutions, limited P2P recommendations, low coordination and ecosystem trust

03 Phygital Approach
- **Why it matters:** On-ground capabilities are needed to make tech actionable
- **Barrier:** Limited internet access, inadequate physical infrastructure, field force and touchpoints to integrate with digital solutions

04 Fragmentation
- **Why it matters:** Fragmented landholdings, lack of ecosystem alignment stalls ecosystem-wide transformation
- **Barrier:** Limited coordination and siloed functioning across industry, academia, policymakers & regulatory bodies

05 Talent
- **Why it matters:** Skilled talent pyramid is the backbone for developing, adapting, deploying, operating, and maintaining frontier technologies
- **Barrier:** Shortage of interdisciplinary researchers, entrepreneurs, skilled technicians, and tech-ready farmers

06 Capital
- **Why it matters:** Capital translates ideas into solutions, innovations in agriculture require patient capital
- **Barrier:** Gap in funding for high-risk, slow-scaling AgTech innovations, constrained credit access for farmers

Exhibit 3.1: Six key roadblocks to agricultural transformation through frontier technologies

3.2 A Vision of the Future: Accelerating Progress Towards Viksit Bharat Goals

Holistically addressing these systemic roadblocks can generate exponential value for India's agricultural ecosystem and transform the agriculture landscape by increasing productivity, improving climate resilience, enhancing price realisation, and reducing wastage.

The following exhibit presents three illustrative models which have been envisaged to demonstrate how de-bottlenecking key roadblocks can deliver real value for the entire ecosystem- including farmers, AgriTech startups, and innovators.

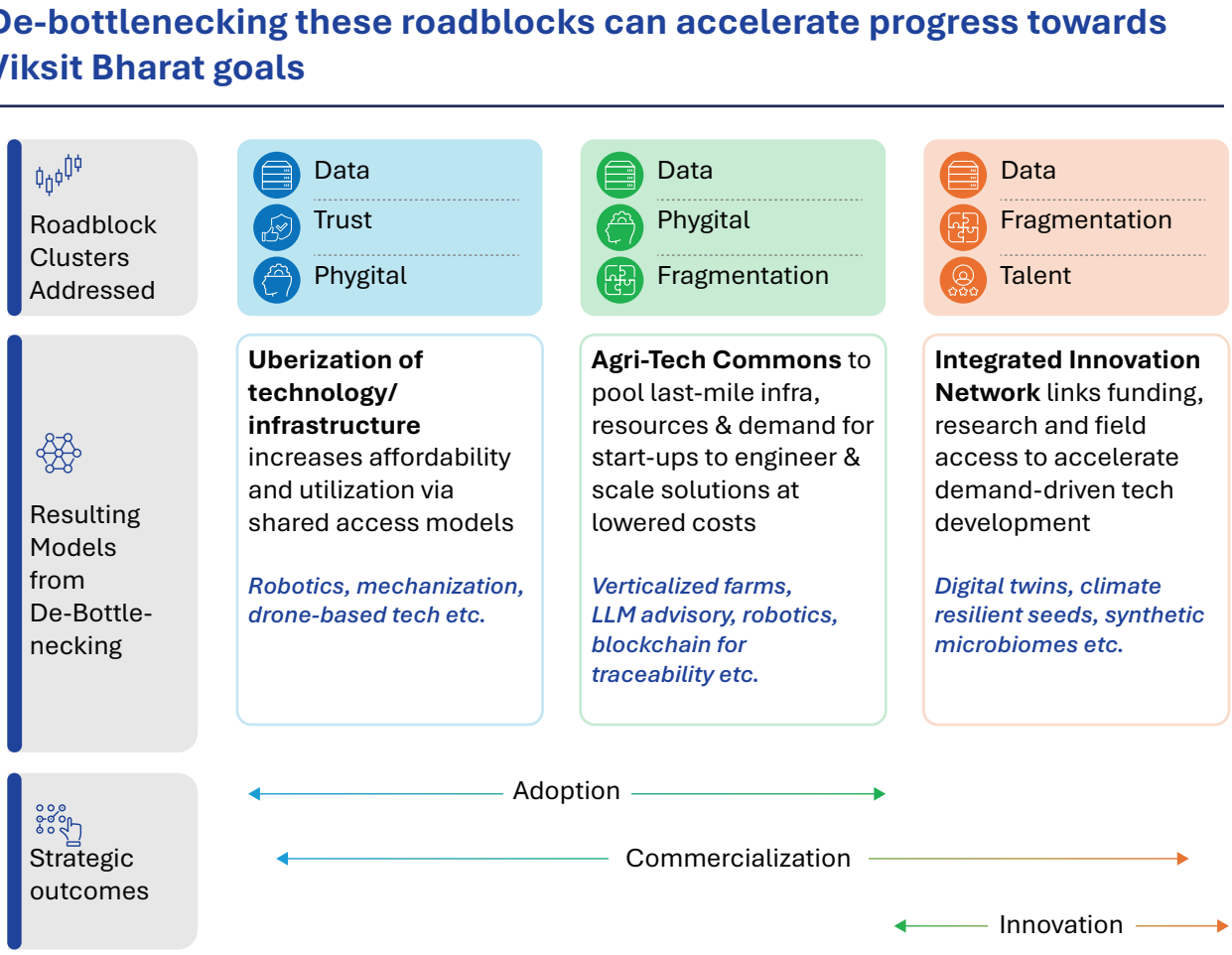


Exhibit 3.2: Three illustrative models that can be unlocked by addressing key roadblocks to frontier technologies

Uberisation of Technology

Aspiring and transitioning farmers can connect directly with machinery-on-demand digital platforms, reducing ownership costs, addressing fragmented rental networks, and boosting farm mechanisation and productivity. Data access through geo-tagged assets will not only enable real-time discovery and booking but also engender trust through secure channels, thereby building ecosystem confidence in transactions. Further, phygital support can activate service delivery to unlock uberisation.

Access to localised, granular **data,** integration of **fragmented** supply chains, and shareable **phygital** structures (public demo farms, field networks like Krishi Vigyan Kendras, distribution infrastructure) can unlock **AgriTech Commons.** Start-ups can plug into pre-established regional systems to discover local markets, customise and validate solutions, and deploy them through trusted networks at minimal costs to scale solutions across India's diverse agro-climatic zones rapidly.

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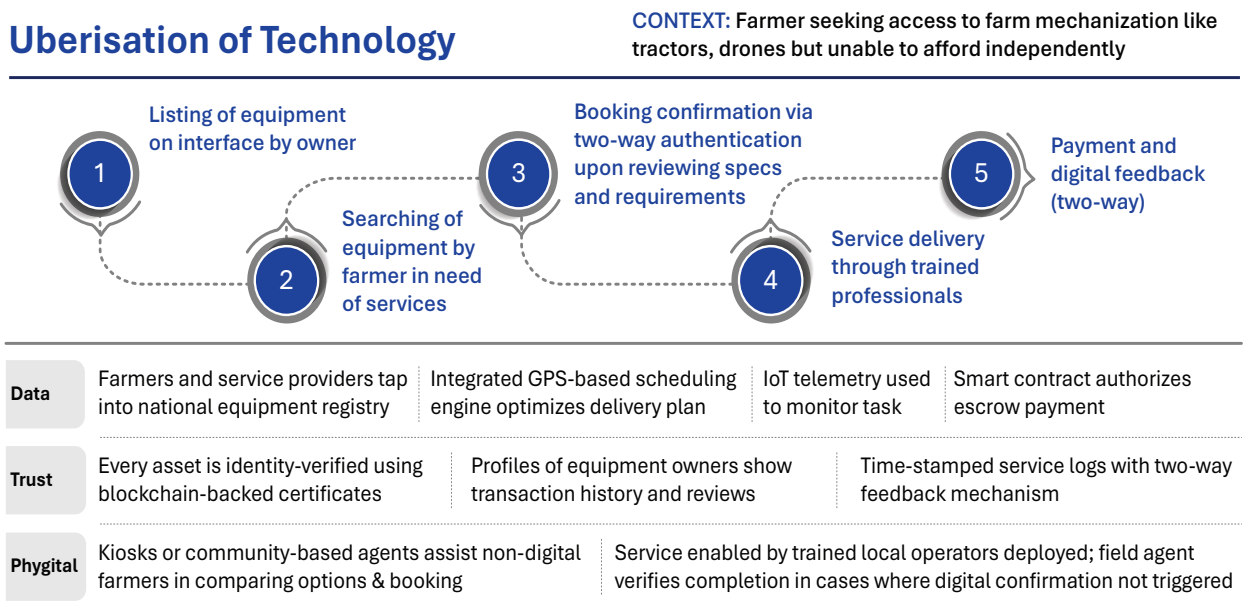


Exhibit 3.3. Uberization of machinery can increase productivity and farmer incomes

AgriTech Commons for Shared Resources

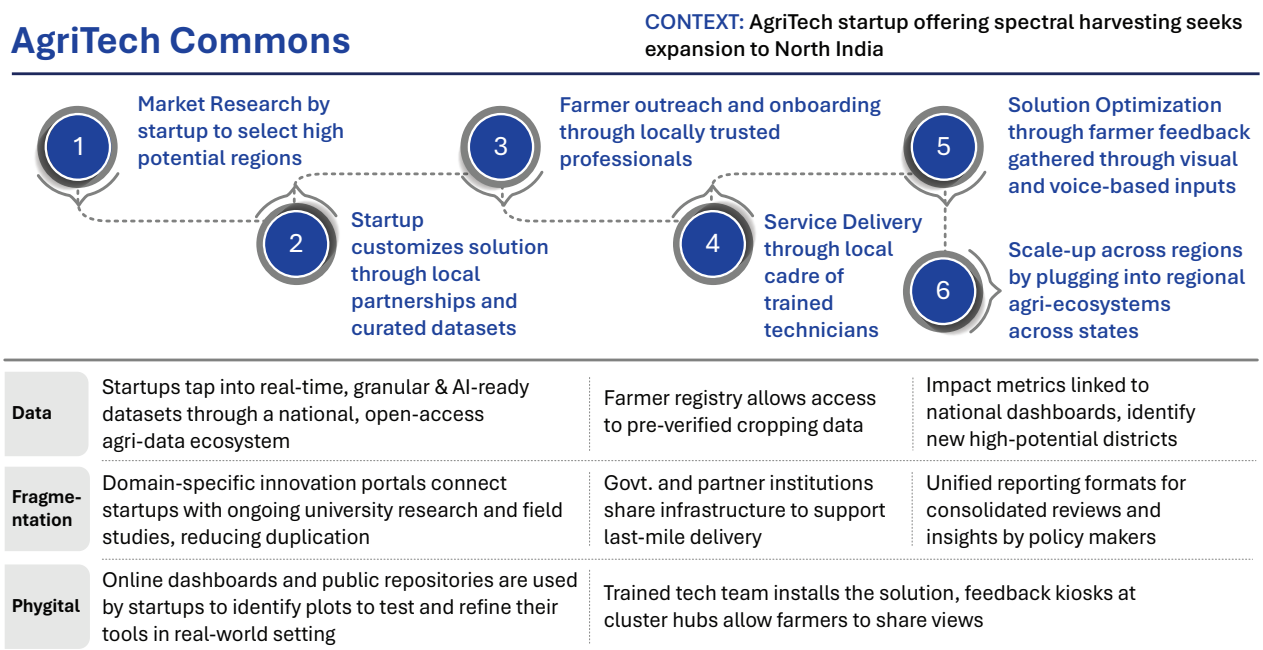


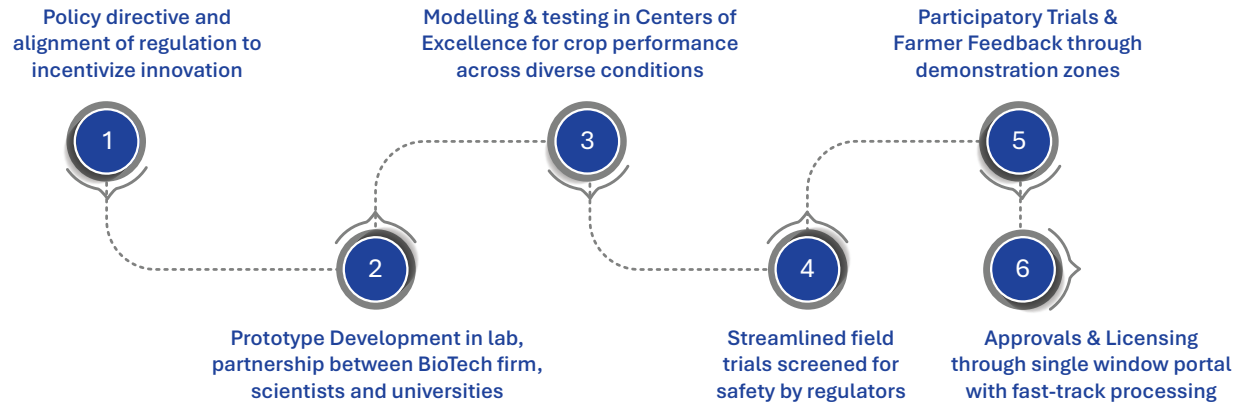
Exhibit 3.4: AgriTech Commons to commercialise solutions for optimum harvesting practices in new geographies

Integrated Innovations Networks for R&D

Integrated Innovations Networks link labs, start-ups, field trial infrastructure, and regulators to accelerate innovation cycles and scale pilots. Cross disciplinary **talent,** standardised **data** sharing systems, and coordination to align **fragmented** funding, regulatory frameworks and research priorities unlock this network.

Integrated Innovations Network

CONTEXT: **Biotech scientist seeks to build Digital Twins prototype for sustainable farming**



Data	Shared data maps ongoing R&D projects, enabling prioritization of high-potential research	Platforms capture sensor data from micro-plots and trial performance data is fed in real time to a shared validation portal	Performance logs are auto-tagged to ensure transparent audit trails
Fragmentation	Central task force aligns goals across ministries and research bodies, ensuring funding, trials, and regulation are coordinated	Domain specific innovation hubs in universities facilitate access to a network of cross-disciplinary experts, historical trial data for modelling solutions, and cutting-edge facilities for safe testing	
Talent	Domain experts (e.g. geneticists, agri-AI specialists) are recruited through the innovation hub and paired with startups via project-based contracting	Universities train the youth and embed them in lab-startup collaborations for live model testing. Trained technicians conduct testing and liaise between farmers, scientists, and regulators to document trial results	

Exhibit 3.5: Integrated R&D Network Drives innovation through ecosystem partnerships & collaboration

4. DEFINING THE PATH AHEAD FOR SCALING UP OF FRONTIER TECHNOLOGIES

India's next agricultural leap will be powered by frontier technologies. Concerted efforts through the Digital Agriculture Mission have laid strong groundwork for a modern agricultural ecosystem. Yet, as agricultural practices and technologies advance rapidly, the system must evolve into its next iteration and overcome the system roadblocks identified in section 3. This section recommends **Digital Agriculture Mission 2.0.,** a comprehensive three-pillar approach that upgrades foundational systems, builds domestic capacity for innovations, and fosters ecosystem convergence to translate them into last mile impact.

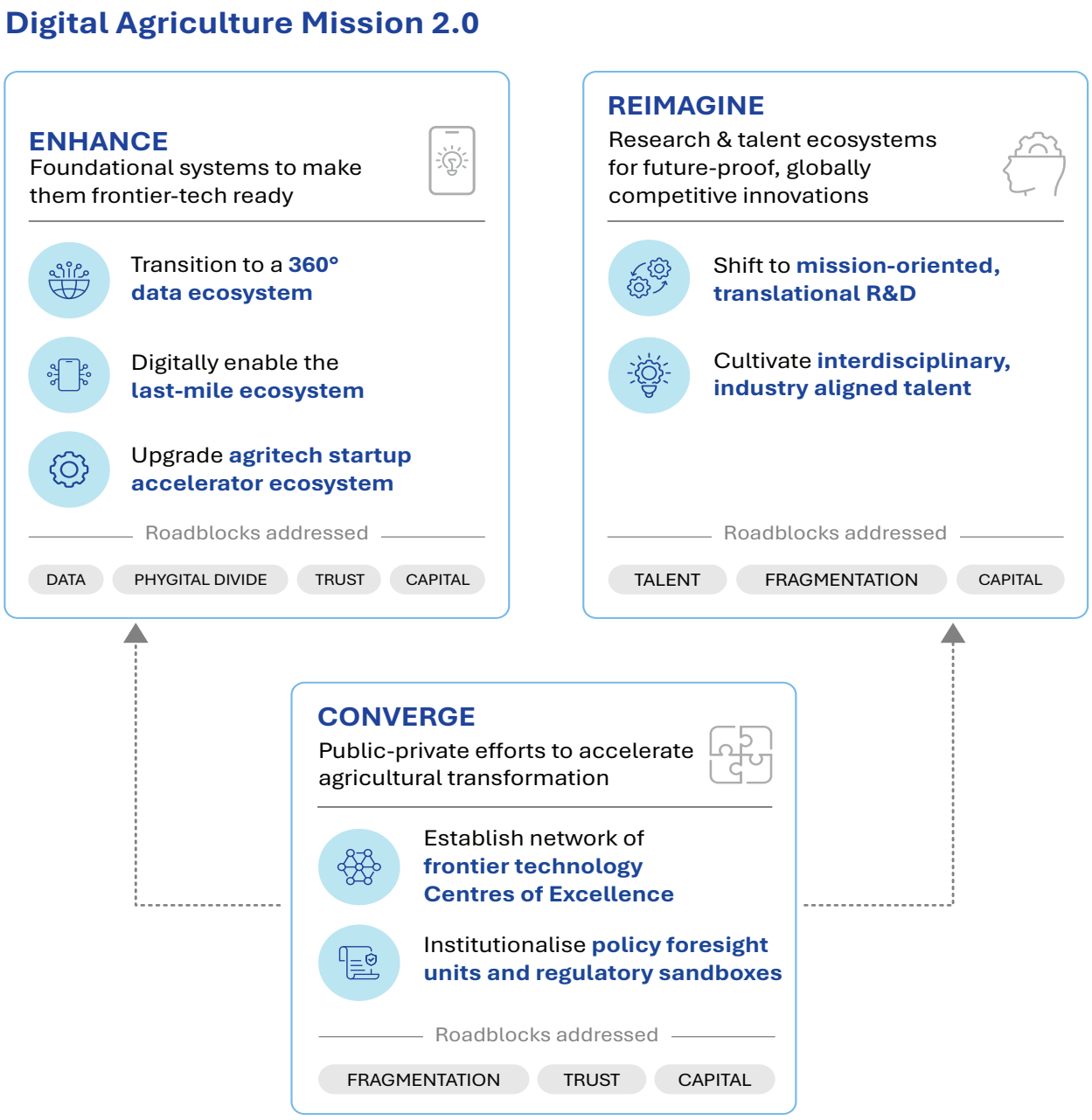


Exhibit 4.1: Three-Part Framework to Enable Scale-up of Frontier Technologies

4.1 Enhance foundational systems to be frontier-tech ready

Several national missions and programs have established robust foundations for deploying and delivering agritech solutions. However, as agricultural technologies mature, these foundational systems remain underutilised. To unlock their full transformative potential, the first pillar recommends advancing three critical enablers, as natural progressions of ongoing efforts under the Digital Agriculture Mission: a robust 360° data ecosystem, a digitally enabled last-mile network, and a strengthened AgriTech startup accelerator ecosystem.

Imperative 1: Transition to a 360-degree data ecosystem

Real-time, reliable, and ready-to-use data for public and private entities to drive innovation, delivery and decision-making

Under Digital Agriculture Mission 1.0, significant progress has already been made in building the foundational data architecture. The **AgriStack** forms the backbone of this system by integrating three core registries viz., farmer ID, geo-referenced village maps, and digital crop survey data, as the identity layer to categorise and tag all other information and services. Alongside this, the **Krishi Decision Support System** (KDSS) adopts a whole-of-government approach to aggregating dynamic datasets encompassing satellite imagery, weather, pricing, government schemes, and business intelligence tools to enable macro-level government planning and micro-level farm advisory. These services converge at the **Unified Farmer Service Interface** (UFSI), which is intended as a common access point for all public benefits and services, with the potential to include private sector offerings.

Imperatives for the system to progress to the next iteration

1. **Two-way data exchange:** Vast volumes of high-value data generated by the private sector remain untapped; enabling mechanisms and incentives can attract contributions from states, local agencies, and private entities to comprehensively capture ground realities.
2. **Data quality and readiness for use:** As agriculture is not a digital-native sector, manual data collection methodologies lead to inconsistencies, gaps, and even obsolescence. Non-standardised formats impede its use for innovation and service delivery.
3. **High degree of interoperability:** Diverse data schemas stemming from the absence of harmonised data and metadata standards and collection protocols, hinder coordination; shared standards and governance are essential to scale a unified ecosystem.

Recommendations to transition to the 360 Data Ecosystem ('Agri Kosh')

1. **Adopt a data mesh architecture**: Enable decentralised data contribution with clearly defined ownership by public and private entities, along with the responsibility to maintain and update the respective datasets. Existing cross-sectoral Digital Public Infrastructure (DPIs), such as AI Kosh, which already operate on such structures, may be leveraged for rapid deployment.
    a. **Agricultural Landscape Map :** Create a spatial grid of agricultural land for layering and contextualising data (e.g. soil profile, water availability, cropping pattern, market and credit access, last-mile network, value chain infrastructure) using GIS tools for data-driven planning, convergence, and optimal resource allocation.
2. **Establish an interministerial apex committee:** Oversee development, implementation, stakeholder coordination, and adoption of the data platform. The committee can be co-anchored by the Ministry of Electronics & Information Technology (MeitY) and the Ministry of Agriculture and Farmers' Welfare (MoAFW). Proposed roles could include:

a. **MeitY:** Ensure data governance, covering security, privacy, data compliance, cost management, and user access.

b. **MoAFW:** Own the agri domain, harmonising data and meta data standards and sharing protocols through consultations with NGOs, industry actors, technology experts, and state government agencies.

3. **Ensure open access with AI-enabled discovery and collaboration**: Leverage AI-powered features linked with DPIs that allow users to search and share curated AI-ready datasets and models, run comparative analytics, and engage through community features, thereby improving data quality and fostering collaborative innovation. Launch structured outreach through innovation challenges, hackathons, and grants to promote real-world use cases, incentivising participation through increased visibility and mutually beneficial monetisation opportunities.

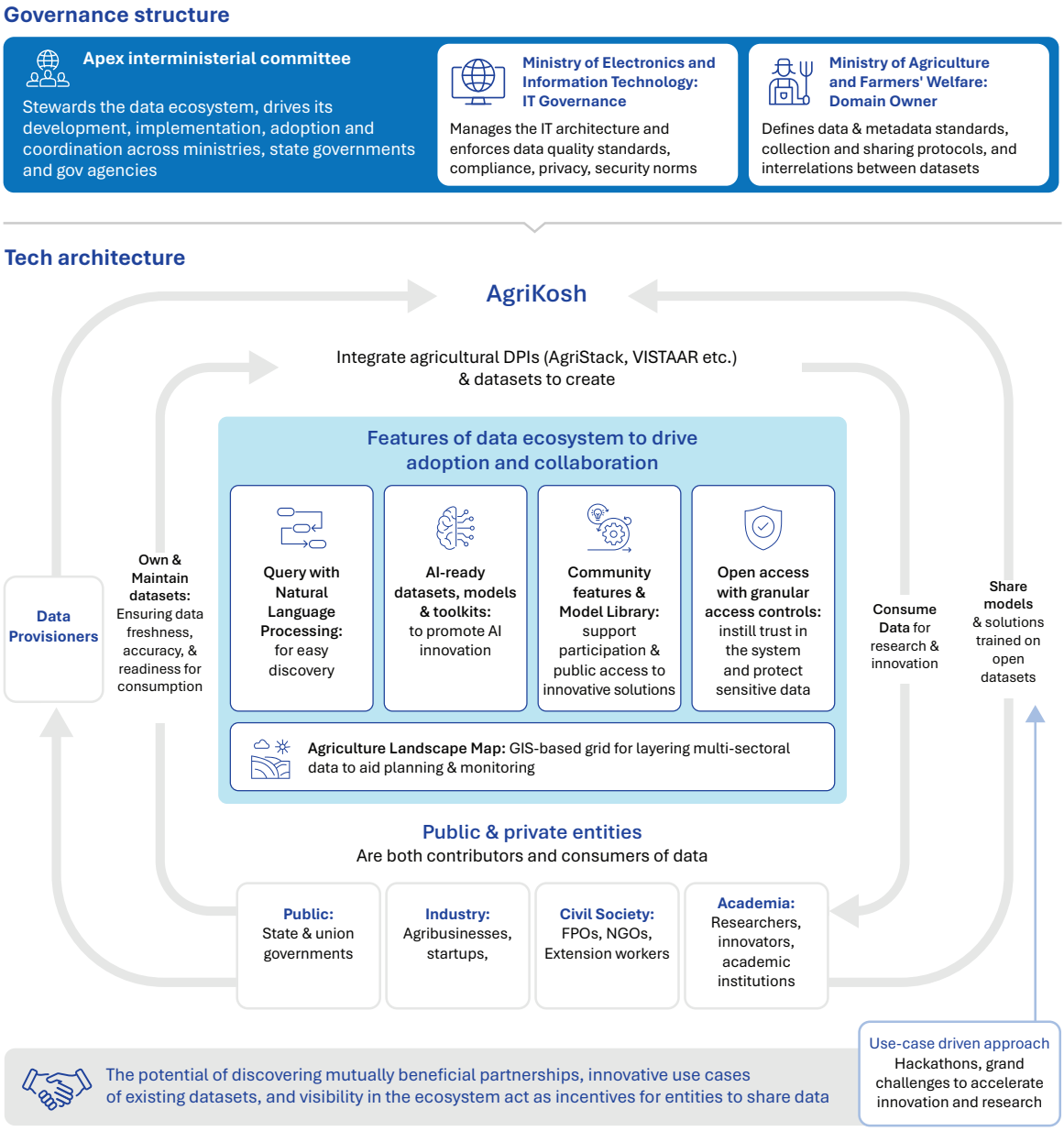


Exhibit 4.2: Vision of a holistic 360-degree data ecosystem

Imperative 2: Strengthen the last-mile delivery system

Expand reach, improve precision and effectiveness of advisory and services, and drive adoption

Though agriculture extension agents remain the government's principal channel for delivering advisory services, a network of producer organisations, cooperatives, self-help groups (SHGs), entrepreneurs, technical cadres (e.g., Drone Didis), local youth and leaders also play an indispensable role in enabling solutions in farms, especially for aspiring and transitioning farmers in remote and digitally underdeveloped regions. While the configuration of this ecosystem varies substantially by region, depending on local institutional strengths and contexts, clearly defining the roles and structure of the last-mile ecosystem is critical to ensuring that innovative solutions translate into impact on ground.

In recent years, this last mile network has been significantly augmented through the development of **VISTAAR,** an AI-powered advisory Digital Public Good (DPG), the digital upskilling of local cadres through Agricultural Technology Management Agency **(ATMA),** and the **computerisation** of PACS and FPOs. With this as the foundation, initiatives like Apurva AI Chatbot (a peer-to-peer learning platform) and **Kisan Call Centres** have been piloted.

Imperatives for the system to progress to the next iteration:

1. **Expanded reach:** Despite a sizeable extension workforce, the ratio of extension officer to farms served remains significantly low at one extension officer for ~1100 farms, higher than the recommended 750[7]. Geographic constraints further restrict reach. Thus, the system needs additional virtual and direct touchpoints to supplement the existing field force and improve access.
2. **Real-time feedback and response loops:** There is a paucity of mechanisms that capture real-time farmer feedback and track service outcomes. As a result, risk signals may be missed, leading to a gap in receiving critical inputs required to refine services. Two-way communication channels are needed to make solutions responsive, accurate, and personalised.
3. **Bridging the digital literacy gap:** Low digital literacy amongst farmers precipitates the need to develop interfaces that are intuitive, multilingual (trained in the local vernacular), multi-format (voice, visual, text), and easy to access to encourage adoption.
4. **Improved accuracy of advisory:** Unreliable advisory can adversely impact farmer livelihoods, and thus, farmers exercise caution while adopting these services. High quality, hyperlocal AI models, trained on granular datasets and validated through field pilots, can build trust and power context-specific advisory and services.

7 Recommended extension functionary to farm ratios for irrigated regions in the Report of the Committee on Doubling Farmers' Income, Ministry of Agriculture and Farmers' Welfare (2017)

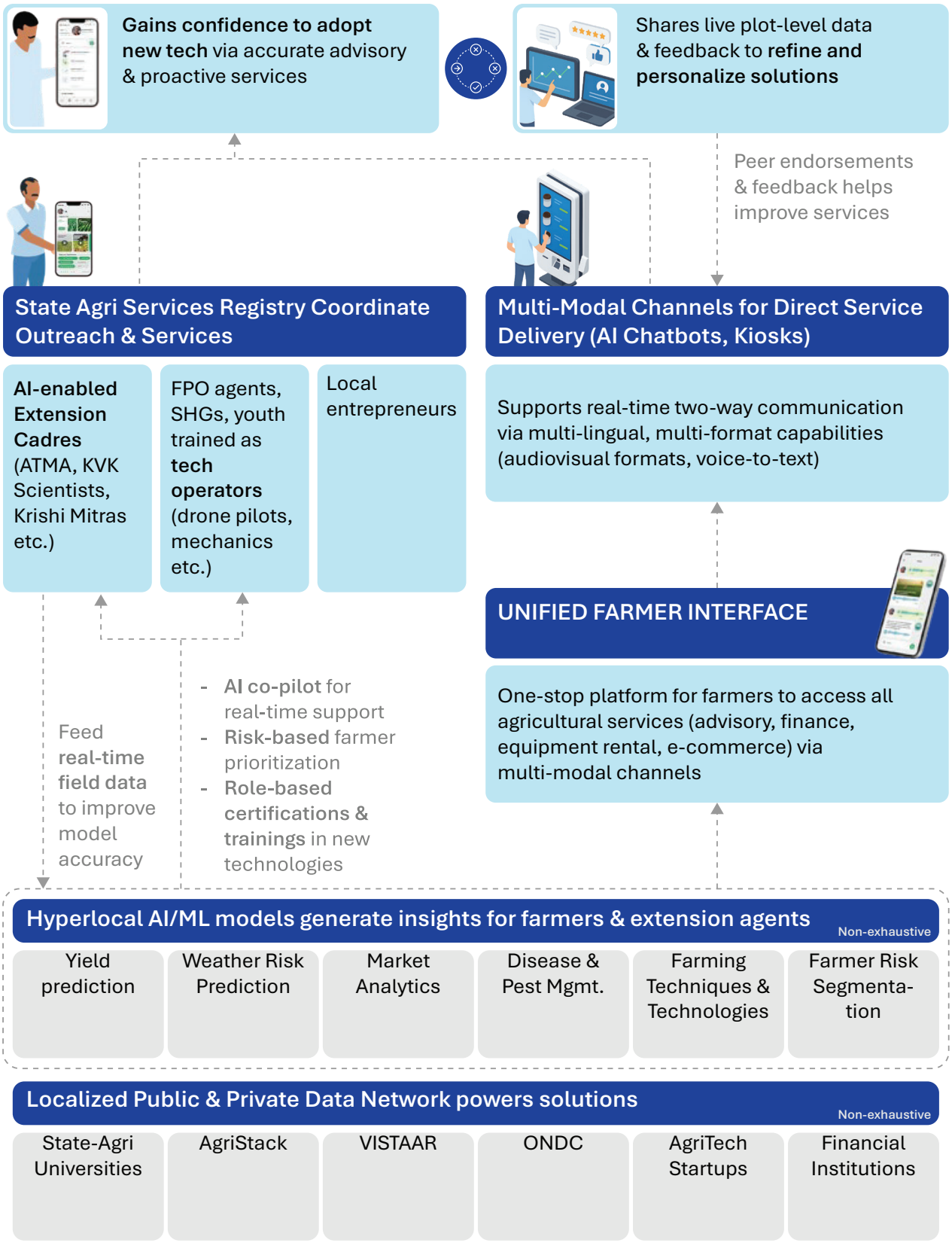


Exhibit 4.3: Tech enabled multi-modal extension ecosystem with two-way communication

Recommendations to modernise all elements of the extension network

1. **Deploy multi-modal, two-way delivery systems:**
    a. **Integrated advisory channels:** Scale AI chatbots, IVR tools, call centres, and kiosks into a unified multi-format, multilingual (vernacular) interface, enabling farmers to share real-time inputs like crop images for diagnostics, advisory, and timely support.
    b. **AI-enabled extension agents:** Supplement AI efforts by equipping field agents with AI co-pilots for diagnostics, hyperlocal advisory, audiovisual demonstrations, and beat planning for risk-based farm prioritisation, thereby enhancing the precision, efficiency and timeliness of outreach.
2. **Develop hyperlocal AI models:** Partner with the private sector to develop and validate AI models tailored to cater to local agroclimatic conditions, crop profiles, farmer archetypes, and farm activities. Prioritise clusters high on data and digital readiness for initial pilots.
3. **Build a trusted ground-level data network of public & private sources:** Curate hyperlocal, AI-ready datasets by leveraging data from private and public last-mile actors (FPOs, NGOs, SHGs), extension workers, and state agricultural universities, as these hyperlocal data sets are essential for training effective localised AI models.

Imperative 3: Upgrade the AgriTech Accelerator Ecosystem

Scale up innovations and deliver impact through outcomes-based investments

India's AgriTech ecosystem is flourishing, fuelled by a combination of public and private investments and over USD 2 billion in startup funding along with initiatives like RKVY-RAFTAAR and AgriSURE, which have incubated 1,900+ ventures through 29+ agribusiness incubators. Revamping this accelerator ecosystem is crucial to contextualise, scale and mainstream transformative solutions for agriculture's evolving needs.

Several frontier technologies developed today are capital-intensive and require long gestation periods. Thus, there is a growing need for strategic partnerships, repeated capital infusion, structured access to data, and robust R&D infrastructure and distribution channels for these ventures to scale successfully and deliver tangible outcomes.

Imperatives for the system to progress to the next iteration:

1. **Strategic coordination:** A prerequisite for strengthening the AgriTech accelerator ecosystem is a mature, outcomes-focused framework for assessing its performance. Limited visibility into investment outcomes hampers identifying underperforming segments, assessing the effectiveness of prioritised areas, and directing resources to areas of maximum impact.
2. **Access to key enablers for scale:** Fragmented distribution channels, lack of granular regional data, inadequate access to R&D infrastructure, and complex regulatory requirements inhibit startups from scaling into new geographies.
3. **Patient capital:** Current investments are primarily concentrated in lower-risk, high-volume, and fast-scaling segments whereas high-risk, frontier solutions witness limited activity. There is a pressing need to systematically diagnose the accelerator ecosystem, assess segmental needs, and channel capital and institutional support to critical areas that will power the nation's big leap toward 2047.

Recommendations to develop a post-acceleration ecosystem for AgriTechs

1. **Sector mapping & outcomes assessment framework:** Develop a national framework to map AgriTech accelerators and track their performance, diagnose ecosystem bottlenecks, identify underperforming segments, and drive growth in priority sectors. Built in consultation with private investors, accelerators, and state-level committees, the framework can also be used by AgriTech accelerators to realign targeted mandates that catalyse impact, drive priorities, and bridge gaps.

2. **Next-generation accelerator capabilities for the scale-up of support:** Develop capabilities within the accelerator ecosystem through linkages with thematic Centres of Excellence (CoEs; details in section 4.3) to support a maturing AgriTech landscape as startups scale into new regions and sectors. These capabilities include access to data, R&D, distribution networks and regulatory guidance:

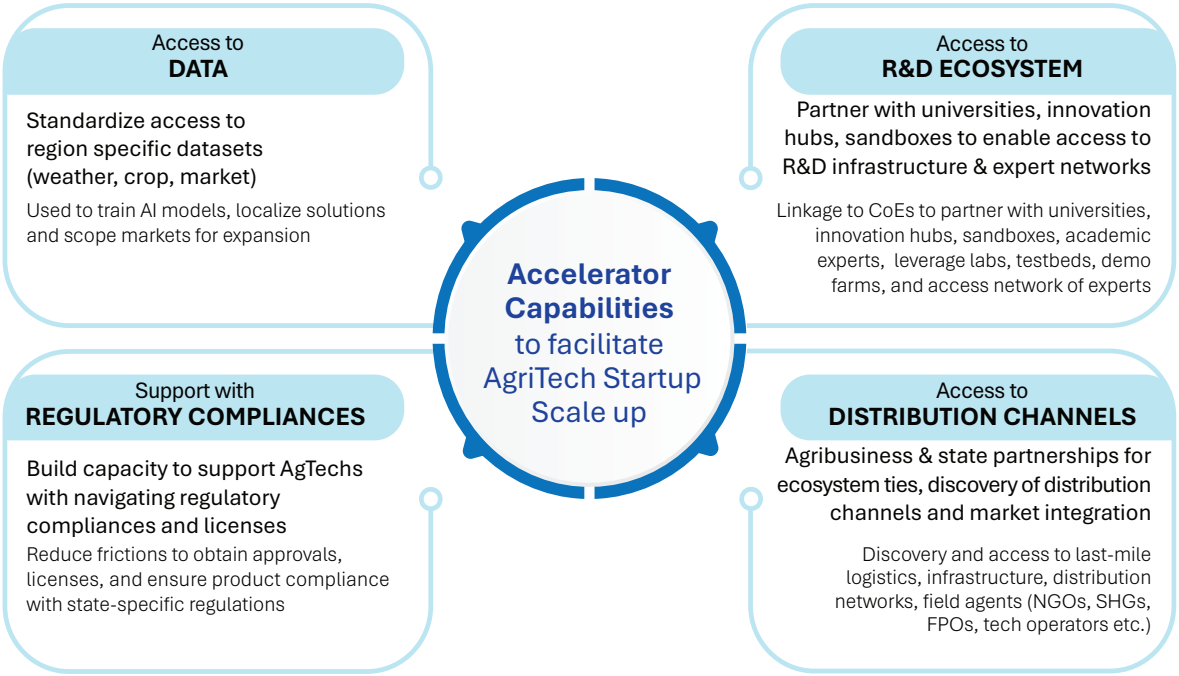


Exhibit 4.4: Four capabilities for AgriTech accelerators to strengthen scale-up support

3. **Joint investment mechanisms to activate patient capital:** Frontier tech solutions in areas like genomics, synthetic biology, precision agriculture, and post-harvest infrastructure require long-gestation periods and patient capital. To incentivise the infusion of patient and strategic capital, a joint corpus of private and public capital can be established. The introduction of layered investment tools (debt, equity, concessional capital) and risk-sharing and financial incentives like first-loss default guarantees, grant matching, and tax credits can further encourage private sector contributions.

4.2 Reimagine Agri-Innovations & Agri-Talent Systems for Future-readiness

India's Green Revolution, anchored by the Indian Council of Agricultural Research (ICAR), represents one of the most transformative stories in agricultural development globally. As the scale, complexity and unpredictability of agricultural challenges increase, driven by climate stress, globalisation and

market volatility, and shifting consumer demands, agriculture itself has become more knowledge and technology intensive to keep pace.

India's next agricultural transformation and the realisation of Viksit Bharat 2047 ambitions hinge on its ability to fundamentally reimagine and revamp this institutional framework to unlock a comparable technological revolution. There is an imminent need to revisit and reform existing systems from a future readiness lens, ensuring that scientific advances and human capacity operate as twin engines of agricultural modernisation. Two foundational levers of this framework viz., the innovations ecosystem and the talent pipeline, if strengthened and executed with intent, can drive frontier breakthroughs in climate-smart, nutrient-rich agriculture, multiplying gains in productivity, resilience, and rural incomes while creating high-value agri-adjacent livelihoods. In the following sections, we identify priority dimensions within these levers that merit a re-examination.

Imperative 1: Shift to mission-oriented, translational innovations systems

A future-ready R&D ecosystem is envisioned as one that fosters and translates India's scientific capacity into scalable, globally relevant, and contextualised agricultural innovations that translate into impactful solutions at the last mile. To enable this, four key dimensions merit reconfiguration:

- **Mission-oriented innovation systems:** The siloed and discipline-specific nature of agricultural R&D and training limits the nation's ability to address complex, interdisciplinary challenges such as climate resilience, protein security, or soil regeneration. A pivot to mission-based research portfolios that reorganise national research and innovation around clearly defined, high-impact problem statements is imperative. These portfolios can facilitate multi-institutional collaboration through shared mandates to innovate and tackle long-horizon challenges, in line with national priorities, supported by reinvented academic institutions, curricula, and pedagogy to facilitate this transition.

Seed technology has been recognised as a national priority through the National Mission on High Yielding Seeds (FY25-26), given its outsized role in driving productivity, nutrition and resilience. Since 2014, ICAR and the National Agricultural Research System (NARS) have advanced from traditional crossbreeding to hybridisation (6,100+ varieties), transgenics, biofortification (900+ varieties), climate-resilient breeding (2,600+ varieties), speed breeding facilities, and seed coatings/biological treatments. As of 2025, India has also launched its first National Speed Breeding Crop Facility in Mohali and developed CRISPR rice. Wider adoption of these technologies, along with continued investment in R&D, will be essential for improved yield and productivity.

- **Translational pathways:** There is a need to reconfigure the R&D ecosystem as an interconnected, translational research network integrating institutions such as innovation hubs, Krishi Vigyan Kendras (KVKs) to move innovations from labs to large-scale adoption with speed and consistency. Mechanisms that embed field validations, market-readiness testing, real-time farmer feedback, and market demand signals into the R&D lifecycle can strengthen the feedback loop between research, regulation, and commercialisation, increasing translational throughput of agri R&D, and generating robust datasets to mobilise investments and global partnerships.
- **Private sector investments:** Agricultural R&D in India remains public sector-led and underfunded, with public investment at just 0.6% of the agricultural budget versus 0.9% globally and ~2% in leading economies, while private contributions remain meagre. Reimagining funding through greater public spending in priority areas as well as robust public-private collaboration coupled with strengthened IP enforcement, risk-sharing

and blended finance to unlock private capital can accelerate innovation for and redefine translational pathways for scale-up in shorter timeframes.

Imperative 2: Cultivate interdisciplinary, industry-aligned talent system

To usher in a technological revolution, India requires a talent pyramid as dynamic as the technological landscape itself. Hence, the need to create inter-disciplinary talent pipelines through next-generation AgriTech curricula and pedagogy, industry partnerships, and meaningful off-farm and post-production employment opportunities. In order to achieve this, a few key levers are:

1. **National agri-talent framework**: Agricultural transformation necessitates a talent shift aligned with current and emerging market requirements. As the first step, there is a need to develop a comprehensive, National Skills Qualification Framework (NSQF)-aligned talent framework mapping the technical and sectoral skills and roles required across the agri-innovations value chain with coherent career pathways enabling both vertical progression and lateral movement across four tiers:
    - **Academic and research talent** (data scientists, agronomists, biotechnologists, AI specialists etc.) to innovate solutions.
    - **Agribusiness leaders and entrepreneurs** trained in fields like sales and marketing, product development, procurement etc. through cross-disciplinary graduate programmes to deploy innovative solutions.
    - **Certified AgriTech service professionals** (e.g., agri-logistics managers, drone pilots, IoT specialists) to enable technology access and adoption at the last mile.
    - **Digitally literate farmers** and producer groups equipped to absorb and monetise new technologies.
2. **Industry-aligned academic and research ecosystems:** To cultivate talent, the agriculture university network needs to embed industry more meaningfully. Centres of Excellence (section 4.3 for details) can facilitate private sector partnerships to co-design cross-disciplinary curricula, co-deliver training programs, support farm innovation fellowships, live projects, apprenticeships, and structured placement pathways to meet the evolving demand of employers and entrepreneurial systems. Concurrently, international collaborations and exchanges and mainstreaming of agricultural courses in prominent technology and business institutions can further develop a globally competitive domestic talent pool.
3. **Skills ladder & certification for vertical mobility:** Skilling needs to shift to modular, stackable nano and micro-credentials that permit progressive learning, advanced specialisations, and broad-based, customisable skill profiles. Combined with an NSQF-aligned certification framework that recognises prior learning to signal expertise to employers, such a system could provide portability and diversified employment opportunities to rural populations across geographies and sectors.
4. **Mass entrepreneurship enablement:** Mass entrepreneurship across the agriculture value chain is a key unlock to enable technological solutions at the last mile, while generating employment. Scaling public-private partnerships to deliver end-to-end support models like 'entrepreneurship-in-a-box' that bring together capital, market linkages, mentorship digital tools, and training tailored to producer organisations and rural enterprises, merit exploration to advance viable ventures at the last mile.
5. **Inclusion as a growth lever:** Women and youth remain central to the future of the agricultural

workforce. There is a need to identify targeted mechanisms to enable their participation in high-value roles, such as leadership in producer organisations, innovation challenges, specialised training in agri-processing, and global exposure opportunities, to ensure frontier technologies are diffused to every beneficiary.

Agriculture's R&D and talent ecosystem cuts across ministries (Agriculture, Skill Development & Entrepreneurship, Education, Rural Development, Biotechnology) and institutions. An exercise that involves redesigning curricula, funding flows, institutional structures, and skilling frameworks requires continuous consultations across stakeholders. Thus, to undertake this exercise, we recommend the establishment of two time-bound thematic task forces, one focusing on the R&D ecosystem and the other, on the agri-talent ecosystem. These task forces would bring together leading cross-sector experts with a mandate to define strategic priorities, draft 10–20-year roadmaps, develop mission blueprints and policy briefs, and recommend institutional reforms.

4.3 Converge public-private efforts to accelerate agricultural transformation

The transformation of Indian agriculture through frontier technologies cannot be driven by the government or industry alone – it will emerge from the strength of their partnership. The scale, speed, and complexity of frontier-tech adoption in agriculture demand a new model of collaboration between government, industry, academia, and innovators, one that unites public vision with private agility.

While public institutions such as ICAR, State Agricultural Universities (SAUs), and government missions bring reach, legitimacy, and long-term perspective, the private sector offers innovation velocity, investment, and operational efficiency. However, these efforts often remain fragmented – research partnerships are ad hoc, data systems remain siloed, and regulatory alignment lags innovation cycles. To overcome these gaps, India must institutionalise a mechanism that unites all relevant stakeholders under a common framework for agricultural innovation and transformation.

Imperative 1: Establish a National Network of Frontier Technology Centres of Excellence for Agriculture

The answer lies in establishing a national network of frontier technology Centres of Excellence (CoEs) which will serve as the institutional backbone for structured private-public collaboration. Their mandate would be to convene diverse stakeholders, startups, corporates, investors, research institutions, state agencies, and FPO networks, to co-develop, pilot, and scale frontier technologies across the agricultural value chain. This network would serve as the nerve centre of India's agricultural transformation, where government priorities, private innovation, and farmer realities converge to power India's journey toward Viksit Bharat 2047.

To translate this vision into practice, we propose:

- **Institutional anchoring and governance:** Joint stewardship of the network, anchored by relevant ministries like the Ministry of Agriculture and Farmers' Welfare (MoAFW) and the NITI Aayog, with representation from key ministries like Ministry of Electronics and Information Technology (MeitY), Department of Biotechnology (DBT), industry bodies[8], and leading academic institutions. To de-risk innovations, ensure long-term continuity, and ensure accountability across public, private and scientific partners, each CoE could adopt clearly defined partnership models and co-investment mechanisms.
- **Thematic-focus:** Each CoE can focus on a specific, high-impact problem statement such

8 Some existing consortia to be considered include Federation of All India Distributors Association (FAIDA), Federation of Seed Industry of India (FSII), the National Agricultural Innovation Project (NAIP), Small Farmers Agribusiness Consortium (SFAC).

as creating climate-smart seeds, precision agriculture for small-scale farming, developing post-harvest intelligence, and unlocking the full potential of agri data, insights and AI. This shift from technology-focused or discipline-specific partnerships to mission-oriented, thematic CoEs reflects a recognition that agricultural transformation is a systems challenge. By mobilising scientific, industrial, and civic capabilities around shared missions, such CoEs create the collaborative architecture needed to address complex, interdependent problems that span ecosystems, markets, and communities, thereby enabling solutions that are both systemic and scalable.

- **Outcomes-orientation:** These COE can have clearly articulated 3–5-year goals, anchored in specific, quantifiable outcomes (e.g. productivity enhancement, resource use efficiency, income growth etc.). To further ensure impact, this can be linked to competitive outcome-based funding mechanisms that reward demonstrable field impact, technology adoption rates, and patent generation.
- **Ecosystem alliances:** The CoEs will function as translational engines, cohesively integrating research, enterprise, and field deployment. To this end, structured linkages with Agritech startup accelerators and incubators to scale promising, mission-aligned solutions and capacity-building pathways for talent through fellowships, internships, curricula design and international collaborations should be considered to strengthen and reorient the translational capabilities of the ecosystem.

Imperative 2: Institutionalise policy foresight and regulatory sandboxes for AgriTech

The rapid evolution of frontier technologies will need continuous changes in governance, regulatory frameworks, and solution dissemination. To achieve this, we need a regulatory paradigm that is proactive, agile and anticipatory, balancing the safeguarding of public interest with efficient last mile technology transfer. To achieve this, we need a mechanism for continuous dialogue between the public and private sector and propose two initiatives:

- **Agritech Policy Foresight Unit:** To address this gap, a dedicated AgriTech Policy Foresight Unit can be established to systematically track scientific and technological frontiers, shifts in global regimes, and assess their socioeconomic and ethical implications to propose anticipatory and adaptive regulatory pathways in consultation with relevant ministries and statutory bodies.
- **Regulatory Sandboxes:** Complementing this, regulatory sandboxes could be operated jointly with the line ministries and state governments to evaluate and test frontier technologies in controlled environments before wider deployment. These mechanisms would create a structured interface between innovation and regulation, allowing policymakers to learn from empirical evidence, refine standards, and build confidence among farmers, investors, and innovators. In doing so, they would embed agility and foresight into India's agricultural governance architecture, ensuring that regulation evolves in tandem with innovation.

In summary, the *Enhance* pillar strengthens foundational systems for development and delivery, Reimagine charts the frontier of AgriTech possibilities, Converge ensures that both are synchronised, guided, and amplified through an institutionalised process of coordination and consensus-building across the vibrant ecosystem. It paves the way for coherent policies, efficient resource utilisation, and an inclusive approach to addressing India's agricultural challenges, ensuring that transformative technologies and ideas reach farmers and contribute to a resilient, prosperous sector.

5. CALL TO ACTION

A robust agricultural system is central to a nation's sovereignty, ensuring the fundamental imperative of food security. India has largely fulfilled this goal, driven by the remarkable productivity gains of the Green Revolution. Yet today, the sector stands at a critical inflexion point. Beyond food systems, India's agriculture holds the promise of becoming a powerful engine of economic growth with a rapidly advancing bioeconomy sector, projected to reach USD 300 billion by 2030[9].

In this evolving context, it is clear that conventional approaches will no longer suffice. The pace of disruption demands bold thinking and novel instruments. Frontier technologies, spanning digital, biological, mechanical, and material science innovations, are redefining what is possible in farming and enabling a new era of agricultural transformation. These innovations offer pathways for mitigation, resilience, and adaptation, and can position India as a global leader and partner of choice in agricultural innovation.

Realising this potential will require nothing short of a Frontier Technology Revolution, one that not only enables greater application of these technologies to India's unique agricultural challenges but also adopts a structured, data-driven approach to scale them from the lab to the field, thereby creating a paradigm shift from rural livelihoods to rural prosperity.

The way forward is not linear. India must invest along two parallel tracks in order to **resolve immediate challenges** that constrain current productivity, income, and resilience, and **build readiness for future breakthroughs** so that when transformative technologies emerge, the system is primed for rapid adoption and scale. **Both tracks are equally urgent.** Focusing only on today's issues risks stagnation. Focusing only on tomorrow leaves millions vulnerable in the present.

This report offers a framework for the ecosystem that will need to come together in order to deliver on the **three-pronged agenda of enhance, reimagine, and converge.**

- The government needs to act as a **facilitator and orchestrator,** helping enhance foundational capabilities by providing a stable and future-ready policy and regulatory environment, building robust digital and physical infrastructure, improving data systems, and enabling last-mile connectivity while also converging efforts across actors.
- The private sector can play the role of **innovators and scalers,** reimagining solutions that are not only advanced but also accessible, affordable, and farmer-friendly, converging with academia and innovators, and scaling with agility, for population-scale impact.
- The academia and research institutions will act as **knowledge anchors,** shifting from siloed research to mission-driven portfolios that address long-horizon challenges, building the talent pyramid, and serving as bridge that connects fundamental research with industry applications.
- Civil society can serve as **connectors and enablers,** enhancing awareness and capacity, facilitating feedback loops, and bridging the phygital divide by combing digital tools with physical networks to reach even the most marginalised farmers.

The stakes are high. By 2047, India aspires to be a developed nation. Agriculture, employing nearly half the workforce and feeding 1.4 billion people, must be at the heart of this transformation. Frontier technologies provide the opportunity to leapfrog structural barriers and herald an era of a more resilient, productive, and global agricultural ecosystem in India.

9 India's Bioeconomy to Touch $300 Billion by 2030, Says Dr. Jitendra Singh; PIB Press Release, August 2025

APPENDIX: CALCULATION OF AGRICULTURAL INCOMES

Agricultural income estimates were derived from the Situation Assessment Survey of Agricultural *Households (2018–19),* isolating **net receipts from crop production** as the principal indicator of agricultural income. This was done to ensure alignment with the report's focus on agricultural productivity rather than composite rural incomes. The computation was undertaken by size class of land possessed, applying both the paid-out expenses and paid-out plus imputed expenses approaches (see Tables 1A and 1B). The analysis indicates a clear income gradient correlated with landholding size.

1A	**Monthly income | July 2018 - June 2019** (excluding paid out expenses)						**Annual agricultural income**	
Size class of land possessed (Ha.)	**Wages**	**Land-leasing**	**Crop production**	**Animal Rearing**	**Non-farm business**	**Total monthly income**	***Crop production x 12***	
< 0.01	6,435	254	1,660	2,084	772	11,204	19920	
0.01 - 0.40	4,491	189	977	1,162	703	7,522	11724	20,000 – 60,000
0.40 - 1.00	3,906	76	2,683	1,335	570	8,571	32196	
1.01 - 2.00	3,647	74	5,269	1,845	613	11,449	63228	
2.01 - 4.00	3,548	146	9,432	2,551	758	16,435	113184	1,00,000 – 2,00,000
4.01 - 10.00	4,273	451	19,645	3,451	472	28,292	235740	
10.00 +	3,943	581	43,599	11,473	1,162	60,758	523188	> 5,00,000
all sizes	**4,063**	**134**	**3,798**	**1,582**	**641**	**10,218**		

1B	**Monthly income | July 2018 - June 2019** (excluding paid out and imputed expenses)						**Annual agricultural income**	
Size class of land possessed (Ha.)	**Wages**	**Land-leasing**	**Crop production**	**Animal Rearing**	**Non-farm business**	**Total monthly income**	***Crop production x 12***	
< 0.01	6,435	254	1,435	1,087	772	9,982	17220	
0.01 - 0.40	4,491	189	657	349	703	6,388	7884	17,000 - 50,000
0.40 - 1.00	3,906	76	2,042	356	570	6,951	24504	
1.01 - 2.00	3,647	74	4,313	541	613	9,189	51756	
2.01 - 4.00	3,548	146	7,945	600	758	12,997	95340	95,000 - 2,00,000
4.01 - 10.00	4,273	451	16,914	342	472	22,453	202968	
10.00 +	3,943	581	37,369	7,087	1,162	50,143	448428	>4,50,000
all sizes	**4,063**	**134**	**3,058**	**441**	**641**	**8,337**		

These estimates were corroborated against comparative evidence from the annual price policy reports by the Commission of Agricultural Costs & Prices (2024-25), using cost-of-cultivation and minimum support price-based revenue benchmarks for subsistence crops. Independent economic analyses of export-grade crops published in reputed journals were used to corroborate the income spectrum for advanced farmers.

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