



National Emerging Technology Roadmap

2026-2035

August, 2026

Statement from Minister, FDRE Ministry of Innovation and Technology



As the Minister of Innovation and Technology, it is both an honor and a privilege to present the **National Emerging Technologies Roadmap**. In our commitment to forging a sustainable and inclusive future, Ethiopia recognizes that emerging technologies are pivotal in transforming our socio-economic landscape.

The swift global advancements in fields such as nanotechnology, advanced computing, intelligent systems, synthetic and systems biology, and advanced materials and manufacturing technologies present us with unprecedented opportunities. These innovations enable us to leapfrog traditional development pathways and position Ethiopia at the forefront of technological progress.

This roadmap embodies our dedication to harnessing these technologies responsibly and inclusively, ensuring their benefits extend to all segments of society. Our focus encompasses the creation of robust innovation ecosystems, the development of human capital, the establishment of conducive policies, and the promotion of dynamic public-private partnerships. Together, these efforts will establish Ethiopia as a regional leader in emerging technologies.

I urge all stakeholders, government agencies, academic institutions, the private sector, civil society, and international partners to unite in collaboration, investment, and relentless innovation. By synergistically leveraging innovation, technology, and sustainable development, we can unlock the profound potential of these technologies. This will allow us to address our unique challenges, create new industries, generate employment opportunities, and ultimately enhance the quality of life for all Ethiopians.

Let this roadmap stand as a testament to Ethiopia's unwavering determination to embrace technological excellence, drive sustainable development, and realize our vision of a prosperous, resilient, and technologically advanced nation.

Sincerely,

Belete Molla Getahun (PhD)
Minister

Belete Molla Getahun (PhD)
Minister, FDRE Ministry of Innovation and Technology

Statement from Director General, BETin



It is an honor to present Ethiopia's strategic vision for emerging technologies through this comprehensive roadmap. As the director general of the Bio and Emerging Technology Institute (BETin), I recognize the significant potential of emerging sciences and technologies for our country's socio-economic development. This roadmap is designed to foster innovation, strengthen research ecosystems, and translate scientific breakthroughs into tangible societal benefits.

Ethiopia boasts immense natural resources, a vibrant workforce, and a growing research community eager to contribute to global knowledge and local solutions. The roadmap highlights our commitment to developing cutting-edge capabilities in nanotechnology, systems and synthetic biology, advanced materials, advanced computing and intelligent systems, and advanced manufacturing. These capabilities are essential for addressing health, environmental, and socio-economic challenges.

BETin is dedicated to fostering an environment where research excellence, innovation, and technology transfer can flourish. Our goals are to build strong collaborations with national and international partners, empower our youth with skills and knowledge, and establish a regulatory framework that safeguards safety, ethics, and sustainability.

Through these collective efforts, we will elevate Ethiopia's scientific standing and translate innovations into tangible societal benefits that improves healthcare, resilient agriculture, sustainable energy, clean water, job creation, and strengthened support for the digital and bioeconomy strategy.

We invite all stakeholders to join us on this ambitious journey to transform Ethiopia. Together, we can unlock the transformative potential of frontier technologies for the prosperity of Ethiopia and beyond.

Sincerely,

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Statement from Deputy Director General



The Bio and Emerging Technology Institute (BETin) was established to conduct pivotal research and coordinate national initiatives in biotechnology and emerging technologies. Our vision is to enhance the development of products and services from these highly advanced sectors, ultimately benefiting Ethiopia's economic growth and development.

The contributions of nanotechnology, materials engineering, advanced computing and intelligent systems, synthetic biology, and systems biology are important for building Ethiopia's sustainable economy and ensuring our competitiveness in an increasingly challenging global landscape. We are honored to support the strategic objectives outlined in this roadmap, which align with Ethiopia's overarching vision for emerging technologies. As the deputy director general of BETin, I am confident that this roadmap will serve as a catalyst for the successful adoption of emerging technologies, driving Ethiopia's socio-economic transformation.

Our focus is on developing a robust ecosystem that nurtures research excellence, fosters collaborative industry-academia partnerships, and promotes responsible innovation in emerging technologies. We recognize that building human capacity, strengthening infrastructure, and establishing enabling policies are fundamental to realizing our technological ambitions.

This roadmap reflects our collective aspiration to leverage emerging sciences for sustainable development, health security, environmental resilience, and economic diversification. We are committed to facilitating the translation of research into commercialization, ensuring that Ethiopia benefits from global technological advancements while safeguarding our cultural and ecological integrity.

In collaboration with our partners, BETin will continue to serve as a catalyst for innovation, inspiring the next generation of Ethiopian scientists, entrepreneurs, and policymakers to cultivate a resilient and prosperous future for our nation.

Sincerely,

Hailu Dadi (PhD)
Deputy Director General, Bio and Emerging Technology Institute (BETin)

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GLOSSARY OF ACRONYMS

ADM	Additive Manufacturing
AI	Artificial Intelligence
AMs	Advanced Materials
AMTs	Advanced Manufacturing Technologies
ATI	Agricultural Transformation Institute
BETin	Bio and Emerging Technology Institute
CAD	Computer-Aided Design
CAE	Computer-Aided Engineering
CAM	Computer-Aided Manufacturing
CNC	Computer Numerical Control
Cobots	Collaborative Robots
DED	Directed Energy Deposition
DfAM	Design for Additive Manufacturing
DMLS	Direct Metal Laser Sintering
EBM	Electron Beam Melting
FDM	Fused Deposition Modeling
FEA	Finite Element Analysis
HPC	High-performance Computing
GDPR	General Data Protection Regulation
IoT	Internet of Things
MiNT	Ministry of Innovation and Technology
NETRA	National Emerging Technology Regulation Authority
PE	Predictive Engineering
PLCs	Programmable Logic Controllers
QST	Quantum Science and Technology
RAF	Robot Assisted Fabrication
RPA	Robotic Process Automation
SDGs	Sustainable Development Goals
SM	Subtractive Manufacturing
SMT	Smart Manufacturing Technology
SMEs	Small and Medium Enterprises
STISA	Science, Technology and Innovation Strategy for Africa
SSB	Synthetic and System Biology
SSGI	Space Science and Geospatial Institute

KEY DEFINITIONS

Emerging Technology	Refers to cutting-edge technologies including, but not limited to, AI, robotics, IoT, nanotechnology, synthetic and system biology, advanced materials, smart manufacturing, predictive engineering and quantum computing characterized by their high transformative potential, dynamic evolution and capacity to disrupt industries, prioritized based on their success potential, socioeconomic and alignment with national goals like digital transformation and homegrown economic reform as well as SDGs and planetary boundaries.
Emerging Technology Roadmap	Refers to Ethiopia's decade-long strategic plan (2026-2035) to adopt, adapt, create and govern technologies such nanotechnology, advanced computing and intelligent system, advanced materials, synthetic and system biology and advanced manufacturing technology through phased R&D, capacity building and policy frameworks, ensuring equitable and sustainable development.
Advanced Computational and Intelligent Systems	The integrated technology domain encompassing advanced computing (infrastructure), IoT, Big Data Analytics (insight extraction), Artificial Intelligence (algorithms) and Intelligent Systems (applications that integrate computing, IoT, AI, big data analytics and robotics) to enable data-driven automation, decision-making and sectoral transformation across Ethiopia's economy.
Advanced computing	Refers to cutting-edge hardware and software technologies including high-performance computing (HPC), quantum computing, and cloud/edge computing along with their infrastructure architectures that provide the foundational processing power and storage capacity necessary to process massive datasets, train complex models, and enable

	real-time decisions for IoT, Big Data Analytics, AI and Intelligent Systems.
Artificial Intelligence (AI)	Involves the creation of systems that perform tasks requiring human intelligence. Within the ACIS framework, AI serves as the cognitive engine algorithms and computational architectures that enable machines to perceive, reason under uncertainty, learn from experience and make autonomous or semi-autonomous decisions.
Big Data Analytics	The computational and statistical layer of ACIS that applies distributed processing frameworks, data mining algorithms, predictive modeling and visualization tools to transform raw/big data into structured and validated insights.
Nanotechnology	The creation and manipulation of materials, devices and systems at the nanoscale (1 to 100 nanometers). This field leverages the unique atomic and molecular properties of materials at this scale to develop innovations in different sectors such as in agriculture, medicine, energy, environment and aviation.
Nano-environment	Refers to the application of nanotechnology to environmental protection and sustainability. It involves developing nanomaterials and nanosystems for water treatment, air purification, pollution control, soil remediation, bioremediation, environmental sensing and carbon capture.
Nano-energy	The use of nanotechnology to develop advanced energy solutions. This includes designing nanomaterials for high-capacity energy storage devices such as batteries and supercapacitors, improving the efficiency of solar cells through nanostructured materials and utilizing nano-catalysts for more efficient energy production and conversion processes.
Nano-agriculture	Involves the application of nanotechnology to improve agricultural productivity and sustainability. It encompasses nano-fertilizers, nano-pesticides, soil nano-sensors and nano-encapsulated nutrients that

	enable controlled release, targeted delivery and real-time soil health monitoring.
Nano-manufacturing	Refers to the use of nanotechnology in the manufacturing sector to enable precise fabrication of materials and devices at the nanoscale. It involves developing scalable processes for producing nanomaterials, nano-coatings and nano-structured products with superior properties such as enhanced strength, durability and functionality.
Nano-medicine	Encompasses the application of nanotechnology to healthcare for diagnostics, drug delivery, therapy and patient monitoring. It includes nano-biosensors, targeted drug formulations, nanoscale imaging agents and nano-enabled wearable devices.
Synthetic Biology	The engineering of biological systems e.g., gene-edited crops and microbial bio-factories to develop sustainable solutions such as drought-resistant seeds for Ethiopian agriculture or lab-grown biofuels, combining biology with principles of design and automation.
System Biology	An interdisciplinary approach using data science and mathematical modeling to decode biological complexity applied in Ethiopia for precision medicine or optimizing crop yields through metabolic pathway analysis.
Internet of Things (IoT)	The network of physical sensors, actuators and connected devices that collect, transmit and receive real-world data from the environment serves as the primary data generation layer for computing, analytics and intelligent systems.
Intelligent Systems	The application layer of the ACIS framework that integrates AI algorithms with IoT-generated data, Big Data Analytics-derived insights and robotics/actuation technologies to autonomously perceive, decide, learn and act in real-world environments across sectors such as agriculture, healthcare, transport, education, manufacturing, environment, and law enforcement.

Advanced Materials	Engineered materials with superior properties that encompass highly diverse applications across multiple sectors, ranging from healthcare and defense to chemical manufacturing.
Advanced Manufacturing Technology	Next-generation production systems and processes such as additive manufacturing (3D printing) and smart factory architectures that integrate digital, physical, and cyber-physical components to enhance manufacturing efficiency, flexibility, and precision, enabling the production of customized components and spare parts on demand while reducing import dependency, material waste and overall production costs.
Emerging Technology Governance and Regulation	Refers to the comprehensive frameworks that involve policies, oversight mechanisms and institutional structures established to ensure the responsible development, deployment and management of emerging technologies across the country.
Bottom-up Synthetic Biology	An emerging research field that aims to construct biological functions and ultimately cells from natural, modified or synthetic biomolecules. Complementary to the top-down approach, it modifies pre-existing cells.
Cell-free System	A flexible *in vitro* technology that separates cell growth from the target production to reformulate cellular processes outside of the living cell.
Omics	Refers to a field of study in biological sciences that ends with *-omics*, such as genomics, transcriptomics, proteomics or metabolomics.

EXECUTIVE SUMMARY

The National Emerging Technology Roadmap is Ethiopia's comprehensive strategic framework for leveraging transformative technologies to achieve sustainable socio-economic development. It promotes the integration of five core cutting-age technologies: nanotechnology, advanced computational and intelligent systems, synthetic and systems biology, advanced materials and advanced manufacturing technology for addressing socio-economic challenges, and enhancing national competitiveness.

As Ethiopia advances toward industrialization and digital transformation, the roadmap emphasizes research, innovation, and collaboration to boost productivity across key sectors including agriculture, healthcare, environment, manufacturing, energy, transport, education, tourism, mining, legal, and law enforcement. The roadmap is in harmony with the country's homegrown economic reform agenda, Science, Technology and Innovation Policy, digital transformation strategy, Science, Technology and Innovation Strategy for Africa 2034, Sustainable Development Goals, agenda 2063 and mandate of the Bio and Emerging Technology Institute.

A comprehensive situational analysis, supported by global trend assessment and national consultations with universities, research institutes, industry, and the private sector engaged throughout roadmap study highlights opportunities and challenges. As a strength, Ethiopia demonstrates strong political commitment and growing human capital, alongside expanding research institutions. However, gaps remain in R&D infrastructure, regulatory frameworks, public engagement, and awareness. PESTEL and SWOT analyses further identify enabling conditions as well as structural constraints that must be addressed.

The roadmaps and implementation strategies have been developed across all five selected emerging technology domains, structured in three progressive phases. For nanotechnology, the roadmap encompasses five sub-domains: nano-agriculture, nano-environment, nanomedicine, nano-energy, and nano-manufacturing. Similarly, the advanced computing and intelligent system roadmap integrates advanced computing, the AI foundation roadmap with its computer vision, geospatial AI, and generative AI sub-roadmaps, in addition to IoT, big data analytics, and the application of intelligent systems across various sectors. Likewise, the synthetic and system biology roadmap covers system biology, medical innovation, gene editing, agriculture and environmental solutions, as well as bio-manufacturing. In the case of advanced materials, the roadmap addresses energy materials, construction materials, green materials, and mineral-based materials. Finally, the advanced manufacturing technology roadmap encompasses smart manufacturing technologies including additive manufacturing, robot-assisted fabrication, hybrid

manufacturing, automation, and the industrial IoT, alongside predictive engineering, which comprises computer-aided design, computer-aided engineering, and AI-driven design.

To operationalize the roadmap, a phased research and development strategy is proposed, covering short-, medium-, and long-term actions. This includes strengthening the national R&D ecosystem, enhancing human resource development, fostering partnerships, and establishing supportive policy and regulatory environments. Key institutional mechanisms, including the proposed National Emerging Technology Council, will provide governance, coordination and oversight.

In conclusion, this roadmap presents a coherent and actionable pathway for Ethiopia to translate emerging technological potential into practical innovations and socio-economic transformation. Through coordinated efforts among government, academia, and the private sector, Ethiopia can accelerate its transition toward a knowledge-based and innovation-driven economy.

INTRODUCTION

1.1 BACKGROUND

The pursuit of national development, industrialization and scientific advancement is closely associated with the adoption and innovation of emerging technologies, including but not limited to nanotechnology, advanced computational and intelligent systems, advanced materials, synthetic and systems biology, and advanced manufacturing technologies. These have the potential to drive transformative change across industries and create new opportunities for socioeconomic growth. However, these technologies are characterized by significant uncertainty, unpredictability, and potential unintended consequences. This makes it essential for stakeholders, including policymakers and businesses, to understand their nature and proactively adapt to mitigate risks. Thus, effective strategic planning is crucial for navigating the complexities of technological development, ensuring optimal resource allocation, risk management, and the maximization of opportunities across various sectors.

This roadmap presents a comprehensive and well-researched framework that effectively navigates the complexities of technological advancement, providing strategic guidance for research and development institutions to select, adopt and innovate technologies. These efforts aim to address socio-economic challenges and enhance global competitiveness. The roadmap also facilitates the prioritization of key technologies such as nanotechnology, advanced computational and intelligent systems, advanced materials, synthetic and systems biology, and advanced manufacturing technologies based on alignment with national development goals and fostering effective transfer, collaboration and investment in emerging technologies. Furthermore, it includes monitoring and risk assessment strategies to ensure the successful implementation of the roadmap and to capitalize on opportunities across various sectors.

1.2 OVERVIEW OF EMERGING TECHNOLOGIES

The emergence of groundbreaking technologies, including but not limited to nanotechnology, advanced computational and intelligent systems, advanced materials, synthetic and system biology, and advanced manufacturing technologies shown in Figure 1.1. It is set to revolutionize various

industries by enabling unprecedented levels of innovation, efficiency and sustainability. Each of the emerging technologies described in Figure 1.1 of this roadmap is summarized below.

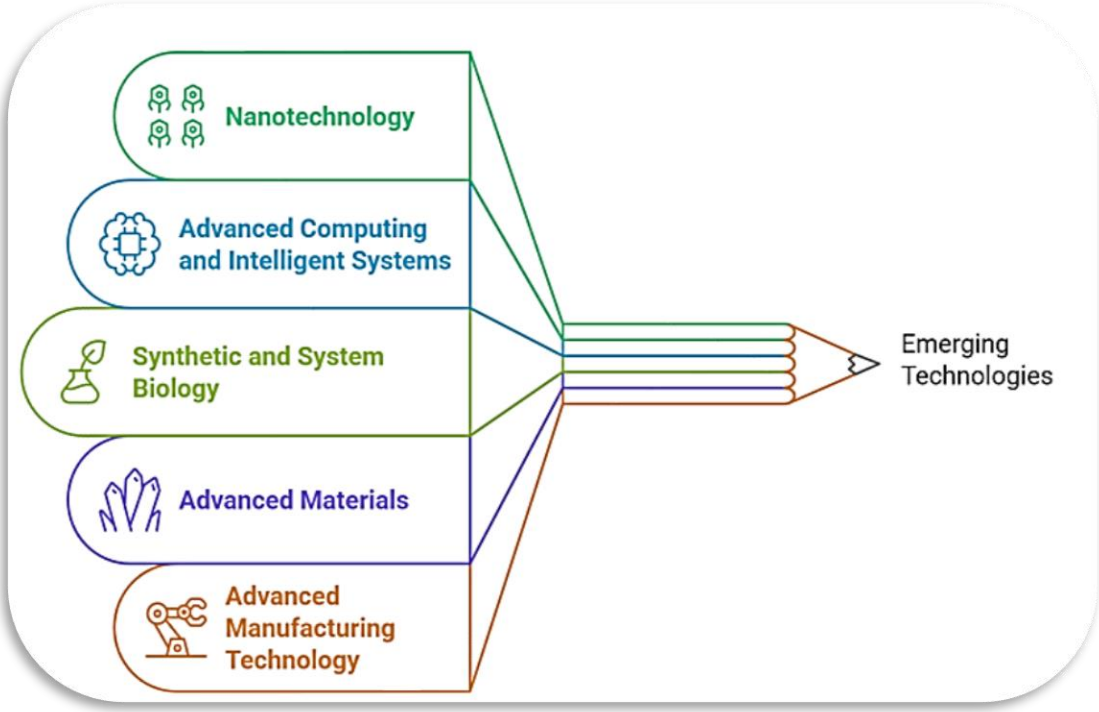


Figure 1-1 Overview of emerging technologies

To begin with, nanotechnology involves the creation and manipulation of matter on a nanometer scale, typically between 1 and 100 nanometers, and has the potential to revolutionize various industries. By working at this scale, scientists can create systems, materials and devices with unique properties, such as increased strength, conductivity or reactivity. Applications of nanotechnology are diverse, ranging from medicine where it can be used for targeted drug delivery and personalized treatments to energy where it can improve the efficiency of solar cells and energy storage devices. Additionally, nanotechnology can enable the creation of smaller, faster, and more powerful electronic devices, leading to advancements in fields like computing and telecommunications.

Similarly, Advanced Computational and Intelligent Systems (ACIS) represent one of the core components of this roadmap. Specifically, ACIS integrates five interconnected technological layers: advanced computing (infrastructure), the Internet of Things (IoT) (data collection), big data analytics (insight extraction), artificial intelligence (AI) (cognitive processing) and intelligent

systems (autonomous applications). Collectively, these layers establish a unified framework that enables data-driven automation, intelligent decision-making, and large-scale transformation across multiple sectors of Ethiopia's economy

In addition, Synthetic and Systems Biology focuses on designing and constructing new biological systems to better understand and manipulate biological processes. Through bio-manufacturing, gene editing, and analysis of complex biological systems, this field aims to provide innovative, transformative solutions in healthcare, agriculture and other sectors while maintaining environmental sustainability. This discipline has the potential to improve human health through the development of new therapies and treatments, enhance agriculture by creating more resilient and productive crops, and produce biofuels as sustainable alternatives to fossil fuels. By engineering biological systems, scientists can create novel pathways, organisms and products, such as biofuels, chemicals and pharmaceuticals. Additionally, it deepens our understanding of the complex interactions within biological systems, leading to new insights and applications.

Likewise, advanced materials are engineered to exhibit enhanced or entirely new properties as well as improved structural characteristics, in order to achieve superior functional performance. These materials are applied across a wide range of sectors, including electronics, aerospace, healthcare, environmental protection and renewable energy. Therefore, their versatility and evolving capabilities make them enablers of technological innovation and essential tools for addressing global challenges.

Furthermore, AMT encompasses a suite of innovative, computer-integrated systems and processes aimed at improving manufacturing efficiency and flexibility. In particular, it transforms how products are designed, produced and utilized by enabling complex geometries, customization and rapid prototyping. For example, it includes technologies such as additive manufacturing, robot-assisted fabrication, hybrid manufacturing, automation and IoT-enabled smart manufacturing. Consequently, these technologies enhance product quality, reduce material waste, shorten production cycles, and lower overall costs, while enabling the production of highly customized and functionally advanced products across industries.

Towards leveraging the potential of these technologies, there is a political commitment to science, technology, and innovation (STI) by African countries, including Ethiopia, for STI-driven socio-

economic growth and development. Moreover, the AU member states have established an advisory think tank, namely the African Union's High-Level Panel on Emerging Technologies (APET), that provides an opportunity for the continent to leverage emerging technologies and innovations and technologies to harness them for economic development. Despite their transformative potential, development and deployment of such technologies in developing countries like Ethiopia face significant challenges due to limitations in investment, infrastructure, and technical capacity. To overcome these barriers, this roadmap provides a comprehensive and evidence-based framework for navigating today's technological dynamics via strategic emerging technology selection, adoption, and innovation. This offers actionable direction for research and development institutions to address socio-economic challenges and strengthen global competitiveness.

1.3 Objectives of the Roadmap

The main objective of the roadmap is to develop a comprehensive emerging technology roadmap that facilitates the effective transfer, adoption, and innovation of key emerging technologies that create sustainable economic growth and global competitiveness. Specific objectives of the roadmap involve:

- ✓ Identify and prioritize emerging technologies that align with SDGs and planetary boundaries to effectively address socio-economic challenges.
- ✓ Set out a short-, medium-, and long-term roadmap that fosters innovative research in emerging technologies that directly addresses local challenges, improving productivity and quality of life and global competitiveness.
- ✓ Develop strategies that strengthen R&D capabilities in emerging technologies by building human resources capacity through targeted training, enhancing infrastructure, and providing institutional support.
- ✓ To lay out monitoring and risk assessment strategies to ensure the effective adoption and deployment of emerging technologies, addressing potential challenges and maximizing their impact on key sectors.

1.4 Importance of Roadmap

This roadmap presents a comprehensive and well-researched framework that effectively navigates the complexities of technological advancement, providing strategic guidance for research and development institutions to select, adopt and innovate technologies. It addresses socio-economic challenges and enhances global competitiveness, ultimately fostering sustainable development and driving national growth. The roadmap also allows for prioritizing fundamental technologies aligned with national development goals and fostering effective transfer, collaboration and investment in emerging technologies. Furthermore, it includes monitoring and risk assessment strategies to ensure the successful implementation and integration of technologies, which ultimately enhance sustainable development and drive national growth.

1.5 Methodological Framework for Roadmap Development

This roadmap is a strategic document designed to guide technological advancement of Ethiopia. It follows a structured process beginning with data collection through surveys, interviews, and literature reviews involving experts from various pertinent institutions. This data helps analyze Ethiopia's current technological landscape including capabilities, resources and potential applications across various sectors. The roadmap also considers international trends and reviews existing government policies and frameworks. A situational analysis using PESTEL and SWOT frameworks identifies internal and external factors influencing technology adoption and development, highlighting gaps and opportunities.

Furthermore, stakeholder engagement with diverse groups ensures the roadmap is inclusive and reflects local needs. The final stages involve formulating strategies, planning implementation and monitoring progress. All these efforts aim to create a tailored roadmap that drives sustainable growth and enhances Ethiopia’s global competitiveness in the emerging technology sector, aligning with Ethiopia's development goals.

1.6 Scope and Structure of the Roadmap

The roadmap provides a holistic framework for identifying and prioritizing the aforementioned emerging technology products and services, R&D ecosystem, including resource allocation and

collaboration, as well as monitoring and risk assessment mechanisms. It ensures the country's technological transformation, covering the decade from 2026 to 2035. It also focuses on five emerging technologies. The following main tasks are within its scope:

- ✓ Identifying and prioritizing trending emerging technologies products and services that enhance national competitiveness through surveys and analysis of the global and national industrial and technological landscape.
- ✓ Proposing an emerging technology roadmap and implementation strategy that guides the development that can positively impact the economy and society.
- ✓ Outlines implementation strategies for optimizing the allocation of financial, human resources and infrastructure to support research and innovation.
- ✓ Identify mechanisms for monitoring and risk assessment to mitigate challenges associated with emerging technology adoption and innovation.

1.7 Roadmap Structure

The roadmap is organized into six chapters as highlighted in Figure 1.2. Chapter one is the introduction section, and chapter two provides insights into global trends and use cases in various emerging technologies, followed by a situation analysis of emerging technologies in Ethiopia. This analysis emphasizes the country's evaluation of emerging technology readiness, as well as the opportunities and limitations it faces. The subsequent chapters focus on assessing current research and development initiatives, infrastructure capabilities, human resources, funding mechanisms and potential applications of emerging technologies in Ethiopia. They then present a strategic roadmap and implementation plan, outlining clear short-, medium-, and long-term research and development timelines with articulated ecosystem requirements, particularly in capacity building (ecosystem and workforce development), policy framework, and stakeholder engagement strategies. Finally, the document provides mechanisms for monitoring and risk assessment.

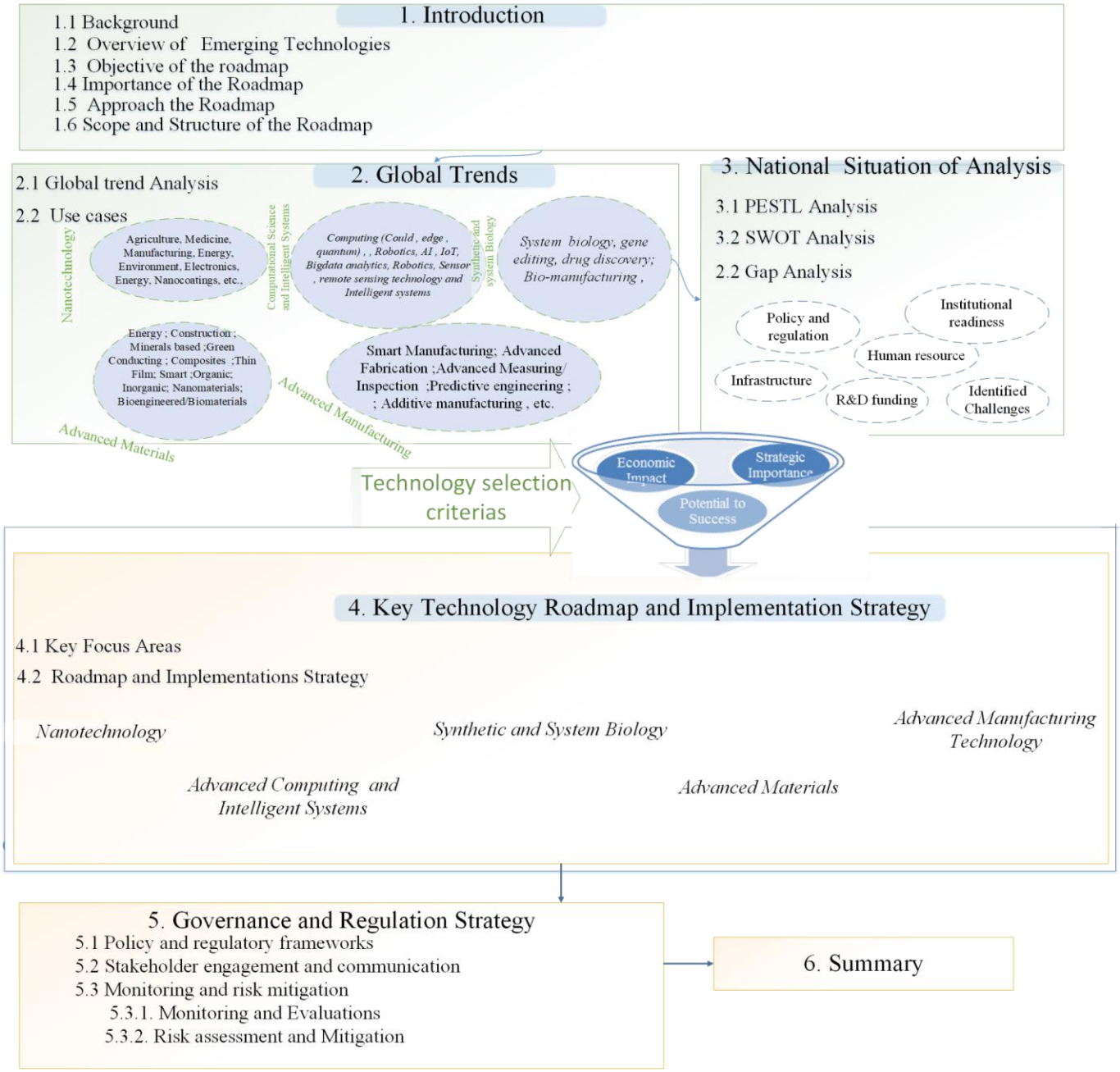


Figure 1-2 Roadmap Structure

GLOBAL TREND ANALYSIS

2.1 GLOBAL TRENDS

Emerging technologies possess the capacity to transform various industries and address global challenges. Nanotechnology, for example, can facilitate significant advancements in medicine, energy production and environmental remediation. The development of advanced materials and manufacturing techniques may lead to the creation of more efficient and sustainable products, while synthetic biology could offer innovative solutions in healthcare and agriculture. Furthermore, computational science and artificial intelligence are set to revolutionize numerous fields, ranging from drug discovery to climate modeling. These technologies are capable of processing extensive datasets and identifying patterns that may elude human observation, resulting in more accurate predictions and novel solutions.

As these advancements continue to progress, emerging technologies are likely to reshape industries, generate new employment opportunities, and fundamentally transform our approach to complex scientific and societal challenges. The global trends in emerging technologies reflect a dynamic and rapidly evolving landscape characterized by significant growth in Gross Domestic Product (GDP) contributions, expanding market shares, and increasing business and R&D spending by countries and top companies toward evolving the above technologies.

2.1.1 NANOTECHNOLOGY

Nanotechnology encompasses the study of nano-devices with applications across chemistry, biomedical science, mechanics and materials science. It operates at scales from single atoms to about 100 nanometers. As the focus of research has shifted from passive to active nanostructures and molecular nano-systems since 2000, topics like quantum technology, graphene and optoelectronics have gained prominence. These developments highlight the transformative potential of nanotechnology across multiple industries. Nano-products include coatings, paints, thin films, semiconductors, lithography and printing products, nano-particulates, nano-powders, energy conversion and storage devices, electronic devices, displays, and optoelectronics, among others [1]. It addresses all major sectors, including medicine, food, agriculture and the environment[1,2].

Due to its importance, nanotechnology is rapidly growing, driven by significant research and development investments from various countries and corporations. The following are some examples of the use of nanotechnology in different countries.

- *United States:* The US National Nanotechnology Initiative (NNI) was established in 2000 with a starting budget of $422 million. It aimed to establish a foundational science and technology discipline. The initiative has invested approximately $19.4 billion to develop global nanotechnology research programs from 2001 to 2020[3]. Federal investment in nanotechnology has grown significantly, expanding educational resources and infrastructure to advance the field. The revenues from nanotechnology investments and increased product competitiveness have been estimated to grow by about 25% annually on average from 2000 to 2020, reaching about $3 trillion worldwide, with approximately one-fourth of that amount in the US[4].
- *China:* Recently China has also emerged as a global leader in nanotechnology, particularly in electronics and materials science[5]. The country has integrated nanomaterials into construction, enhancing building strength and energy efficiency. Significant advancements include the use of carbon nanotubes for hydrogen storage, aiding clean energy technologies, and improving lithium-ion battery efficiency which supports renewable energy initiatives. The Chinese Government prioritizes nanotechnology through long-term strategies that promote research, establish nanotechnology centers, and invest in key laboratories. Notable initiatives include the National Science Research Centre for Nanotechnology and the National Engineering Research Centre for Nanotechnology, which focus on innovation and industrialization [6].
- *Nanotechnology in other countries:* Other countries such as Japan, Russia, South Korea, India and others from Asia Pacific, Latin America and the Middle East countries have been also actively working in this sector[7–9]. The South Korean Government has implemented the Nanotechnology Development Plan (NTDP) to promote research and development in nanotechnology[10]. As a result, South Korea has made significant advancements in nanotechnology, particularly in electronics and biotechnology, contributing to sustainable development and improved quality of life [8]. The estimated annual spending in this area is

around $1.0 billion, with a growth rate of 5-7%. Figure 2.1 highlights the estimated market share of the Asia-Pacific Countries (APAC) in nanotechnology.

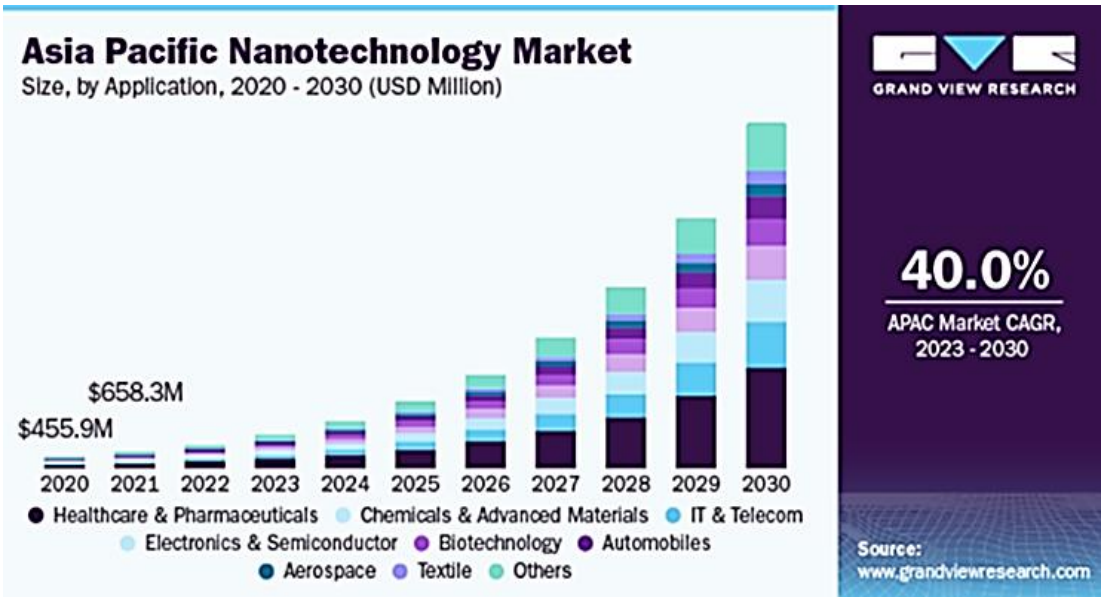


Figure 2-1 Global market share of nanotechnology [10].

Japan has a long-standing commitment to nanotechnology, focusing on applications in electronics, energy and advanced nanomaterials science[3]. Bangladesh also recognizes nanotechnology as crucial for sustainable economic growth through introduction of national plans under the Bangladesh Atomic Energy Commission that is a significant step forward in leveraging nano-based materials to improve sustainability, productivity and efficiency in garment agriculture and other sectors [3]. In Brazil, researchers have utilized magnetic nanoparticles to remove pollutants from water bodies and developed nanotechnology-based pest control solutions. These innovations include nano-capsules for effective pesticide delivery, reducing environmental harm. Additionally, nanoparticles are being explored for targeted cancer therapies, improving treatment efficacy while minimizing side effects [3]. Kenya is developing a comprehensive nanotechnology policy to promote its use across various sectors, including medicine and agriculture.

In summary, nanotechnology's increasing adoption in various fields' fuels market expansion of the technology[10]. The global nanotechnology market size was estimated at USD 3.69 billion in 2022 and is expected to grow at a compound annual growth rate (CAGR) of 33.1% from 2023 to 2030[11]. By 2023, over thirty U.S. research and regulatory agencies had contributed to a cumulative public R&D investment of about $40 billion. Revenues from nanotechnology-related products are

projected to grow by an average of 25% annually while Asia Pacific Countries expected to grow with a CAGR 40%, potentially reaching $3 trillion worldwide.

2.1.2 ADVANCED COMPUTATIONAL AND INTELLIGENT SYSTEMS

The pace of technological innovation is accelerating, reshaping how we live, work and interact. According to the World Intellectual Property Organization (WIPO) Global Innovation Index 2024, summarized in Figure 2.2, the ICT hardware, electrical equipment, and software/IT services sectors experienced a significant slowdown in growth rates between 2022 and 2023 [12].

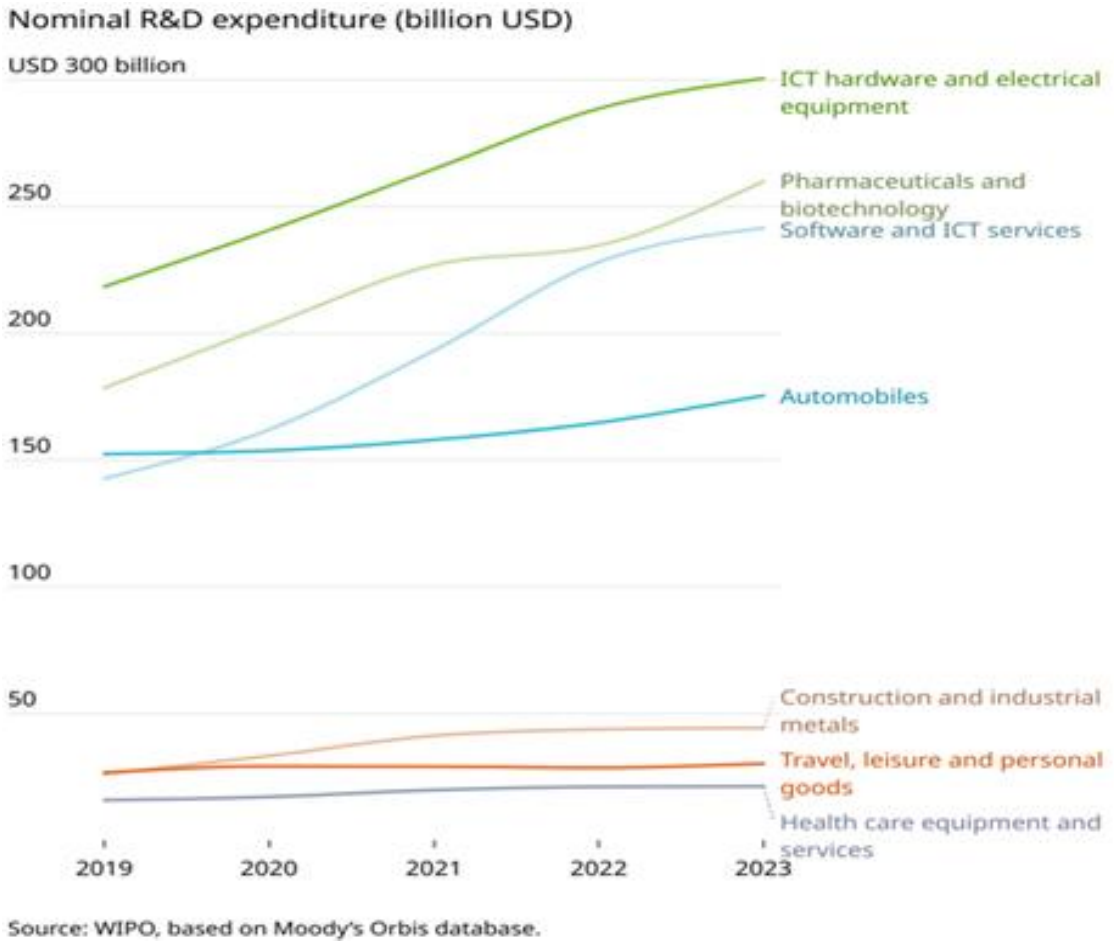


Figure 2-2 Top R&D spenders in ICT by industry and year, 2019–20231 [12].

In contrast, the pharmaceutical sector saw a remarkable rebound, with R&D expenditure increasing more than threefold, followed by automotive, construction, industrial metals, travel, leisure goods and healthcare equipment/services. ICT hardware and electrical equipment led in R&D intensity,

followed by pharmaceuticals, software/IT services, automotive and industrial engineering[12]. These trends highlight the dynamic shift in R&D expenditure in emerging technologies. More recently, cutting-edge technologies like advanced computational ecosystems, artificial intelligence, deep learning, big data analytics, IoT, robotics and intelligent systems are driving transformative changes across industries.

- *Advanced computational technologies:* According to the National Science and Management Council (NMSC) report 2025, the advanced computing technologies (e.g., data center solutions and AI chips) attained a value of USD 214 billion in 2023 and is anticipated to exceed USD 421.4 billion with a compound annual growth rate (CAGR) of 10.2% from 2024 to 2030[13–16]. Thanks to advances in computing power, AI is experiencing rapid growth and performance of AI based solutions across various domains including handwriting, speech and image recognition, natural language processing and predictive reasoning. It has surpassed human performance in recent benchmarking tests[16,17].
- *AI:* On the basis of AI technology, Machine Learning (ML) and Natural Language Processing (NLP) generative AI acquired a major AI market size on the basis of technology followed by computer vision, AI and robotics, autonomous and sensor technologies [18,19]. Regionally speaking, North America held over 36.92% of the market share in 2024, while the Asia Pacific market is projected to grow at a CAGR of 25.5% from 2025 to 2034. The U.S. is a leader in AI with strong tech ecosystems and R&D from companies like Google, Microsoft and Amazon. However, China emerges as a leader with 58% of companies actively deploying AI technologies and an additional 30% evaluating their integration into business operations. The EU countries like Germany, France and UK are investing in AI, focusing on industrial automation, healthcare and regulatory initiatives like the AI Act. In Asia-Pacific, Japan, South Korea and India emphasize robotics and AI startups. In Latin America, Brazil and Mexico are adopting AI in finance and healthcare, though adoption is slower and faces challenges. The UAE and South Africa are also advancing in AI, with the UAE prioritizing smart city initiative. AI-related patent[20] experienced a significant surge from 20,000 in 2000 to 100,000 in 2020. Geographically, China dominates in patent volume (with 12,945 AI patents), exceeding the U.S. (holding 8,609 AI patents), though U.S. patents show higher citation impact. Japan and South Korea are second with 1,537

patents each. These data underscore accelerating AI innovation and strategic investments worldwide.

- *IoT and big data analytics:* IoT refers to interconnected devices that collect and exchange data, enhancing monitoring and control over various systems. According to IoT Analytics' 2024 report, there were 16.6 billion connected IoT devices by the end of 2023 (a growth of 15% over 2022) and has grown 13% to 18.8 billion by the end of 2024 and is projected to reach 40 billion by the end of 2032[21]. The industrial and consumer electronics segment held significant shares of the market, at 42.1% and 23.3% respectively. Approximately 40% of global IoT connections are concentrated in China and the United States, while retail and wholesale will make up 3002.1 million devices.
- *Robotics and intelligent systems:* Robotics and intelligent systems are rapidly evolving technologies that enhance efficiency and safety by using machines to perform tasks traditionally done by humans. The adoption of intelligent robots within the industrial, commercial as well as domestic purposes is fueling growth and is expected to reach $40.12 billion by 2033. It is growing at a compound annual growth rate (CAGR) of 4.8% from 2024 to 2033, driven by technological advancements and the increasing need for automation across industries, according to the International Federation of Robotics report 2023[22]. In 2023, the robotics industry achieved the second-highest robotics technologies installation count in history, with annual installations exceeding 500,000 units for the third consecutive year, underscoring sustained demand for robotics. Additionally, the total robot stock (number of operational robots) reached 4.3 million units in 2023, reflecting a 10% increase from the previous year. Geographically, the industrial robot market was dominated by China, Japan, the United States, the Republic of Korea and Germany accounted for 74 percent of the operational stock of robots in 2022. Beside industrial robotics, there is also evidence of rapid growth and innovation in drone technology catalyzing various applications across various sectors, including precision agriculture, rapid delivery services and advanced surveillance. According to 2024 drone industry reports, the global drone market was valued at USD 64.32 billion in 2023 and is projected to grow at a compound annual growth rate (CAGR) of 14.5% from 2024 to 2030 [22–24].

In general, the global landscape on adoption, implementation and innovation of advanced computational and intelligent systems, encompassing artificial intelligence, the Internet of Things, robotics, big data analytics, and drones is characterized by significant variation in market share, R&D investment, patent activity, policy frameworks, and adoption rates. The following analysis examines these dynamics on a country-by-country and region-by-region basis.

- *United States:* The United States remains the global leader in AI and advanced computational technologies, underpinned by a robust ecosystem of technology giants—including Google, Microsoft, Amazon, and a vast network of innovative startups. North America as a whole held over 36.92% of the global AI market share in 2024, with the U.S. contributing the vast majority of this figure. American companies lead in foundational AI research, venture capital investment, and the development of cutting-edge hardware such as AI chips and data center solutions. In terms of patent activity, the U.S. holds 8,609 AI patents—second only to China in volume—but American patents demonstrate significantly higher citation impact, indicating that U.S. innovations are more foundational and widely referenced in subsequent research and development. This suggests that while China leads in patent quantity, the U.S. maintains an edge in patent quality and technological novelty. The U.S. also excels in enterprise AI adoption, with companies across finance, healthcare, retail, and manufacturing integrating AI solutions to enhance efficiency and decision-making. However, the country faces growing competition from China, particularly in the deployment of AI technologies at scale. The U.S. government has responded with policy initiatives aimed at maintaining technological supremacy, including increased federal funding for AI research and efforts to secure domestic semiconductor supply chains.
- *China*: China has emerged as a formidable competitor to the United States in the global AI landscape, particularly in enterprise adoption and patent volume. According to the data, 58% of Chinese companies are actively deploying AI technologies, with an additional 30% evaluating their integration into business operations—making China the global leader in enterprise AI adoption. This aggressive deployment is supported by a national AI strategy that prioritizes technological self-sufficiency and industrial

modernization. China dominates in patent volume, with 12,945 AI patents, far exceeding the United States' 8,609. While Chinese patents tend to have lower citation impact than their American counterparts, the sheer volume reflects the country's massive investment in AI R&D and its strategic focus on securing intellectual property across a wide range of applications, including computer vision, autonomous systems, and natural language processing. China also plays a central role in the IoT ecosystem, with approximately 40% of global IoT connections concentrated in China and the United States combined. The country's industrial sector is a major driver of IoT adoption, leveraging connected devices to enhance manufacturing efficiency and supply chain management. In robotics, China is the dominant market, accounting for the largest share of operational robots globally, alongside Japan, the United States, South Korea, and Germany, which together represent 74% of the world's operational robot stock.

- *Europe*: European countries are investing heavily in AI and intelligent systems, with a particular focus on industrial automation, healthcare applications, and regulatory leadership. Germany, France, and the United Kingdom are the primary hubs of AI activity on the continent, each pursuing distinct but complementary strategies. Germany leverages its strong industrial base to integrate AI into manufacturing, automotive, and engineering sectors, driving the development of "Industry 4.0" technologies. France has positioned itself as a leader in AI research, with significant government investment in AI hubs and talent development. The United Kingdom boasts a thriving AI startup ecosystem, particularly in fintech, healthcare, and creative industries, and is home to world-class AI research institutions. The European Union's AI Act represents a landmark regulatory framework that seeks to balance innovation with risk management, establishing clear rules for high-risk AI applications. This regulatory leadership is shaping global standards and influencing AI governance discussions worldwide. However, Europe's AI adoption rates and patent volumes lag behind those of the United States and China, reflecting a more cautious, compliance-oriented approach to AI development.
- *Asia-Pacific (Excluding China):* The Asia-Pacific region is the fastest-growing market for AI and other advanced commuting technologies, projected to grow at a compound

annual growth rate (CAGR) of 25.5% from 2025 to 2034. This growth is driven by aggressive investments in AI, robotics, and digital infrastructure across several key economies. Japan and South Korea are global leaders in robotics and industrial automation. Both countries have strong R&D ecosystems, with Japan holding 1,537 AI patents and South Korea matching that figure. These nations are at the forefront of developing intelligent robots for industrial, commercial, and domestic applications, leveraging their advanced manufacturing bases and government-backed innovation initiatives. India has emerged as a vibrant hub for AI startups, supported by a large pool of technical talent, a growing digital economy, and government initiatives promoting AI adoption in sectors such as agriculture, healthcare, and financial services. The country's AI ecosystem is characterized by a focus on affordable, scalable solutions tailored to emerging market needs. Other countries in the region, including Singapore, Taiwan, and Australia, are also making significant investments in AI research, data center infrastructure, and semiconductor manufacturing, contributing to the region's overall momentum. The Asia-Pacific region's combination of manufacturing capacity, technical talent, and supportive policy environments positions it as a critical driver of global innovation in advanced computational systems.

- *Middle East:* The Middle East is emerging as a noteworthy player in the advanced computational landscape, driven primarily by the United Arab Emirates. The UAE has prioritized AI as a cornerstone of its national development strategy, with a strong focus on smart city initiatives, government services, and urban planning. The country has established dedicated AI ministries and invested heavily in AI research, talent development, and international partnerships. Other countries in the region, including Saudi Arabia and Israel, are also making strategic investments in AI and related technologies. Israel, in particular, has a vibrant AI startup ecosystem, with strengths in cybersecurity, autonomous systems, and agricultural technology. However, the Middle East's overall market share remains modest compared to North America and Asia, and the region faces challenges related to talent retention and diversification beyond oil-dependent economies.
- *Africa*: South Africa is the leading hub for AI innovation on the African continent, with emerging investments in AI applications across finance, healthcare, and agriculture.

The country is home to a growing number of AI startups and research initiatives, supported by partnerships with international technology companies and development organizations. However, AI adoption across Africa remains in its early stages, constrained by limited infrastructure, low internet penetration, skills shortages, and insufficient investment in R&D. The continent faces significant digital divides, with urban centers far outpacing rural areas in access to advanced technologies. Despite these challenges, there is growing interest in leveraging AI to address pressing developmental challenges, including food security, disease surveillance, and climate resilience. International organizations and African governments are beginning to prioritize digital transformation, but sustained investment and policy support will be critical to realizing AI's potential on the continent.

Table 2.1 provides a comprehensive summary of country and regional performance in the adoption, implementation, and innovation of advanced computational and intelligent systems (ACIS), highlighting key metrics across market share, patent activity, policy frameworks, and sectoral deployment.

Table 2-1 Country and Regional performance in adoption, implementation and innovation of ACIS techs.

Country/Region	AI and Robotics Market Share	Patent Volume	Key Policy/Initiatives	Adoption/Deployment Focus
United States	36.92% global AI and Robotics market share (2024)	8,609 AI patents (higher citation impact)	Federal R&D funding; semiconductor security initiatives	Enterprise AI across all sectors; foundational research
China	Fastest-growing enterprise adoption	12,945 AI patents (volume leader)	National AI strategy; technological self-sufficiency	Enterprise AI (58% actively deploying); IoT leadership
Japan	Moderate share; strong robotics presence	1,537 patents	Government-backed robotics and AI initiatives	Industrial robotics; manufacturing automation
South Korea	Moderate share; strong robotics presence	1,537 patents	AI R&D investment; national innovation programs	Robotics; industrial automation; smart manufacturing
India	Rapidly growing startup ecosystem	Growing portfolio	Startup promotion; digital economy initiatives	Affordable AI solutions; agriculture; healthcare

Germany	Leading European market	Moderate	Industry 4.0 integration; manufacturing AI	Manufacturing; automotive AI; industrial automation
United Kingdom	Strong startup ecosystem	Moderate	AI research funding; innovation hubs	Fintech; healthcare; creative industries
France	Growing market	Moderate	National AI strategy; research hubs	Healthcare AI; industrial applications
Europe (EU)	Moderate share; regulatory leader	Lower than U.S./China	EU AI Act; intelligent manufacturing/industrial and healthcare focus	Compliance-first approach; industrial and medical AI
Asia-Pacific (Overall)	Fastest-growing region (25.5% CAGR, 2025–2034)	Growing across multiple countries	Diverse national strategies; regional cooperation	Manufacturing; robotics; digital services
Latin America (Overall)	Small but growing	Minimal	Emerging national strategies; international partnerships	Finance; healthcare (slow but increasing adoption)
Middle East (Overall)	Small but strategic	Minimal	Smart city and diversification initiatives	Urban planning; government services; smart cities
Africa (Overall)	Nascent stage	Minimal	Continental AI policy and strategy; global partnerships	Cross-sectoral digital transformation: Finance; agriculture; healthcare

In summary, while North America and China maintain dominance in market size and technological leadership, the Asia-Pacific region emerges as the fastest-growing market, Europe assumes a leadership role in regulatory standard-setting, and emerging economies in Latin America, the Middle East, and Africa are progressively developing specialized niches tailored to their unique developmental contexts.

2.1.3 Synthetic and System Biology

Synthetic and system biology presents innovative approaches to engineer new biological systems or re-design existing ones for the purpose of improving the livelihood of humankind. Synthetic biology in general has been described as a ground-breaking technology at the heart of bioeconomy which is capable of delivering new solutions to global healthcare, agriculture, manufacturing and environmental challenges. As a result, there is a growing trend worldwide. The key drivers for its demand include market growth, convergence with other technologies, its application in various fields, focus on novel technologies, influence of system biology as well as standards and regulations[25]. The global synthetic and system biology market was valued worth USD 192.95 billion by 2034 at a 25% CAGR based on Precedence Research [26] and is forecasted to grow at 25% (Figure 2.3). Covid-19 pandemic contributed to an increased utilization of synthetic biology

products worldwide. The global market will also expand as a result of expansion of research and development initiatives in a variety of disciplines. Several fashion companies also employ biotechnology to develop sustainable materials. Moreover, growing emphasis on precision medicine, the development of gene editing technologies and the increasing demand for renewable energy sources drive the market expansion for synthetic and system biology.

- *United States:* Due to well-equipped laboratories and infrastructures for R&D, SynBio is a major focus area. It is supported by institutions like MIT, Harvard, and Stanford, alongside government agencies such as NIH, NSF, and DARPA[27]. The U.S. leads in commercial applications through companies like Ginkgo Bioworks and Moderna, which leverage SynBio for industrial microbes and mRNA vaccines respectively[28]. The R&D for SynBio is greatly supported by substantial investments and increased funding from public and private sectors.
- *Europe*: The European market has shown significant growth due to strong public funding and investment from the EU. The UK has a significant share of the EU SynBio market. The UK has established itself as a hub for SynBio innovation, with initiatives like SynbiCITE fostering collaboration between academia and industry[29]. The same growth is also expected in Germany. Germany emphasizes sustainability, with institutions like the Max Planck Society driving research into synthetic enzymes and plant-based alternatives[30] .

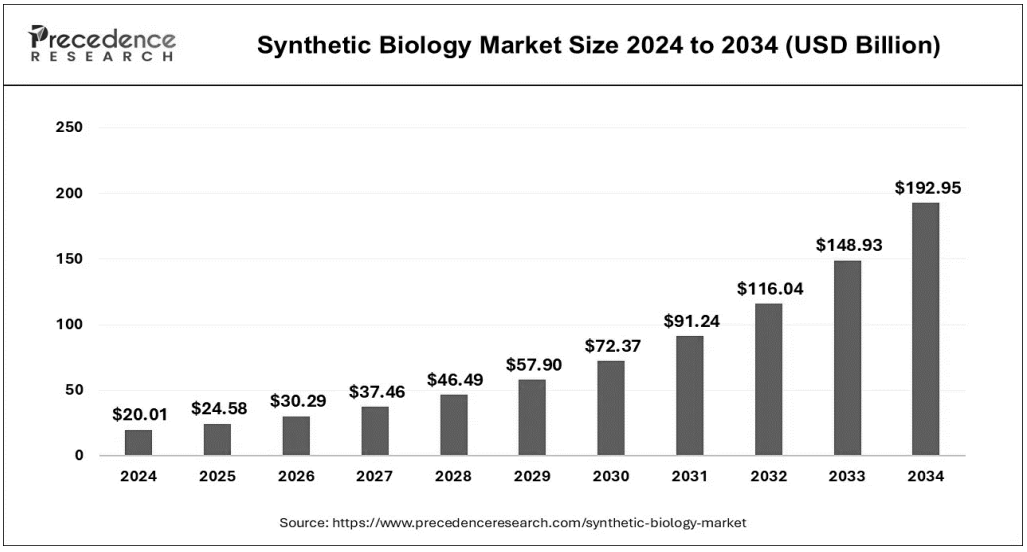


Figure 2-3 Synthetic Biology market share.

- *Asia Pacific regions:* Among Asia Pacific regions, China's rapid rise in SynBio is fueled by massive governmental support under programs like "Made in China 2025" enabling breakthroughs in agricultural biotechnology and pharmaceuticals[31]. The other prominent country in this regard is Japan. Japan integrates SynBio into its "Society 5.0" vision, focusing on biomaterials and aging-related diseases while South Korea excels in precision medicine and biodegradable plastics[35,36]. India also leverages its IT expertise to advance computational tools in systems biology, addressing challenges in crop improvement and low-cost diagnostics[32]. Australia and Brazil also apply SynBio to their natural resources, tackling issues like coral reef restoration and sugarcane-based biofuels[33,34].
- *South East Asia:* Southeast Asia has emerged as a regional hub for synthetic biology, driven by government-led innovation strategies, public-private partnerships, and a shift toward commercialization and outsourced services. Countries like Singapore, Thailand, Malaysia and Indonesia are prioritizing biotechnology to address agricultural productivity, healthcare and environmental sustainability. For example, the business models and commercialization aspects are outlined below. Governments in Southeast Asia are adopting hybrid models combining state funding with private-sector incentives to scale synthetic biology. For example: Singapore established Biopolis (a biomedical research hub) and JTC's Jurong Island Chemical Hub to attract multinational biotech firms (e.g., Lonza, Merck) and incubate startups[35]. Thailand's Bioeconomy Strategy (led by the National Center for Genetic Engineering and Biotechnology, BIOTEC) supports startups like Insectta, which uses engineered silkworms for sustainable materials[36]. Malaysia's BioNexus Status offers tax incentives for companies developing synthetic biology solutions, such as Progenesis Technologies, which produces microbial-based agrochemicals[37]. In commercialization perspective, southeast Asian nations are accelerating the transition from research to market-ready products in Agriculture, Healthcare and Industrial Biotech. Vietnam's Vĩnh Xuân Group commercializes biofertilizers using genetically engineered microbes to reduce chemical fertilizer use in agriculture[38]. Indonesia's PT Kalbe Farma collaborates with the U.S.-based Amyris to produce plant based pharmaceutical ingredients via synthetic biology[39]. Singapore's Esco Ventures funds startups like Argrigo, engaged in industrial biotech, develops CRISPR-edited crops for regional markets[40].

- *Africa:* Africa is still emerging, beginning to utilize SynBio for local challenges, including drought-resistant crops and malaria diagnostics [41]. Despite these advancements, challenges such as regulatory hurdles and limited infrastructure persist globally[42]. The focus is more on the computational biology aspect as well as drug and vaccine development. Collaborative international efforts will be crucial to address global challenges like climate change, pandemics, and food security through SynBio and systems biology. Several collaborative projects have been initiated in different African Countries. For example, Singapore established Biopolis (a biomedical research hub) and JTC's Jurong Island Chemical Hub to attract multinational biotech firms (e.g., Lonza, Merck) and incubate startups. Vietnam's Vĩnh Xuân Group commercializes biofertilizers using genetically engineered microbes to reduce chemical fertilizer use [37]. African nations are leveraging synthetic biology through regional and international initiatives like NEPAD (under AUDA-NEPAD) [37,171] to enhance food security and advocating biosafety and policies frameworks[1] for CRISPR based innovations[43–45]. The Open Forum on Agricultural Biotechnology (OFAB) engages stakeholders across 15 countries to build trust in GM crops. The African Orphan Crops Consortium (AOCC) is also engaged in training African plant breeders in genomics and advanced plant breeding tools. A collaborative project between Ethiopia and Kenya, *Striga* Smart Sorghum for Africa (SSSfA)[175], also engaged in improving sorghum through gene editing technologies. As part of this initiative, SSSfA trained Ethiopian researchers on the techniques of enzyme production as well as gene editing. Ethiopia has also initiated a gene editing project on teff. The Genome Editing in teff for Uplifting Productivity (GET-UP) has been initiated by EIAR to validate the gene edited teff varieties. Moreover, DNA-free genome editing research project on Brassica carinata has been conducted with the support of SLU-AU SIDA funded project [172-175]. Computational biology is also a growing field with increasing recognition of the importance of the field for tackling multifaceted challenges in Africa. Unlike other regions, the key trends include capacity building, collaborative research and application of computational and system biology technologies to address regional specific health issues. South Africa is the leading country

followed by Kenya and Nigeria[46]. All these initiatives indicate the growing interest of African countries towards the use of synthetic and system biology to develop innovative solutions that fit the needs of resource poor farmers. Collaborative projects like Striga Smart, led by IITA with Kenyan and Nigerian universities, use gene editing to combat Striga weeds threatening maize and sorghum[47]. Ethiopia's Teff Improvement Project (EIAR and University of Bern) employs CRISPR to enhance teff's drought tolerance and yield. The SynBioAfrica, supported by the Bill and Melinda Gates Foundation, trains researchers in genome engineering and bioethics across institutions like the University of the Witwatersrand[48,49]. Partnerships such as the Africa Bioscience Challenge Fund (via BecA-ILRI Hub) develop virus-resistant cassava and livestock vaccines[50]. These align with the AfCFTA agenda for science-driven agricultural growth[51]. By integrating local knowledge with synthetic biology, Africa addresses food insecurity, disease and environmental challenges through tailored solutions.

2.1.4 Advanced Materials (AMs)

Advanced materials, also referred to as novel materials, value-added materials or materials innovation, are regularly listed as an emerging technology, encompassing highly diverse applications across multiple sectors from healthcare to defense to chemical manufacturing[180]. These modifications involve creation or modification of materials to provide superior performance in specific properties essential for targeted applications[16]. Consequently, the impact of this discipline on a nation's economy varies significantly across countries. These countries' contributions vary ranging from advanced materials publication to product development. Research and development can significantly impact various sectors. For instance, it can contribute to cleaner production processes, effective waste utilization, and the creation of more sustainable and user-friendly materials. It can also play a vital role in addressing climate change by developing energy-efficient materials for insulation, storage and lightweight components.

It also ensures the safety and reliability of infrastructure by engineering robust and durable materials. In healthcare, it enables the development of biocompatible materials for implants, prosthetics and drug delivery systems. This field has wide-ranging applications, including energy, transportation, tissue engineering, drug delivery, construction and nanotechnology. The global

materials market is projected to reach approximately $2.5 trillion by 2026, reflecting a compound annual growth rate (CAGR) of around 5.5% from 2021 to 2026. According to A.J. Wiley, by 2030, advanced materials are expected to contribute to over three-quarters of all economic growth, with the global direct market projected to reach approximately $317 billion[186].

This growth is driven by the rising demand for innovative materials in sectors such as construction, automotive and electronics, which are essential for enhancing efficiency and reducing environmental impact[52]. As industries adopt AMs to improve product performance and sustainability, the growth rate of business R&D has been accelerated. In the Nature Index 2023 annual report, China has emerged as the leading country in the natural sciences, while the United States leads in health-related fields[53]. The Nature Index 2024 data also indicate China's continual of strengthening its position in the natural sciences, including AMs, computer science and others by a considerable margin [53,54]. The synergy between academic institutions and industry leaders has resulted in groundbreaking discoveries and innovations in AMs. These partnerships have not only accelerated the development of novel materials but also facilitated the transfer of knowledge from research laboratories to practical applications.

The global landscape of advanced materials from 2015 to 2021 was characterized by a high volume of academic output, led primarily by China and the USA. While China produced the highest total number of publications surpassing 60,000 the United States demonstrated a significantly higher H-index, peaking near 150. This suggests that while China led in quantity, the research originating from the USA during this period had a deeper impact and higher citation rate. Other nations like Germany and England also showed a strong balance between volume and impact, maintaining H-indexes that exceeded those of countries with higher publication counts, such as Japan. This data highlights a competitive research environment where Western nations often led in citation impact, while East Asian nations focused on rapid output expansion, as illustrated in Figure 2.4.

The 2023 data on Patent Cooperation Treaty (PCT) applications highlights a significant shift towards commercialization and intellectual property, with China leading the field with 69,610 applications. This suggests a strong progression from laboratory research to industrial protection. The United States and Japan follow as major contributors to innovation, with 55,678 and 48,879 applications, respectively.

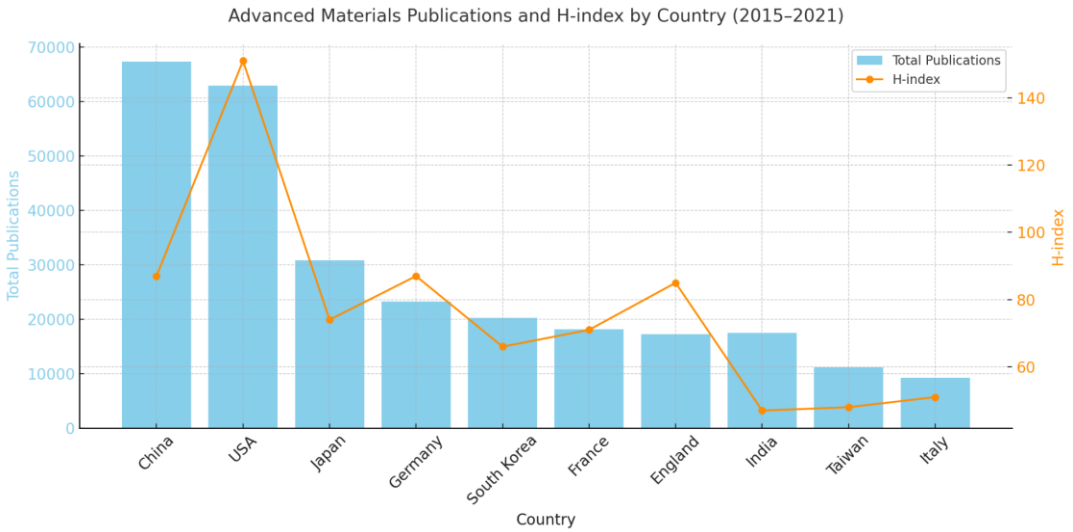


Figure 2-4 Top countries in advanced materials research publication [53].

Notably, there is a considerable disparity between these leading nations and others; South Korea and Germany occupy an intermediate position with applications ranging from 16,000 to 23,000, while countries such as France, the United Kingdom, and Switzerland form a smaller, more specialized segment of the patenting landscape as depicted in Figure 2.5. This pattern emphasizes a concentrated global innovation hub located in East Asia and North America, which is pivotal in shaping the commercial future of advanced materials.

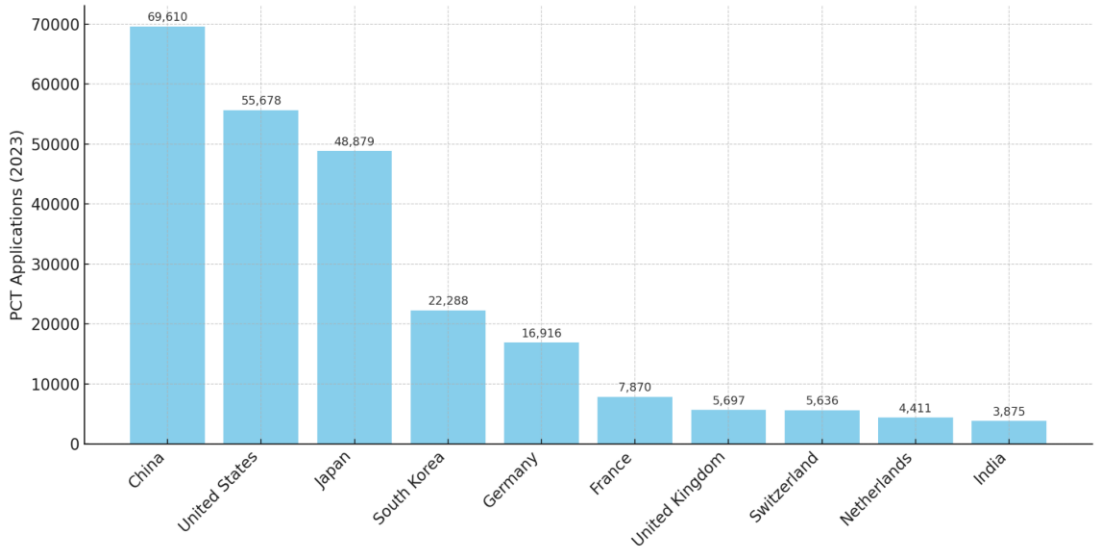


Figure 2-5 Top 10 countries by the number of patent applications (filed in 2023 Under WIPO).

- *Advanced materials in the US*: The United States currently occupies a leading position in the global advanced materials revolution, as illustrated in table 2.2 and Figure 2-7. This leadership is founded on a decentralized, "bottom-up" innovation model that effectively integrates academic research with market demands through a "seamless web" of universities, incubators, and small-to-medium enterprises (SMEs). In contrast to the traditional top-down corporate structures of the past, contemporary U.S. innovation is propelled by these agile SMEs, which frequently license university patents to develop pioneering technologies such as nanocarbon materials and organic electronics. Supported by a robust and specialized venture capital community, the U.S. adeptly manages the technical and financial risks inherent in high-technology development, thereby facilitating the efficient translation of scientific discoveries into commercial products more effectively than its global counterparts[186]. Today, AMs research thrives across numerous US universities and institutions, including Caltech, Stanford, Harvard, MIT and Princeton, as shown in Table 2.2. The US Defense Advanced Research Projects Agency (DARPA) also plays a crucial role in advancing materials research. The field has experienced remarkable growth and diversification, with advancements in nanotechnology, biomaterials, and smart materials driving innovation across various sectors. Collaborative efforts between academia, industry and government agencies have accelerated the pace of discovery and application of novel materials. As we move further into the 21st century, AMs continue to play a pivotal role in addressing global challenges such as energy sustainability, environmental conservation and healthcare improvements.

Table 2:2 U.S. Institutions in Advanced Materials Research (2015–2024).

Institution	Estimated Publications	Citation Impact (Relative)	Key Subfields	Notable Journals
Massachusetts Institute of Technology	~3,200	Very High	Energy materials, nanomaterials, quantum materials	*ACS Energy Letters*, *Nano Letters*, *Advanced Materials*
Stanford University	~2,900	Very High	Photonics, 2D materials, battery technology	*ACS Nano*, *Advanced Optical Materials*, *Nano Letters*

University of California, Berkeley	~2,700	Very High	Catalysis, polymers, quantum materials	*Chemistry of Materials*, *ACS Applied Materials & Interfaces*, *Nano Letters*
California Institute of Technology (Caltech)	~2,500	Very High	Nanophotonic, energy storage, quantum materials	*ACS Photonics*, *Advanced Energy Materials*, *Nano Letters*
University of Illinois Urbana-Champaign	~2,300	High	Soft materials, biomaterials, polymers	*ACS Applied Materials & Interfaces*, *Advanced Healthcare Materials*, *Macromolecules*
Northwestern University	~2,100	High	Nanomaterials, energy storage, catalysis	*Nano Letters*, *ACS Nano*, *ACS Energy Letters*
University of Michigan	~2,000	High	Electronic materials, polymers, energy materials	*ACS Applied Materials & Interfaces*, *Advanced Functional Materials*, *Macromolecules*
Georgia Institute of Technology	~1,800	High	Nanomaterials, energy materials, flexible electronics	*ACS Nano*, *Nano Letters*, *ACS Applied Materials & Interfaces*
University of California, Los Angeles (UCLA)	~1,700	High	Photonics, materials chemistry, energy materials	*ACS Photonics*, *Chemistry of Materials*, *ACS Energy Letters*
University of Texas at Austin	~1,600	High	Energy materials, catalysis, polymers	*ACS Energy Letters*, *ACS Applied Materials & Interfaces*, *Macromolecules*

- *Advance materials in People's republic of China:* China's rapid economic growth is driving a sustained, long-term demand for a greater volume and variety of advanced materials. To address emerging socio-technical challenges, the industry is shifting toward materials that prioritize high quality, reliability, and cost-effectiveness. There is an urgent need for multifunctional and high-performance materials, particularly in the energy, biomedical, and environmental sectors. Furthermore, future material development must focus on resource efficiency and environmental sustainability to mitigate pollution and energy consumption. Supporting this, the Chinese government allocates 15-30% of its research budget to AMs, funding initiatives like the National Natural Science Foundation, 973 and 863 Programs. With over 300 research institutes, 200 universities and 100,000 researchers, China ranks

first globally in AMs publications, showcasing its significant research capabilities and commitment to innovation in this field. China's advanced materials industry has transitioned from a low-end manufacturing base into a sophisticated global leader through aggressive, state-led industrial policies. Central to this ambition is the Made in China 2025 initiative, which sets a clear target of achieving 70% domestic self-sufficiency in core components and basic materials by 2025. This strategic push aims to eliminate dependence on foreign technology, particularly in high-stakes sectors like aerospace, semiconductors, and telecommunications. To support these goals, the Chinese government has deployed massive financial resources: a $146.49 billion USD investment target and over $1 trillion in government guidance funds for R&D. Technologically, China's work is characterized by its absolute dominance in the supply and processing of minerals. As of 2023, the nation controls the refining of 19 out of 20 key strategic materials, including over 70% of the world's rare earth capacity. This dominance extends into the energy sector, where Chinese firms manage roughly 85% of global battery anode production and 70% of cathode production. Looking ahead, China's projections remain highly ambitious; its nanomaterials market is expected to grow at a rapid compound annual rate to reach approximately $3.2 billion by 2033. While the industry faces international scrutiny regarding market distortions and intellectual property, the sheer scale of state-backed R&D and regional industrial clusters, such as those in Suzhou, has positioned China as the primary architect of the global advanced materials supply[22,178]. In general, due to many years of R&D in AMs, China has formed a comparatively integrated system of basic materials and has become a great country for basic materials production[22]. Moreover, a strategic approach to developing advanced materials involves industry clustering. For example, the establishment of advanced material industry clusters has markedly enhanced regional competitiveness, as exemplified by Shenzhen's battery material cluster, which boasts an annual output exceeding 100 billion CNY, and Ningbo's rare earth magnetic materials, which contribute 40% of the national output[179]. By cultivating world-class clusters within the dual-cycle framework, China aspires to elevate its industries to the medium-high end of the global value chain, thereby bolstering economic resilience and international influence[179].

- *Advanced materials in Japan:* The development of advanced materials in Japan is anchored by the National Institute for Materials Science (NIMS). Originally founded as the National

Research Institute for Metals in 1956, it evolved through a 2001 merger to focus on both the scientific and engineering dimensions of materials research. A major milestone occurred in 2007 when NIMS established the International Center for Materials Nano-architectonics (MANA). This unit is part of the government-supported World Premier International (WPI) program, which funds elite research centers at prestigious institutions like the University of Tokyo and Kyoto University. MANA's work is driven by the concept of nano-architectonics, a technology centered on the precise manipulation of atoms and molecules. This focus has led to significant breakthroughs in the synthesis of nanomaterials and smart materials designed to adapt to environmental changes. These advancements are increasingly directed toward improving quality of life, particularly in the fields of healthcare, energy, and sustainable technology. In recent years, Japan's advanced materials sector is managed through a highly coordinated, state-led framework that treats materials science as a pillar for both national competitiveness and economic security. To maintain this competitive edge, Japan utilizes massive, multi-ministerial R&D frameworks such as the 6th Science, Technology, and Innovation (STI) Basic Plan (2021–2025). Currently, the materials industry remains vital to Japan's economy, accounting for nearly one-third of its manufacturing GDP. By integrating data-driven development and supporting "materials unicorns," Japan aims to bridge the gap between high-level laboratory research and practical, market-ready industrial applications.

- *Advanced materials in South Korea*: South Korea's revolution in advanced materials is centered on a robust framework of government-funded research, primarily led by the Korea Institute of Machinery and Materials (KIMM). Established in 1976, KIMM has expanded into a multi-divisional powerhouse that drives industrial innovation through its specialized regional centers and its subsidiary, the Korea Institute of Materials Science (KIMS). This institutional focus aims to position South Korea as a dominant force in the rapidly growing Asia-Pacific market, which is currently challenging the traditional leadership of the U.S. and EU. Driven by the needs of the aerospace, automotive, and electronics sectors, the nation is investing heavily in R&D to bridge the technological gap with global competitors, ultimately fostering a landscape defined by high-performance innovation and international collaboration[180]. South Korea has undergone a significant advanced materials revolution, transitioning from a mass-production hub to a global leader in high-value, technology-

driven manufacturing. Central to this shift is a massive financial commitment: in 2015, the nation allocated 4.23% of its GDP to research and development, the second-highest intensity in the world with the government later injecting approximately US$1.38 billion (KRW 1.52 trillion) specifically through the Ministry of Science and ICT. This economic injection is strategically funneled into the manufacturing sector, which accounts for 90% of business-led R&D and drives over 40% of the nation's GDP through exports. Under its "Fourth Basic Plan," South Korea aims to cement its position by developing 100 world-leading material technologies by 2025[181].

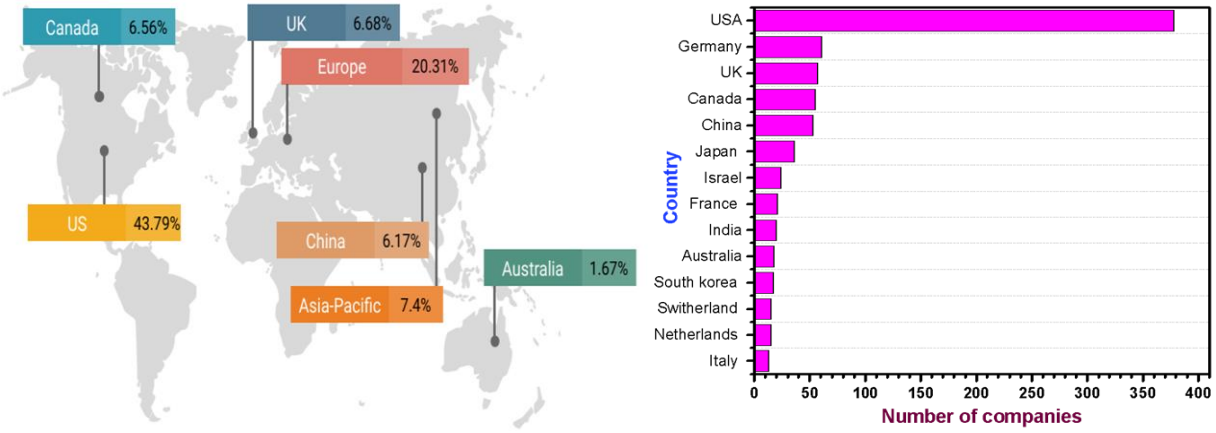


Figure 2-7 Market share of AMs by countries[55] and companies[56]

- *Advanced materials in Africa:* The revolution in advanced materials in Africa, especially South Africa and Nigeria, currently driven by two distinct processing philosophies: the beneficiation of solid minerals and value addition to biowaste. Mineral beneficiation efforts include using environmentally friendly bioleaching processes to recover metals like zinc and copper from complex ores, as well as developing advanced alloys such as vanadium-nickel (VC-Ni) systems and low-cost titanium alloys for automotive and biomedical applications. Additionally, the revolution extends to ceramics and composites through the utilization of local clay and agricultural waste. Researchers have identified specific clay deposits suitable for high-temperature furnace linings and are enhancing them with additives like zirconia and yttria to improve mechanical properties. Simultaneously, biowaste materials such as plant fibers (e.g., Entanda mannii) and agro-waste ashes from groundnut shells or rice husks are being used as reinforcements in hybrid aluminum and polymer-based composites. These "waste-to-wealth" strategies provide cost-effective,

lightweight alternatives to synthetic materials, offering a viable pathway for Africa to achieve rapid industrial growth and address socio-economic challenges like unemployment and poverty[182]. The Advanced materials revolution in South Africa focused on mineral beneficiation, aiming to transition from a raw material exporter to a high-tech manufacturer. This strategy is led by the Department of Science and Innovation (DSI) through the Advanced Materials Initiative (AMI), which coordinates research across four main pillars: light metals (titanium and magnesium), precious metals (platinum group metals), nuclear materials, and advanced polymers. Economically, the nation invests approximately 0.62% of its GDP into R&D, with a specific focus on high-growth areas like the hydrogen economy, where platinum-based fuel cells are crucial. By leveraging its vast natural reserves of chromium, manganese, and platinum, South Africa is working to bridge the "innovation chasm" through entities like Mintek and the CSIR[183].

2.1.5 Advanced Manufacturing Technology (AMT)

Advanced Manufacturing Technology is another emerging technology with huge potential in revolutionizing several industries and increasing productivity. Global research, innovation and development around AMTs tools such as smart manufacturing technologies are summarized. As highlighted in Figure 2.8, the United States contributes ~39% to global outlook with China and UK being the second and third with ~ 11% and 10.5, respectively (Figure 2.8). South Africa, Tunisia, Egypt, Nigeria, Morocco and Tunisia are among top African countries that advance in advanced manufacturing technologies. South Africa has massive investment in SMT facilities across the manufacturing value chain. There is an intentional and systematic infusing of SMT technologies in most of the light manufacturing sector. This is backed by research from various research councils, and institutions of higher learning.

The commitment of the South African public and private sector through the establishment of the Presidential Commission of the Fourth Industrial Revolution has been a contributing factor to increased awareness for various emerging technologies. Prior to the installation of the first fully functional SMT facility in 1994, there were pockets of centers of excellence in SMT research across South Africa. One of the first was the Rapid Product Development Association of South Africa (RAPDASA)[25], a phenomenal organization in pushing for SMT research and product

commercialization as well as forging strong international collaboration with entities such as Global Alliance of Rapid Prototyping Associations (GARPA). South Africa through the Department of Science and Technology in 2015 implemented the strategic roadmap for smart manufacturing[57]. These research entities and universities have increased due to increased awareness and slow transition of light manufacturing industries into smart manufacturing.

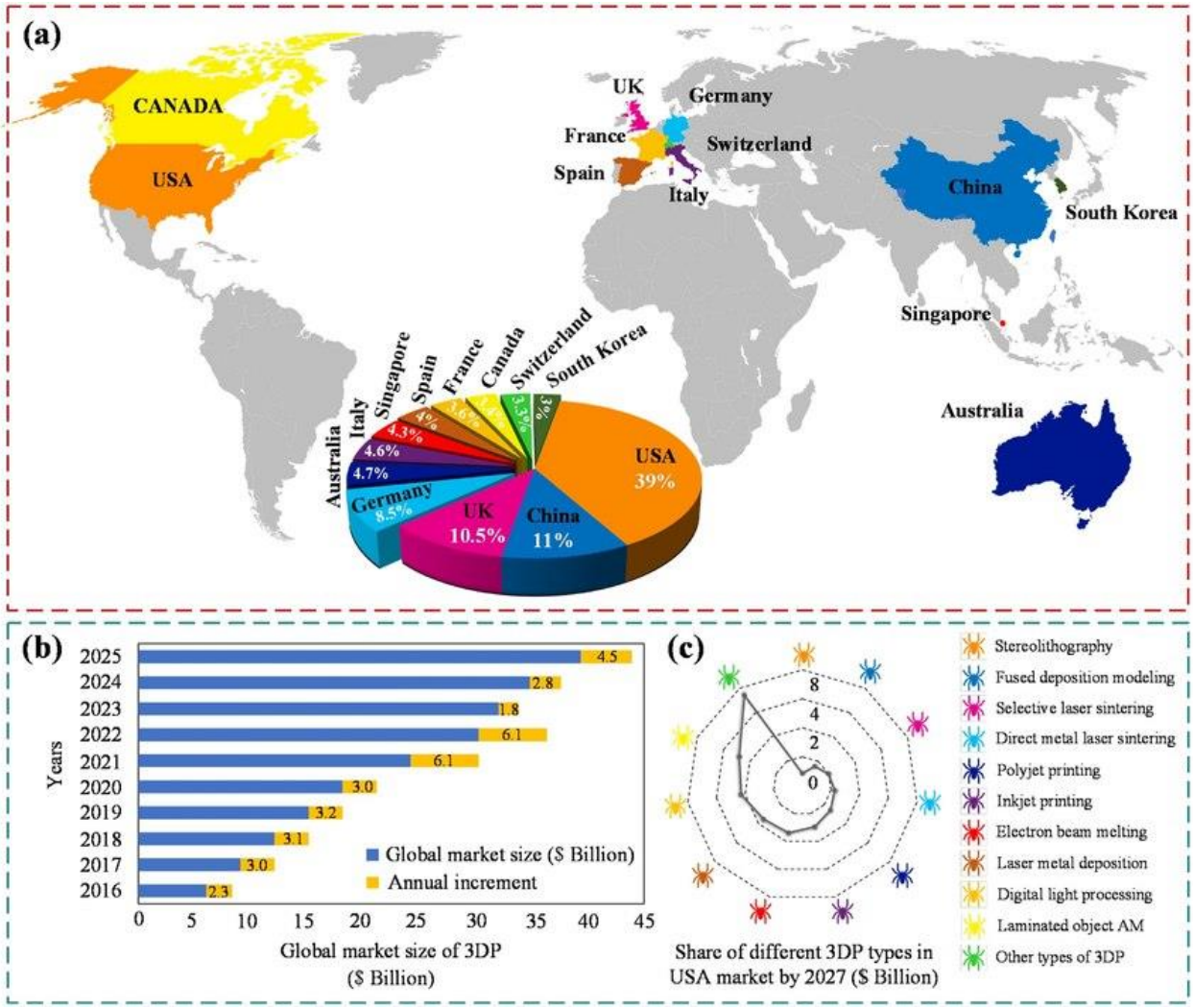


Figure 2-8 Global outlook of SMTs [58]

Figure 2.8 Global outlook of SMTs showing: (a) Research intensive in developed countries, (b) Yearly distribution of milestones and global market share in US dollars and (c) Estimated market share of various SMT techniques in the United State market by 2027 [58]. The second most published country in smart manufacturing is Egypt[59]. There are two principal areas of application of SMT processes in Egypt, construction and medical industry. In the construction sector, knowledge,

awareness, and perceptions (KAP) study of 3D printing of ~55 participants. The local designers and planners in the Egyptian market were done in 2019. The results are staggering ~27% of participants and industry practitioners had some prior knowledge but were not fully engaged with it.

The Egyptian National Development plan focuses on intensifying and investing in emerging technologies, i.e., smart manufacturing focusing on construction and medical devices industries. Similarly, the "Print Lab Egypt" runs the SMT Company which continues to drive SMT research and product development. This has resulted in retooling and reskilling the next generation workforce in an era of overwhelming complexities, accelerated change and tremendous competition under the guise of the Industrial 4.0. Currently, 3D printers, model software, online courses, curriculum assessment and design are gradually being included in most formal education in Egypt. This is to position the nation to leverage from the benefits of SMT and Egypt to become a global player in this arena. Some of the ancient Egyptian artifacts have been redesigned and modeled using 3D printing technologies.

Nigeria has also made several initiatives in promoting SMT research and awareness creation in regions like south western Nigeria where over 60% of the samples have no knowledge of SMT[60]. A similar study focused on the perception and implementation of 3D printing has been conducted in the educational sector where about 93% of engineering professionals in study were aware of the technologies in the educational sector[61]. In 2017, Nigerian Foundries Limited purchased one of the largest 3D printing facilities from Titan Robotics. This has been used for the preparation of complex and intricate mold patterns. The full functionality is barely realized due lack of awareness and skills deficit. Adopting 3D printing has faced numerous challenges in the Economic Community of the West Africa States (ECOWAS), where Nigeria is one of the biggest economies. Over reliance of ECOWAS member states on importation of spare parts hindered the light manufacturing sector in the sub region[62]. This has stifled growth and adoption of such technologies by local manufacturers.

In Morocco, smart manufacturing technology research and development has improved through various private-public initiatives such as the creation of an industrial competence center for metal SMT research in 2016[63]. The formation of the Moroccan Association of Additive Manufacturing and 3D printing and series of International Conference on smart manufacturing, where the first was

held between 19 and 20 November 2020. These conferences were aimed at providing a platform for local and international researchers in various areas of SMT technologies and industry for revolution. These initiatives were in response to the 2015 industrial acceleration plan with 10 foci to accelerate industrial transformation of the Kingdom of Morocco[63].

Since its inception, Casablanca International Conference on Additive Manufacturing has concluded its second edition. Some of the areas of focus are engineering design for smart manufacturing, modeling and simulation, quality control and assurance, SMT challenges and future prospects for Africa, artificial intelligence, machine learning, automation and digitalization, SMT education, training, and research strategy. These initiatives have public-private partnership buy-ins and are supported by intensive research from centers of higher learning such as Rabat International University and Institute, Telecommunications and Universities of Tangiers. SMT awareness in Morocco is growing steadily but there is still room for improvement. This can be achieved by increasing collaborative partnership from the sub region and globally.

In Tunisia, the National Engineering School of Tunis (ENIT), one of the largest engineering schools, introduced the first fabrication laboratory (FabLab) for smart manufacturing technologies and research. Regarding design and innovation management modules, ENIT has organized seven workshops according to the “Innovation week” model, two of them were “International weeks.” The FabLab was launched as an in-situ students association, with students from different specialties who are responsible for running and managing the FabLab activities. More than 500 students have benefitted through training on design, innovation management and creativity. Some of the projects by FabLab include; development of a model for the calculation of prototype's cost needs analysis for rapid prototyping in Tunisian companies.

Overall, AMTs tools are rapidly growing with global market size estimated to grow by 25–30% by 2025 and estimated value at US$ 40 Billion[58]. Figure 2.8, shows Global outlook of SMTs (a) research intensive in developed countries, (b) yearly distribution of milestones and global market share in US dollars and (c) estimated market share of various SMT techniques in the United State market by 2027. As of 2019, at least 1.5 million well equipped 3D printers are distributed and being used by various industries and academia which is estimated to increase to ~8 million by 2027. This underscores the growing research and development efforts supporting the 3D printing industry and highlights the advantages of smart manufacturing over traditional subtractive methods.

As seen in Figure 2.8, there has been an increased installation and geographical distribution of 3D printing industrial systems globally. Between 2010 and 2018, 37% of industrial systems were installed in North America, 28.4% in continental Europe, ~30% in Asia and the Pacific and ~4.6% for the rest of the world. The pervasive nature of the technology is due to massive use by most of the world leading industries. There are enormous resources dedicated to research and development that are industry driven. This has led to strong industry-academia partnership bridging the gap between the two. New insights from research centers, university laboratories and industry inform the applicability and acceptability of the technology.

2.2 Use Cases of Emerging Technologies

To develop a robust national emerging technology roadmap, it is essential to review relevant use cases that effectively link emerging technologies with practical applications. By analyzing sector-specific use cases, stakeholders can clearly identify priority areas for investment and development. Therefore, the applications of selected emerging technologies across various sectors are summarized below.

2.2.1 Agriculture

Emerging technologies are revolutionizing agriculture, driving unprecedented improvements in productivity, sustainability and efficiency. Figure 2.9 highlights the application of emerging technology for revolutionizing agriculture traditional to intelligent agriculture (agriculture 4.0).

Nanotechnology is among one of the emerging technologies that offers the ability to manipulate materials at the nanoscale and create innovative agricultural products such as nano-fertilizers, nano-pesticides and others that enhance agricultural productivity[64–68]. For instance, nano-fertilizers and bio-pesticides can improve nutrient uptake and pest control efficiency. Nanoparticles can be also engineered to release nutrients in a controlled manner, optimizing plant absorption and minimizing runoff [66]. Nanotechnology can also enhance soil health through the use of nanomaterials that improve soil aeration, moisture retention and nutrient availability which is especially beneficial in arid regions where water conservation is crucial [65,67].

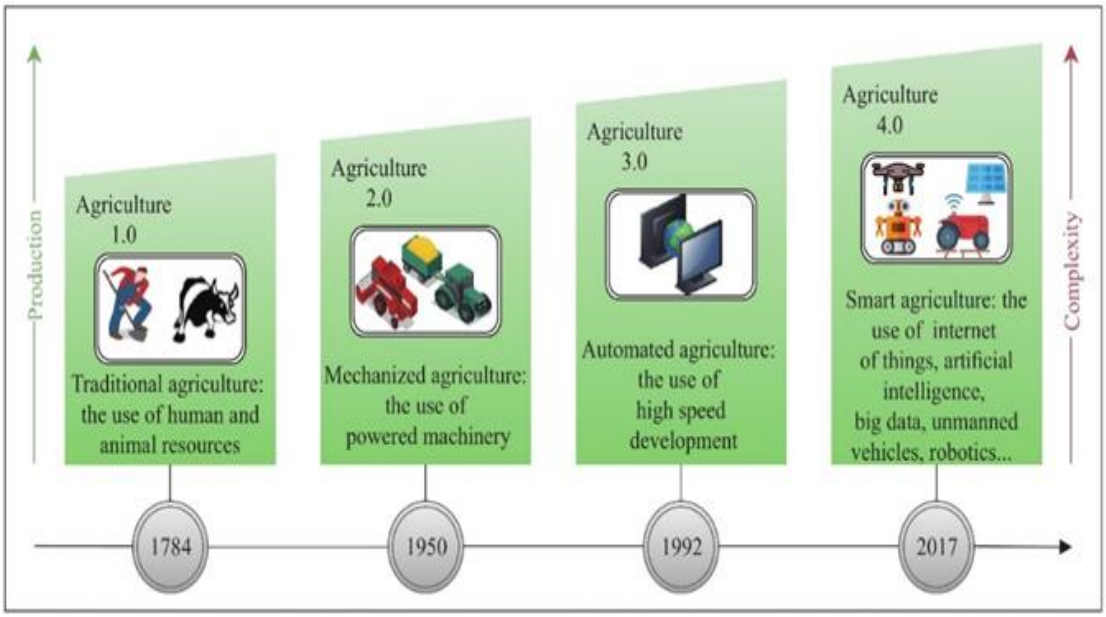


Figure 2-9 Application of emerging technologies for transforming agriculture.

Similarly, *synthetic and systems biology* advances agricultural resilience by genetically optimizing plants and animals for higher productivity, improved nutritional content, and enhanced adaptability to climate change. These innovations directly address global food and nutritional insecurity by creating more robust and efficient agricultural systems. For instance, gene editing is used to enhance vitamins and micronutrients in crops such as lettuce, maize and rice. Biofortification using CRISPR-Cas led to improved several crops nutrient profiles (e.g., increased levels of starch, protein, vitamin, and oleic acid), sweetness and shelf life of perishable crops[69,70]. Synthetic biology also plays a significant role in improving the health and productivity of domestic animals. It can also be used to improve growth rate, milk production and meat quality in livestock [71]. Moreover, it was possible to develop protocols for DNA-free genome editing using protoplast based CRISPR/Cas9 for *Brassica Carinata* which is demonstrated in improvement of its oil quality[184].

Ethiopia is increasingly adopting synthetic and systems biology to enhance its agricultural sector. The country has approved national guidelines for genome editing, demonstrating its commitment to modern biotechnology[72]. The country also showed its dedication to the responsible use of genetically modified organisms (GMOs) via signing of the Cartagena Protocol on Biosafety. By signing the Cartagena Protocol on Biosafety. Through partnerships with Africa's NEPAD and AOCC initiatives[73,74]. Collaborative projects like the Ethiopia-Kenya *Striga* Smart Sorghum for Africa (SSSfA) aim to combat Striga weed using gene editing tools. Ethiopia has also adopted Bt-

cotton to reduce pest damage and increase yields, while participating in the WEMA program to develop drought-tolerant maize varieties suited to local conditions[75,76]. These efforts reflect Ethiopia's growing role in applying synthetic and system biology to improve food security and agricultural sustainability in Africa.

On the other hand, *Advanced Materials (AMs*) are revolutionizing the physical infrastructure of farming. These materials enable the development of durable, lightweight, and eco-friendly solutions, ranging from high-performance farming equipment to biodegradable packaging and specialized soil health enhancers. By integrating these materials, producers can improve operational efficiency while significantly reducing the ecological footprint of traditional agricultural practices. Furthermore, advanced manufacturing technology is reshaping farming through industrial automation and precision agriculture. Vertical farming, supported by automated hydroponic systems, enhances food production in urban areas with limited space.

Most recently, agriculture 4.0 powered by *AI, IoT, robotics and smart sensors* has transformed traditional farming into a data-driven and automated/precision agriculture system. Autonomous tractors, AI-powered drones and robotic harvesters optimize planting, irrigation, and pesticide application. Real-time monitoring of soil conditions, crop health, and automated irrigation systems ensures precision farming. Robotics in harvesting and sorting reduce labor costs and improve efficiency. These technologies contribute to higher yields, reduced environmental impact, and improved food security, particularly in regions facing labor shortages and climate challenges.

2.2.2 HEALTHCARE

Recent advances in nanotechnology, synthetic and system biology, advanced materials, intelligent systems, and advanced manufacturing technology are revolutionizing the healthcare sector. For instance, the integration of nanotechnology into medicine, often referred to as nano-medicine, significantly advances medical diagnostics, targeted treatments, and real-time patient monitoring capabilities. Figure 2.10 highlights systematic approach to efficient and affordable biosensor for clinical and POC applications[77]. Specifically, nanoscale biosensors enable precise detection of diseases at earlier stages, which is crucial for effective treatment[77], enhancing clinical decision-making by improving early disease detection. This allows healthcare providers to achieve better imaging contrast and resolution, leading to more precise diagnoses[78]. Further, the deployment of

nanoscale drug formulations and therapeutic agents allows for treatments that are tailored to specific medical conditions and individual patient profiles[79]. The development of wearable medical devices that leverage nanotechnology enables real-time monitoring of health parameters[80]. Nanomaterials and other carriers like nanoparticles, liposomes and polymeric micelles are used for targeted drug delivery[81–84].

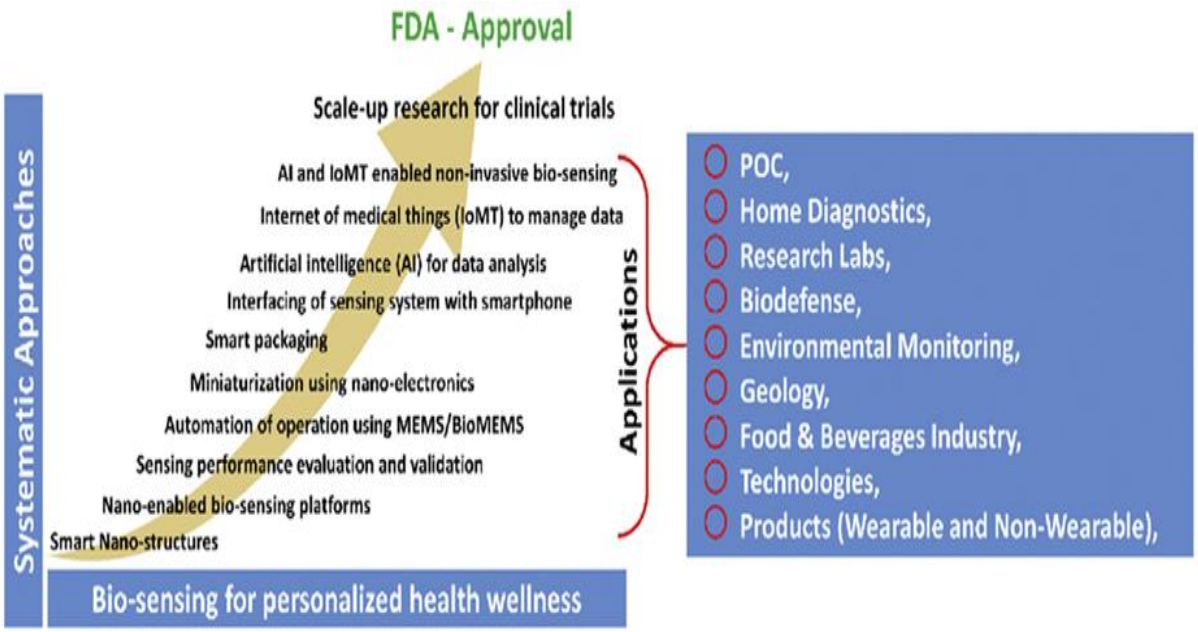
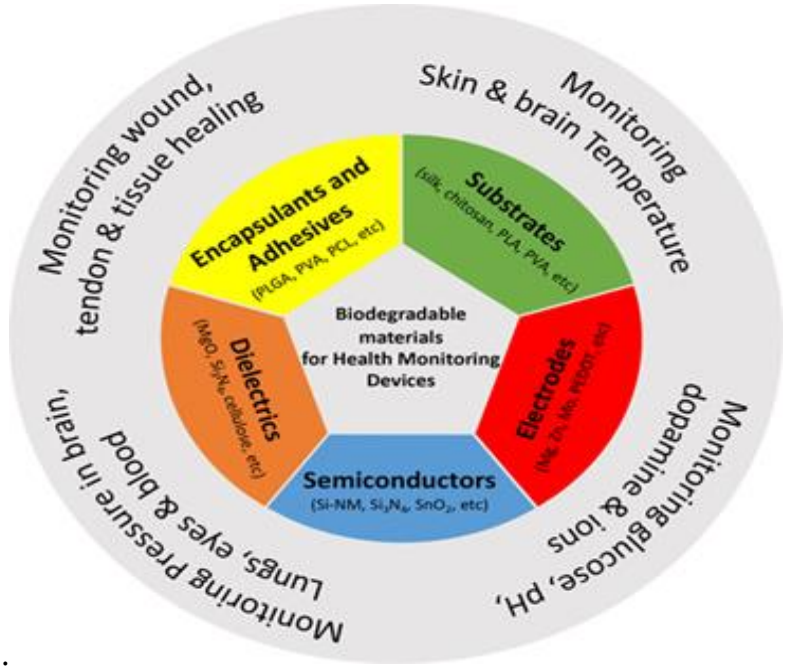


Figure 2-10 Application of biosensor for clinical and POC applications[77].

Other advanced materials are also essential for significantly enhancing properties including mechanical strength, biocompatibility and functionality of medical implants and devices[79,85–87]. As highlighted in Figure 2.11 Biodegradable materials for sustainable health monitoring devices. For example, biomaterials including metals, ceramics and polymers, are designed for compatibility with biological systems. Stainless steels and titanium alloys are also commonly used in implants due to their durability and biocompatibility. Advanced materials also facilitated the creation of scaffolds for tissue engineering, providing structures for cell growth and tissue regeneration. These scaffolds often use biodegradable polymers that dissolve as new tissue forms[88,85]. Smart materials that respond to environmental stimuli are also emerging in healthcare, enabling devices to release medication based on physiological conditions[89]. Advanced materials also support the development of wearable devices to monitor health parameters in real-time [90,91].



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Figure 2-11 Biodegradable materials for sustainable health monitoring devices [87].

Complementing these physical innovations, synthetic and systems biology offers transformative tools for disease diagnosis, drug discovery, and vaccine development. For instance, synthetic biology contributes to personalized medicine and targeted drug delivery[92–94]. Microbes such as bacteroides, *Lactococcus lactis* and attenuated strains of *Salmonella typhimurium* have been modified to serve as drug delivery vehicles. Similarly, using bottom-up synthetic biology, synthetic beta cells can be used to produce and deliver insulin. Multicompartment systems are also developed and used to contain drugs and release in a controlled manner [95].

There are also several cases that show the contribution of synthetic biology as a means of personalized medicine. By engineering T-cells, researchers managed to target and kill cancer cells[62,96]. Drugs and vaccine design and development has become efficient because of the advancement in synthetic and system biology. One good example could be RNA based covid-19 vaccines[97–99]. Computational biology involving large scale biological databases and advanced computing infrastructure have dramatically accelerated biomedical discovery. Key innovations transforming African healthcare include: (1) Precision medicine leveraging H3 Africa's genomic research[100]; (2) CRISPR-Cas9 gene editing for genetic disorders[43]; (3) Emerging CAR-T cell therapies for cancer[101]; and (4) Novel glycopeptide vaccines against infections and malignancies[102];

showcasing promising potential applications of synthetic biology synthetic and system biology in Ethiopia.

On the other hand, *Advanced Manufacturing Technology* like prosthetics and bioprinting of tissues[103] enhance the healthcare system. More recently, advances in medical robotics as well as AI based systems enhance diagnostics, personalized treatments and surgical precision. AI-driven diagnostic tools are utilized for early disease detection, humanoid robots for elderly care, and optimizing resource allocation. IoT enables remote patient monitoring, self-maintenance medical devices, and telemedicine with virtual visits [104,105]. 5G networks will drive IoT adoption in healthcare, enabling real-time patient monitoring and predictive maintenance through IoT sensors [106,107].

Wearable IoT devices also enable industrial safety benefits e.g., through monitoring workers' health in hazardous environments. Drones inspect high-risk infrastructure, reducing human exposure to dangers. These applications enhance workplace safety and healthcare outcomes. Advanced computational technologies like edge computing and quantum computing have also become a new opportunity in clinical trial design and optimization[108,109]. Cloud platforms like AWS and Microsoft Azure enable scalable data storage and processing, facilitating real-time data analysis and collaboration in healthcare.

2.2.3 MANUFACTURING

Similar to other sectors, the manufacturing and industrial landscape is undergoing a radical transformation through cutting-edge technologies that enhance efficiency, productivity, and sustainability. For instance, application of nanotechnology plays a crucial role in food packaging by incorporating nanomaterials like silver and nanoclays[110]. These materials enhance barrier properties and functionality, improving mechanical strength and thermal resistance while inhibiting microbial growth. Nano-fibers, with diameters under 100 nanometers, exhibit high surface area and enhanced mechanical strength, making them suitable for various applications including in textiles as they improve breathability; in filtration systems, they facilitate effective pathogen removal; and in biomedical fields, they serve as scaffolding and drug delivery systems, demonstrating their versatility and effectiveness[111].

Complementing these advancements, advanced materials have become integral to modern manufacturing. They drive the development of high-performance materials characterized by increased strength, reduced weight, and superior resistance to environmental degradation, which allow manufacturers to produce more durable and efficient products[103]. Production of eco-friendly materials, such as biodegradable plastics and recycled composites leads to sustainability. Manufacturers reduce their environmental impact by incorporating these advanced materials into their products [112]. Understanding the properties of materials allows manufacturers to optimize their production processes. For example, knowledge of thermal properties can inform decisions about heating and cooling processes [103]. Advanced materials have new manufacturing techniques such as additive manufacturing (3D printing). This technology allows for the creation of complex geometries and customized products, reducing waste and enabling more efficient production methods[112].

Another significant advancement is synthetic and computational biology, particularly in bio-manufacturing and industrial biotechnology. This field is transforming industry by enabling innovative production methods that enhance efficiency and productivity. The key use cases in this area include chassis engineering and cell free systems. Through these innovations, biomanufacturing reduces reliance on fossil fuels and minimizes greenhouse gas emissions by engineering biological systems to produce chemicals, materials, and fuels. Consequently, production costs are reduced while supporting global sustainability goals. In manufacturing, organisms like *Bacillus subtilis and Z. mobilis are* utilized as versatile platforms for producing valuable biomolecules such as succinic acid, ethylene glycol, glycolic acid and other biomolecules[113]. In addition to microbial chassis, plant chassis such as *Nicotiana benthamiana* and *Arabidopsis thaliana* are being used to produce medicinal compounds (antibiotics and anti-cancer drugs), agricultural products (biopesticides) and industrial chemicals (bioplastics and biofuels).

Furthermore, synthetic biology helps address challenges related to metabolic burden and complexity, facilitating the development of genome-reduced cell factories and synthetic microbial consortia[114]. The other biomanufacturing system is the Cell-Free Systems that utilizes biological machinery such as enzymes and ribosomes to synthesize biomolecules outside of the living organism[115]. It enables the production of biomolecules and other products using portable and on-site production systems while overcoming limitations associated with traditional manufacturing

methods that require specialized equipment[115,116]. The versatility of cell-free systems allows for rapid prototyping and production of diverse biomolecules, making it a highly adaptable platform for various applications. Biomolecules such as therapeutic proteins, short chain of amino acids, antibodies, and nucleic acids have been manufactured. Furthermore, their open nature facilitates the incorporation of non-natural amino acids or other synthetic components, expanding the range of possible products[94]. By enabling decentralized and scalable manufacturing, cell-free systems hold immense potential to revolutionize industries such as healthcare, agriculture, and environmental remediation, while also addressing challenges related to supply chain logistics and cost efficiency[116,125].

Notably, advanced manufacturing technology enables mass customization and energy-efficient production. 3D printing allows for personalized products, from footwear to electronics and huge, complicated industrial products. Smart appliances, integrated with IoT and AI, optimize energy usage and provide real-time diagnostics for maintenance. For example, refrigerators with AI can track food inventory and suggest recipes, while robotic vacuum cleaners use machine learning for efficient cleaning paths. It also reduces material waste in production, supporting sustainability in fast-moving consumer goods industries.

Recently, more advanced technologies such as robotics, AI, IoT and big data analytics have had a transformative impact in the manufacturing sector[118–120]. These technologies are reshaping production processes, enhancing efficiency and driving innovation. Robotics also allows for the automation of complex processes, leading to improved safety and reduced labor costs[121,122]. IoT enables smart factories where machines communicate with each other and with human operators [123,124]. IoT applications can also enhance supply chain visibility and enable manufacturers to respond quickly to market changes[119,124]. By leveraging big data, manufacturers can make informed decisions that enhance operational efficiency and drive innovation[125,126]. The ability to analyze data from various sources allows for a more comprehensive understanding of market trends and customer needs.

2.2.4 ENERGY

As fossil fuel resources reduce and global CO_2 emissions continue to rise, there's an urgent need to adopt renewable energy sources and require a fundamental change in how scientists, students, and

leaders approach renewable energy and climate issues. Thus, emphasizing sustainability in emerging technologies such as energy technology is essential for a sustainable future.

Nanotechnology is one such technology that is revolutionizing the energy sector through the development of innovative solutions aimed at optimizing energy systems. In recent years, innovations in electronic components at the nanoscale are enhancing energy storage, efficiency and performance[127–129]. By miniaturizing electronic components, manufacturers can reduce energy consumption and improve the functionality of devices, leading to more efficient energy systems[127]. For example, nanostructured materials can improve the performance of photovoltaic cells, making solar energy a more viable and efficient option for power generation[128]. Nano-catalysts can also increase reaction rates and selectivity, making processes like fuel production and energy conversion more efficient and environmentally friendly[129].

Similarly, advanced materials play a pivotal role in the energy sector by enabling the development of materials that enhance energy production, conversion, storage and efficiency[127,130]. Advancements in materials have led to the creation of high-capacity batteries and supercapacitors, solar cells, fuel cells, and thermoelectric devices, among others. Innovations such as perovskite solar cells, which utilize novel materials, have shown great promise in enhancing light absorption and energy conversion rates. The development of advanced thermal materials also helps in managing heat in energy systems, improving the efficiency of thermal power plants and reducing waste heat[130].

Recently, synthetic and system biology are opening new frontiers in bioenergy by enabling the design of biological systems that generate, store and convert energy more efficiently. One emerging application is bio-based energy storage, where biological molecules such as carbohydrates or lipids are used to store chemical energy in a renewable and sustainable way. These systems mimic natural energy storage mechanisms and can be engineered for scalable and eco-friendly alternatives to conventional batteries. One promising innovation is the bio dry cell, which uses biocatalysts or engineered microbes to convert biochemical energy into usable electrical or metabolic energy. These cells leverage microbial metabolism to generate power, offering potential applications in low-cost, portable energy solutions, especially in remote or resource-limited areas like rural Ethiopia[62].

Another key area is improving lignin for bioenergy. Lignin, a complex polymer in plant cell walls, is often a barrier in biofuel production. Through synthetic biology, researchers are engineering plants with modified lignin structures to enhance biomass digestibility, making biofuel production more efficient and cost-effective[131]. Additionally, biochips are being developed to integrate engineered biological components such as DNA circuits, enzymes, or cell-free systems to perform sensing, computation, or energy generation functions. These biochips can power small devices using biological energy sources, paving the way for sustainable, biologically driven microelectronics[62].

Advanced manufacturing technology also plays a crucial role in renewable energy and waste reduction. For example, additive manufacturing is used to produce lightweight wind turbine blades and solar panel components, enhancing efficiency. Recycling technologies, such as advanced sorting robots, improve waste management by separating materials more accurately. These innovations support circular economy models, minimizing industrial carbon footprints and promoting sustainable energy solutions.

More recently, Smart grids, supported by IoT and AI, optimize energy distribution and reduce losses via optimizing energy management and reducing labor costs[132–134]. Robotics is increasingly used for maintenance tasks in energy facilities, such as inspecting wind turbines and solar panels. Drones equipped with cameras and sensors can perform visual inspections, reducing the need for human intervention in hazardous environments. AI algorithms analyze data from energy systems to predict equipment failures and optimize maintenance schedules. The combination of robotics, AI, IoT and big data analytics creates a synergistic effect that enhances the overall efficiency of the energy system[135].

2.2.5 Construction

Recently, nanotechnology is increasingly being applied in the construction industry to develop innovative, sustainable materials. It enhances the properties of conventional materials such as silica and carbon nanotubes, into concrete which not only can significantly improve its mechanical strength, durability and resistance to cracking but also improves material performance and contributes to the longevity and sustainability of structures[141]. For example, silica nanoparticles enhance the hydration process in concrete, leading to increased strength and reduced permeability.

As a response to global carbon emissions, accounting for approximately 11% of total emissions by the construction industry, materials scientists are focusing on developing sustainable alternatives to traditional materials. For instance, geopolymer cements are being explored as a more environmentally friendly alternative to Portland cement, which is responsible for 5-7% of global CO_2 emissions. Geopolymers utilize industrial byproducts like fly ash and metakaolin, resulting in lower carbon footprints during production. Researchers have demonstrated the wood composites' potential structural applications which not only provide comparable strength to traditional timber but also offer benefits in terms of sustainability and resource efficiency[136]. Advanced techniques, such as 3D printing and digital fabrication, are enabling the creation of complex structures with optimized material usage[137,138]. Smart materials such as sensors can also respond to environmental changes, such as temperature and humidity, enhancing the durability and safety of structures. For instance, materials embedded with sensors can provide real-time data on structural health, allowing for proactive maintenance and management[139].

Advanced manufacturing technology (AMT) has had many advantages in construction technology by representing technologies which reduce the level of waste generated during construction[58]. A second related advantage of AMT compared to traditional construction methods is the capacity to produce complicated large-scale structures[140].

A notable use case of synthetic and systems biology in the construction industry is self-healing concrete, which incorporates engineered bacteria such as Bacillus species that produce calcium carbonate to seal cracks when water enters the structure[142,143]. This bio-based repair mechanism extends the lifespan of concrete infrastructure and reduces maintenance costs. Similar approaches are being explored for asphalt pavements, where microbial or enzymatic reactions are used to improve durability and enable autonomous healing of road surfaces.

Other emerging applications include bio-cementation for soil stabilization and the development of living building materials capable of responding to environmental changes. These innovations leverage engineered microorganisms to improve soil strength or create adaptive, self-regulating structures, enhancing the durability and sustainability of construction projects[144]. Such technologies hold promises for infrastructure development in regions like Ethiopia.

More recently, advanced computational and intelligent system technologies improve effectiveness in construction management and operations through automating project management, warehouse, transport and logistics practices as well as increasing efficiency and safety by reducing human exposure to hazardous conditions[145–149]. Particularly, emerging technologies like deep learning optimizes concrete properties and project management, enabling data-driven decisions, improved efficiency, enhanced safety and productivity. Robotics and AI automate hazardous tasks, enhancing safety, and providing real-time site insights[146,149]. By leveraging historical data and real-time information, construction firms can identify trends, optimize workflows and enhance overall project efficiency[137,146]. Moreover, IoT devices are used to monitor construction sites in real-time, allowing better resource management and enhanced safety protocols.

2.2.6 ENVIRONMENT

The application of nanotechnology in the environment allows enhancing quality and sustainability through various innovative approaches by effectively removing pollutants from water [150–152]. For instance, it offers advanced solutions for environmental remediation, including targeted nanoparticle systems that enhance water treatment efficiency by selectively removing contaminants from soils, water and air[152]. These can enhance the degradation of pollutants and facilitate the restoration of contaminated sites. By optimizing conditions at the nanoscale, the activity of these microorganisms can be significantly improved, leading to more efficient bioremediation processes. Additionally, it enables real-time pollution monitoring with highly sensitive sensors, delivering actionable data for hazard response. It also enhances bioremediation efficiency through nanoscale optimization and explores carbon capture solutions to mitigate climate change[150,151].

In parallel, AMs represents a crucial emerging technology for promoting long-term sustainability. By enabling scientists to modify the molecular structure of polymers, these materials facilitate the creation of plastics that microorganisms can readily degrade. Current research in this area focuses on developing materials that break down more quickly and safely in the environment [153–155, 156]. Materials scientists are creating novel filtration materials that enhance water treatment processes, making them more efficient and environmentally friendly which are crucial for addressing global water scarcity and pollution challenges[153,155]. Innovative materials, such as recycled concrete and

low-carbon cement contribute to greener construction practices by reducing the environmental impact of building projects. Ongoing research aims to develop materials that not only reduce carbon emissions during production but also enhance the durability and lifespan of structures [155,156].

Synthetic biology also enables the development of microbes that can degrade pollutants, such as heavy metals and organic toxins[157]. These microbes can break down complex contaminants such as heavy metals, petroleum hydrocarbons, pesticides, and organic toxins into less harmful substances[158]. Engineered microbes can function as biosensors, detecting specific pollutants in real-time, which aids in monitoring environmental health and guiding remediation efforts[159]. The ability to rapidly identify and respond to contamination not only enhances the efficiency of cleanup operations but also minimizes long-term ecological damage[158,159]. It also plays a pivotal role in advancing sustainable production practices by reducing reliance on fossil fuels and minimizing environmental waste. Through microbial engineering, scientists can produce biodegradable materials such as green biopolymers, which serve as eco-friendly alternatives to traditional plastics. These biopolymers decompose naturally, and reduce plastic pollution[160], supporting a circular economy. Additionally, synthetic biology facilitates the sustainable synthesis of chemicals, dyes, and other industrial products that traditionally rely on petrochemicals. For instance, engineered microorganisms can produce bio-based dyes for the textile industry, eliminating the need for toxic chemical processes[161]. This shift toward renewable resources not only mitigates environmental harm but also aligns with global efforts to combat climate change and resource depletion.

Nowadays, advanced computational and intelligent systems technologies have been widely used in forest and natural resource management[162], natural disaster prediction[163] and climate change mitigation tasks[164,165]. AI and robots are employed in reforestation and forest management. Drones equipped with IoT sensors assess forest conditions and manage resources more effectively, while remote sensing technologies enable innovative approaches to manage forest resources and assess environmental impacts. They have also significantly transformed disaster management and search and rescue missions, offering enhanced situational awareness, reduced risks for first responders, and improved operational efficiency. Drones, in particular, have proven indispensable in providing real-time aerial views of disaster zones, enabling rapid assessment and response. For example, AI and big data analytics provide predictive insights, enabling authorities to anticipate disaster risks, optimize resource allocation, and improve decision-making during emergencies [159,166].

2.2.7 OTHER SECTORS

Similar to other sectors mentioned above, emerging technologies like advanced computing, cloud computing and HPC, AI, IoT, Big data analytics and robotics are also transforming the education sector[167–169]. For instance, advanced computational systems provide scalable and efficient infrastructure for educational applications while AI-powered adaptive learning systems are also being employed to personalize education, tailoring the learning experience to individual students' needs, abilities, and learning styles. Furthermore, AI-powered Chatbots and virtual assistants are being used to provide students with personalized support and guidance, helping to alleviate the workload of teachers and improve student outcomes. Similarly, IoT facilitates smart classrooms through real-time monitoring and interactive learning environments, such as tracking attendance, monitoring classroom conditions, and providing insights into student behavior and engagement. Nanotechnology also enhances mineral detection and extraction through ultra-sensitive sensors and cutting-edge filtration systems, ensuring precision and resource maximization.

In similar fashion, emerging technologies are transforming the mining sector by driving efficiency, safety and sustainability of mining to unprecedented levels. Advanced computational and intelligent systems power real-time data analysis and predictive maintenance, enabling optimized operations and minimizing downtime. Emerging technologies are also applied in different sectors such as transport and logistics, the legal and law enforcement systems, as well as hotels and tourism.

NATIONAL SITUATION ANALYSIS

In this chapter, a national situation analysis is presented. It begins with a comprehensive PESTEL and SWOT analysis to assess the current technological landscape in Ethiopia. This is followed by an evaluation of the country's level of technology readiness. Finally, a gap analysis is conducted to identify the key barriers hindering the adoption, as well as the research and development of emerging technologies, with particular emphasis on challenges related to infrastructure, human resources, and policy and regulatory frameworks.

3.1 PESTEL ANALYSIS

A PESTEL analysis explores the Political, Economic, Social, Technological, Environmental, and Legal factors influencing the adoption and growth of emerging technologies in Ethiopia. In June 2024, Ethiopia's Council of Ministers approved the nation's first strategy for implementing Artificial Intelligence (AI) across diverse sectors. This milestone signals growing governmental commitment to leveraging emerging technologies such as advanced materials, AI, nanotechnology, synthetic and systems biology, and advanced manufacturing technology to accelerate national development. The AI strategy emphasizes transformative applications in healthcare, including telemedicine to improve access for underserved rural populations, and in education through digital learning platforms aimed at expanding quality instruction.

Beyond AI, Ethiopia has begun exploring the potential of nanotechnology in agriculture and medicine, advanced materials for infrastructure development, and synthetic biology in bio-based industries. Advanced manufacturing technologies, including 3D printing and automation, also present opportunities to enhance local production and reduce import dependency. However, despite these forward-looking efforts, the regulatory landscape remains underdeveloped. While policies exist to support innovation, comprehensive frameworks to govern the ethical, environmental, safety and legal implications of these technologies are still lacking. This regulatory gap can generate uncertainty for investors and slow the pace of technological adoption, underscoring the urgent need for integrated and adaptive governance mechanisms to keep pace with innovation.

Ethiopia has a growing institutional framework to support emerging technologies, with several universities and research institutes dedicated to innovation. Key institutes include Agricultural Transformation Institute, Manufacturing Industries Development Institute, AI, BETin, and newly established AI University which coordinate R&D efforts across various sectors. The establishment of the emerging technology center under the Ethiopian BETin provides a platform to advance fields like nanotechnology, materials science and engineering, computational science and intelligent systems.

The government has also launched research centers in different universities and research institutes to promote initiatives in emerging technologies. In addition, Ethiopia is actively developing its capabilities in advanced materials and nanotechnology research and development. Key 'centers of excellence' or leading institutions in this field include Adama Science and Technology University, particularly its Center of Excellence for Materials Science and Engineering, which focus on energy, electronic, nano, bio, polymer, metal and ceramic materials. Additionally, Jimma University's Faculty of Material Science and Engineering and Addis Ababa Science and Technology University, with its Biotechnology and Bioprocess Center of Excellence, are significant contributors. These institutions emphasize materials for industrialization, energy, biomedical applications and infrastructure development. Other universities, such as Bahir Dar and Mekelle, also offer strong programs in Materials Science and Engineering, contributing to the nation's growing expertise in the field.

As highlighted in Figure 3.1, Centers of Excellence such as Addis Ababa University, Bahir Dar University, and the University of Gondar enhance research capabilities and the ecosystem, driving innovation particularly in AI and Robotics. Private institutions also have robotics centers of excellence and are working toward training, researching and developing emerging technologies. Under the United Nations Development Programme, the Timbuktoo Africa Innovation Foundation has launched a manufacturing technologies hub in Addis Ababa, which supports startups in areas such as IoT, robotics and automation.

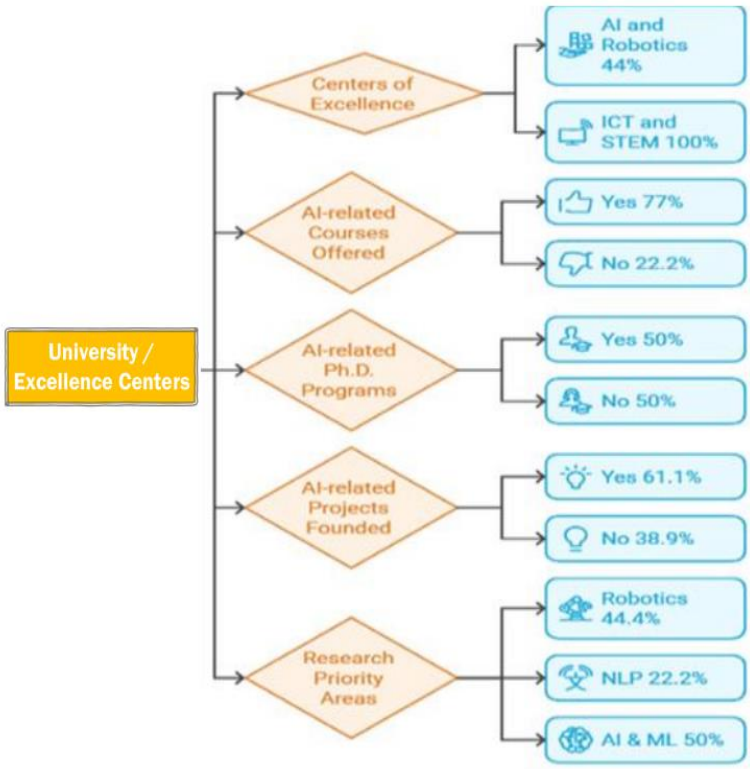


Figure 3-1 ACIS focused Universities/Center of Excellences in Ethiopia[170].

Politically, Ethiopia demonstrates a strong commitment to technological advancement through initiatives like the Digital Ethiopia 2025/30 Strategy and the establishment of specialized institutions including AI institute, BETin, newly established AI university as well as excellence centers across universities. These efforts indicate government support for R&D in areas such as nanotechnology, AI and advanced materials. However, regulatory frameworks remain underdeveloped and regional conflicts, bureaucratic inefficiencies and geopolitical instability pose risks to progress. Strengthening governance and policy reforms are essential to fully leverage these emerging technologies for national development. At continent level, Ethiopia, as a one of the AU member state countries, is also committed to implement the STISA 2034.

Investment in emerging technologies like nanotechnology, advanced materials and intelligent systems could diversify Ethiopia's economy beyond agriculture, creating jobs in R&D and high-tech manufacturing. While limited local funding and high implementation costs pose challenges, partnerships with global tech firms e.g., in semiconductor or biomanufacturing offer avenues for growth. Prioritizing sectors like precision agriculture (e.g. using AI and nanosensors), healthcare

(e.g. synthetic biology) and in the mining sector could position Ethiopia as a regional leader in emerging tech-driven industries.

The successful adoption of emerging technologies in Ethiopia hinges on enhancing public awareness and understanding across various sectors. Low digital literacy and cultural skepticism toward automation may hinder adoption, but integrating emerging tech into education e.g., nanoscience curricula can bridge skill gaps. Public awareness campaigns are needed to address ethical concerns around AI and nanomaterial safety. Urban innovation hubs may accelerate acceptance, but equitable access must be ensured to prevent rural-urban disparities in tech benefits, particularly for applications like AI-driven diagnostics and biodegradable nanomaterials.

Ethiopia's R&D infrastructure requires upgrades such as nanofabrication labs and high-performance computing facilities to support breakthroughs in advanced materials and synthetic biology. Collaborations with global institutions e.g., Korea's KIMS or Japan's NIMS could accelerate knowledge transfer in nano-manufacturing. Local startups focusing on AI-driven logistics or bioengineered materials need scalable platforms to commercialize research, leveraging Ethiopia's nascent but growing tech ecosystem. Advanced materials can revolutionize sustainability enabling smart water purification, carbon-capture and biodegradable packaging. AI and IoT systems should be deployed to monitor pollution and optimize energy use in industries like textiles (e.g., smart manufacturing). Ethiopia would also balance innovation with environmental regulations to ensure green tech adoption.

Although there are legal frameworks in place, Ethiopia faces challenges due to weak implementation of intellectual property protections and the absence of specific laws governing nanomaterials and safety standards for emerging technologies. Developing frameworks similar to the EU's REACH regulation and aligning AI governance with international standards e.g., OECD AI Principles, UNESCO's Ethical AI recommendations are vital. Clear patent laws for advanced manufacturing and synthetic biology will incentivize R&D investment. Additionally, policies like tax incentives for clean-tech startups can foster innovation and position Ethiopia prominently within Africa's emerging technology landscape. Table 3-1 highlights PESTEL analysis of emerging technologies in Ethiopia.

Table 3-1 PESTEL analysis of emerging technologies in Ethiopia.

Factor	Description	Future Prospect
Political	Government support and existence of policy for AI, lack of clear policies, regulatory and liability frameworks for robotics and intelligent systems, nanotechnology, lack of specific policies and strategies for synthetic and system biology, government support for research and development is growing but requires structured policies, political instability and regional conflicts can disrupt raw material supply chains and deter investments in advanced materials technologies	National emerging technologies regulatory authority for unified governance and regulation of emerging technologies
Economic	Market opportunities for advanced manufacturing technology, resource availability and growing market demand in advanced materials, limited financial resource and low investment in R&D restricts the exploration and application of advanced materials in industries, global partnerships for AI and robotics development, high R&D costs for nanotechnology, limited funding for synthetic and system biology, synthetic and system biology has the potential to contribute to Ethiopia's economic growth particularly in agriculture, healthcare and bio-manufacturing	Increased government funding, public-private partnerships for emerging technologies
Social	Job creation, improved productivity, potential job displacement by automation, ethical and safety concerns related to AI, robotics, nano/biotech, low awareness and limited expertise in advanced materials, improved healthcare solutions, enhanced food security and environmental sustainability (synthetic and system biology)	Public awareness programs and targeted workforce retraining for emerging technologies; ethical concerns regarding gene editing and artificial biological systems need to be addressed through education and policy frameworks
Technological	Improved efficiency, high R&D and infra development costs, technical challenges, growing interest in artificial intelligence and computational biology could support synthetic and system biology advancements, lack of R&D infrastructure and technology transfer in advanced materials and emerging opportunities	Improved computational infrastructure as well as local R&D support for emerging technologies

Environmental	Sustainable development through nanotech, biotech, advanced manufacturing technology, advanced materials, IoT and AI, potential environmental and health risks from nanotech and biotech, energy consumption by HPC/data centers, synthetic biology can offer solutions for climate change mitigation including bio-remediation, carbon sequestration, and biodegradable plastics, risk of unintended environmental consequences, such as genetically modified organisms affecting ecosystems, opportunities for developing bio-based sustainable agricultural practices to enhance food security and reduce reliance on chemical inputs, resource extraction impact advanced materials and climate resilience in advanced materials	Impact assessment strategies, green technology adoption for emerging technologies
Legal	Policy for AI, intellectual property protection for emerging technologies, lack of framework for solving liability and accountability issues of emerging technologies, absence of clear regulatory frameworks for nanotechnology, synthetic and system biology and lack of regulatory framework and standardized protocols for advanced materials	Clear governance, accountability laws, regulatory reforms for emerging technologies, strengthening national institutions to oversee and regulate emerging technologies

3.2 SWOT Analysis

A SWOT analysis examines the strengths, weaknesses, opportunities and threats related to global innovation, particularly in emerging economies in adoption and innovation of emerging technologies in Ethiopia.

Strengths: Ethiopia's emerging technology sector is supported by various strengths. The country is rich in minerals such as tantalum, gold and rare earth elements, which is crucial for the selected emerging technologies. Government initiatives, including Digital Ethiopia 2025/2030 and the establishment of AI Institute, newly established AI University as well as BETin, offer a supportive ground for R&D in this domain. The country's strategic location also grants it access to African and Middle East markets, making it an attractive location for tech exports. Local startups, particularly in Addis Ababa's tech hubs, are demonstrating growing entrepreneurial agility, with a

focus on applications of AMs, AMT, AI and robotics in various fields. Ethiopia is rich in biodiversity and is one of the eight centers of origin and diversity of several important species. For proper use and conservation of its biodiversity, Ethiopia has developed national bioeconomy and biotechnology road maps that provide strategic direction for sustainable development. The country has also approved guidelines on gene editing and biosafety, demonstrating its commitment to responsible innovation and regulatory preparedness. These frameworks create a conducive environment for research, development and application of synthetic biology technologies.

Weaknesses: Despite aforementioned strengths, Ethiopia's R&D in emerging technology is hindered by various weaknesses. Limited infrastructure such as electricity, disrupts the operation of high-tech R&D labs and hinder R&D progress. The low level of public/workforce tech literacy, combined with cultural resistance to automation and emerging tech solutions, slows down the adoption of new technologies. This situation is further complicated by the country's reliance on imported equipment for material/nanofabrication, AMT, AMs, robotics and AI model training. This dependency not only increases costs but also highlights the sector's vulnerability to external geopolitical factors. Moreover, lengthy purchasing process, lack of advanced laboratories and equipment, lack of consumables as well as local providers, affect the advancement of synthetic and system biology in Ethiopia. Collectively, these weaknesses hinder the growth and competitiveness of Ethiopia's emerging technology sector, underscoring the need for targeted interventions to address these challenges and unlock the sector's full potential.

Opportunities: Ethiopia's emerging technology sector, particularly in advanced computing, nanotechnology, AMs, and AMT, is well positioned to seize several opportunities amid current challenges. The global push for climate-tech solutions aligns with Ethiopia's natural resources, offering a unique chance to innovate in areas such as biodegradable packaging using nanocellulose derived from agricultural wastes. This not only appeals to environmentally conscious environmental, social and governance investors but also supports the country’s sustainable development goals. Collaborations with the Ethiopian diaspora, especially tech professionals in the U.S. biotech and AI sectors, could facilitate knowledge transfer, mentorship and funding, which foster the growth of local startups and innovation ecosystems.

Niche manufacturing opportunities that leverage Ethiopia's cost advantages for African markets could also drive industrial growth while addressing regional demands. The COP28 climate fund, with its allocation of over $100 billion, provides a significant opportunity to scale emerging technologies. For instance, Ethiopia could secure grants to develop AI-driven carbon-capture materials, renewable energy grids, or other green technologies. Additionally, Ethiopia has been selected to host the upcoming COP32. By capitalizing on these opportunities, Ethiopia can overcome existing weaknesses, attract investments, and position itself as a leader in sustainable and innovative technologies within Africa.

Threats: Despite several opportunities, several threats could undermine the growth of Ethiopia's emerging technology sector, including geopolitical instability, which risks disrupting supply chains, R&D materials and technology transfer. The absence of material/nano/bio-tech standards and safety regulations are also a concern, as it mirrors the country's past mismanagement of agrochemicals, raising ethical concerns and potential risks to the environment and public health. Furthermore, the threat of tech colonialism looms, where foreign AI solutions could dominate the market, stifling local innovation and intellectual property (IP) development. IP and patent issues related to gene editing tools and other advanced biotechnological tools will also hamper the use of these technologies for local uses. Climate shocks, such as droughts and floods, may also divert R&D resources away from long-term innovation and towards crisis mitigation. These will further hinder the sector's growth and make it challenging for Ethiopia to realize the potential of its emerging technology sector, emphasizing the need to address these challenges proactively.

3.3 GAP ANALYSIS

To assess the gaps, questionnaires were prepared and distributed to individuals selected purposively, representing different institutes and educational backgrounds. A total of 228 respondents submitted their responses: 145 from Advanced Computing and Intelligent Systems, 26 from Advanced Materials, 24 from Nanotechnology, 17 from Synthetic and Systems Biology, and 16 from Advanced Manufacturing Technology. The situational assessment involved interviewing key stakeholders from emerging technology sectors such as universities, research institutions and industrial organizations. Pre-testing and expert review were used to validate the questionnaires, ensuring their clarity, relevance and reliability. The assessment results showed that, despite efforts,

Ethiopia has several gaps that significantly challenge the advancement of emerging technologies. Key challenges include regulatory frameworks, insufficient infrastructure, human capacity, funding and weak collaboration among stakeholders. The assessment results are summarized as follows.

3.3.1 Human resource

Nanotechnology: The data indicates that a significant portion of staff involved in nanotechnology research possess advanced qualifications, predominantly PhDs, with approximately 75% of respondents holding doctoral degrees, and the remaining around 25% holding master's degrees. A notable challenge faced by institutions is limited awareness about nanotechnology, affecting recruitment and skill development, cited by approximately 60% of respondents. Budget constraints are another major obstacle, impacting hiring and training efforts, acknowledged by about 50% of institutions. According to the respondent, despite the high qualification levels, some institutions report a lack of specialized nanotechnology departments, which hampers research initiatives.

ACIS: The survey result shows that the respondents were experts and researchers of AI/big data analytics/IOT and robotics, representing 23.1%, 15.4% and 22.1% respectively. Out of it 53.8% were Bachelor's Degree holders following 30.8% master’s degree holders and a promising 15.4% PhDs holders. According to the survey participant, one of the most challenges in recruiting qualified personnel in the area were limited talent pool accounts 69.2%, budget constraints 30.8% with expertise demanding high salary and resulting high employee turnover. Incompetency with an ever-changing technological landscape is also another challenge. Accordingly, 11.1% of respondents argue that for the past 2 to 3 years they didn’t take any training related to AI/big data analytics/IOT and robotics, 55.6% were taken various capacity building training annually and 22.2% were taken training quarterly.

More recently, the Ethiopian government, through the Ministry of Innovation and Technology, launched the 5 million coders initiative in collaboration with the UAE, as depicted in Figure 3.2. The initiative aims to train five million Ethiopian youth in essential digital skills, including programming, artificial intelligence (AI) and data science, significantly enhancing the workforce's capacity to participate in the digital economy and advance the country's technological development. The government has also established research centers across 11 universities, focusing on research

and development in emerging technologies. However, a significant skills gap persists as many professionals lack the advanced training necessary for these technologies.

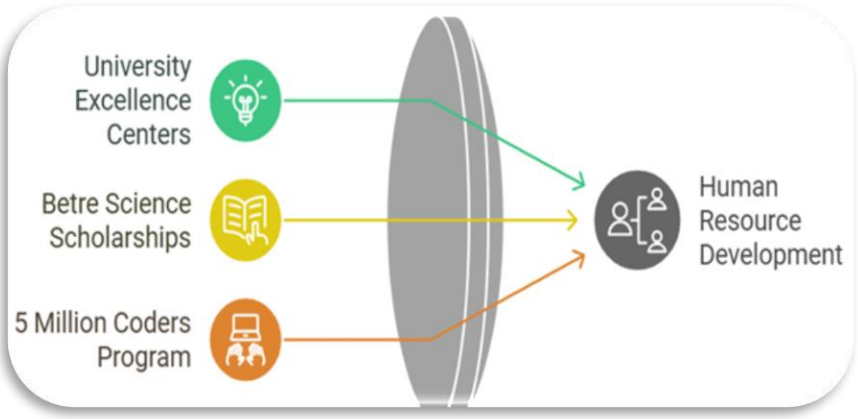


Figure 3-2 Ethiopia's human resources development in ACIS and other emerging technologies.

SSB: All respondents were from fields related to biotechnology, microbiology and molecular biology. The majority (47%) had expertise in the field of plant biotechnology followed by bioinformatics, health biotechnology, genomics and animal biotechnology. There were also experts in the field of synthetic biology, system biology, molecular biology as well as microbiology. The respondents' educational backgrounds include postdoc (17%), PhD (76%) and MSc/MA (7%). According to the respondent, there are few synthetic and system biology professionals in Ethiopia. 76% of the respondents mentioned that the availability of professionals in their respective institute is less than five. Even for those with more than 5 professionals, they are not actually the graduates of synthetic and system biology. Almost all the respondents indicated that there are no educational and training programs related to synthetic and system biology in Ethiopia. They mentioned several factors for lack of these programs including lack of trained manpower, lack of national roadmap related to synthetic biology, lack of understanding of its contribution to the economic growth of the country.

AMs: The expertise of the participants is predominantly concentrated in the domain of materials science, representing 53.8% of the respondents. This is further complemented by specializations in advanced materials (11.5%) and materials science and engineering (15.4%). Additionally, many participants extend their expertise into interdisciplinary fields, including chemical engineering. A substantial majority hold advanced degrees: 53.8% possess PhDs, while 38.5% hold MSc degrees.

Collectively, over 90% of the participants have postgraduate qualifications. Despite the high level of individual qualifications, the availability of skilled professionals in the field of advanced materials remains limited. Notably, 38.5% of the 26 surveyed institutions reported having fewer than five experts in this domain. This shortage is closely linked to inadequate training opportunities, cited by 61.5% of respondents, and is largely attributed to resource constraints. Furthermore, knowledge exchange appears infrequent, with 53.8% of respondents indicating that workshops and similar activities occur only annually or less frequently.

The surveyed experts exhibit considerable proficiency in specific core areas, notably in quality assurance (73.1%) and the synthesis/processing of materials (53.8%). However, they display significant deficiencies in other essential domains, with only 46.2% indicating competence in computational modeling and a mere 3.8% possessing expertise in materials characterization. These findings underscore several systemic challenges, including the limited number of national programs dedicated to advanced materials, insufficient collaboration between academia and industry, and outdated research infrastructure.

AMT: Most universities and research institutes acknowledge a significant gap in skilled manpower, particularly in the area of smart manufacturing technologies and systems. From the response gathered from different institutions using purposive data collecting sampling method, in terms of human power, including PhD, MSc and BSc holders, the current situation appears relatively strong, with 50% of experts rating availability as very high and 35% as moderate. However, 15% still perceive a low availability, pointing to uneven distribution of skilled individuals. Most of the respondents agreed that because of lack of university-industry collaboration as the primary challenge. Meanwhile, 20% indicated that the lack of training programs is the second major obstacle to human resource development in AMTs and the remaining 30% of respondents highlighted multiple key challenges, including limited government support, lack of university-industry linkages and the absence of training programs. The data also showed that in Ethiopia, while universities have integrated CAD/SMT into engineering curricula and trained many technicians across various disciplines, practical exposure to digital manufacturing tools, CNC programming and hands-on experience with modern equipment is minimal. Students graduate with limited proficiency in essential tools like CSMT, CIM and CNC technologies.

3.3.2 Research infrastructure

Nanotechnology: The research infrastructure for nanotechnology varies significantly across the surveyed institutions. Approximately 40% of respondents report having no specialized facilities dedicated specifically to nanotechnology research, relying instead on general laboratories or limited equipment such as spectrometers and characterization labs. A smaller proportion, roughly 15%, have access to key instruments including electron microscopes, spectrometers, and other characterization tools. Accessibility of resources is generally limited, with about 35% indicating resources are only somewhat accessible, and 20% stating they are not accessible. Support services such as administrative, technical and financial assistance are available in some institutions, particularly those with better-equipped facilities, but in many cases, support is minimal or nonexistent. While some institutions have established infrastructure and support for nanotechnology research, many still lack dedicated facilities and sufficient funding, which constrains the development and progress of nanotech research initiatives.

ACIS: The Ethiopian government is also making significant progress in expanding its data center infrastructure to support its economic growth and digital transformation. Figure 3.3 highlights the advanced computing ecosystem a) in Ethiopia[170] b) African. The Ethiopian government has launched the construction of a data center in the country, which provides hosting services to government agencies and private companies uptime tier III standard data center currently located in Artificial Intelligence Institute (AII), the Minister of Innovation and Technology (MINT) and Minister of Education (MOE) started providing service for the customers in need. The data center located in the Ministry of Education provides cloud service and high-performance computing (HPC) service to universities, TVET and other accountable institutions to MOE. Similarly, the data center is located in AII and MINT mainly provides data center service for government institutions and cloud service for limited private organizations. One of the challenges for data center service in Ethiopia is limited skilled human resource gaps, especially in governmental-based organizations and the availability of reliable and affordable energy. Another challenge for data center infrastructure in Ethiopia is connectivity. Despite ongoing efforts, Ethiopia's R&D infrastructure remains inadequate, lacking high-performance computing facilities and other essential resources needed to drive innovation in emerging technologies.

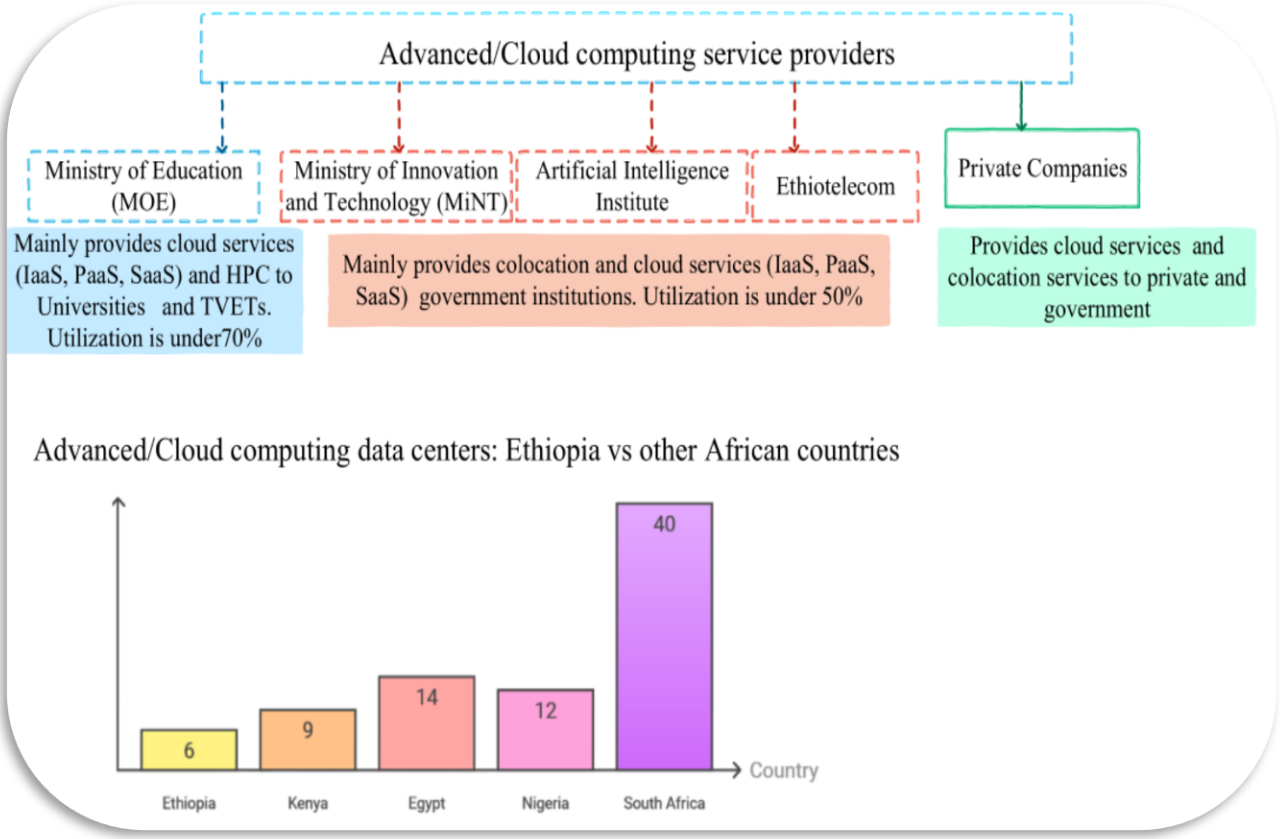


Figure 3-3 Ethiopia's advanced computing a) ecosystem b) Comparison with African countries[170].

SSB: It requires advanced laboratories equipped with the latest equipment, technologies, and funding. However, the current state of infrastructure for synthetic and systems biology in Ethiopia is considered to be poor (65% of the respondents) to fair (29%). There is basic laboratory equipment that supports synthetic and systems biology research, including incubators (15), PCR machines (17), HPCs (4), DNA sequencers (7), flow cytometers (4), bioreactors (3), mass spectrometers (3), confocal microscopes (3) and more. These instruments are distributed across different institutes and primarily provide services for internal purposes.

AMs: A substantial proportion of respondents conveyed a positive evaluation of the existing infrastructure supporting advanced materials research. Specifically, 46.2% rated the overall infrastructure as "Excellent," 34.6% as "Good," and 19.2% as "Fair." This suggests a generally favorable perception of the foundational facilities and resources available in the field.

Nevertheless, when it comes to access to sophisticated high-tech instrumentation, the situation is considerably more mixed and reveals notable disparities. Equipment that is frequently utilized in

day-to-day research such as Scanning Electron Microscopy with Energy Dispersive X-ray spectroscopy at 57.7%, Thermogravimetric Analysis at 76.9%, and X-ray Fluorescence at 76.9% is generally accessible across the surveyed institutions. These tools appear to be reasonably well-distributed and support routine materials characterization and analysis.

By contrast, highly specialized and advanced analytical tools are severely limited. Instruments such as transmission electron microscopes and zeta potential analyzers are entirely unavailable in any of the surveyed institutions. Nuclear magnetic resonance spectrometers are particularly rare, with access reported in only 3.8% of the participating institutions. This stark contrast highlights a significant gap between basic and cutting-edge research capabilities.

AMT: It heavily relies on the presence of sophisticated infrastructure, including state-of-the-art research centers, industry-ready laboratories and precision manufacturing facilities. In technologically advanced nations such as China and Germany, national smart manufacturing (SMT) hubs have been established, equipped with industrial-scale 3D printers, advanced metrology instruments and post-processing tools like CNC machines. These hubs form the backbone of innovation and production in the field of AMTs. In contrast, Ethiopia faces a significant infrastructural gap. The country currently lacks national SMT centers and research and development (R&D) facilities equipped to support metal-based smart manufacturing. The few available 3D printers are limited to producing small-scale plastic models, which do not meet the requirements for industrial applications. Existing efforts to establish manufacturing research and training facilities remain fragmented, poorly funded and lack centralized coordination.

The assessment data indicates the severe scarcity of infrastructure for smart manufacturing in Ethiopia. Specifically, regarding additive manufacturing and smart fabrication including laser welding, only 9.1% of experts reported the presence of relevant infrastructure, particularly plastic-based 3D printing. A striking 89.1% indicated that such facilities were completely absent, demonstrating the substantial limitations in infrastructure necessary for both research and industrial applications. Furthermore, in terms of essential smart manufacturing tools such as CNC machines, CAD systems and computer simulation-based manufacturing technologies (CSMT), 36.4% of respondents acknowledged some availability. However, a significant 73.6% reported limited access, suggesting that even where equipment exists, it is not widely accessible across institutions.

The quality of existing research infrastructure is also a concern. About 50% of respondents classified their laboratory facilities as poor, while 30% described them as average and only 20% considered them to be of good quality. The smart manufacturing infrastructure which includes CNC, CSMT and CAD systems 36.4% of experts acknowledged the availability of the infrastructure in the country, but 73.6% still reported limited access. This suggests that while some institutions are well-equipped and access remains fragmented. However, about 50% of the respondents confirmed that they have poor laboratory facilities for AMTs. Meanwhile, 30% of the respondents classified their lab facilities as average and the remaining 20% identified them as being in good condition.

3.3.3 Research and development

Nanotechnology: Approximately 70% of respondents reported no active government policies or initiatives specifically supporting nanotechnology research and development. Similarly, over 75% of institutions do not have access to targeted funding programs, such as outreach initiatives, venture capital or government incentives like tax credits and subsidies. Regarding ongoing research projects, more than 70% of institutions have more than 7 projects underway, with some reporting over 10 active projects. These highlight a considerable level of research activity despite limited institutional infrastructure. Some respondents indicated that they have no knowledge of such achievements. Even if research activity exists related to nanotechnology, the infrastructure comprising research centers, funding, regulatory frameworks and commercialization support is largely underdeveloped or absent across most surveyed institutions.

ACIS: As outlined in the Sustainable Development Goals (SDGs) Agenda 2030, leveraging STI advancements is crucial for building resilient infrastructure, promoting inclusive industrialization and fostering innovation. Europe and North America, and Eastern and South-Eastern Asia have made notable investments, allocating 2.62% and 2.31% of their GDP to R&D, respectively. In contrast, most developing regions fall short of the world average, with R&D expenditure below 1% of GDP. The regional breakdown reveals that Northern Africa and Western Asia allocate 0.90% of GDP to R&D, while sub-Saharan Africa invests a mere 0.32%. In East Africa, only Malawi has achieved the coveted '1% target', whereas Kenya, Tunisia and South Africa have reached levels above 0.7% of GDP. Ethiopia's investment in R&D which is under 0.6% of GDP, which not only

falls short of regional averages and heavily relies on international donors, which can be unpredictable and may not align with national priorities. To drive innovation and sustainable development, the country needs a more sustainable funding and resource allocation model to support R&D in emerging technologies. According to the survey result, R&D funding for AI/ big data analytics/IOT and robotics in Ethiopia vary from one to another. Based on our survey, dedicated annual budgets for AI/big data analytics/IOT and robotics R&D were significantly low. In terms of research outputs, approximately 30.8% of institutions have ongoing research/projects and 15.4% have not yet any ongoing or completed research/project.

SSB: It is inherently multidisciplinary and requires substantial funding. In Ethiopia, only a limited number of research activities are currently being implemented in this field. Majority of the institutes (71%) allocate a budget less than 100,000 ETB while 29% of the representative institutes allocate a budget between 100,000 to 500,000 ETB. Although the budget allocation is not enough, the R&D in synthetic and system biology strongly aligned to 38% of the institute's mandates while 25% mentioned that it does not align with their institute needs. This applies only to 67% of the respondents. However, synthetic and system biology research remain a priority to most of the institutes while 12% of the respondents mentioned that it is not a priority to them at all. The primary reasons for its prioritization include involvement in training and product development, its recognition as a global priority, and its alignment with institutional strategic goals, among others... 88% of the respondents anticipated steady progress and significant growth and innovation in the near future.

AMs: The survey provides essential insights into the state of advanced materials. It indicates that funding sources for advanced materials in R&D are limited. Although 75.9% of respondents anticipate significant growth in the field's role in advanced materials, current outputs are constrained, with 61.5% having published no research papers in the past three years and 65.4% having no ongoing projects. The alignment with industry needs is moderate, impeded by weak collaboration frameworks, low industry engagement, and infrastructure deficiencies.

AMT: According to the data, 63.6% of respondents identified lack of funding as the primary obstacle to conduct R&D within their institutions. Limited facilities were cited by 18.2% as the second major barrier, while 9.1% pointed to limited collaboration, and another 9.1% highlighted

the lack of awareness or understanding of AMTs within their organizations as a hindrance. Public investment in research and development (R&D) has grown notably, with spending increasing from 931.3 million ETB in 2010 to 5,242.6 million ETB in 2013, rising from 0.24% to 0.61% of GDP. However, this increase was largely due to a 41% rise in overall R&D personnel, while the number of qualified researchers grew by only 13%. Furthermore, the role of the private sector in R&D remains minimal, with business contributions dropping to just 1.2% of total R&D spending in 2013. At the firm level, innovation is still underdeveloped: only about one-third of firms reported introducing new products or improving existing processes.

3.3.4 Stakeholders' engagement

Nanotechnology: Approximately 30-40% of the institutions report active partnerships with industries, universities, or research centers. Notably, some institutions have more than seven collaborations, emphasizing a robust research network, while others have no formal partnerships at all. Regarding the industries utilizing nanotechnology in Ethiopia, healthcare, materials, electronics, and textiles are the primary sectors engaged, with healthcare and materials being the most common. A few institutions mention notable companies or startups focused on nanotechnology applications, although this is not widespread. Support mechanisms for commercialization, such as incubator programs, industry partnerships, and technology licensing, are employed by a subset of institutions, while others lack clear strategies or active engagement in commercialization efforts. Knowledge exchange platforms like conferences, online forums, collaborative projects, and thematic disciplinary projects are frequently used, facilitating collaboration and knowledge sharing.

ACIS: Collaborating and networking with key stakeholders offers numerous advantages, from the sharing of information, expertise, and perspectives for more informed and efficient outcomes. 41.7% of respondents have direct collaboration and networking with 1-3 stakeholders and identified that partnerships with other institutions or industries in artificial intelligence/big data analytics/IoT and robotics systems become significantly crucial as the technology landscape changes in advance. 25% of respondents identified that they have direct involvement with more than 6 national and international stakeholders, and the rest of 33.3% of respondents, still do not have any engagement and collaboration. The majority of them identified academic institutions to

be the most important stakeholders, followed by research institutes, government agencies, industry partners, and non-profit organizations.

One of the most identified types of collaborations experienced by respondents were joint research projects, which accounts for 4.2%, followed by consultation services (23.1%), technology transfer (30%), on-the-job training (15.4%), and graduate training (7.7%). The rate of commercialization of artificial intelligence/big data analytics/IoT and robotics system research findings was very low, ranging from 15.4% technology licensing and incubator programs, 7.7% startup and industry collaboration, and 53.8% industry partnerships.

SSB: Respondents identified several stakeholders who are involved in the implementation of synthetic and system R&D. Research institutes were identified as the most important stakeholders, followed by academic institutions, government agencies, industry partners, and non-profit organizations. Respondents use different channels and platforms for knowledge exchange and collaboration. The majority uses conferences (11%), online forums (11%), and collaborative projects (8%) as means of communication. Moreover, institutes support synthetic and system research output and technology dissemination and commercialization through trainings (40%), industry partnerships, incubation programs, technology demonstration and technology licensing

AMs: The involvement of key stakeholders in advanced materials research initiatives, as reported by respondents, reveals a strong emphasis on collaboration with academic institutions, which were selected by 96.2% of participants. Government agencies followed closely, with 80.8% engagement, underscoring their role in funding and policy support. Industry partners were also prominently involved at 73.1%, reflecting practical applications and partnerships aimed at innovation. Non-profit organizations, however, lagged significantly at 38.5%, suggesting limited integration with NGOs or foundations in these initiatives. This distribution highlights a research ecosystem where academia, government and industry form the core triad of collaboration, while non-profits remain peripheral. The survey also reveals that collaborative projects are the predominant platform for knowledge exchange and collaboration, utilized by 88.5% of respondents. Conferences (80.8%) and online forums (69.2%) also play significant roles, reflecting a reliance on structured partnerships and digital communication.

AMT: There have been initial efforts toward stakeholder engagement among research institutes, universities, industries and other organizations. However, 80% of respondents indicated that these engagements remain limited and fragmented, particularly between governmental, non-governmental and research institutions. Only 20% acknowledged some level of engagement, though even these are not systematic or solution-oriented. This lack of structured collaboration hinders the ability to address societal challenges and share resources for effective research and development. Stakeholder engagement thus remains a weak area, limiting opportunities for collaborative innovation and policy alignment. To address this, there is a need for organized, rule-based partnerships through stakeholder forums, industry-academia councils and government-supported innovation clusters. All of these focused on problem-solving and advancing AMTs in Ethiopia.

3.3.5 Emerging technology adoption and awareness

Nanotechnology: A significant portion of respondents (approximately 40-50%) identify government initiatives and funding availability as key prospects for advancing nanotechnology research, though some respondents (around 20-25%) perceive limited opportunities or are unsure. In terms of regulations, many participants (about 60-70%) report the absence of specific policies or regulatory frameworks related to nanotechnology, indicating a regulatory gap. Major challenges faced by the sector include funding limitations (noted by roughly 50-60%), technical challenges (around 40-50%) and a lack of advanced instruments, with some respondents highlighting ethical considerations and environmental impacts.

Based on the provided data, the institutional perceptions of nanotechnology vary significantly in terms of awareness, strategic vision and prioritization. Approximately 20% of respondents have no awareness about nanotechnology, indicating a substantial knowledge gap. Regarding the strategic vision, about 15% rate it as very strong, 25% as strong, 20% as moderate and the remaining 40% as weak or have no clear stance. These suggested a generally moderate to low emphasis on nanotechnology at many institutions. When asked about prioritization within their research agendas, around 25% consider nanotechnology a high priority, 35% as medium priority and approximately 40% as low priority or not prioritized.

In terms of potential focus areas for nanotechnology in Ethiopia, the most commonly selected areas include health care, agriculture, energy and manufacturing, with some respondents indicating all sectors as relevant. Specifically, health care and agriculture are identified as high-priority focus areas by over 20% each, while energy and manufacturing are also noted as significant. A smaller proportion expressed no awareness or low priority for nanotechnology across sectors, highlighting the need for increased awareness and strategic emphasis to harness nanotechnology's full potential in Ethiopia.

Public awareness of nanotechnology remains generally low, with approximately 70-80% of respondents indicating the public is not aware at all or only somewhat aware of nanotechnology and its applications. Common misconceptions among the public include fears related to health risks, environmental impacts and misinformation from media sources, with about 50-60% expressing concerns about the scale, function and ethical implications. The strategic vision of institutions varies with some rating it as very strong or strong (about 40-50%), while others see it as weak or moderate (around 30-40%), reflecting diverse levels of institutional commitment and preparedness towards nanotechnology development in Ethiopia.

ACIS: While adoption of AI is still in early stages, Ethiopia is laying the groundwork for digital transformation. Ethiopia’s potential to leverage ACIS for socioeconomic development is closely tied to strategic sectors, with high priority for healthcare following agriculture, manufacturing, energy and environment respectively based on the collected survey data. However, as the number of sectors increasing and benefiting from the fruit of AI, lack of governing policy, strategy and procedures continues to be challenging.

Accordingly, 61.5% of respondents argue that they have no policy, strategy, procedure or principle related to the use and access to technologies related to artificial intelligence/big data analytics/IOT and robotics. The rest of 38.5% respondents assure that they have guiding policy, strategy, procedure or principle related to the use and access to technologies related to artificial intelligence/big data analytics/IOT and robotics. About 84.6% witnessed that they have no national data-sharing agreement designed to facilitate the secure, ethical and efficient exchange of data across government institutions, private sector entities and research organizations. The rest of 15.4%

respondents witnessed that they have an initiative with various governmental and non-governmental institutions for open data and national data sharing.

SSB: Institutes in synthetic and system biology are engaged mostly on gene editing using CRISPR technology, drug discovery and vaccine development, computational biology, microbiome engineering as well as metabolic engineering. Based on their experience, respondents identified key focus areas for synthetic and system biology roadmap. They identified agriculture to be one of the focus areas followed by healthcare, environment, industry and energy in the order from high to low priority focus area. Likewise, they indicated the global trend they observed. The global research trend is around gene editing, drug and vaccine development, development of synthetic biology applications and increased focus on sustainability.

Respondents were also asked to identify main barriers to conduct cutting age research in their institute. 47% mentioned lack of funding was the major problem followed by insufficient infrastructures (35%) and regulatory challenges (12%). They also indicated other challenges such as lack of skilled manpower, little attention from government side, public perception, and lack of access to global platforms and others. Moreover, they also identified the current priorities to be considered at national and industrial level. These are gene editing, enzyme production, drug and vaccine development, agriculture and industrial biotechnology, biofuel production, chemical synthesis, carbon capture and more. In order to strengthen partnership among stakeholders, respondents suggested several important mechanisms including thematic and grand projects, co-development between public and private sectors, establishing strong collaboration, resource sharing, co-funding, establishing core laboratory and facilities, short- and long-term training as well as a well-coordinated national research system.

AMs: Ethiopia's potential to harness advanced materials for economic and scientific advancement is closely linked to several strategic sectors. Energy (92.3%) and industry (88.5%) are identified as the primary drivers of growth, followed by environment (80.8%), agriculture (73.1%) and healthcare (61.5%). Current research aligns with global trends, with a strong focus on nanomaterials (88.5%) and sustainable materials (88.5%), as well as biomaterials (61.5%) and smart materials (42.3%). However, energy storage materials, a main component for renewable energy systems remain significantly underexplored, with only 3.8% of research attention. Industry

trends reveal a growing emphasis on sustainability (80.8%) and nanotechnology applications (80.8%), alongside increasing integration of artificial intelligence (73.1%) in materials development.

Conducting pioneering research in advanced materials in Ethiopia faces formidable barriers, main among them are lack of funding (92.3%), insufficient infrastructure (88.5%), compounded by limited access to data/resources (57.7%) and regulatory hurdles (38.5%). Industry challenges show these issues, with heavy reliance on expensive imported raw materials, shortages of advanced laboratory instruments, and a skills gap that widens the divide between academic outputs and industrial standards. Despite these constraints, advanced materials important to national priorities such as metallic composites, Li-ion/Sodium-ion batteries, polymers, biomaterials and solar energy materials highlight opportunities in renewable energy, healthcare and climate resilience. Strengthening partnerships requires sustainable funding models, collaborative projects and MoUs between academia and industries to bridge infrastructure gaps.

AMT: According to the survey findings on the potential focus areas of AMT in their respective organizations, an overwhelming majority of respondents (81.8%) identified the manufacturing sector as the primary domain for AMT application, ranking it as the top priority. This strong consensus highlights the perceived significance of AMT in enhancing industrial productivity, automation and technological advancement within the country's manufacturing landscape. On the other hand, a smaller but notable proportion of respondents about 18.2% suggested that AMT holds broader potential beyond manufacturing, extending to key sectors such as agriculture, healthcare, environment, energy and other industries. These findings indicate that while manufacturing remains the dominant focus for AMT adoption in Ethiopia, there is also recognition of its cross-sectoral applicability which could drive innovation and efficiency across multiple areas of the economy.

4.1 KEY FOCUS AREAS

Ethiopia is poised to emerge as a pioneering regional technology hub, driving sustainable development, innovation and economic growth across the African continent. The government's digital transformation vision prioritizes emerging technologies to propel Ethiopia towards middle-income status through industrialization and technological advancement. By harnessing the potential of its youthful population and integrating these cutting-edge technologies, the vision aims to boost productivity, drive socio-economic transformation, and foster a culture of innovation through institutions like the BETin, Artificial Intelligence Institute of Ethiopia, Universities and Industries. The roadmap offers a comprehensive strategic framework to innovate and leverage emerging technologies such as nanotechnology, advanced computational and intelligent systems, advanced materials, synthetics and system biology, and advanced manufacturing technologies as outlined in Figure 4.1.

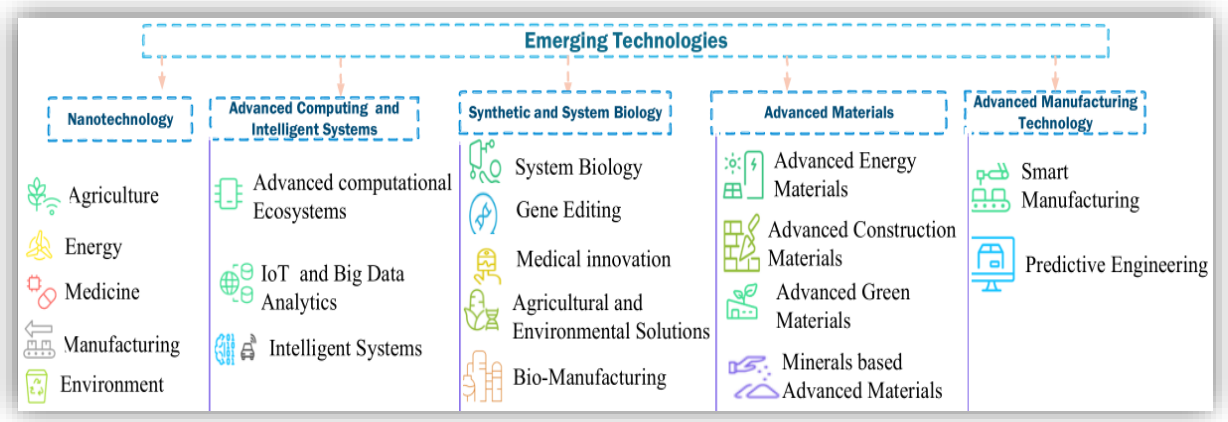


Figure 4-1 Key emerging technologies and associated R&D areas.

4.1.1 Nanotechnology

Nanotechnology is a manipulation of matter on a nanometer scale and creating materials/devices with unique properties. It can be used for targeted drug delivery and personalized medicine to improve the efficiency of solar cells and energy storage devices. Additionally, nanotechnology enables the creation of smaller, faster and more powerful electronic devices, leading to

advancements in fields like computing and telecommunications. Nanostructured filters remove microplastics and heavy metals, with safety testing for deployment. Applications include air purification and oil spill cleanup using hydrophobic nanosorbents. Furthermore, nano-sensors, catalysts, diagnostics, electronics, coatings and fibers are being applied in various fields such as healthcare and industry to improve productivity and efficiency, ultimately contributing to driving more sustainable growth. The use of nanofabrication techniques to create nanoscale materials and devices, the development of nanocoatings that enhance product durability, and the design of smart products embedded with nanosensors that offer improved functionality are also noteworthy examples of the transformative power of nanotechnology. Based on our situational assessments, e.g., alignment with government policies, socio-economic impact and success, the focus areas for nanotechnology R&D areas or products/services are presented in Figure 4.2.

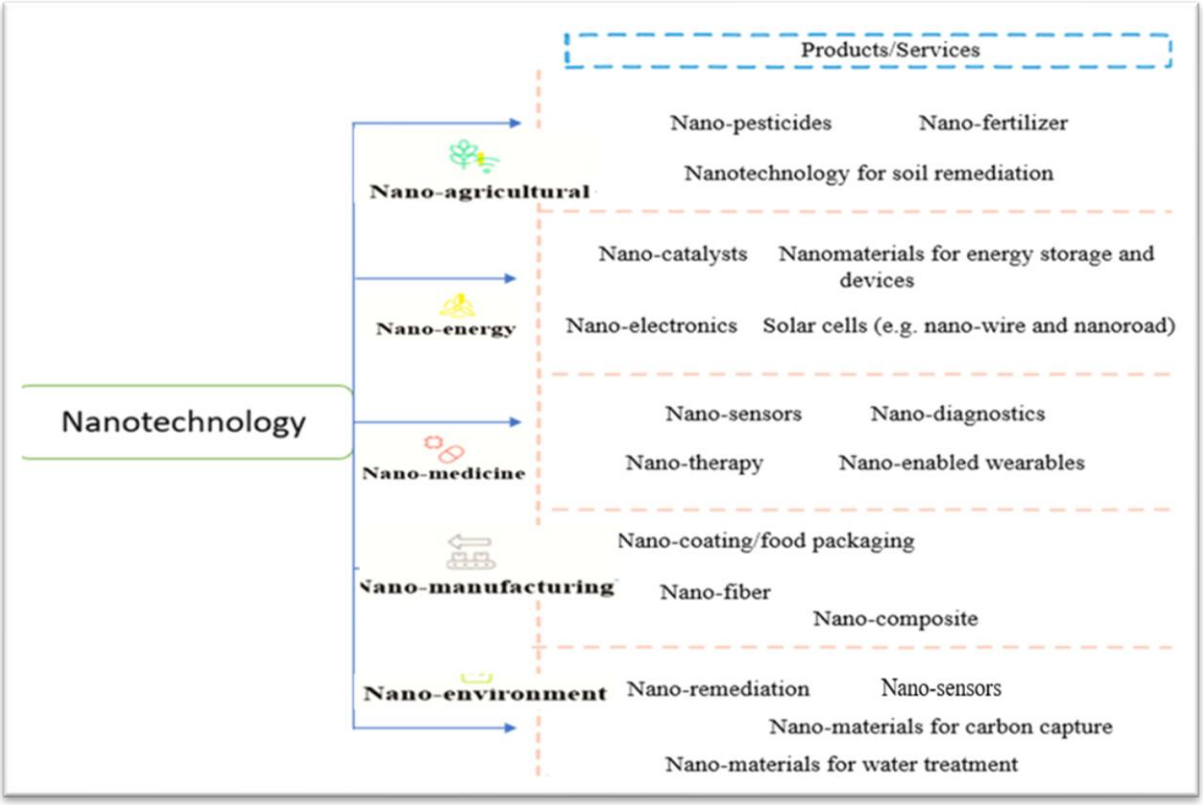


Figure 4-2 Mapping of nanotechnology products/services.

4.1.2 ACIS

ACIS is an integrated, multi-layer technology framework that follows a bottom-up dependency structure, where each layer cannot function without the layer beneath it. As shown in Figure 4.3, the hierarchical dependency chain of ACIS technologies (R&D areas) and products/services establishes that advanced computing serves as the foundational infrastructure layer, enabling all higher-level components to function.

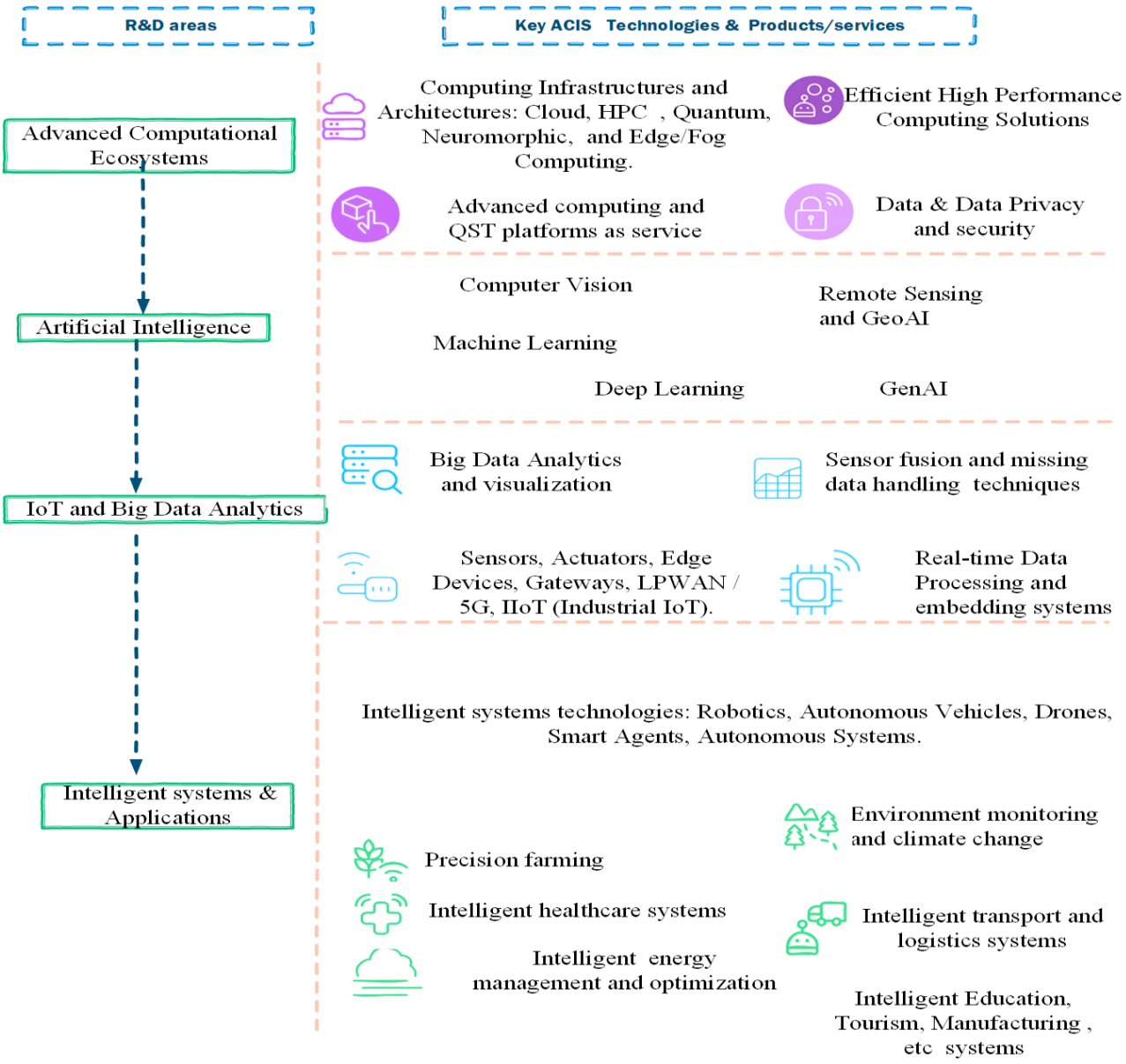


Figure 4-3 Hierarchical chain map of ACIS technologies (R&D areas) and products/services.

Advanced computing layer provides the essential processing power, storage capacity, and connectivity through HPC, cloud computing, edge/fog computing, quantum computing, neuromorphic computing, data centers, and enabling infrastructure (networks, power, storage facilities, etc.). Building on advanced computing, IoT and Big Data Analytics layer first enables collection of raw data from the physical world using IoT devices/ platforms (e.g., sensors, actuators, edge devices, and gateways, 5G and others) and then processes, mines, and visualizes this raw data and identify patterns, trends, and insights from the data using Big Data Analytics. Artificial Intelligence layer, which involves including machine learning, deep learning, computer vision, natural language processing, generative AI, and GeoAI consume the structured insights from Level 3 to make decisions, predictions, classifications, and inferences, serving as the cognitive engine for ACIS solutions. Finally, the intelligent systems and application layer, integrate AI, IoT, big data analytics and autonomous technologies including robotics, autonomous vehicles, drones, smart agents and closed-loop control systems for various applications e.g. in agriculture (precision farming, autonomous tractors), healthcare (AI diagnostics, robotic surgery), manufacturing (predictive maintenance, digital twins), transportation (traffic management, autonomous delivery), education (adaptive learning, intelligent tutoring) and energy (smart grids, consumption monitoring).

4.1.3 SSB

SSB is one of the emerging interdisciplinary technologies that integrates biology, engineering, computational modeling and data science to modify biological systems for practical applications. It offers enormous opportunities and solutions for countries like Ethiopia by utilizing advanced tools like gene editing, metabolic engineering and biological modeling. Ethiopia's healthcare system faces several challenges such as disease burden, food insecurity and environmental degradation. In order to combat these challenges, the country needs to exploit synthetic biology technologies in order to provide innovative solutions through precision healthcare therapies, climate-resilient crops and sustainable manufacturing processes. Synthetic biology also enables cost-effective medical innovations such as rapid diagnostics and locally produced vaccines, addressing gaps in accessibility and affordability of healthcare services. Additionally, it can improve agricultural productivity by developing drought-tolerant crops, improved animal breeds,

biopesticides and biofertilizers which contribute significantly to food and nutritional security of the population.

Moreover, it supports the transition to a bio-based economy through the production of biofuels, bioplastics and enzymes, reducing reliance on imports. Its broad application in the environment can help Ethiopia achieve its home-grown green economy goals while combating climate change. Figure 4.4 highlights deeply interconnected and inseparable synthetic and systems biology R&D areas including synthetic biology, computational biology, gene editing, drug discovery, etc. transforming various sectors manufacturing, healthcare, agriculture, environment, etc.

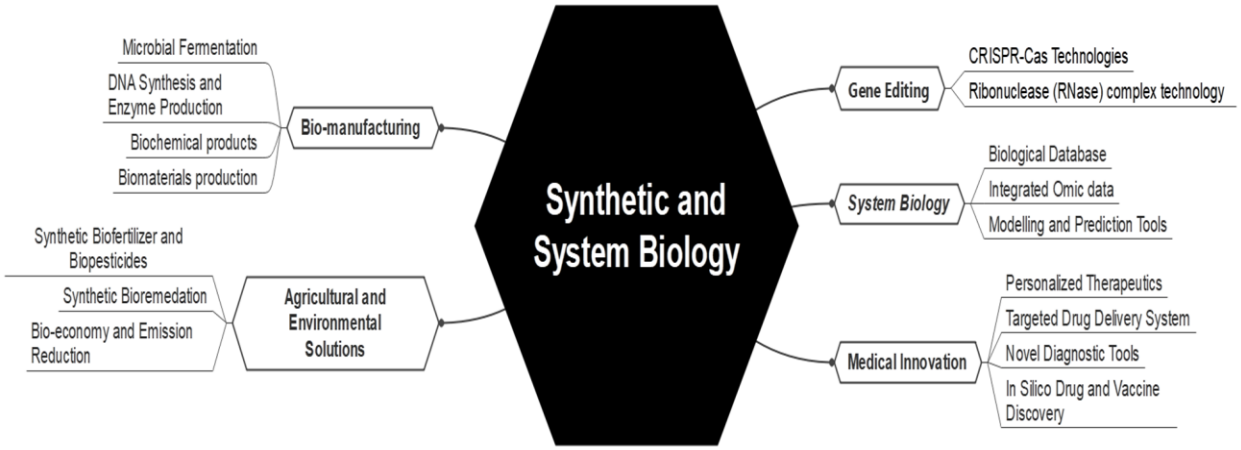


Figure 4-4 Highlights synthetic and systems biology R&D areas.

4.1.4 AMs

*AM*s are an essential field of study that promotes environmentally friendly practices and improving productivity across various sectors. As highlighted in figure 4.5, R&D AMs involve advanced polymers, advanced ceramics, bioengineered materials, advanced composites, smart materials and advanced alloys. They are pivotal for revolutionizing industries including energy, healthcare, environment and construction and creating new opportunities for growth and innovation. In the energy sector, AMs such as energy materials, advanced composites and nanomaterials are being used to improve energy conversion and storage. In healthcare, biomedical materials, biopolymers and advanced bioengineered materials are being used to develop new medical devices and implants, improving patient outcomes and enhancing the quality of life.

The construction sector is also benefiting from advanced materials, with the use of advanced organic/inorganic/construction materials enabling the creation of sustainable infrastructure and building materials. Additionally, advanced composites and alloys are being used in the aerospace and automotive industries to create lightweight and high-performance applications. Conducting polymers/biopolymers are being used in electronics to enhance device performance and efficiency.

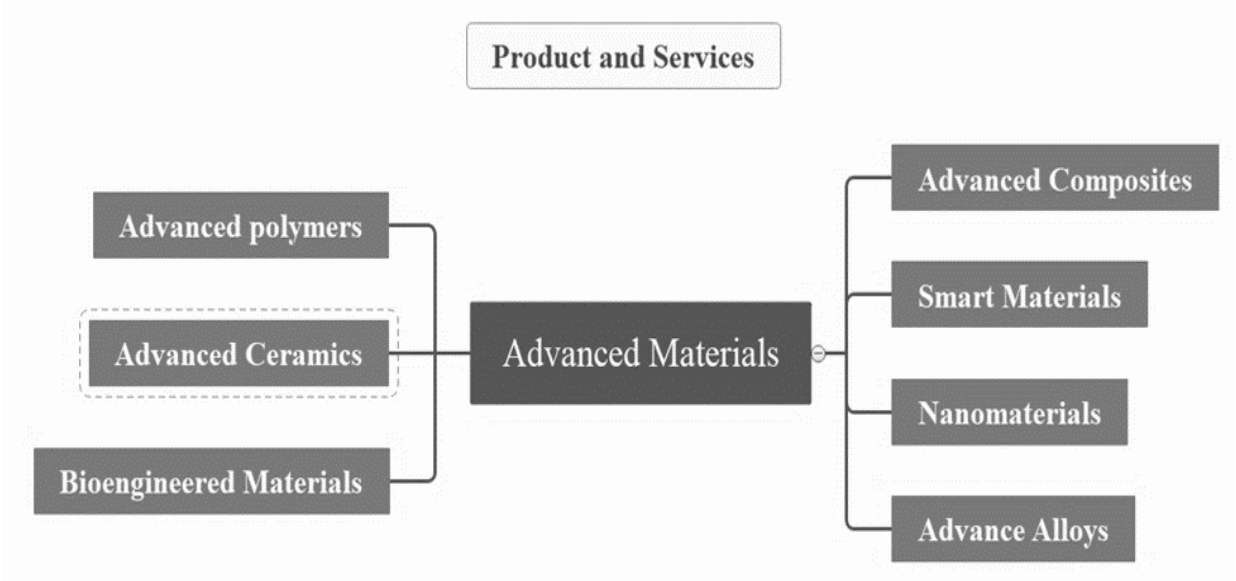


Figure 4-5 An overview of AMs and their associated sub-thematic areas/product and service.

4.1.5 AMT

AMT roadmap focuses on key technologies that can enhance researchers' capabilities and support the modernization of Ethiopia's conventional manufacturing sector. The roadmap prioritizes smart manufacturing technology and predictive engineering simulation as foundational pillars. As shown in Figure 4.6, smart manufacturing technology encompasses several advanced techniques each with unique characteristics and applications. For example, additive manufacturing contains Fused Deposition Modeling (FDM), which is one of the most commonly used methods, where metals and thermoplastic filaments are melted and extruded layer by layer to create three-dimensional objects. On the other hand, Direct Metal Laser Sintering (DMLS), utilizes a laser to fuse metal powder particles together, producing complex geometries that are essential in industries such as aerospace, industries and medical sectors. Similarly, Directed Energy Deposition (DED) combines the delivery of energy and material to create parts, allowing for repairs and modifications to existing components with high precision. Whereas, smart fabrication and robotics play a key role in

automated manufacturing. These technologies focus on streamlining production processes through the use of robots for tasks like welding and assembly. Their implementation is important in both industrial environments and research institutions. These help to improve productivity, consistency and operational efficiency.

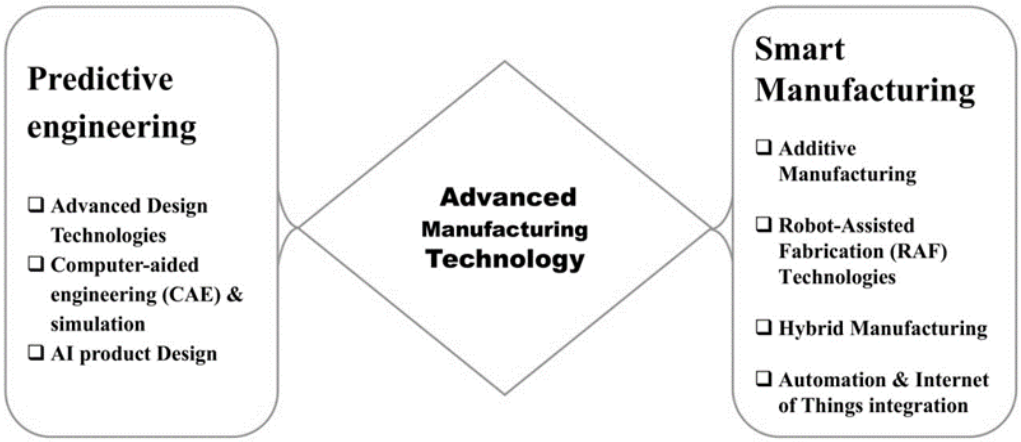


Figure 4-6 Mapping of AMT technologies.

Some of the products or technologies manufactured/delivered by applying advanced manufacturing technologies including smart manufacturing (e.g., additive production, robotic fabrication, hybrid processes, automation and IoT integration) combined with predictive engineering (e.g., CAD, CAE and AI-driven design) are transforming industries. In agricultural tools and equipment, these innovations enable durable, precision-engineered machinery with optimized performance. Medical equipment and tool parts benefit from high-precision, customized solutions that enhance safety and efficiency. For energy and power supply devices, advanced manufacturing ensures robust, high-efficiency components, while predictive engineering optimizes reliability. The automotive sector leverages these technologies for lightweight, aerodynamic and AI-enhanced vehicle designs. Industrial machinery achieves greater automation, durability and smart functionality through integrated IoT and AI-driven predictive maintenance. In relation with the above stated key focus areas, technologies associated with sustainable and green manufacturing such as renewable energy, waste reduction and recycling, lean manufacturing and green product design development are key technology areas which will be addressed within this roadmap.

4.2 Proposed Roadmap And Implementations Strategy

This section outlines the proposed roadmap and implementation plan for key research and development areas within each selected cutting-edge technology.

4.2.1 Nanotechnology

a) Nano-agriculture

Nanotechnology is poised to transform agriculture through innovative solutions such as in soil remediation, nano-fertilizers and targeted nano-pesticides (Figure 4.7).

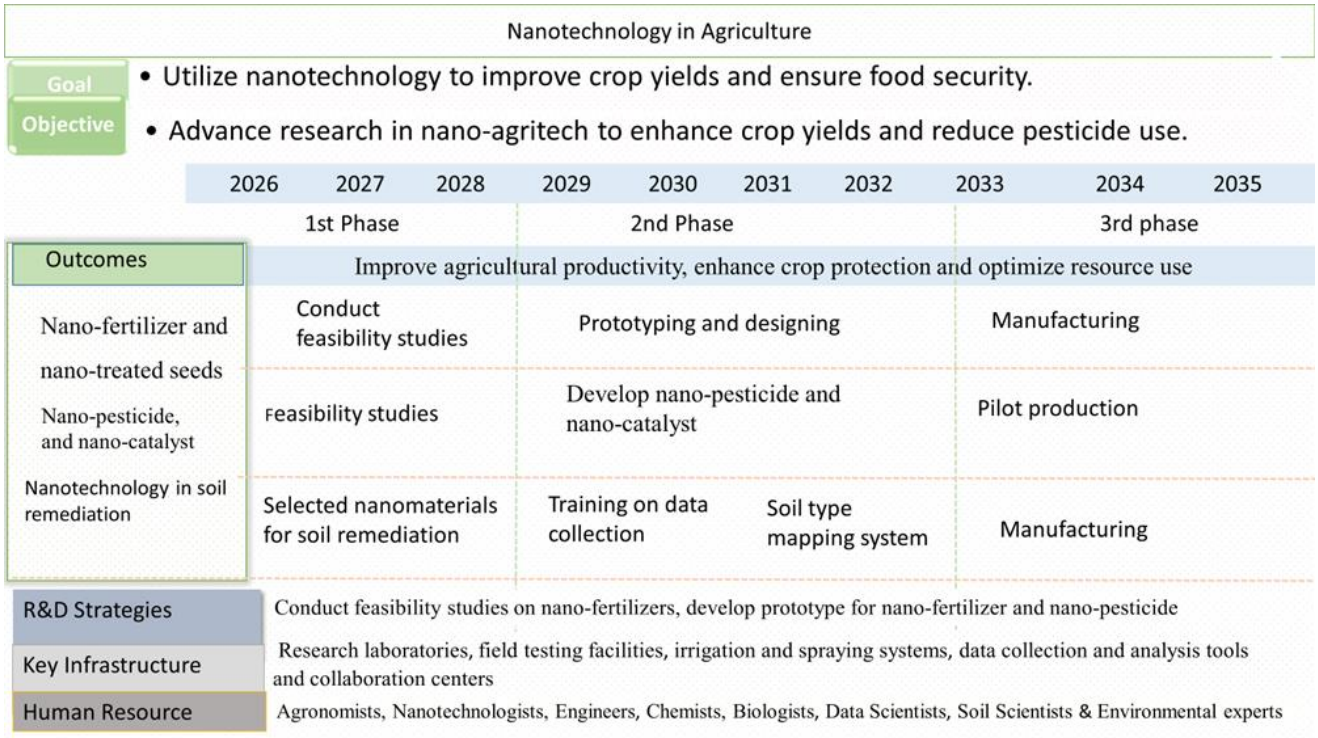


Figure 4-7 Strategic roadmap and implementation plan of nanotechnology for agriculture.

A decade-long vision aims to enhance agricultural productivity sustainably and ensure food security. The objective of this roadmap is to develop nanotechnology-based agricultural innovations, focusing on controlled nutrient release via nano-fertilizers, precise pest management with nano-pesticides, and real-time soil health monitoring through nano-sensors. Initial stages will prioritize research and feasibility studies, engaging agronomists, soil scientists, nanotechnologists and engineers. Subsequent phases will involve refining prototypes and developing data analytics applications for intelligent resource management and yield prediction. These efforts will ensure

that advancements in nanotechnology contribute effectively to sustainable practices and bolster food security.

b) Nano-environment

This initiative focuses on leveraging nanotechnology for environmental protection and sustainability. It emphasizes the development of innovative nanomaterials to address significant environmental challenges. Its primary goal is to utilize nanotechnology for effective resource management including water treatment, air purification, pollution control, soil remediation, bioremediation, environmental sensing and carbon capture. Figure 4.8 highlights the goals, objectives, outcomes, R&D strategies and human resources required for utilizing nanotechnology for environmental protection and resource management. This 10-year strategic plan aims to leverage nanotechnology to enhance environmental protection and resource management through the development of innovative nanomaterials. The initiative is segmented into three phases, each focusing on a specific objective that addresses environmental concerns. In the first two years, the focus will be on developing nanomaterials for effective water purification, resulting in improved water quality and accessibility through research on nanofiltration techniques. The subsequent phases aim to tackle pollution control and soil remediation. The objectives set for years three to six target the reduction of environmental pollutants and the enhancement of soil health using nano-adsorbents and field trials, respectively.

As the plan progresses into the latter half of the decade, attention will shift to biodegradable nanocomposites. The expected outcomes include reducing plastic waste, developing environmental sensors, and advancing carbon capture technologies to enhance monitoring and lower carbon footprints in the final years. It emphasizes eco-friendly alternatives and utilizes nano-enabled sensors for effective environmental monitoring. The strategic plan aligns with international sustainable development goals, aiming to achieve a sustainable environmental impact through targeted research and development strategies supported by a diverse range of human resources. These efforts will foster collaboration among environmental engineers, chemists, soil scientists and agronomists.

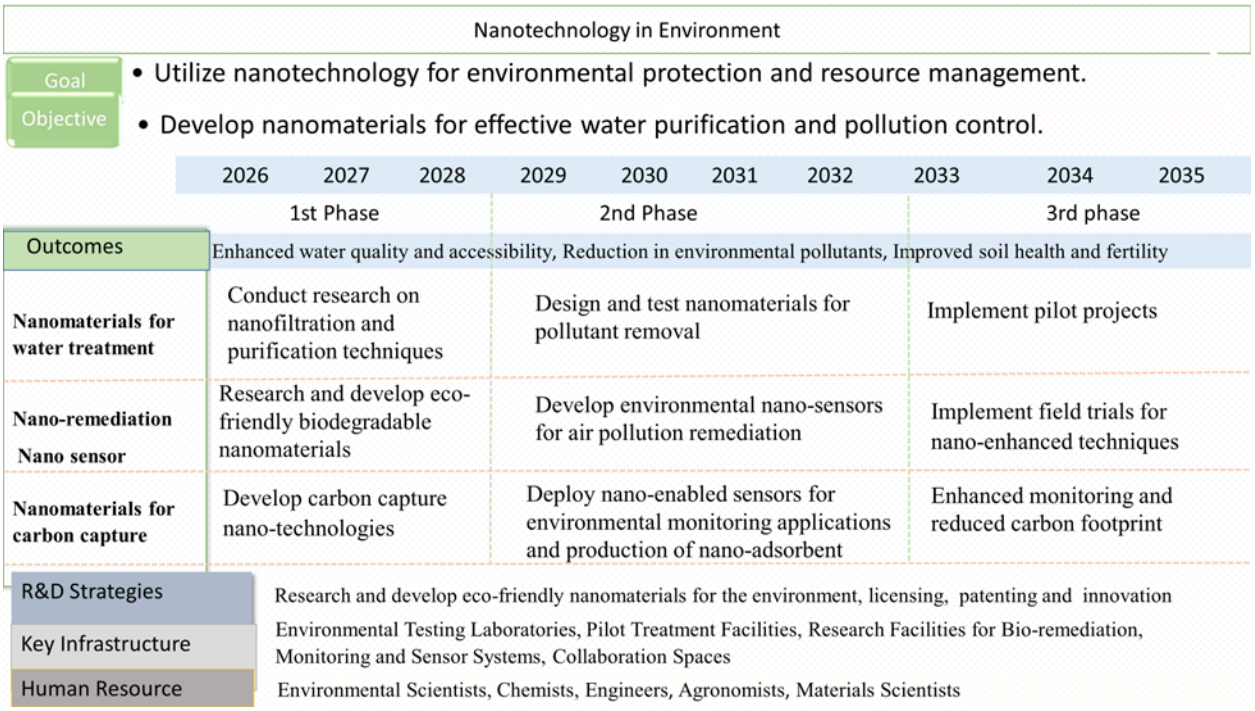


Figure 4-8 Nano-environment roadmap and implementation strategy.

c) Nanomedicine

It represents a groundbreaking approach to healthcare by integrating nanotechnology to enhance diagnostics, treatment and patient monitoring. Key advancements include the development of nanoscale biosensors for accurate biomarker detection, nano-diagnostics and tailored nanoscale drug formulations that increase treatment efficacy. Furthermore, nano-enabled wearables facilitate real-time health monitoring, promoting personalized healthcare strategies. Figure 4.9 illustrates the nanomedicine roadmap and implementation strategy. The main goal of the strategic roadmap for nanomedicine is to improve healthcare delivery through innovative nanotechnology solutions. This roadmap emphasizes research and development in nano-sensors, nano-diagnostics, nano-therapy and nano-enabled wearable technology to address prevalent diseases. For implementation, the roadmap outlines a 10-year plan consisting of foundational research on drug delivery systems in the initial years, followed by the development of nano-biosensors, targeted therapies through clinical trials and the design of wearable health devices. The later stages focus on commercialization through partnerships, aiming to enhance healthcare outcomes in Ethiopia by integrating advanced methodologies and fostering collaboration among diverse experts in the field.

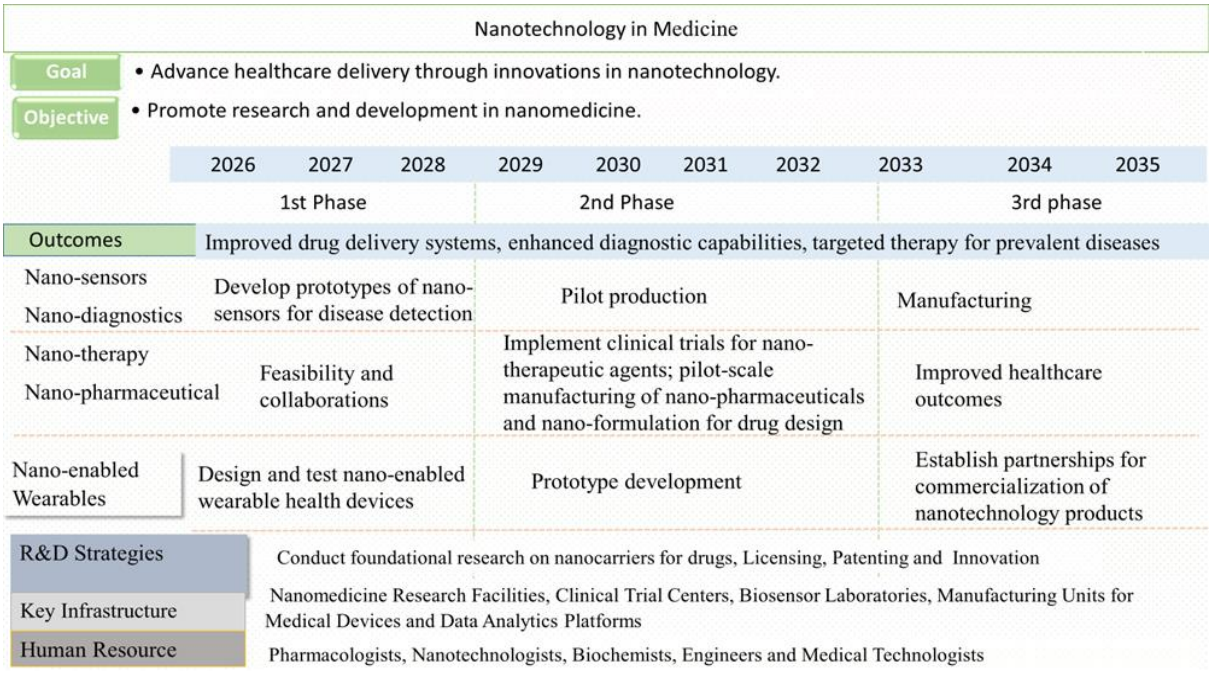


Figure 4-9 Strategic roadmap and implementation plan of nanomedicine.

d) Nano-energy

It is dedicated to advancing innovative energy solutions through the application of nanotechnology. This encompasses a range of initiatives, including the development of advanced nanomaterials for energy storage in devices such as batteries and supercapacitors. These leverage nanoscale properties to achieve higher capacity and faster charging capabilities. In the realm of solar energy, researchers are designing next-generation solar cells that utilize nanomaterials to improve light absorption and energy conversion efficiency. Nanoelectronics plays a crucial role in the evolution of electronic components at the nanoscale, enhancing energy efficiency and performance across various applications. The development of nano-catalysts at the nanoscale enhances the chemical reactions involved in energy production and conversion processes. The main goal of the roadmap is to propel innovative energy solutions utilizing nanotechnology, with a focus on enhancing efficiency and sustainability across various energy systems. Key objectives of the roadmap include the development of advanced nanomaterials for energy storage in batteries and supercapacitors, next-generation solar cells (e.g., nanowires, nanorods and nanoporous structures) for improved light absorption and energy conversion, and innovations in nanoelectronics. The program also explores energy harvesting devices, technologies and nano-catalysts to optimize chemical reactions

in energy production, thereby elevating overall efficiency. As shown in Figure 4.10, the strategic roadmap is divided into three phases spanning ten years.

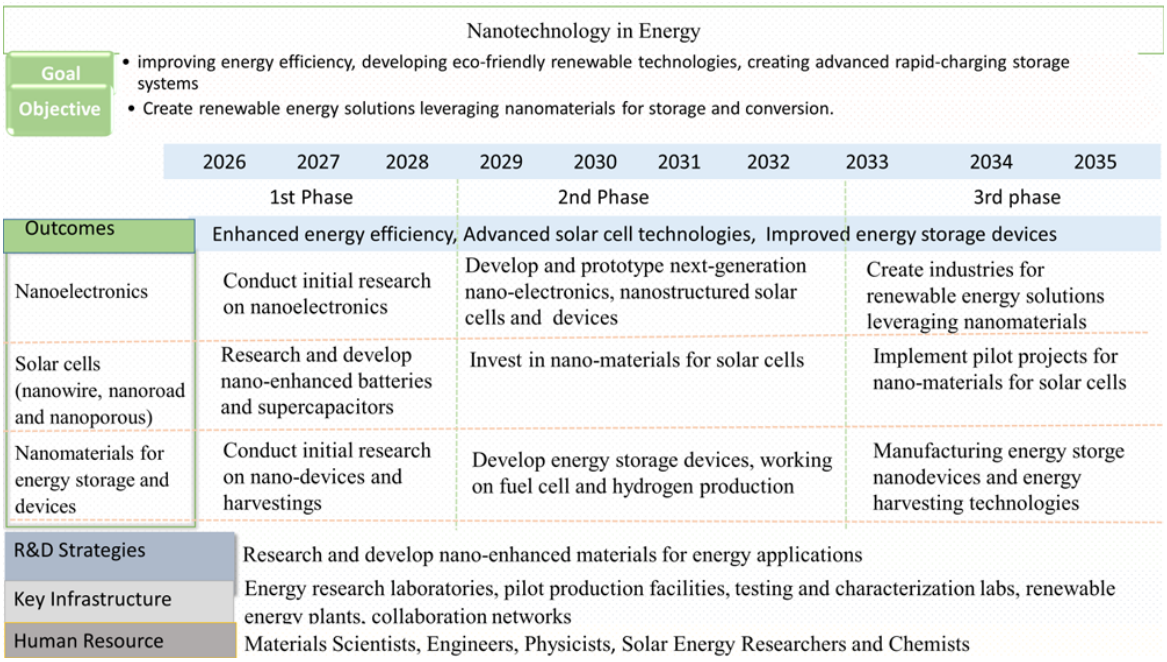


Figure 4-10 Nano-energy roadmap and implementation strategy.

Each phase outlines specific R&D and capacity-building strategies, emphasizing collaboration among institutions for ecosystem and human resource development, including materials scientists, engineers, and researchers. As the timeline progresses, this roadmap will prioritize advanced energy storage and optimize hydrogen production, culminating in significant greenhouse gas reductions through advanced catalytic technologies and energy harvesting systems. This comprehensive approach necessitates a diverse team of specialists to effectively drive the transformation of energy solutions via nanotechnology.

e) Nano-manufacturing

Figure 4.11 highlights the goals, objectives, outcomes, R&D strategies and human resources required for utilizing nanotechnology in the manufacturing sector. This strategic plan is designed to leverage nanotechnology to revolutionize the manufacturing sector by focusing on four goals: enhancing precision in nanoscale fabrication, improving manufacturing efficiency and

sustainability, developing innovative materials with superior properties, and enabling scalable production methods for nanomaterials.

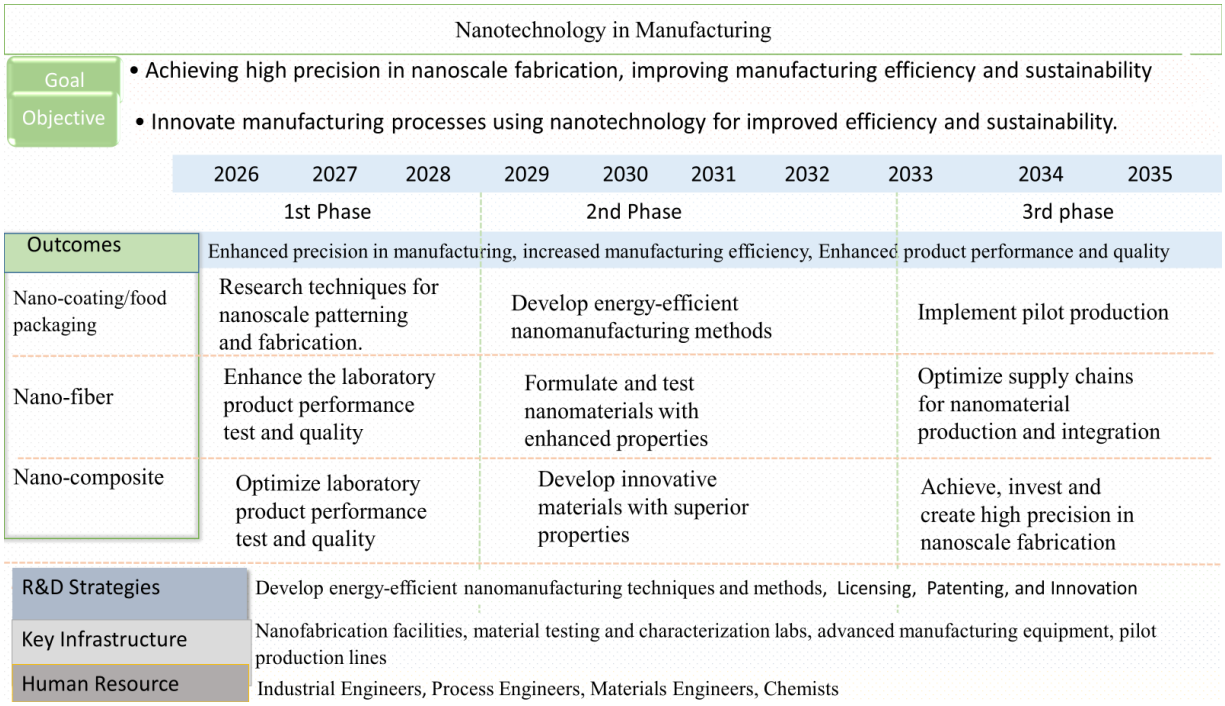


Figure 4-11 Nano-manufacturing roadmap and implementation strategy.

The plan is structured for ten years, with specific stages outlined to guide the progression towards these goals. The initial two years prioritize achieving high precision in nanoscale fabrication, followed by a focus on improving efficiency and sustainability in the next four years. Years five and six are dedicated to the development of advanced materials, while the latter part of the decade emphasizes the scaling up of production capabilities, leading to optimized manufacturing processes. To ensure the successful execution of this strategic plan, detailed objectives and outcomes are aligned with each goal, including the need for innovative manufacturing processes driven by nanotechnology. Specific research and development strategies, such as investigating nanoscale patterning techniques and formulating new nanomaterials, are identified, along with the necessary human resources, like materials scientists and engineers. The culmination of these efforts aims not only to enhance the precision, efficiency, and sustainability of manufacturing but also to improve

overall product performance and quality. Ultimately, these efforts will foster a powerful and innovative manufacturing landscape through the application of nanotechnology.

4.2.2 Advanced Computational and Intelligent Systems

a) Advanced computing ecosystem

The vision of this ACIS sub-roadmap is the development and deployment of advanced computing-based products and services that result in enhanced R&D and productivity across various sectors through efficient and scalable computing resources and benchmark R&D datasets. As highlighted in Figure 4.12, the advanced computational ecosystem is a comprehensive roadmap encompassing two sub-roadmaps: Advanced Computing Ecosystems and Benchmark Dataset Preparation. Each sub-roadmap is structured into three R&D phases with specific outcomes, working in parallel to create a robust and innovative computational ecosystem that drives national progress and competitiveness.

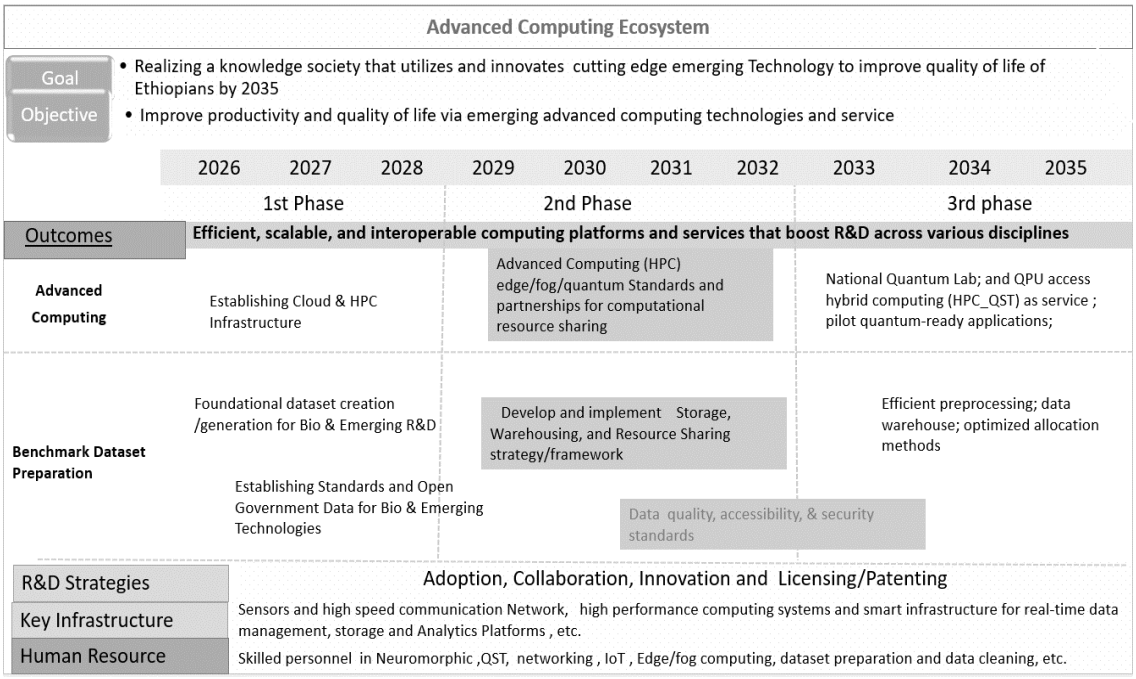


Figure 4-12 Advanced Computing Ecosystem roadmap and implementation strategy

- *Advanced Computing Infrastructure* focuses on establishing the foundational computing infrastructure and progressively advancing toward cutting-edge capabilities, including High-Performance Computing (HPC), Cloud Computing, Edge/Fog Computing, Quantum Computing, and Neuromorphic Computing. Phase 1 focuses on establishing HPC facilities

and cloud computing infrastructure, involving the setup of state-of-the-art computing resources, including HPC clusters, cloud platforms, edge/fog nodes, and data centers to support advanced research and development across various fields, such as healthcare, agriculture, manufacturing, and climate science. Quantum readiness activities begin with feasibility studies, training of the first cohort of quantum-aware researchers (minimum 20), and establishment of international partnerships with leading quantum research institutions. Phase 2 emphasizes establishing standards and partnerships for computing facility and resource sharing, aiming to create a collaborative environment where resources are shared efficiently, reducing redundancy and enhancing productivity. A National Quantum Working Group is established, quantum simulators and emulators are deployed on existing HPC infrastructure, and pilot quantum algorithm research begins in priority sectors including healthcare (drug discovery), advanced materials (material synthesis), and agriculture (optimization). A dedicated quantum R&D budget (minimum 5% of the advanced computing budget) is allocated. Edge and fog computing standards are developed and integrated with cloud infrastructure. The last Phase 3 concentrates on development and application of pilot advanced computing and Quantum Science and Technology (QST) research facilities as a service, enabling researchers and industries to access cutting-edge computing resources. By the end of this phase, at least five quantum-ready applications are demonstrated across priority sectors.

- *Benchmark Dataset Preparation*: ensures that the computational ecosystem is supported by high-quality, accessible, and secure data. In phase 1, it involves establishing foundational standards for data management, including data formats, metadata schemas, and interoperability protocols. Collaboration frameworks for open government data are developed, encouraging public institutions to share non-sensitive datasets for research and innovation. Building on Phase 1, Phase 2 focuses on creating a robust data management system that ensures data quality, accessibility, and security. Data storage infrastructure and data warehousing solutions are implemented, and resource sharing mechanisms are established to enable researchers and industries to access and utilize datasets efficiently. Last phase 3 aims to establish efficient raw data preprocessing, data warehouse, and allocation methods. Advanced techniques for data cleaning, integration, transformation, and reduction are deployed, optimizing data processing and utilization. This enables faster

and more accurate decision-making across various sectors including agriculture, healthcare, transport, and energy.

b) Artificial Intelligence

This roadmap is the cognitive engine layer of the ACIS roadmap that builds sovereign foundation models (Computer Vision, GeoAI and GenAI), localized benchmark datasets, and pilot AI applications serving as the foundational for AI-based solutions across all domains. As shown in Figure 4.13, Phase 1 of the CV sub-roadmap focuses on identification and adoption state-of-the-art foundational computer vision models as well as benchmark datasets are curated in local contexts (e.g., applications in agriculture, healthcare, security, and manufacturing sectors of Ethiopia).

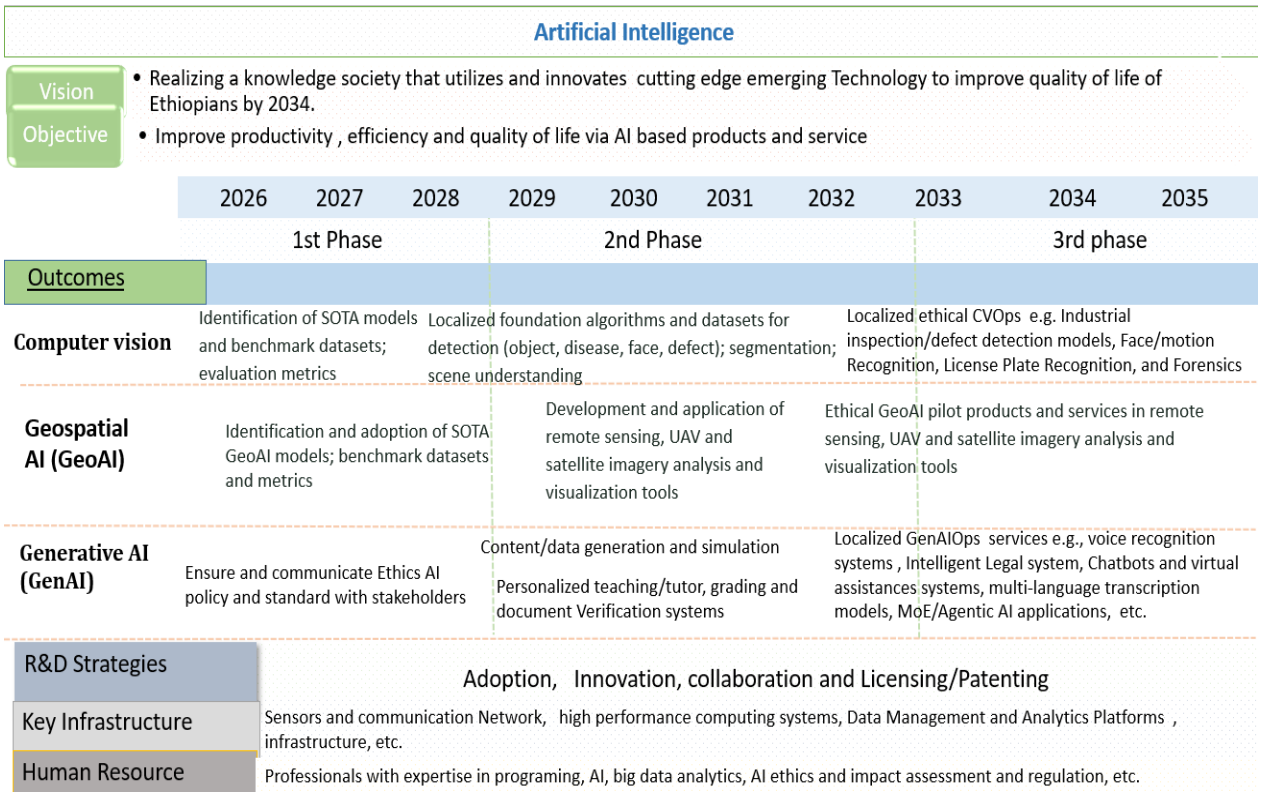


Figure 4-13 AI foundation roadmap and implementation strategy.

In Phase 2, it advances to developing localized foundation algorithms for object detection, disease detection, face recognition, defect detection, semantic and instance segmentation, and cognitive scene understanding. The final phase of this sub-roadmap focuses on large-scale deployment of pilot computer vision operation services. These include medical image analysis for eye diseases and cancer detection, industrial defect detection for textiles and manufacturing quality control,

license plate recognition for traffic management and toll collection, and forensic image and video analysis for law enforcement and criminal investigation.

GeoAI is another key focus of the AI foundation roadmap. As shown in Figure 4. 13, Phase of this sub roadmap emphasizes on the identification and adoption of state-of-the-art foundational GeoAI models/architectures for remote sensing. Benchmark datasets are curated from satellite imagery, UAV data, SAR and LiDAR, weather patterns, soil properties, tree cover, and elevation data. Evaluation metrics such as Intersection over Union (IoU), pixel accuracy, Root Mean Square Error (RMSE), F1-score, and Kappa coefficient are established. Then the sub roadmap shifts the focus towards development and testing of localized GeoAI foundation models for various tasks crucial for Ethiopia. Land cover classification, deforestation detection, crop health monitoring, disaster prediction (floods, wildfires, and earthquakes), soil moisture estimation, and tree species identification. Physics-informed neural climate simulation models are also built during this phase to enable advanced environmental forecasting. In final stage, phase 3, the sub roadmap emphasizes on deployment of Large-Scale Pilot GeoAI Services including real-time autonomous drone-based surveying, near-real-time climate change detection, disaster early warning systems, crop yield prediction for teff, wheat, maize, and coffee, land-cover change detection, urban planning and infrastructure mapping, and water resource monitoring across the country.

The Generative AI sub-roadmap progresses through three phases spanning 2026 to 2035. In Phase 1, Ethiopia establishes foundational AI and GenAI ethics policies and standards, ensuring responsible development, deployment, and governance of generative AI technologies across all sectors, including data privacy, bias mitigation, intellectual property, and safety guidelines. In Phase 2, the roadmap advances to the development and deployment of personalized teaching and tutoring systems for adaptive education, automated grading systems for educational institutions, document verification systems for government and financial services, and content and data generation and simulation capabilities for synthetic data creation to augment limited real-world datasets. In Phase 3 , Ethiopia deploys localized GenAIOps services at scale, including voice recognition systems for hands-free interaction, intelligent legal systems for contract analysis and case management, chatbots and virtual assistance systems for citizen services and customer support, multi-language transcription models for Ethiopia's diverse linguistic landscape, and mixture of experts and Agentic AI applications for autonomous, multi-step task completion across

industries delivering tangible, operational generative AI solutions that enhance education, governance, legal services, public engagement, and enterprise productivity across the nation.

The AI Foundation Roadmap is enabled by four interconnected R&D strategies: Adoption, Innovation, Collaboration, and Licensing/Patenting. Adoption leverages proven SOTA and frameworks from global leaders, adapting them to Ethiopian contexts. Licensing and Patenting protect Ethiopian AI innovations, enabling commercialization and technology transfer. Collaboration emphasizes strategic partnerships between government, academia, industry, and international research institutions. Innovation focuses on developing localized foundation algorithms, synthetic data generation, and Ethiopian-scenario training (medical, agricultural, urban). The roadmap is supported by three pillars of key infrastructure including Sensors and Communication Networks (IoT devices, 5G/LPWAN, edge nodes) for real-time data collection; High-Performance Computing Systems (HPC clusters, cloud platforms) for AI model training and inference; and Data Storage and Management Platforms (data lakes, warehouses, visualization tools) for secure, scalable data processing. The human resource pillar ensures a skilled workforce of professionals with expertise in programming, AI, big data analytics, AI ethics, impact assessment, and regulation, supported through university degree programs, technical certifications, and continuous professional development. Collectively, these strategies, infrastructure, and talent deliver sovereign AI foundation models and solutions across Computer Vision, GeoAI, and Generative AI that serve as the foundational layer for various domains by 2035.

c) *IoT and big data analytics*

Research in the IoT and big data analytics is of paramount importance for effectively managing the vast amounts of data generated by IoT and other devices. As illustrated in Figure 4.14, the proposed IoT and Big Data Analytics roadmap, aims to enhance productivity and efficiency in various sectors including agriculture, healthcare, transportation, and energy through the adoption of IoT and Big Data analytics technologies. The roadmap is divided into three phases.

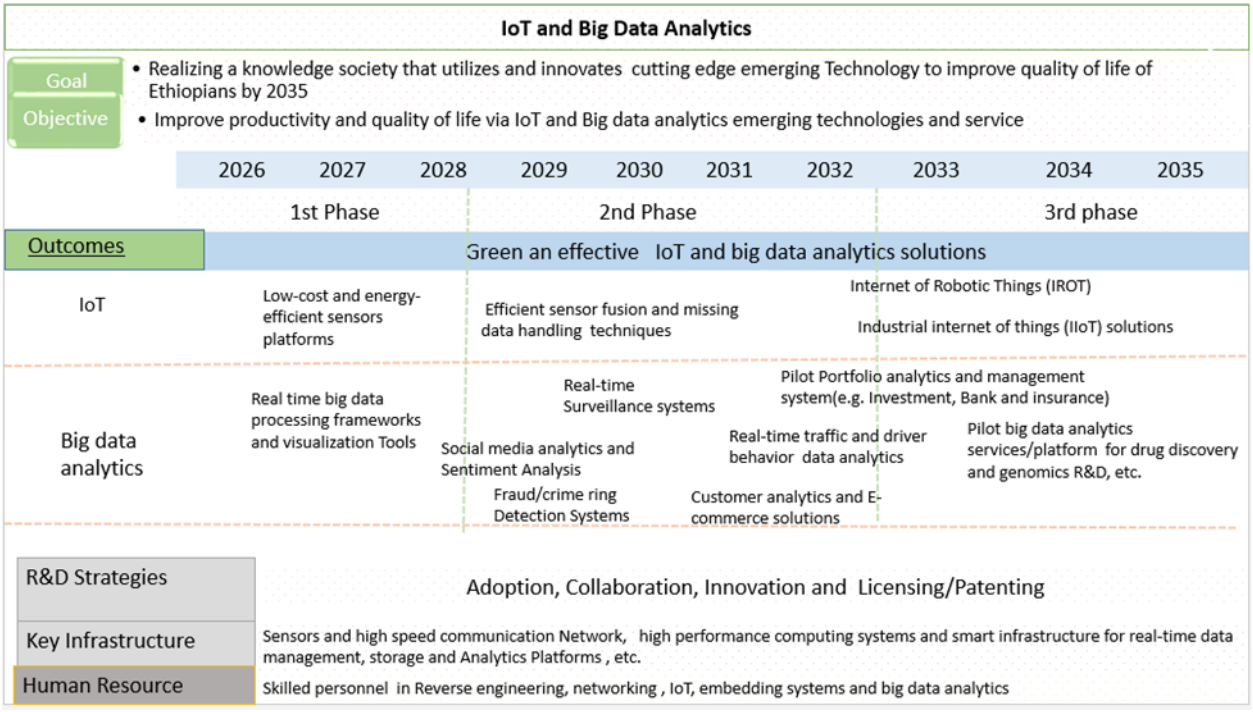


Figure 4-14 Roadmap and implementation strategy of IoT and big data analytics.

In the first phase, the roadmap emphasizes adopting, and implementing low-cost, energy-efficient IoT sensors, as well as building robust big data processing frameworks and user-friendly visualization tools. This will involve researching suitable sensor technologies, developing partnerships with local and international tech firms, and piloting sensor deployments for monitoring in agricultural and urban settings. In the second phase, the focus is on development of sensor fusion techniques and real-time multi-source data processing systems. This includes researching algorithms for sensor integration and testing these systems in real-world environments, particularly in smart agriculture. Additionally, the roadmap envisions building analytical models for social media analytics, fraud detection, and customer analytics, and collaborating with businesses to implement these solutions effectively. Finally, the roadmap builds and implements smart home technologies and Industrial Internet of Things (IIoT) solutions in pilot sites. It will also develop and implement real-time traffic management and driver behavior analytics and energy consumption monitoring systems.

To successfully implement the roadmap, a comprehensive R&D strategy has been outlined, which includes the adoption of IoT and big data technologies, collaboration with stakeholders such as universities, research institutions, and industries, and encouraging innovation through incubators

and funding for startups. Additionally, the importance of licensing and patenting to protect innovations has been emphasized. As a capacity-building strategy, enhancing infrastructure including high-speed communication networks and high-performance computing systems, while also prioritizing human resource training in relevant fields such as networking, IoT, and Big Data analytics, has been identified as crucial.

d) Intelligent systems

As highlighted in Figure 4.15, the vision of the Intelligent System Applications General Roadmap is to realize a knowledge society that utilizes and innovates cutting-edge emerging technology to improve productivity and quality of life of Ethiopians by 2035. The key objective involves the development of robotics and intelligent system products and services that improve productivity, efficiency, and sustainability across multiple sectors of the Ethiopian economy.

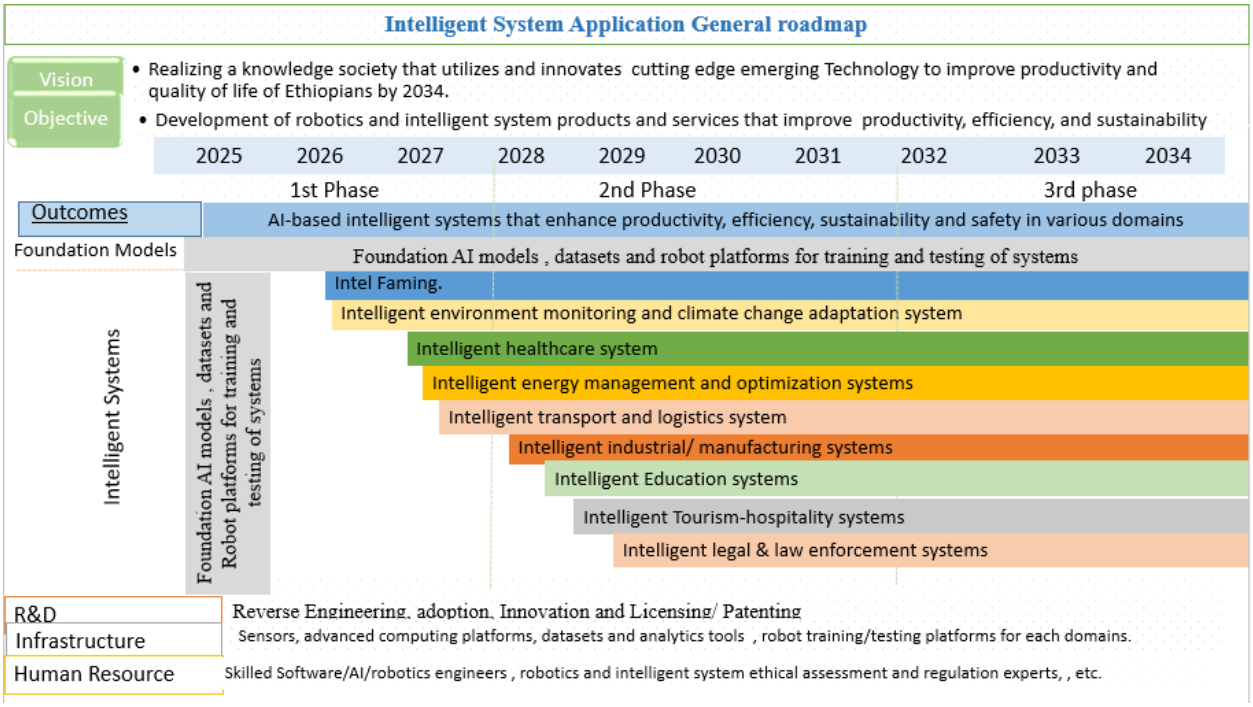


Figure 4-15 General intelligent system application roadmap and implementation strategy.

The intelligent system application roadmap focuses on establishing foundational AI models, comprehensive datasets, and robotic platforms for training and testing across all domains. It then deploys intelligent solutions sequentially across interconnected sectors.

- Precision Farming sub-roadmap focuses on development and deployment of AI and autonomous systems technologies that transform agricultural productivity through AI-powered field mapping, disease and pest detection, and livestock health monitoring. It deploys robotic systems for sowing, spraying, irrigation, feeding, and harvesting. It culminates in smart inventory management and AI-based farm monitoring.
- Intelligent Environment Monitoring and Climate Change Adaptation system sub-roadmap aims to leverage remote sensing, UAV and satellite imagery, and AI models for land cover classification, deforestation risk prediction, and disaster detection for floods, wildfires, and earthquakes. It enables autonomous reforestation, biodiversity monitoring, and disaster response.
- The Intelligent healthcare system focuses on development and deployment of AI-powered disease detection for eye diseases, cancer, and cardiovascular conditions. It utilizes intelligent medical advisory systems, AI-assisted radiology and oncology, and robotic patient care. It delivers advanced medical expert systems for personalized and accessible healthcare.
- Intelligent Transport and Logistics system sub-roadmap focuses on development and deployment of AI-driven traffic management, autonomous delivery systems, and intelligent warehouse technologies. It integrates mobility as a service platforms and blockchain-enabled logistics. It achieves fully autonomous driving to reduce congestion and optimize supply chains.
- Intelligent Education sub-roadmap targets development and delivery of personalized adaptive learning, intelligent tutoring, and automated grading. It provides braille recognition, assistive AI for learners with disabilities, and automated lesson planning. It implements comprehensive student monitoring to enhance quality, accessibility, and inclusiveness.
- Intelligent Energy Management and Optimization Systems aims for the integration of AI-based load forecasting and smart meters for industrial, residential, and nationwide coverage. It deploys demand response programs, AI peak shaving, renewable integration

with battery storage, and virtual power plants. It develops digital twins of the national grid and enables autonomous infrastructure maintenance.

- Intelligent Industrial and Manufacturing Systems revolutionizes production through predictive maintenance and AI-based quality inspection. It deploys digital twins, smart factory automation, and intelligent manufacturing process management, integrating advanced robotics and AI.
- The Intelligent Tourism and Hospitality system emphasizes enhancing visitor experiences through intelligent site management and personalized tour services. It enables AI-assisted emergency recognition and tourist localization systems. It deploys autonomous search-and-rescue vehicles and drones.
- The Intelligent Mining and Construction system sub-roadmap aims at improving safety and precision through AI-based site management, 3D modeling, digital twins, and quality inspection. It deploys autonomous vehicles and implements disaster detection and search-and-rescue systems.
- The Intelligent Legal and Law Enforcement sub-roadmap focuses on strengthening forensic accuracy through image, video, and audio forensics. It enables fraud and crime pattern recognition, AI-driven case management, and predictive analytics for case outcomes. It deploys bias detection systems, autonomous patrol robots, and surveillance drones.

*Precision farming**:*** This roadmap outlines a comprehensive 10-year strategy to transform agricultural productivity and efficiency through AI and robotics. By developing intelligent farming solutions, we aim to revolutionize crop management, livestock monitoring, and resource optimization to enhance food security and sustainability. As illustrated in Figure 4.15, the roadmap outlines a comprehensive 10-year strategy to transform agricultural productivity and efficiency through AI and robotics.

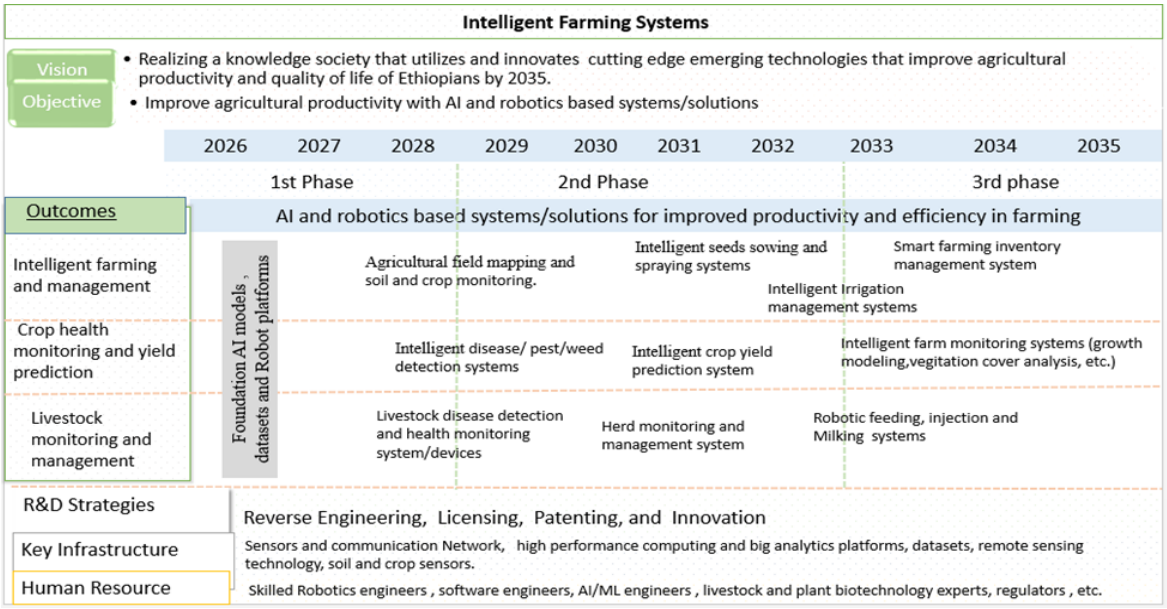


Figure 4-16 Intelligent framing systems roadmap and implementation strategy.

The roadmap aims to revolutionize crop management, livestock monitoring, and resource optimization, ultimately enhancing food security and sustainability through developing AI, IoT and robotics-based solutions by 2035. In the initial phase, the roadmap focuses on establishing the technological backbone for intelligent agriculture. This includes developing foundational AI models, curating agricultural datasets, and deploying robotic platforms to enable precision farming. Early deployments will feature AI-powered systems for field mapping and analysis, disease/pest/weed detection, and livestock health monitoring. These tools will empower farmers with real-time insights into soil health, water usage, and crop conditions to optimize resource allocation and boosting yields.

The second phase aims to introduce advanced agricultural automation and predictive analytics methods. This includes development of intelligent seed-sowing and spraying systems, AI-driven crop yield prediction models, and herd monitoring and management solutions. Concurrently, development of robotic systems for irrigation management, livestock feeding, veterinary injections, and milking will begin for autonomous farm operations. The final phase focuses on deployment and completion of intelligent irrigation and livestock management systems/tools. This includes smart inventory management systems and AI-based farm monitoring systems that are capable of growth modeling, vegetation cover analysis and holistic farm performance optimization.

The roadmap emphasizes technology development, funding, incubation and transfer. Furthermore, the roadmap will have capacity building initiatives that focus on training farmers and agricultural professionals in precision farming technologies, data analytics and sustainable practices. Infrastructure development, such as expanding high-speed internet connectivity and establishing agricultural data centers will be also prioritized to support the deployment of precision farming systems.

Intelligent environment monitoring and climate change adaptation systems: As highlighted in Figure 4.17, the primary objective of this roadmap is to leverage intelligent emerging technologies to enhance forest restoration and climate change mitigation efforts. The roadmap focuses on three core areas: forest restoration and monitoring, disaster prediction and response, and sustainable natural resource management systems, each having several phase-by-phase R&D activities.

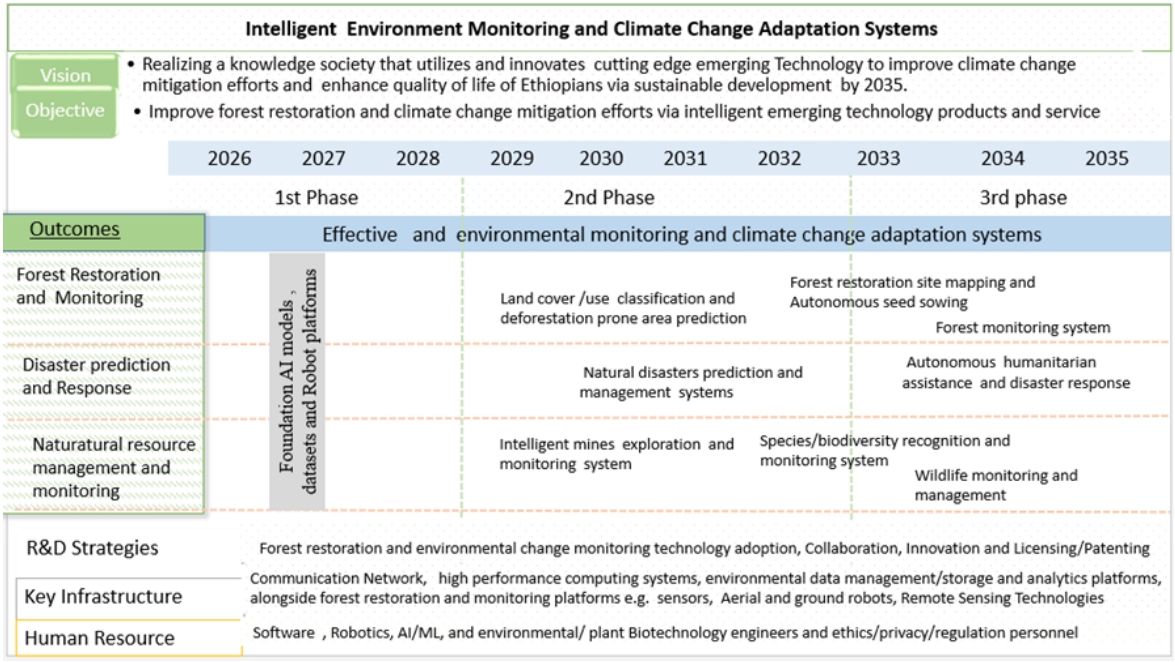


Figure 4-17 Roadmap and implementation strategy of intelligent environment monitoring and climate change adaptation systems.

The first phase establishes the foundational infrastructure, including AI models, comprehensive datasets, and robotic platforms, to enable scalable and accurate environmental monitoring. Building on this foundation, the second phase develops intelligent systems for land cover classification, deforestation risk prediction, and disaster management. It also introduces solutions for smart mineral exploration and monitoring. Concurrently, this phase initiates forest restoration

efforts through AI-powered site mapping and autonomous seed-sowing systems, alongside biodiversity recognition and monitoring tools. The final phase focuses on deploying fully operational systems, including real-time forest monitoring, wildlife tracking and habitat management, and autonomous disaster response mechanisms in pilot sites. Together, these phases create an integrated, technology-driven framework to address pressing environmental challenges while promoting ecological resilience and sustainability.

Intelligent healthcare systems: This roadmap aims to revolutionize healthcare by leveraging AI, robotics, and IoT to enhance diagnostics, patient care, and operational efficiency. The ultimate objective/goal of this roadmap is to develop and implement AI- and robotics-assisted diagnostics, medication, surgical, and other healthcare service systems that enhance efficiency, interoperability, and accuracy of disease diagnostics, detection, surgery, and other healthcare services by 2035. As highlighted in Figure 4.18, the implementation of the roadmap occurs across three strategic phases.

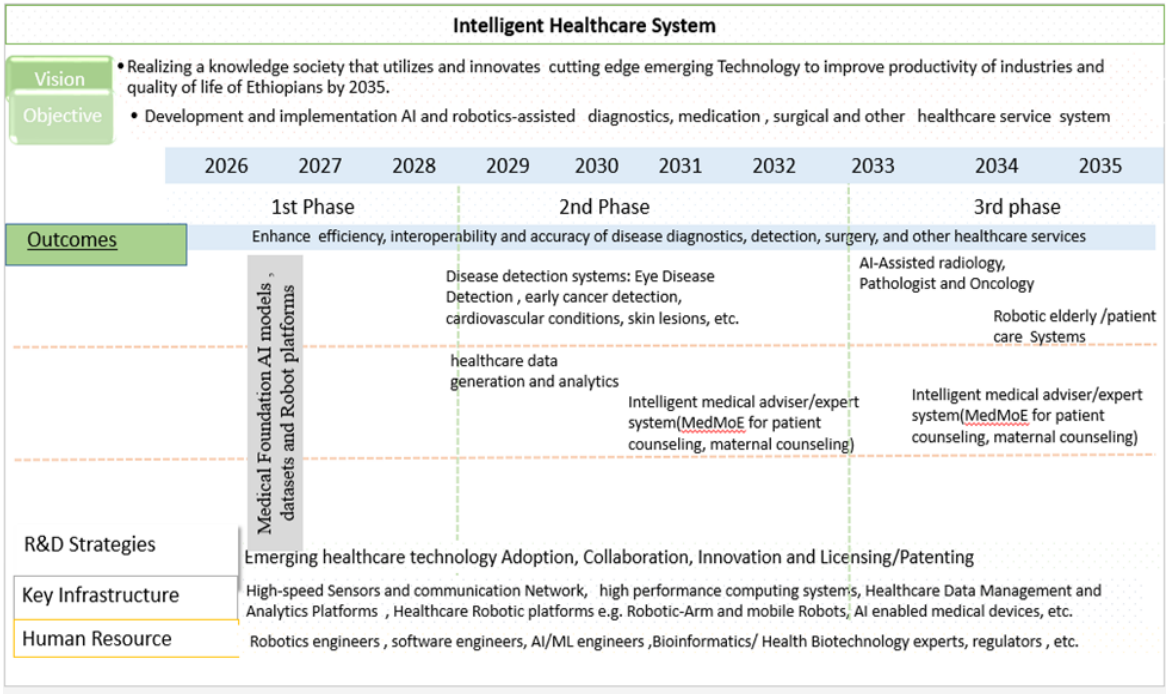


Figure 4-18 Intelligent healthcare system roadmap and implementation strategy.

The foundational phase establishes the necessary infrastructure, including medical AI models, comprehensive healthcare datasets, and robotic platforms. Phase 2 focuses on developing applications: AI-powered disease detection systems for conditions like eye diseases, cancer, and cardiovascular issues; advanced healthcare data analytics models; and intelligent medical advisory

systems for patient counseling and language transcription services. These tools will enhance doctor-patient communication and enable more accurate, accessible healthcare services. The final phase delivers sophisticated healthcare solutions for deployment, including AI-assisted radiology and oncology systems, robotic patient care solutions for elderly and vulnerable populations, and advanced medical expert systems for specialized counseling. This phased approach ensures a systematic transition from foundational development to full implementation, creating a future where intelligent healthcare systems provide precise, personalized, and accessible medical care while optimizing healthcare costs and outcomes.

Intelligent transport and logistics systems: The vision of this roadmap is realizing a knowledge society that utilizes and innovates cutting-edge emerging technology to improve the quality of life of Ethiopians by 2035. The main objective of this roadmap is to create a knowledge-driven society that utilizes cutting-edge technologies to improve mobility, reduce congestion, and optimize transport and supply chain operations. As highlighted in Figure 4.19, the roadmap has a three-phase R&D and implementation strategy for the effective development and deployment of intelligent, green, accessible, safe, and efficient transportation and logistics technologies.

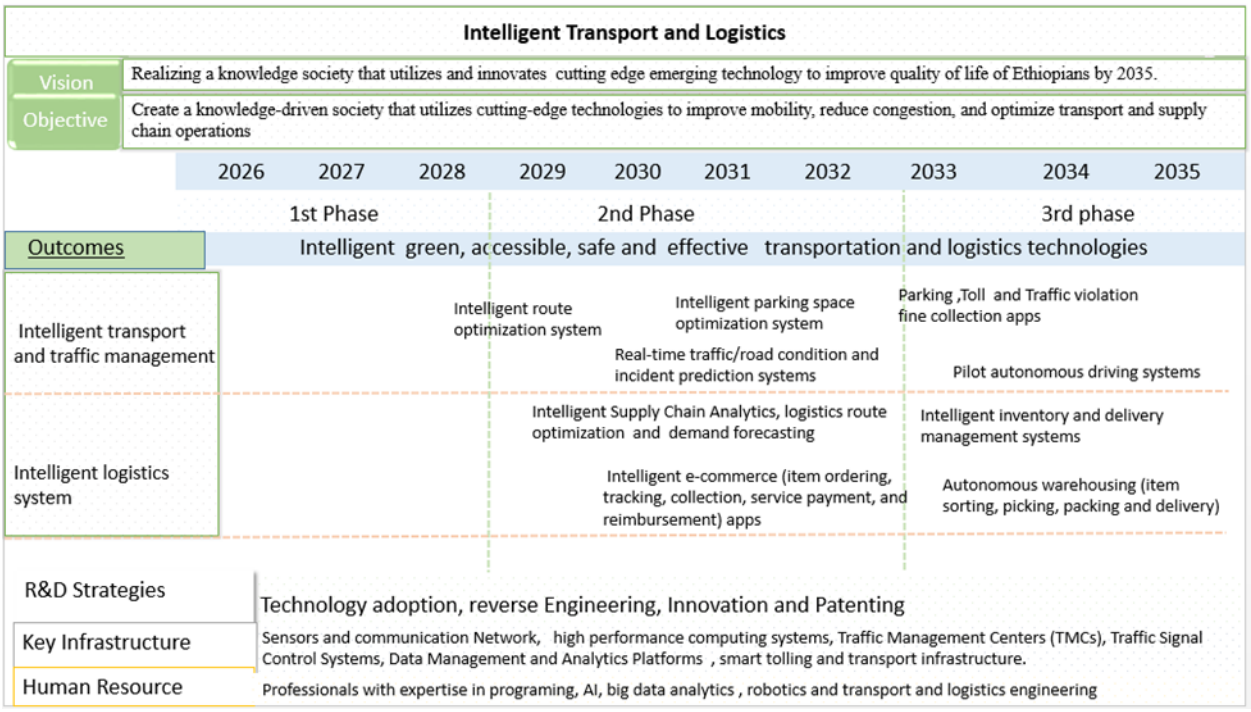


Figure 4-19 Intelligent transport and logistics roadmap and implementation strategy.

The first phase focuses on laying the foundation for intelligent transport and logistics systems. This includes deploying AI-driven traffic management solutions to analyze real-time traffic patterns, optimize traffic flow, and reduce congestion in urban areas. Intelligent logistics systems will be introduced to enhance route optimization, minimizing fuel consumption and emissions. Additionally, pilot projects for autonomous delivery systems and intelligent warehouse technologies will be launched to streamline supply chain processes. Capacity-building efforts will begin with training programs for professionals in programming, AI, big data analytics and transport engineering to ensure effective implementation and operation of these systems. Building on the foundational technologies, the medium-term phase will focus on scaling intelligent transport and logistics solutions. Advanced traffic signal control systems and smart tolling infrastructure will be implemented to further enhance traffic management. Research into AI applications for logistics will continue, with a focus on developing autonomous transport systems and integrating mobility as a service platform. These platforms will offer personalized travel planning and routing options, integrating various transportation modes for seamless mobility. Intelligent warehouse systems will be expanded to optimize inventory management and operational workflows, ensuring a more responsive and agile supply chain.

Capacity-building programs will expand to include advanced training in robotics and logistics engineering. The long-term vision is to achieve widespread adoption of fully autonomous transport and logistics systems. Autonomous driving and delivery systems will be deployed to enhance safety and efficiency in transportation. AI-driven predictive analytics will be used to anticipate and mitigate traffic congestion, ensuring smooth mobility. Intelligent logistics systems will also integrate with blockchain technology to ensure transparency and efficiency in supply chain operations. By this phase, Ethiopia will have a comprehensive intelligent transport and logistics ecosystem that supports sustainable and efficient mobility. Capacity-building efforts will culminate in the establishment of specialized training centers and innovation hubs to sustain technological advancements and foster continuous learning. The roadmap also emphasizes reverse engineering, and technology adoption as R&D strategies. Key infrastructure such as sensors and communication networks, high-performance computing systems, and traffic management centers will be developed to support these technologies. Human resource development will focus on training professionals in AI, big data analytics, robotics and transport engineering.

Intelligent education system: Emerging technologies such as advanced computing, AI, IoT, BDA, and robotics are revolutionizing the education and mining sectors in profound ways. In education, these technologies provide personalized learning experiences, automate administrative tasks, and enhance decision-making, with AI-powered adaptive learning systems tailoring the learning experience to individual students' needs, abilities, and learning styles, while IoT facilitates smart classrooms and AI-powered chatbots provide personalized support and guidance. This roadmap presents a strategic vision for transforming education through artificial intelligence, with the overarching goal of enhancing quality, accessibility, and inclusiveness in learning. As highlighted in Figure 4.20, the vision of this roadmap is to realize the learning and teaching process through personalization, automation, and enhanced support for both students and educators by 2035. The main objective is to improve quality, inclusiveness, and accessibility of education through development and implementation of intelligent solutions that focus on four key pillars: personalized adaptive learning, intelligent tutoring, teacher support automation, and inclusive learning systems.

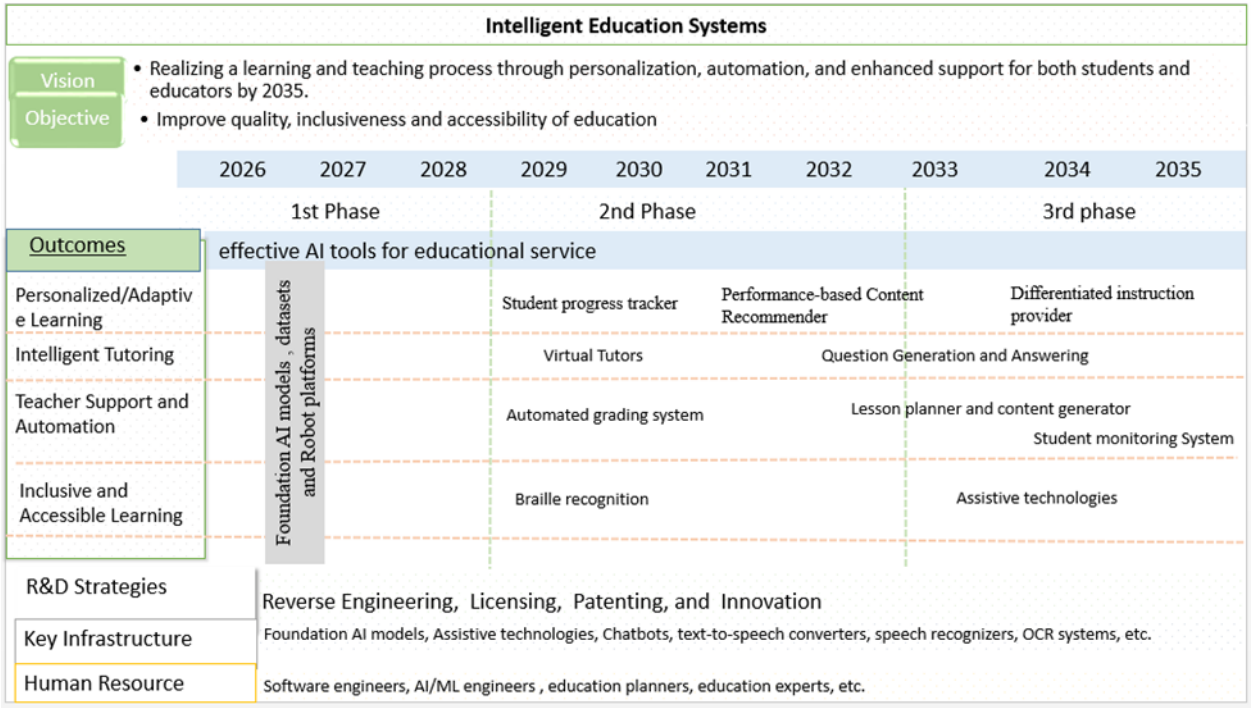


Figure 4-20 Intelligent education systems roadmap and implementation strategy.

The first phase of this roadmap focuses on the establishment of foundational technological infrastructure, including specialized education AI models, comprehensive learning datasets, and

robust computing platforms tailored for academic applications. Building on this foundation, the second phase develops transformative tools, including student progress tracking systems, performance-based content recommenders, localized virtual tutors, automated grading solutions, and Braille recognition technology. This phase also initiates work on advanced systems for automated lesson planning, content generation, and intelligent question-answering capabilities. The final phase completes the deployment of these advanced systems while introducing specialized solutions for inclusive education. Key deliverables include assistive AI technologies for learners with disabilities, differentiated instruction providers that adapt to diverse learning styles, and comprehensive student monitoring systems. This ensures a gradual yet comprehensive transformation of the education landscape.

Intelligent energy management and optimization system: As shown in Figure 4.21, Ethiopia's Intelligent Energy Management roadmap uses three sub-roadmaps and three phases to reduce grid losses, integrate renewables, and deploy autonomous operations enabled by R&D strategies, IoT sensors, edge AI, drones, digital twins, and a trained workforce of engineers, AI specialists, and technicians by 2035.

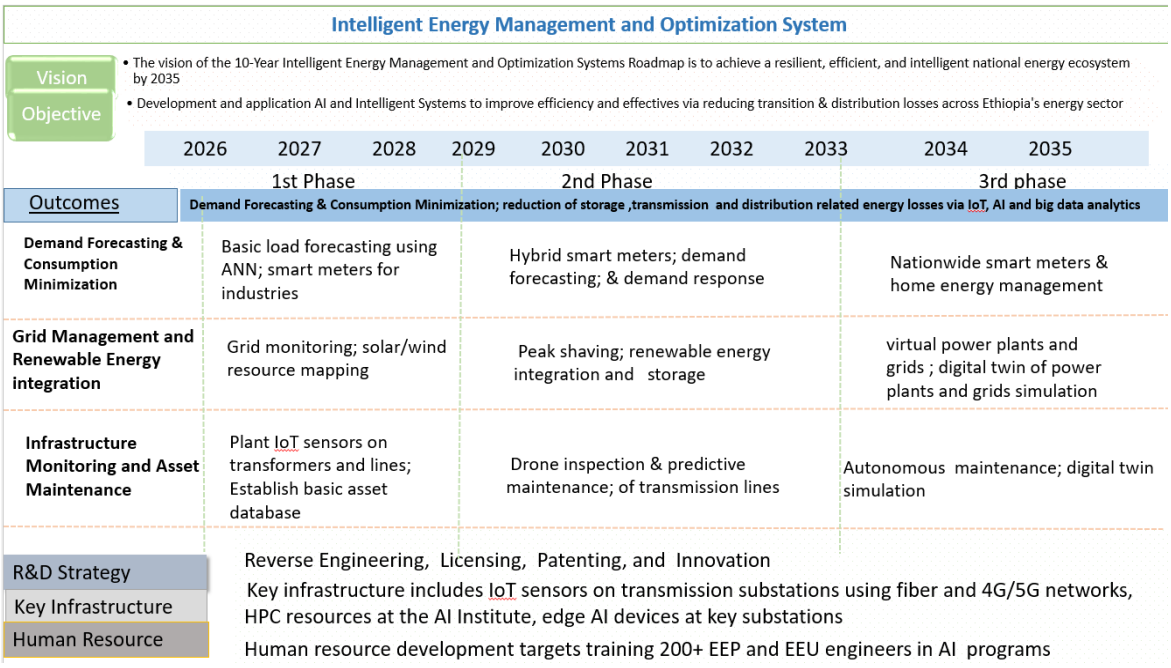


Figure 4-21 Intelligent energy management and optimization system roadmap.

Demand Forecasting and Consumption Minimization: The Demand Forecasting and Consumption Minimization sub-roadmap progresses through three phases. In Phase 1, Ethiopia establishes basic load forecasting using artificial neural networks and deploys smart meters for industrial customers to enable real-time consumption tracking. In Phase 2, the roadmap advances to hybrid smart meters that integrate multiple data sources, enhanced demand forecasting models incorporating weather and economic indicators and implementation of demand response programs that allow utilities to reduce load during peak periods. In Phase 3, Ethiopia achieves nationwide smart meter coverage across all customer segments, industrial, commercial, and residential, and deploys home energy management systems that enable consumers to monitor and optimize their energy usage automatically.

Grid Management and Renewable Energy Integration: The Grid Management and Renewable Energy Integration sub-roadmap progresses through three phases. In Phase 1, Ethiopia implements basic grid monitoring systems to track voltage, frequency, and load in real-time, and conducts comprehensive solar and wind resource mapping to identify optimal locations for renewable energy development. In Phase 2, the roadmap advances to AI-based peak load shaving to reduce demand during peak hours, integration of renewable energy sources into the national grid, and deployment of battery storage systems for renewable smoothing and grid stabilization. In Phase 3, Ethiopia deploys virtual power plants that aggregate distributed renewable resources into a single dispatchable entity and develops digital twins of both power plants and the national grid for simulation, optimization, and training purposes.

Infrastructure Monitoring and Asset Maintenance: The Infrastructure Monitoring and Asset Maintenance sub-roadmap progresses through three phases. In Phase 1, Ethiopia installs IoT sensors on transformers and transmission lines for real-time condition monitoring and establishes a basic asset database containing maintenance history, performance metrics, and geospatial data for all major grid assets. In Phase 2, the roadmap advances to drone-based automated inspection of transmission lines using computer vision to detect corrosion, vegetation encroachment, and structural damage, along with predictive maintenance using machine learning algorithms to forecast equipment failures before they occur. In Phase 3, Ethiopia deploys autonomous maintenance systems with automated work order generation and crew dispatch, and implements digital twin simulation for asset management to enable what-if analysis and failure scenario testing.

The implementation strategy for Ethiopia's Intelligent Energy Management roadmap combines R&D through reverse engineering, licensing, patenting, and innovation; key infrastructure including IoT sensors on transmission substations, HPC systems at the AI Institute, edge AI devices at regional substations, drone fleets for line inspection, and digital twins of the national grid; and human resource development targeting 200+ energy engineers, 100+ AI specialists, 50+ drone operators, 500+ field technicians, and 20+ AI ethics regulators—phased from 2026 to 2035 to ensure sustainable, locally owned energy AI capabilities across Ethiopia.

Other intelligent systems: This comprehensive roadmap involves the development and deployment of AI and robotics-based systems for four main sectors: intelligent manufacturing, tourism and hospitality, mining and construction, and law enforcement. Each sector will undergo a phased transformation to integrate cutting-edge technologies that enhance efficiency, safety, and service delivery. As shown in Figure 4.22, the roadmap begins with foundational AI models, datasets, and robotic platforms, which are essential for ensuring a robust technological base for subsequent innovations.

- Manufacturing: the intelligent manufacturing system sub-roadmap focuses on revolutionizing production through automation and digital twins. In its initial phase, it prioritizes manufacturing process automation and management systems. Starting from the midpoint of the second phase, the roadmap focuses on development of intelligent manufacturing process management systems that enhance automation, efficiency, and decision-making in manufacturing environments via integrating advanced robotics and AI-based solutions.
- Tourism and hospitality: The intelligent tourism and hospitality sub-roadmap, on the other hand, aims to transform visitor experiences and safety through advanced technology through a three-phased approach. The first phase begins with the development and implementation of intelligent tourist site management and personalized tour services, enhancing operational efficiency and visitor engagement. In the second phase, the focus expands to include AI-assisted emergency recognition and tourist search and localization systems, enabling rapid response to incidents and improving situational awareness. The roadmap culminates in the final phase with the deployment of autonomous search-and-rescue vehicles and drones, ensuring proactive safety measures and strengthening emergency response capabilities. Together, these phases aim to create a smarter, safer, and more personalized tourism ecosystem.

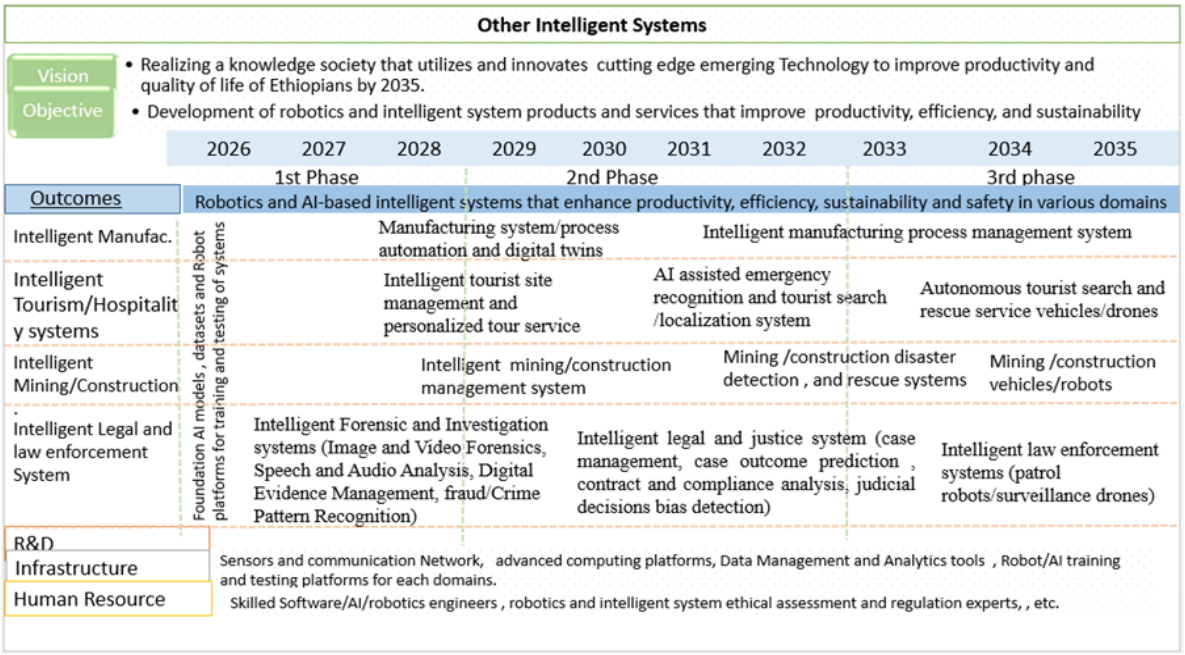


Figure 4-22 Roadmap and implementation strategy of other intelligent systems.

- Mining and construction: For the mining and construction sector, the first phase of the road map emphasizes development of intelligent systems that enhance safety and precision through intelligent site management. This involves introducing 3D modeling, digital twins, and quality inspection systems. Phase two aims at development and deployment of autonomous vehicles in mining and construction. The third phase culminates in disaster detection and search-and-rescue systems, ensuring safer and more efficient operations.
- Legal and law enforcement: The intelligent legal and law enforcement sub-roadmap aims to enhance legal and law enforcement processes efficiency, strengthen forensic accuracy, ensure judicial fairness, and public safety through AI and robotics assisted solutions. The roadmap begins with the development of Intelligent Forensic and Investigation Systems in the first and second phases, focusing on advanced technologies such as image and video forensics, speech and audio analysis, digital evidence management, and fraud/crime pattern recognition. Starting from the midpoint of the second phase, the roadmap transitions to the development of an intelligent legal and justice system via integrating AI-driven solutions for case management, predictive analytics for case outcomes, contract and compliance analysis, and detection of bias in judicial decisions. In the final phase, the focus shifts to the deployment of autonomous systems—including patrol robots, surveillance drones, and intelligent vehicles—to enhance law

enforcement capabilities through real-time monitoring, rapid response, and improved operational efficiency.

4.2.3 Synthetic and System Biology

a) System biology

System biology, which encompasses computational biology and bioinformatics, helps us better understand how an organism functions as a whole. This is possible with proper use of different computational tools, omics data and biological databases. This information is vital for all other synthetic biology approaches and activities. Establishing advanced computational infrastructures together with easy-to-access specialized biological databases and computational tools are fundamental to reap the fruits of synthetic biology in the context of Ethiopia's bioeconomy. Therefore, the system biology roadmap's main goal is to develop and utilize biological databases, innovative computational tools and models that enable researchers to study and understand the complex biological systems that exist in Ethiopia. Hence, the roadmap emphasizes on the development of biological databases and omics data integration as well as modeling and prediction tools.

The system biology roadmap presents a 10-year strategic plan designed to harness the power of computational methods for advancing biological research. Its main goal is to develop integrated infrastructures, data generation and integration frameworks, and predictive models which are capable of analyzing complex biological systems, with applications covering human health, pathogen surveillance, and biodiversity conservation and management. This roadmap is divided in three distinct but interconnected phases, each contributing to the overall goal of the roadmap.

As highlighted in Figure 4.23, the main goal of this roadmap is to develop and utilize biological databases, innovative tools and technologies that enable the study of complex biological systems to benefit from the wealth of Ethiopia's bioeconomy. The plan emphasizes not only technological and methodological innovation but also the development of infrastructure and human resources to sustain long-term progress in synthetic and system biology. The system biology roadmap is divided into three phases.

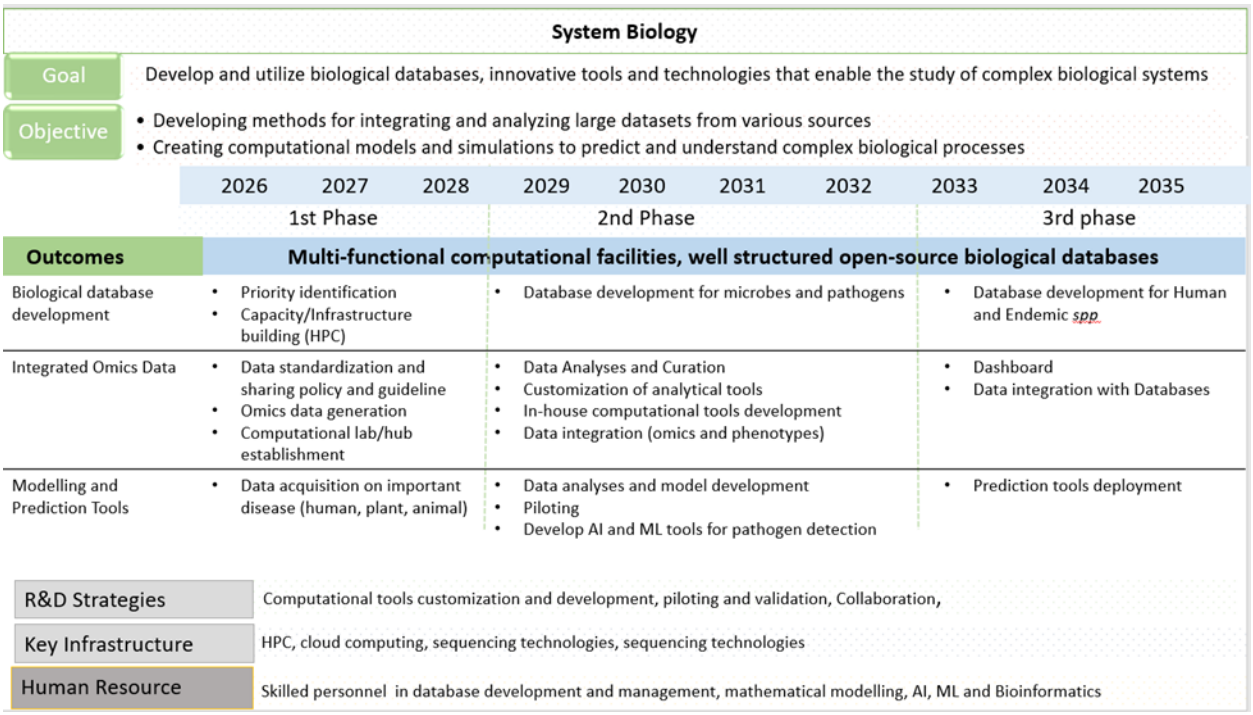


Figure 4-23 System biology roadmap and implementation strategy.

Phase first will be dedicated to resource allocation, establish the necessary infrastructure and create enabling environments such as guidelines and policies necessary for large-scale computational biology research. The primary focus will be priority focus area identification, establishment of high-performance computing (HPC) systems and computational hubs. This hub will have the capacity to process and store vast amounts of phenotypic and omics data. To facilitate collaboration and reproducibility, this phase will also prioritize the creation of standardized data-sharing policies and guidelines considering the experience of international institutes such as National Institutes of Health NHI (USA), Biotechnology and Biological Sciences Research Council BBSRC (UK) and DoB-MoST (India). While working on the aforementioned activities, several exploratory fields as well as omic studies will be initiated on human, agricultural and environmental important species, disease causing pathogens as well as beneficial microorganisms. Data from these studies will be used for future analyses, modelling and prediction.

Following the infrastructure and datasets established in Phase 1, the second phase focuses on developing specialized databases, computational tools and predictive models. More emphasis will be given on customizing open-source resources and creating in-house computational tools tailored to specific research needs that facilitate data analyses, data integration, modelling and prediction.

Following the priorities identified in phase 1, multi-omics data analyses and curation will be carried out during this phase. This phase will also include the use of AI and machine learning applications, particularly for pathogen detection and simulation of biological processes.

Pilot studies will be conducted to validate these models, ensuring their accuracy and applicability to real-world scenarios. This phase will also see the development of specialized biological databases for important microbes and pathogens which have significant impact on health, agriculture and environment. Several computational tools will be integrated in this database. With the help of these tools, it will serve as an open-source and user-friendly repository cataloging microbial and pathogen genomic and phenotypic data. This database will lay the foundation for the next phase activities such as data integration, additional database development for human and other endemic species as well as prediction tool deployments.

The final phase will focus on expanding the database to include human and endemic species, data integration and deployment of prediction tools. This database will be developed to integrate genomic, phenotypic, and epidemiological data for human and other economically important species, ensuring seamless interoperability with existing microbial databases. The data integration with databases will enhance cross-species analyses, supporting comparative studies between human and environmental pathogens. The other deliverables in this phase include the integration and deployment of user-friendly dashboards on the databases. These dashboards will be designed to visualize complex datasets thereby enabling researchers and public health professionals to monitor trends and extract actionable insights. In addition, validated AI and ML based prediction tools will be operationalized for use in diagnostics, epidemiology, and conservation biology. By the end of the roadmap, it is expected to have a fully integrated computational biology infrastructure where data, tools, and expertise come together to address some of the most pressing challenges of Ethiopia's bioeconomy.

In order to realize the goal of this roadmap, structured implementation strategy is vital. Collaboration with higher learning and research institutions, government agencies, international research institutions, and other relevant stakeholders is essential to pool resources and expertise together. Similarly, this collaboration will help identify and refine the priority areas that the system biology needs to focus. Depending on the number of priority areas, a consortium comprising

researchers, policy makers and universities will be established. Availability of advanced sequencing technologies as well as data centers will also support the success of this roadmap. Establishing state-of-the-art computational hubs is another area of the strategy. Without this facility, all the research and development activities in relation to synthetic biology would not be realized and fruitful. Since there are open-source computational tools, customizing them to our context should be considered until we develop our own tools. Above all, policies and guidelines related to data standards and sharing will be scrutinized to match the national and international standards.

As system biology fundamentally depends on processing of massive datasets, it is also crucial to establish dedicated HPC and cloud computing platforms tailored for computational biology and bioinformatics applications. These advanced computing resources will serve dual essential functions: (1) secure, scalable data storage for multi-omics datasets, and (2) high-throughput processing power for complex analyses such as genome assembly, molecular dynamics simulations, and network biology modeling. To fully leverage these computational capabilities, the genomic research center requires upgrading with next-generation sequencing technologies (including single-cell and long-read platforms) to generate the high-quality data needed across synthetic biology applications. This integrated infrastructure will enable transformative research in metabolic engineering, genome editing, and synthetic pathway design. Furthermore, a comprehensive capacity-building program must be implemented through both long-term degree programs and short-term specialized training focusing on database management, bioinformatics, AI and ML modelling, software development as well as biological data curation and integration.

b) *Medical innovation*

Ethiopia's healthcare system faces significant challenges, including limited access to advanced diagnostic and disease detection tools, high burdens of infectious and non-infectious diseases, as well as lack of personalized treatment options. As a result, use of medical innovation that exploits the advancements and technologies of synthetic biology is imperative for growth and development of Ethiopia. Hence, a 10-year roadmap, focusing on medical innovation, is developed. This roadmap aims at transforming the national healthcare system through the use of innovative and affordable diagnostics and personalized therapeutics medical solutions.

The overall goal is to enhance healthcare delivery by developing personalized therapeutics, affordable rapid diagnostics, and AI-driven drug/vaccine design that ensures safer, more effective interventions. By leveraging *in silico* approaches and personalized therapeutics, this roadmap aims to address both infectious and non-infectious diseases while fostering infrastructure, collaboration and commercialization. As shown in Figure 4.24, medical innovation roadmap is divided into three phases and the detail is presented below:

The first phase focuses on establishing the groundwork for medical innovation. Key activities include priority disease identification, capacity building (labs, computational facilities), and drafting biosafety and ethical guidelines. Researchers, in collaboration with policy makers and other stakeholders, will identify and determine the most pressing healthcare needs in Ethiopia. This task is the most important task of this phase because it affects and guides all other activities and subsequent interventions. Biosafety and ethical guidelines will be also developed and aligned with related policies of the country so as to ensure responsible innovation and implementation. While utilizing the computational facilities and tools developed under system/computational biology roadmap, the necessary infrastructures and state-of-the-art laboratories will be established for proper development of personalized therapeutics as well as drug and vaccine development. The other focus area of these laboratories will be exploring the potential of indigenous medicinal plants for phytochemical screening as well as identification of chemical constituents important for drug design and development. Efforts will also be invested in developing low-cost, rapid diagnostics and disease detection tools. Likewise, AI and ML tools will also be developed and customized so that disease detection will become easy and fast.

The second phase shifts to translational research, development of innovation tools, and pilot testing of innovative medical solutions. For personalized medicine and therapeutics, a series of experimental researches will be conducted in designing disease-specific delivery systems, developing localized therapies and conducting preclinical trials. Preclinical trials will assess the efficacy and safety of these treatments, paving the way for clinical deployment in the next phase. In addition, diagnostics tools developed in phase 1 will also undergo rigorous field testing to validate their accuracy and usability in urban and rural conditions and healthcare system setup.

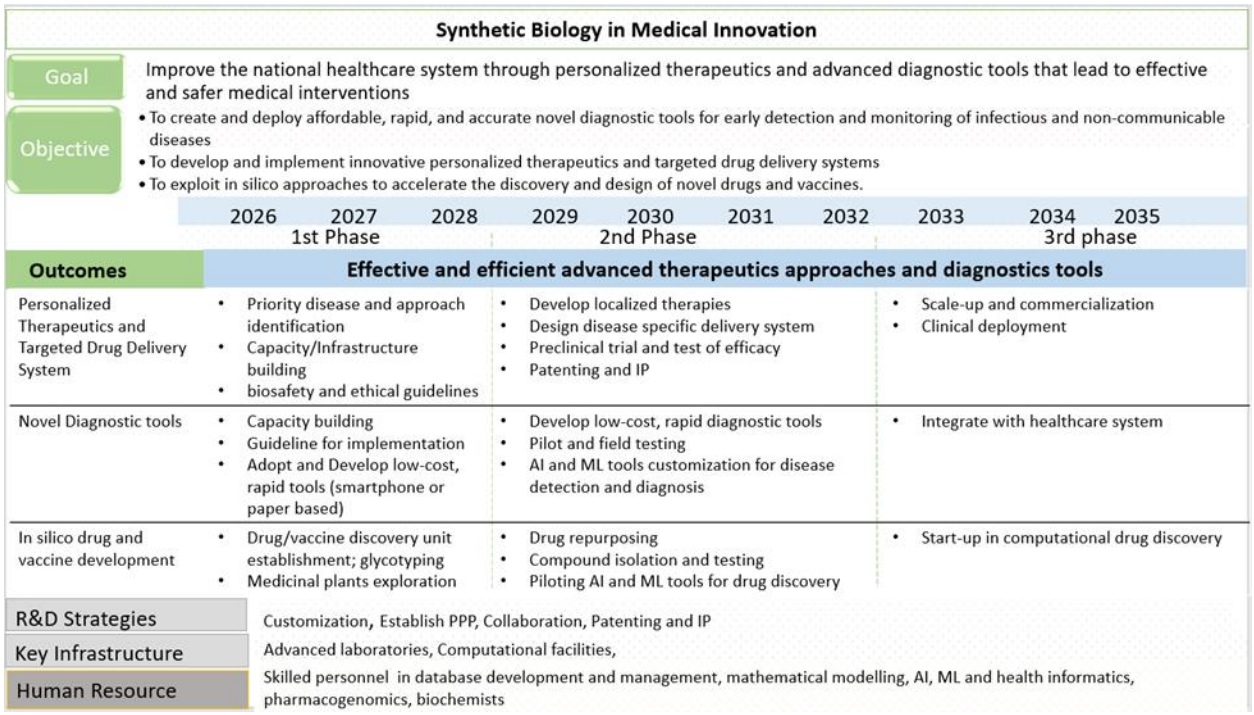


Figure 4-24 Medical innovation roadmap and implementation strategy.

AI and ML tools will be customized and tested for drug discovery as well as disease detection and prediction. By the end of this phase, all the innovations will be ready for clinical trial, scale-up and deployment in phase three. Those novel innovations will be patented and protected as per the country's IP regulations. Patenting and intellectual property (IP) protections will ensure that Ethiopian innovations are recognized and safeguarded globally.

The final phase emphasizes scaling-up and application of successful innovations into the healthcare system. Diagnostic tools and personalized therapies that demonstrated efficacy and affordability in the second phases will be commercialized and deployed in the healthcare system. Clinical deployment of targeted drug delivery systems and AI-driven diagnostic tools will be expanded nationwide. The *in-silico* unit evolves into a start-up ecosystem for computational drug discovery, capitalizing on earlier AI/ML tools. By connecting with Phase 2 outputs such as validated delivery systems and AI models this phase ensures innovations reach end-users, achieving the roadmap's goal of affordable and precision healthcare.

By the end of this roadmap, Ethiopia will have reliable and self-sustaining healthcare, characterized by advanced diagnostics, effective personalized treatments, and a skilled workforce capable of driving continuous improvement in healthcare delivery. This requires effective R&D strategy,

robust infrastructures and skilled workforce. Strategic partnership is a key R&D aspect of this roadmap. Without public-private partnership (ppp), none of the activities and objectives will be realized. Hence, establishing strong collaboration and partnership with hospitals, pharmaceutical companies, national and international academic and research institutes, healthcare governing bodies such as MOH, WHO and the like are imperative. Such partnership facilitates funding, knowledge and technology transfer, as well as commercialization. It is also crucial for sharing data, experts and resources.

Customization of computational tools to fit our needs is one of the strategies to be followed while developing in-house computational tools as well as AI and ML models for faster, more efficient vaccine and drug development. Long-term monitoring will evaluate the impact of these innovations on healthcare outcomes, guiding future policy decisions. Emphasis will be given to developing medical innovations and solutions tailored to Ethiopia' specific challenges such as low-cost but effective diagnostic tools and therapies while exploiting our biodiversity as a source of medicine. Strong data governance policy is also essential to ensure patient privacy and data security while allowing for open access and collaboration. Beyond R&D, implementation of this road map also requires an ecosystem well-equipped with laboratories, preclinical testing as well as high performance computing infrastructure for molecular diagnostics, drug formulation, and AI based drug discovery, disease detection/prediction and characterization.

The implementation of this roadmap requires a diverse team of specialists, researchers, data scientists, bioinformaticians, clinicians, and regulatory experts who work in collaboration to translate the new medical innovations into practical applications. Therefore, a series of long- and short-term training programs will be designed to ensure proper implementation of this roadmap.

c) *Gene editing*

Gene editing technologies, such as CRISPR technologies, have the potential to revolutionize agriculture, medicine, and environmental sustainability. Ethiopia, with its rich biodiversity and agricultural heritage, is uniquely positioned to benefit from gene editing technologies. This roadmap outlines a comprehensive plan for Ethiopia's gene editing research and development over the next decade. The Ethiopian 10-year gene editing roadmap is guided by four overarching goals focusing on agricultural innovation, health improvement, environmental sustainability as well as

capacity building. The goal of agricultural innovation is to enhance food and nutritional security by developing climate-resilient crops and livestock through advanced gene editing technologies. The health improvement through gene editing addresses genetic disorders, infectious diseases, and malnutrition by leveraging gene editing for medical advancements. Environmental sustainability promotes biodiversity conservation and sustainable resource management and conservation through targeted gene editing applications. The capacity building aspect ensures the establishment of a robust research ecosystem with skilled human resources and cutting-edge infrastructure to sustain long-term innovation.

Gene editing roadmap promises transformative outcomes in agriculture, health, and the environment. In agriculture, climate-resilient crops and improved livestock breeds could boost food security, reduce post-harvest losses, and enhance nutritional quality. In healthcare, gene editing may enable treatments for genetic disorders like sickle cell anemia, combat malnutrition, and address infectious diseases through innovations like malaria-resistant mosquitoes. Environmentally, it offers tools for biodiversity restoration, ecosystem rehabilitation and sustainable farming by reducing pesticide use and improving water efficiency. Together, these advancements support a resilient and sustainable future. As shown in Figure 4.23, the R&D activities are structured into three phases over a ten-year period to ensure systematic progress in gene editing applications.

The first phase focuses on priority areas identification such as improving staple crops like teff and maize, enhancing livestock resilience, and addressing endemic diseases. Partnerships with international institutions will facilitate knowledge transfer and technical support, while ethical guidelines and regulatory frameworks will be developed to govern the responsible use of gene editing technologies. Pilot laboratories equipped with basic CRISPR and RNase complex technology tools will be established, and initial cohorts of researchers and technicians will be trained to build foundational capacity.

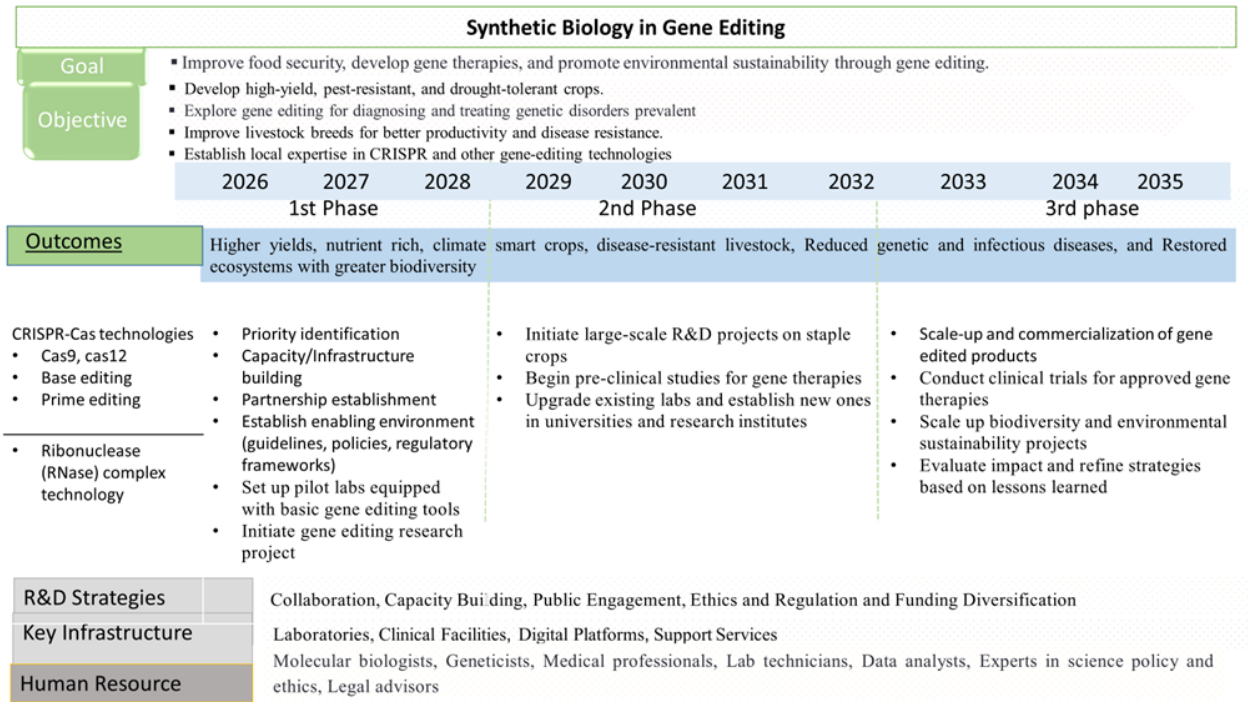


Figure 4-25 Gene editing roadmap and implementation strategy.

In the second phase, large-scale R&D projects will be launched to enhance the productivity and climate resilience of key crops and livestock. Pre-clinical studies will begin for gene therapies targeting genetic disorders and malnutrition, alongside biodiversity conservation initiatives using gene editing to restore endangered species or enhance ecosystem services. Training programs will expand to include advanced techniques such as base editing, prime editing, and bioinformatics, while existing labs will be upgraded and new ones established in universities and agricultural research centers to support growing demands.

The final phase focuses on field-testing and commercializing genetically edited crops and livestock, ensuring their accessibility to smallholder farmers. Clinical trials for approved gene therapies will be conducted, and production will be scaled up for public health interventions. Biodiversity and environmental sustainability projects will be expanded, with measurable outcomes such as restored habitats and reduced pest infestations. The impact of gene editing initiatives will be evaluated to refine strategies based on lessons learned, and efforts will transition to locally lead funding models to ensure financial sustainability beyond the 10-year roadmap.

Successful execution of the Gene Editing roadmap requires R&D strategies and capacity building. As an R&D strategy, this roadmap relies on collaborations with global leaders in gene editing to drive innovation, engaging the public through workshops and campaigns to build trust, and establishing transparent regulatory bodies to address ethical concerns and ensure compliance. Diversifying funding sources such as government budgets, international donors, and private investments will ensure financial sustainability. Considering the current global challenge in funding, transition to locally-led funding is important for long term sustainability. Additionally, prioritizing inclusivity in training and R&D activities will empower women and underrepresented groups, promoting equitable participation in the gene editing ecosystem. Another cornerstone for successful execution of the roadmap is to create a skilled workforce and self-sustaining research ecosystem capable of driving innovation in gene editing. This involves the following capacity building components:

To fully leverage gene editing technologies like CRISPR, a comprehensive human resource development strategy must be implemented, combining long-term academic training with short-term specialized programs to build capacity across multiple levels. Researchers require advanced training in CRISPR applications, bioinformatics, and gene therapy, while lab technicians need hands-on instruction in equipment operation and biosafety protocols. Policymakers and regulators must be educated on the ethical and legal implications of genome editing to develop appropriate governance frameworks, and trainers need updated curricula to effectively disseminate knowledge to students, farmers, and communities.

Structured training should include foundational CRISPR courses progressing to advanced techniques like base and prime editing, supplemented by practical internships and collaborative projects with international partners, while actively promoting gender equality and diversity in all programs. Community outreach initiatives are equally important to educate farmers about agricultural applications and healthcare providers about therapeutic uses, ensuring broad societal understanding and acceptance. This multi-pronged approach – combining specialized technical training, policy education, and public engagement – will create a skilled workforce capable of advancing gene editing innovation while maintaining ethical standards and social responsibility.

Key infrastructure development is another essential strategy to support advanced gene editing research and applications, requiring multi-tiered facility upgrades and digital transformation. This

includes constructing Biosafety Level 2/3 laboratories equipped with CRISPR-Case systems, next-generation DNA sequencers, and high-resolution imaging technologies for crop, livestock, and medical research. Parallel clinical infrastructure must establish GMP-compliant trial units for gene therapy development, adhering to international regulatory standards. Digital infrastructure should deploy secure cloud platforms with AI-powered genomic analysis tools, enabling collaborative data sharing and predictive modeling of editing outcomes. Complementary support systems must encompass ultra-low-temperature biobanks for sample preservation and specialized waste management solutions for biohazard containment, creating an end-to-end ecosystem that bridges basic research with translational applications while maintaining safety protocols.

d) Agriculture and environmental solutions

The roadmap aims to revolutionize agriculture and environmental management by leveraging engineered microbes to achieve sustainable soil health, pest control, pollution remediation, and carbon sequestration. The overarching goal is to replace chemical inputs with eco-friendly bio-based solutions while reducing environmental degradation and promoting sustainable practices. The overarching goal of this roadmap is to transform agriculture and environmental management through synthetic biology, specifically leveraging engineered microbes to develop sustainable solutions for soil health enhancement, targeted pest control, pollution remediation, and carbon sequestration.

By replacing chemical fertilizers with optimized biofertilizers and developing precision biopesticides, we aim to boost crop resilience while reducing agricultural chemical use by 40%. The initiative will deploy microbial bioremediation to rehabilitate contaminated soils and waterways, with parallel carbon sequestration programs to offset emissions. These bio-based innovations, supported by emissions reduction policies and a strengthened bioeconomy, will collectively advance Ethiopia's transition to climate-resilient food systems - ensuring simultaneous progress in food security, environmental restoration, and sustainable economic growth. As illustrated in Figure 4.26, the roadmap is strategically divided into three implementation phases.

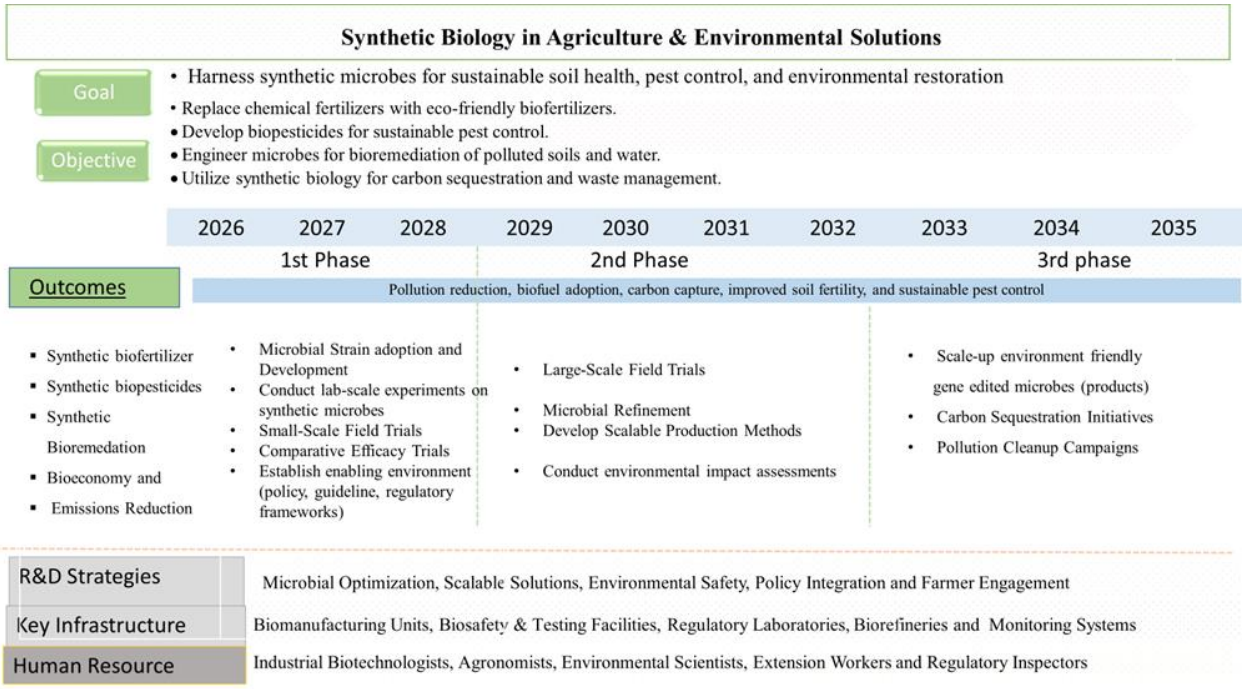


Figure 4-26 Agriculture & environmental solutions roadmap and implementation strategy.

The first phase focuses on laying the groundwork for research and development of agriculture & environmental solutions by identifying and optimizing beneficial microbial strains for agriculture and environmental restoration, focusing on traits such as drought tolerance, nitrogen fixation, and biodegradability using tools like synthetic biology. Controlled lab-scale experiments will evaluate the effectiveness, stability, and scalability of these strains under varying conditions, while assessing potential ecological risks.

Comparative efficacy trials will compare bio-based solutions like biofertilizers and biopesticides with chemical inputs, measuring parameters such as crop yield and environmental impact to refine formulations. Biosafety protocols will be developed to address risks like genetic drift or contamination, aligning Ethiopia's standards with global best practices. Policies will also be created to integrate synthetic biology into national regulations, promoting recyclability and incentivizing adoption through subsidies or tax breaks.

The second phase focus shifts to testing and refining microbial solutions in real-world conditions. Small-scale field trials will assess the performance of engineered biofertilizers, biopesticides, and bioremediation agents across diverse agro-ecological zones, incorporating feedback from farmers and stakeholders. Environmental impact assessments will evaluate the durability, biodegradability,

and long-term effects of these solutions on ecosystems, soil health, water quality, and biodiversity. Microbial refinement efforts will enhance traits like enzyme production and stress resistance, while scalable production methods will be developed using locally available materials to reduce costs. Partnerships with private companies and research institutions will establish pilot production facilities to ensure affordability for smallholder farmers. The final phase focuses on scaling up innovations and promoting nationwide adoption. Large-scale field trials will validate the reliability of microbial solutions under diverse conditions, finalizing formulations and region-specific recommendations.

Nationwide adoption will be encouraged through subsidies, training programs, and awareness campaigns, supported by strengthened extension services. Carbon sequestration initiatives will scale up the use of synthetic microbes for emissions reduction in agriculture and industry, integrating them into soil carbon sequestration programs and collaborating with international partners for funding and expertise. Pollution cleanup campaigns will restore polluted soils and water bodies using engineered bioremediation techniques, engaging local communities in cleanup efforts to degrade contaminants like heavy metals and pesticides. Together, these efforts aim to transform Ethiopia's agricultural and environmental landscapes, ensuring resilience, sustainability, and prosperity for future generations.

As illustrated in Figure 4.26, the research and development strategies to ensure successful execution of the roadmap involves continuously optimizing microbial strains for enhanced performance in biofertilizers, biopesticides, and bioremediation, while developing affordable, scalable production methods to make these solutions accessible to smallholder farmers. Biosafety protocols and environmental monitoring will minimize ecological risks, ensuring long-term safety for ecosystems and biodiversity. Collaboration with regulators will integrate synthetic biology into national policies, balancing innovation with public concerns about ethics and sustainability. Finally, engaging farmers through extension programs, pilot projects, and training will build trust and demonstrate tangible benefits, encouraging widespread adoption of bio-based solutions. Infrastructure and human resource development is also essential for successful implementation/execution of this roadmap. Infrastructure development includes establishing biomanufacturing units for large-scale production of biofertilizers, biopesticides and

bioremediation agents, alongside biosafety and testing facilities to evaluate the efficacy and environmental impact of microbial solutions.

Regulatory frameworks are also essential to ensure compliance with national and international standards, while biorefineries will convert agricultural waste into value-added products like biofuels and bioplastics, advancing the circular bioeconomy. Additionally, integrated digital monitoring systems will track soil health, emissions, and ecosystem recovery, enabling data-driven decision-making. Further, the roadmap prioritizes building specialized expertise through targeted training programs for in different roles: (1) biotechnologists to engineer microbial solutions, (2) agronomists to optimize field implementation, (3) environmental scientists to lead large-scale bioremediation, (4) extension workers to translate research into farmer-friendly practices, and (5) regulatory specialists to ensure compliance with biosafety standards.

e) Bio-manufacturing

This roadmap aims to position Ethiopia as a regional leader in sustainable bio-manufacturing by leveraging cutting-edge technologies like microbial fermentation, DNA synthesis, and enzyme production to build a competitive bioeconomy. The initiative will reduce reliance on non-renewable resources through bio-based alternatives. By fostering innovation in industrial biotechnology, the program will simultaneously address several environmental challenges - reducing greenhouse gas emissions, plastic waste, and fossil fuel dependence - while improving public health through affordable biopharmaceuticals.

As illustrated in Figure 4.27, the roadmap is strategically divided into three implementation phases. In the first phase, the roadmap focuses on establishing the foundational infrastructure, policies, and human resources required for synthetic bio-manufacturing. This includes developing national policies supporting bio-manufacturing, such as biosafety regulations, intellectual property rights, and export incentives, while aligning with international standards like ISO certifications for synthetic biology-based products.

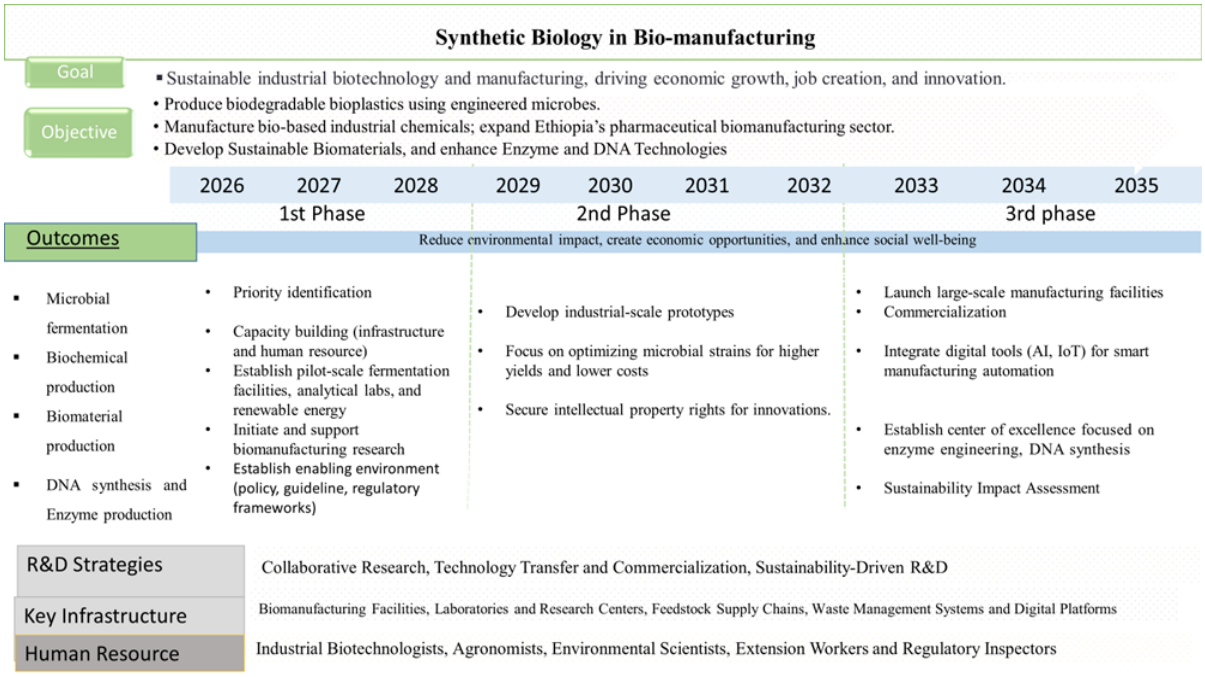


Figure 4-27 Bio-manufacturing roadmap and implementation strategy.

The integrated approach will empower marginalized groups, strengthen Ethiopia's STEM capacity, and establish the nation as a model for sustainable development in Africa. Infrastructure development will involve setting up pilot-scale fermentation facilities and analytical labs equipped with bioreactors, chromatography systems, and mass spectrometers, alongside renewable energy integration systems powered by solar or biomass. Capacity building will prioritize training scientists, engineers, and technicians in synthetic biology, metabolic engineering, and bioprocessing, while launching MSc/PhD programs in collaboration with global institutions. Feasibility studies and pilot projects will explore producing bioplastics, bio-based chemicals, and biomaterials using locally available feedstock such as agricultural residues and sugarcane molasses. Public awareness campaigns, workshops, and stakeholder engagement initiatives will promote synthetic bio-manufacturing as a sustainable economic opportunity and foster collaboration among government agencies, private sector players, and local communities.

The second phase aims to scale up synthetic bio-manufacturing capabilities and diversify product portfolios. Key activities include engineering microbes to produce biodegradable bioplastics like Polyhydroxyalkanoates (PHAs) and Polylactic Acid (PLA) using optimized feedstocks, followed by scaling up production in pilot plants and conducting market testing. Synthetic biology tools will be used to design metabolic pathways for manufacturing organic acids, solvents, and specialty

chemicals, while enzyme-based catalysts will enhance efficient biomass conversion. The pharmaceutical sector will focus on localizing the production of antibiotics, vaccines, and therapeutic proteins using recombinant DNA technology, alongside developing low-cost diagnostic kits tailored to local health challenges.

Sustainable biomaterials for packaging, textiles, and construction will be prototyped, with life cycle assessments validating their environmental benefits. Enzyme and DNA technologies will advance through optimized enzyme production for industrial applications and investment in automated platforms for custom DNA synthesis and metabolic pathway design. Market expansion efforts will identify global markets for bio-based products, ensuring alignment with export opportunities and obtaining necessary certifications for exporting synthetic bio-based chemicals and biomaterials.

Final phase three seeks to achieve full commercialization of synthetic bio-manufactured products and establish Ethiopia as a regional leader in sustainable biotechnology. This phase will transition from pilot-scale to commercial-scale production of bioplastics, synthetic bio-based chemicals, and synthetic biomaterials, while expanding pharmaceutical biomanufacturing capacity to meet domestic and regional demand. Strengthening the innovation ecosystem will involve expanding innovation hubs and establishing incubators/accelerators for startups in synthetic bio-manufacturing, promoting open-access databases and shared platforms for genomic data and metabolic pathway models. Research excellence will be driven by world-class R&D centers focused on enzyme engineering, DNA synthesis, and metabolic pathway optimization, facilitating seamless technology transfer from research centers to industry. Sustainability impact assessments will measure reductions in greenhouse gas emissions, plastic waste, and fossil fuel dependency, with annual sustainability reports highlighting progress toward environmental goals. Through this roadmap, Ethiopia aims to harness its rich biodiversity and agricultural resources to drive economic growth, job creation, and environmental sustainability, positioning itself as a global hub for innovative and sustainable synthetic bio-manufacturing solutions.

Research and development Strategies focuses on high-impact areas like microbial engineering, metabolic pathway optimization, enzyme development, and DNA synthesis, with investments in producing biodegradable bioplastics, bio-based chemicals, pharmaceuticals, and sustainable biomaterials. Collaborative research models will foster partnerships between universities, private

companies, and international organizations to access cutting-edge technologies. Mechanisms for technology transfer and commercialization will support startups and SMEs in scaling innovations, while open innovation platforms will enable shared genomic data and synthetic biology tools. Sustainability-driven R&D will prioritize life cycle assessments (LCAs) and solutions to reduce greenhouse gas emissions, plastic waste, and fossil fuel dependency, ensuring environmentally beneficial outcomes.

Capacity building strategy lies in developing world-class infrastructure to enable cutting-edge bio-manufacturing. This includes establishing: (1) biomanufacturing facilities with modular fermentation systems and downstream processing units for scalable production; (2) advanced research laboratories equipped for microbial engineering, DNA synthesis, and analytical characterization (HPLC, GC-MS, NMR); (3) sustainable feedstock supply chains utilizing agricultural residues through farmer-industry partnerships; and (4) digital transformation platforms integrating AI-driven process optimization with collaborative research databases. Further, the roadmap human resource development strategy focuses on building a skilled workforce through targeted training initiatives focuses on: creating specialized academic programs in industrial biotechnology; facilitating international knowledge exchange through fellowships and expert collaborations; supporting bio-entrepreneurs via incubators and funding mechanisms; and promoting inclusive participation through targeted STEM education for women and marginalized communities. Together, these elements will create an innovation ecosystem with a skilled workforce that bridges scientific discovery with industrial-scale production.

4.2.4 Advanced Materials

This section outlines the strategic roadmap and implementation strategies designed to realize the roadmap’s goals. The technologies are aimed to transform sectors such as agriculture, healthcare, and manufacturing, while ensuring technological advancements support Ethiopia’s transformation agenda to achieve Sustainable Development Goals (SDGs). A key priority will be advancing materials, particularly in semiconductors, electronic, magnetic and optoelectronic materials. They are foundational to achieving self-reliance in industries such as electronics, lighting, telecommunications, and renewable energy systems.

Special emphasis is on advanced energy materials, advanced green materials, advanced construction materials and minerals based advanced materials for different applications. The roadmap also implements a strategy that fosters an innovation ecosystem through prioritizing infrastructure development and capacity building through education and training to develop a skilled workforce capable of addressing local challenges. A clear implementation strategy will be outlined to attract domestic and international investment in R&D to enhance the country's technological capabilities.

a) Advanced energy materials

Advanced energy materials constitute a main subset of advanced materials, specifically engineered to enhance the performance, functionality, and efficiency of modern devices across various industries. These materials such as graphene, quantum dots, perovskites, conductive polymers, and carbon synthesized from biomass exhibit exceptional properties like high electrical conductivity, flexibility, thermal stability, and optical tunability, making them indispensable for cutting-edge applications. Beyond electronics, advanced device materials such as shape-memory alloys and biocompatible polymers are transforming healthcare by enabling smart implants, stents, and wearable sensors. These materials are often developed using advanced techniques like nanotechnology, AI-driven modeling, and computational design to meet the precise demands of specific applications.

Advanced battery materials, including silicon anodes and solid-state electrolytes, are revolutionizing energy storage by improving capacity, safety, and lifespan in lithium-ion batteries. Beyond solar energy and batteries, materials like hydrogen-absorbing alloys and MOFs (Metal-Organic Frameworks) are advancing hydrogen storage and carbon capture technologies which are important for clean energy transitions. These materials leverage cutting-edge techniques such as nanotechnology and computational modeling to optimize their properties for specific energy applications.

Figure 4.28 highlights the strategic roadmap and implementation plan of advanced energy material technologies. The main goal is to develop and utilize advanced materials for energy generation, storage, conversion and opto electronic devices to enhance the performance and efficiency of energy and electronics devices. The objectives of AMs in the context of energy and devices focus

on several areas. These include improving durability and efficiency for reliable functioning in adverse environments, as well as developing recyclable and biodegradable materials specifically designed for renewable energy applications. Another key objective is the development of smart materials that can react to environmental changes and seamlessly integrate with Internet of Things (IoT) technologies. Strategic roadmap of advanced energy materials involves three implementation phases.

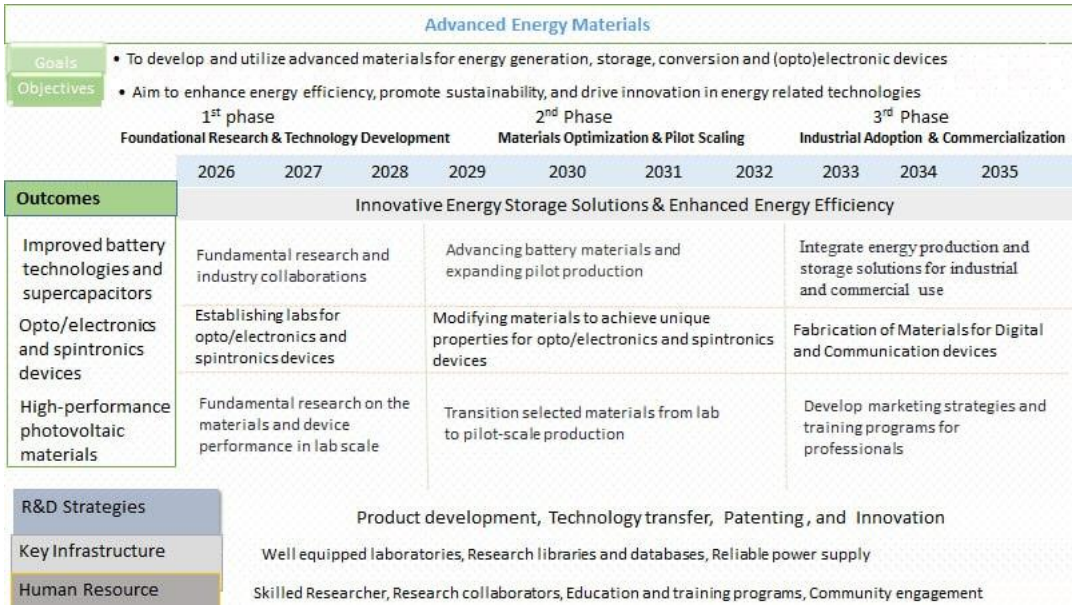


Figure 4-28 Advanced energy materials roadmap and implementation strategy.

The initial phase focuses on foundational research and technology development of efficient energy storage materials such as improved batteries and supercapacitors, which significantly enhance the performance of consumer electronics and electric vehicles. This involves optimizing existing materials such as lithium-ion batteries, perovskite solar cells, and supercapacitors. Additionally, the roadmap will put concerted effort to create lightweight materials for device casings that help reduce energy consumption during the manufacturing process. The second phase focuses on materials optimization and pilot scaling advancements in photovoltaic technologies that are expected to lead to higher efficiency solar panels, making renewable energy more accessible and cost-effective for consumers. This involves building on foundational advancements, the shift of R&D toward next-generation materials like solid-state batteries, sodium-ion batteries and organic photovoltaics, aiming for scalable energy storage and harvesting applications. Strategic partnerships with renewable energy companies, universities and other private and governmental

institutions will facilitate the deployment of these materials in grid-scale storage materials and off-grid solutions. This phase will also target patents for novel material designs such as hybrid nanostructures or bio-inspired energy-harvesting systems to solidify competitive advantages.

The final phase focuses on the industrial adoption and commercialization of pioneering revolutionary technologies such as quantum-dot solar cells, graphene-based spintronic devices, hydrogen storage alloys, and self-healing batteries that utilize the electron's spin and charge. These technologies offer lower energy consumption, faster switching speeds, greater data density, non-volatility, and ultra-efficient, sustainable energy systems. They are drastically reducing reliance on fossil fuels, lowering carbon emissions, and accelerating the adoption of next-generation energy devices with unprecedented efficiency. Together, these advancements will drive a global movement toward scalable, sustainable energy solutions.

As R&D and implementation strategy, the roadmap aims to establish strategic partnerships with renewable energy companies and universities to facilitate the deployment of these materials in grid-scale storage systems and off-grid solutions. Through this partnership, breakthroughs of the road map including smart grids and carbon-neutral cities will be integrated into global infrastructure through collaborations with industry leaders and policymakers. Additionally, the roadmap will also emphasize on patenting incremental innovations, including material doping strategies for enhanced conductivity or stability to secure early-stage intellectual property through establishing a robust patent portfolio. Further, the roadmap prioritizes technology transfer and integrates these advanced energy storage solutions into consumer electronics and electric vehicles through collaborating with industries.

A strong infrastructure is essential to drive innovation in advanced energy materials. Key priorities include establishing advanced laboratories for materials synthesis and testing, pilot-scale manufacturing facilities to support scale-up and industrialization, and high-performance computing centers for predictive modeling and design. Shared research hubs and innovation centers will promote collaboration between academia, industry, and government. In addition, smart energy testbeds and digital platforms for data management and AI-driven analysis will accelerate development and commercialization. These infrastructure investments will enhance national capabilities in clean energy technologies and support long-term competitiveness in the global

materials sector. To support the long-term growth of advanced energy materials, this roadmap plan prioritizes capacity building through targeted education by providing training curriculum, workforce training and skills development in collaboration with universities and other governmental and private companies. It focuses on equipping scientists, engineers, and technicians with expertise in areas such as nanomaterials, electrochemistry, computational modeling and sustainable fabrication techniques. Strategic investments will be made in academic-industry partnerships, hands-on training facilities and professional development programs to ensure a skilled and innovative workforce. Over the next decade, initiatives will also promote diversity, entrepreneurship and global collaboration to strengthen national and regional capabilities in energy materials research and manufacturing.

b) Advanced construction materials

AMs allow development of cutting-edge technologies and eco-friendly solutions designed to incorporate innovative features such as improved strength, thermal resistance, chemical stability and adhesive properties, enabling them to excel in even the most demanding environments. For instance, thin film coatings applied through techniques like physical vapor deposition (PVD) or chemical vapor deposition (CVD) will be used to create ultra-thin protective layers on surfaces.

They are widely employed in high-tech industries like microelectronics, aerospace, and medical devices, where precision and reliability are paramount. These coatings, which may include zinc-based galvanization, epoxy resins, or ceramic-based solutions, act as a barrier against moisture, chemicals and other corrosive agents, significantly extending the lifespan of infrastructure. In addition, as the global construction industry seeks to reduce its environmental footprint, the adoption of eco-friendly construction materials and low carbon materials has become a priority. These materials are designed to minimize resource depletion, lower carbon emissions, and improve building performance while supporting sustainable development goals. Figure 4.29 shows the strategic roadmap and implementation of advanced construction materials. The main goals of the strategic roadmap are to develop high performance materials that meet the demanding requirements of construction applications.

The objective of this roadmap is to develop high performance materials that improve durability, efficiency and sustainability. This involves developing high-performance materials with improved

strength and corrosion resistance for demanding environments, prioritizing sustainable and recyclable materials to minimize environmental impact. In the short term, this roadmap focuses on selecting and enhancing advanced materials to extend product lifespans, reduce maintenance costs, and optimize manufacturing efficiency through techniques like additive manufacturing and thin-film coatings. Additionally, this phase aims to upgrade existing materials with additional functionality/properties such as antimicrobial coatings, hydrophobic surfaces and thermal insulation for specialized applications in healthcare, textiles and consumer goods.

As we progress into the medium term, the roadmap shifts its focus toward developing high-performance alloys, composites, and smart materials capable of responding to external stimuli such as temperature-sensitive polymers, piezoelectric sensors, and adaptive coatings to meet stringent demands in aerospace, biomedical, automotive, and construction applications. This phase will also prioritize the creation of futuristic materials with breakthrough functionalities, including advanced adhesives and self-assembling nanomaterials for corrosion resistance.

Looking ahead to the long term, the integration of added functionality materials will make significant contributions to industry to enhance operational efficiency and productivity. This period will also see the creation of a robust framework for sustainable industrial practices, ensuring that the life cycle impacts of materials are minimized, ultimately leading to a more responsible and efficient industrial sector. To accelerate innovation and commercialization, collaborative networks between academia and industry will be established, fostering dynamic knowledge exchange and resource sharing. Concurrently, patenting efforts will protect key advancements in multifunctional materials, particularly those with integrated sensing and actuation capabilities, ensuring a competitive edge in the evolving advanced materials landscape. Further, the roadmap prioritizes technology transfer to accelerate market adoption while securing patents for innovations.

The R&D and implementation strategy for the green materials roadmap, as illustrated in Figure 4.29, is divided into three distinct phases. In the short-term, the focus will be on enhancing existing materials with advanced features such as antimicrobial coatings, hydrophobic surfaces and thermal insulation for niche applications. These functional materials will be introduced into healthcare, textiles and consumer goods to improve product performance. Concurrently, patents will be filed

for innovations in surface modification techniques, thin-film coatings and composite reinforcements.

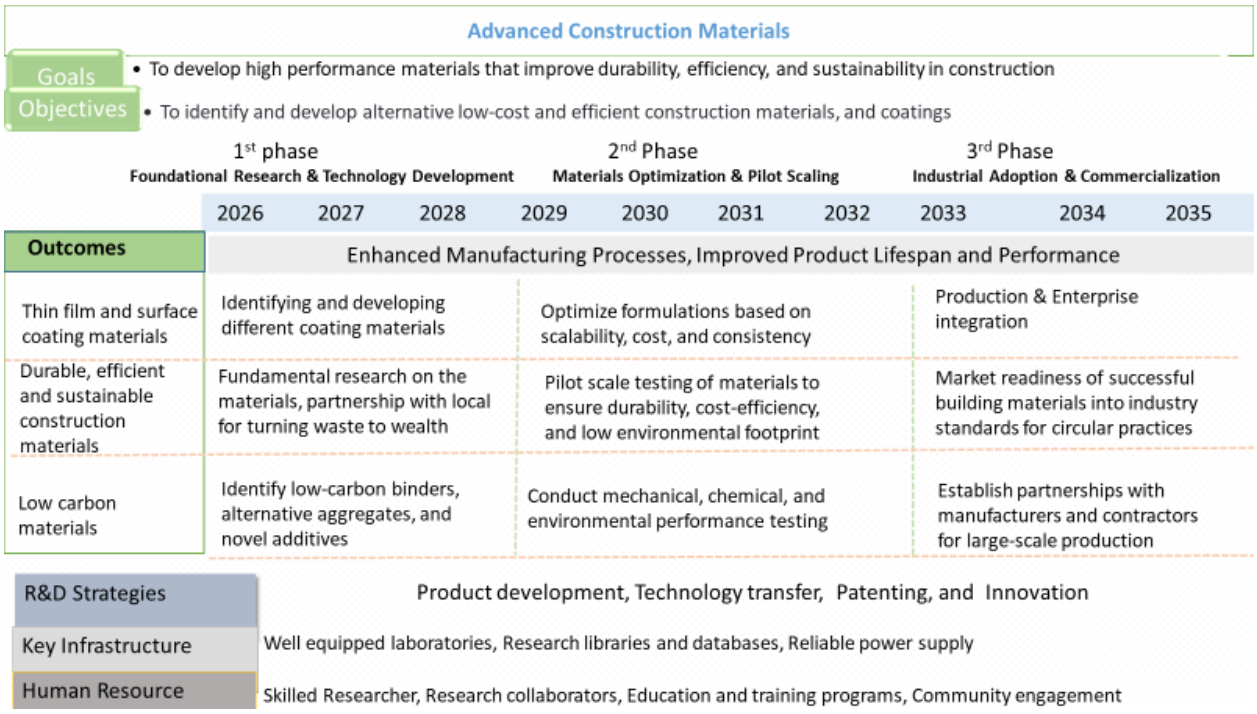


Figure 4-29 Advanced construction materials roadmap and implementation strategy.

In the medium-term, the development efforts will shift toward smart materials capable of responding to external stimuli, including temperature-sensitive polymers, piezoelectric sensors and adaptive coatings for aerospace and biomedical applications. Additionally, futuristic materials such as self-assembling nanomaterials and advanced adhesives will be explored. In the long-term, these advanced materials focused on reducing embodied carbon, enhancing performance, and promoting circular economy principles. This initiative prioritizes areas such as low-carbon cements by using resource-available materials like Ethiopia's volcanic ash, kaolin, and pumice, bio-based materials, recycled composites, and carbon-negative technologies. The phased approach includes discovery, optimization, demonstration, and commercialization stages, supported by industry collaboration, policy alignment with Ethiopian Minerals Development Policy, Science Technology and Innovation (STI) roadmap, and Education Sector Development Program (ESDP) and Digital Innovation. By driving sustainable material solutions, this plan aims to support global climate goals and position the construction sector toward a net-zero future.

A resilient infrastructure is vital to support the research, development, and deployment of advanced construction materials. Key requirements include modern materials testing laboratories equipped for structural, thermal and durability analysis; pilot-scale production facilities to transition lab innovations to industry-ready solutions; and digital platforms for computational modeling, BIM integration and AI-driven design optimization. Effective implementation of a strategic plan for advanced construction materials requires strong capacity building across education, training and workforce development. This includes equipping engineers, architects, technicians and construction professionals with expertise in sustainable materials science, smart manufacturing, digital design tools (such as BIM) and life-cycle performance analysis. Investment in academic-industry partnerships, vocational training programs, and continuing professional development will ensure a skilled and adaptable workforce. Additionally, promoting interdisciplinary collaboration, innovation labs, and knowledge-sharing platforms will enhance local and national capabilities to adopt and scale next-generation construction materials and technologies.

c) *Advanced green materials*

Advanced green materials are revolutionizing multiple sectors by combining sustainability with cutting-edge functionality to address global challenges. Self-healing materials, for instance, are being developed to extend the lifespan of products and reduce waste by autonomously repairing damage caused by wear, corrosion or environmental exposure. These materials hold immense potential in industries such as construction, automotive, and electronics, where durability and resource efficiency are crucial. In agriculture, smart materials are being engineered to improve agricultural productivity by enabling precise monitoring and optimization of growth conditions.

Meanwhile, in the biomedical field, advanced green materials are transforming healthcare through innovations such as biodegradable implants, tissue-engineered scaffolds and drug-delivery systems that reduce reliance on non-renewable resources and minimize post-surgical waste. By integrating principles of sustainability, functionality and adaptability. These materials address pressing environmental concerns for a more resilient and resource-efficient future across diverse domains.

The development of these materials often integrates advanced technologies like nanotechnology and AI-driven design to optimize their sustainability and performance. By addressing global challenges such as climate change, resource depletion, and pollution, advanced green materials are

paving the way for a more sustainable future, enabling industries to transition toward eco-friendly practices without compromising efficiency or innovation. Figure 4.30 highlights the strategic roadmap of green materials. The main goal of the roadmap is to promote sustainability and reduce environmental impact throughout the lifecycle of materials while maintaining high performance and functionality across various applications. The objectives are minimizing environmental impact throughout their entire lifecycle and prioritize sustainability. This includes sourcing materials from renewable resources, ensuring non-toxicity and safety for human health, maximizing recyclability and biodegradability, and enhancing energy efficiency during both production and use. Ultimately, the roadmap envisioned to develop /produce high-performing materials that are environmentally friendly.

The R&D and implementation strategy for the green materials roadmap, as illustrated in Figure 4.30, is divided into three distinct phases. In the short-term, the roadmap focuses on optimizing biodegradable polymers, plant-based composites, recyclable packaging materials, and value-added minerals to facilitate immediate industrial adoption. Particularly, it involves identifying and setting up laboratory facilities for the production of greener materials, including advancements in water purification technologies. Moreover, the roadmap emphasizes the development of processes that minimize environmental impact while maximizing efficiency and sustainability. The creation of value-added products derived from these materials is also a key priority to enhance their economic viability and reduce waste.

In the medium term, the roadmap concentrates on scaling up the development and production of green materials, such as self-healing polymers, bio-based foams, and carbon-negative concrete, for use in large-scale infrastructure projects, automotive manufacturing and agriculture. This phase also involves shifting R&D efforts towards improving the productivity of smart materials and biomedical materials through innovative practices and technologies. Additionally, the roadmap aims to enhance post-harvest processes to reduce losses and improve food quality, as well as implement better storage, processing, and distribution methods to ensure that food reaches consumers and the health sector efficiently and sustainably.



Figure 4-30 Advanced green materials roadmap and implementation strategy.

In the long-term, the roadmap shifts its focus towards engineering fully sustainable, multi-functional materials that integrate energy generation, sensing and biodegradability for a zero-waste future. Ultimately, the roadmap aims to achieve significant progress in the production of biomaterials, smart materials, and self-healing materials to replace traditional ones, reducing pollution and toxic materials, and promoting a more sustainable and environmentally friendly economy.

As an R&D strategy, this roadmap aims to collaborate with universities and manufacturers to replace single-use plastics and chemicals with sustainable alternatives across key sectors, including packaging, agriculture, healthcare, and construction. Furthermore, it seeks to lead global efforts in green material innovation by securing patents for disruptive technologies, such as programmable biomaterials and carbon-capture-enabled structures, ultimately driving a more sustainable future.

This strategic plan for advanced green materials requires key infrastructure: modern R&D labs, sustainable industrial parks powered by renewables, and efficient supply chain networks with smart logistics. Recycling and waste management systems must support material recovery. Technology centers, training facilities, and testing labs for quality and environmental compliance are essential.

International collaboration hubs and financial support mechanisms will further enable growth. Together, these elements create a sustainable ecosystem for green materials in Ethiopia.

Building skilled human capital is essential to drive innovation in advanced green materials. This includes training scientists, engineers, technicians and entrepreneurs in sustainable materials design, circular manufacturing, life-cycle analysis and eco-friendly production techniques. Partnerships between universities, technical institutes and industries will ensure relevant education and hands-on experience. Professional development programs, workshops and international collaborations will enhance expertise. Promoting gender inclusion and supporting startups and Small and Medium-sized Enterprises (SMEs) will further strengthen local capabilities. These efforts will create a competent, innovative workforce ready to lead Ethiopia's transition to a green materials economy.

d) Minerals based advanced materials

Mineral-based materials are naturally occurring inorganic substances derived from minerals. These materials are widely used in construction, electronics, energy, and environmental sectors due to their durability, abundance and versatile properties. Common types include silicates (used in glass and ceramics), carbonates (like limestone for cement), oxides (such as hematite for iron production), clays (for pottery and drilling) and zeolites (used in water purification and catalysis). They also include metallic ores that provide essential metals like copper, aluminum, and lithium. While these materials offer cost-effective and high-performance solutions, their extraction and processing can harm the environment.

Mineral-based materials in Ethiopia refer to a wide range of products and raw materials extracted from the country's rich and diverse mineral resources. These include valuable metallic minerals such as gold, iron, nickel and tantalum, which are important both for local industrial use and as significant export commodities that contribute to foreign exchange earnings. In addition, Ethiopia possesses abundant industrial minerals like limestone, kaolin, gypsum, and silica sand, which serve as inputs for the construction sector-supporting the production of cement, ceramics, glass, and other building materials. Energy minerals such as coal, natural gas, and emerging resources like lithium and graphite play a growing role in meeting Ethiopia's energy needs and supporting industrial applications. The country is also known for its gemstones, including opals and sapphires, which

add value through export markets. Furthermore, dimension and decorative stones like marble and granite are widely used in construction and architectural projects, enhancing both functionality and aesthetics.

Recognizing the strategic importance of these mineral-based materials, the Ethiopian government has prioritized the exploration, sustainable development, and responsible management of mineral resources to stimulate economic growth, diversify the economy, create employment opportunities, and accelerate industrialization. By leveraging its mineral wealth, Ethiopia aims to build a robust industrial base, reduce dependency on imports, and enhance its position in regional and global markets. Figure 4.31 presents the strategic roadmap for mineral-based advanced materials. The primary objective of this roadmap is to develop sustainable, high-performance advanced materials from minerals through improved extraction and processing technologies. Key goals include enhancing mineral recovery techniques, their utilization in development of advanced mineral based materials to ensure environmentally responsible production.

The R&D and implementation strategy for the mineral based materials roadmap, as illustrated in Figure 4.31, is divided into three distinct phases. In the short-term, the focus will be on exploration and small-scale validation, prioritizing high-potential minerals like silica and kaolin while establishing pilot plants for beneficiation and refining processes. This phase includes conducting cradle-to-gate life-cycle assessments to identify environmental hotspots and targeting a 20% reduction in production costs through process assessment. The medium-term shifts to scaling and optimization, expanding pilot plants into modular processing hubs and developing first-generation advanced materials like battery-grade lithium and geopolymer cement. This stage emphasizes achieving cost parity with imports through renewable energy integration and refining LCAs to incorporate circular economy metrics.

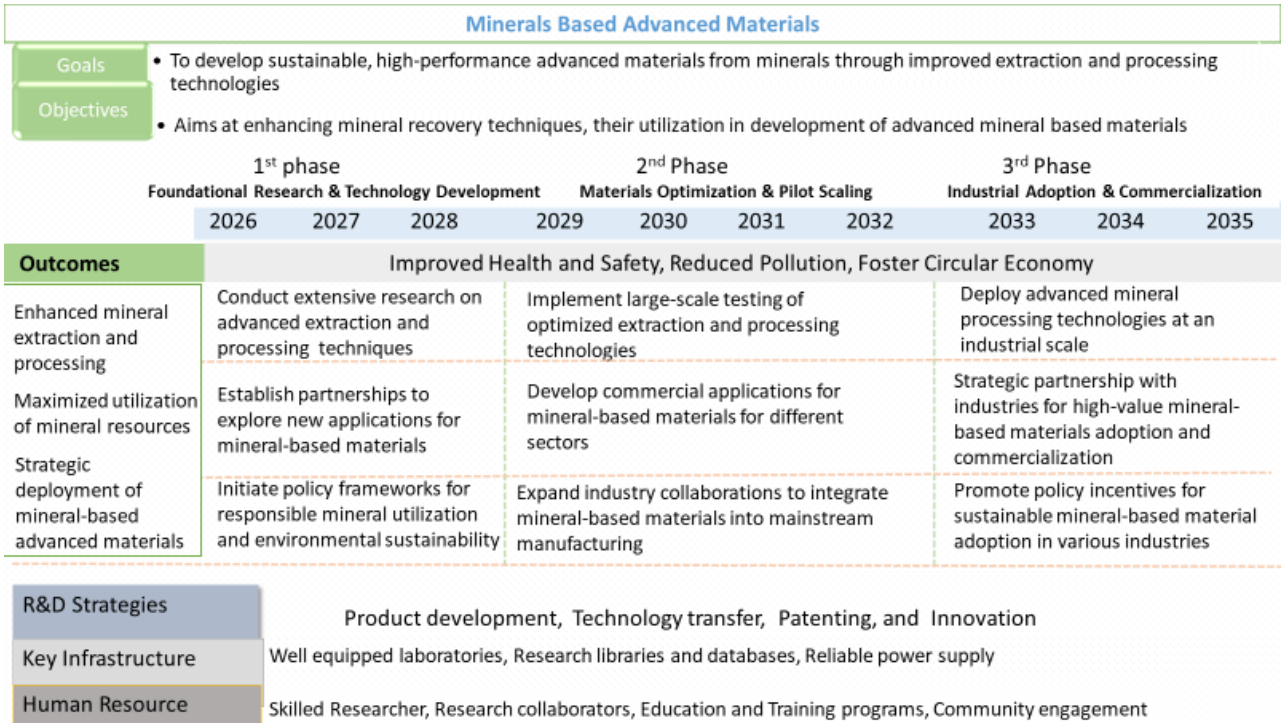


Figure 4-31 Minerals based advanced materials roadmap and implementation strategy.

The long-term vision aims for sustainable industrialization, establishing full-scale mineral parks for end-to-end production of high-value materials and transitioning to zero-waste facilities with closed-loop systems. This final phase targets net-zero mineral production through innovations like mineral carbonation and positions Ethiopia as a regional hub for green mineral-based materials, capable of supplying 10-15% of regional clean-tech demand. Throughout all phases, success will depend on supportive policies, workforce development, and strategic global partnerships to transform Ethiopia's mineral wealth into sustainable economic value.

A robust infrastructure is essential to support the sustainable development of mineral-based advanced green materials. Key requirements include modern research and testing laboratories equipped for mineral characterization, material synthesis and environmental impact analysis. Establishing pilot-scale processing and manufacturing facilities will enable scalable, low-carbon production. Industrial parks powered by renewable energy should be developed to attract eco-friendly mineral processing and downstream industries. Efficient transportation networks, storage facilities, and digital logistics systems are vital for raw material supply chain management. Recycling and waste recovery centers will support circular economy practices. In addition,

technology innovation hubs, training centers, and quality control testing labs will drive local capacity and global competitiveness in sustainable mineral-based materials.

Developing mineral-based advanced green materials requires building a skilled and innovative workforce. This includes training geologists, material scientists, engineers, and technicians in sustainable mineral processing, eco-friendly material synthesis, life-cycle assessment, and circular production methods. Collaboration between universities, technical institutions, and industry will ensure relevant education and hands-on experience. Strengthening vocational training, offering professional development programs, and promoting international partnerships will enhance local expertise. Supporting startups, SMEs and community engagement initiatives will broaden participation and innovation.

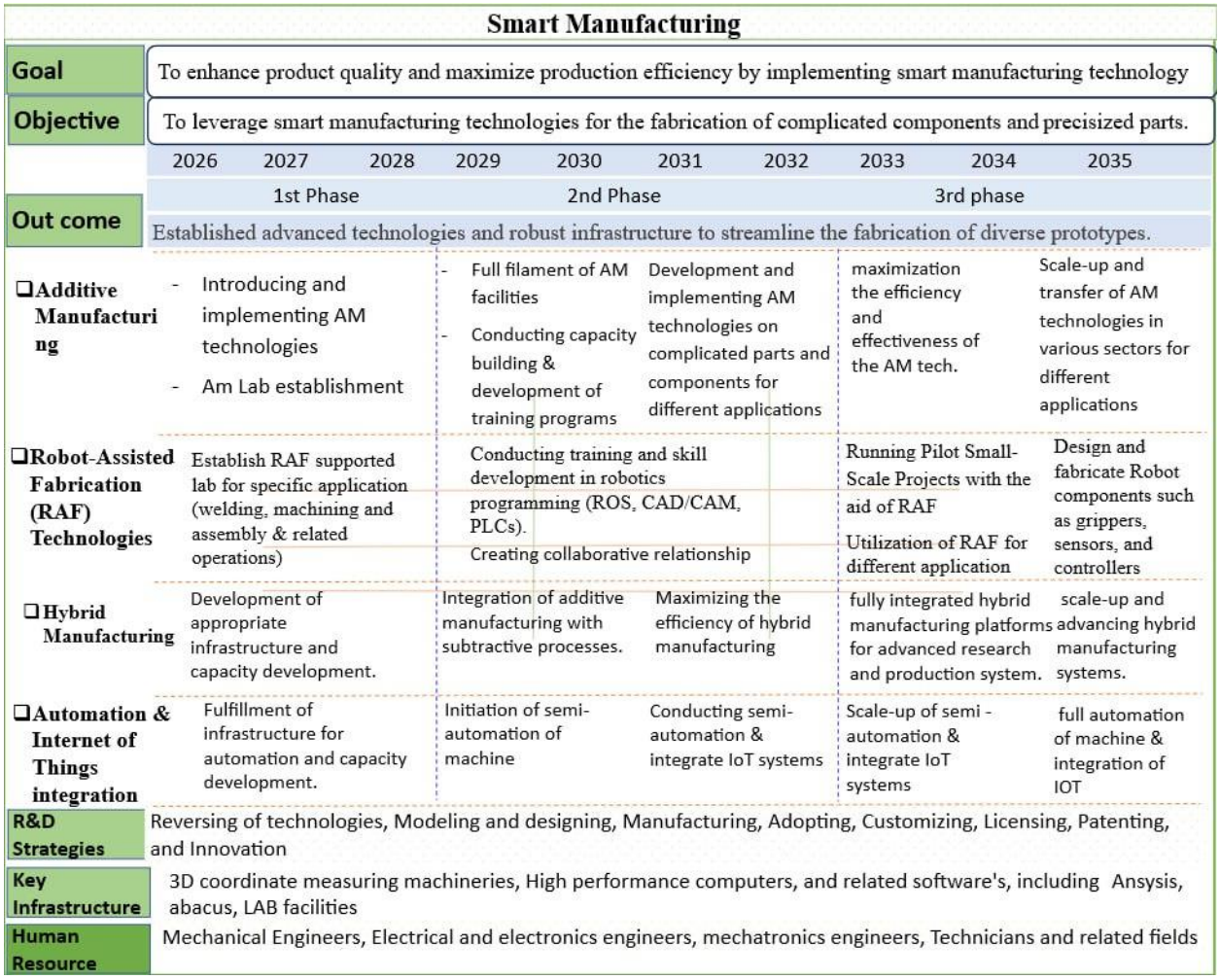
4.2.5 Advanced Manufacturing Technology

It represents a transformative shift in industrial production, integrating cutting-edge tools and methodologies to enhance efficiency, precision, and innovation. Two major categories under this umbrella are Smart Manufacturing Technology (SMT) and Predictive Engineering, each incorporating specialized technologies that redefine modern production.

a) Smart manufacturing technology

leverages digital and automated systems to optimize production processes, reduce waste, and improve flexibility as shown in Figure 4.32, which will be implemented over the coming ten years. A key component of SMT is Additive Manufacturing (3D Printing) technology, which builds products layer-by-layer, enabling complex geometries, reduced material waste and rapid prototyping. Industries such as manufacturing, aerospace and healthcare benefit from its ability to produce lightweight and customized components. Robot-assisted fabrication further enhances precision and speed, with collaborative robots working alongside humans to perform repetitive or hazardous tasks, improving workplace safety and productivity. In addition, to meet rigorous engineering standards, hybrid fabrication will be employed to refine additive manufacturing technology components via subtractive processes. A primary research application of this technology is, for the development of "material-substitution" strategies: utilizing hybrid methods and advanced surface coatings to replace expensive stainless steel agricultural components, bio

medical equipment and expensive small part of vehicle components with low-cost, durable alternatives.



Smart Manufacturing										
Goal	To enhance product quality and maximize production efficiency by implementing smart manufacturing technology									
Objective	To leverage smart manufacturing technologies for the fabrication of complicated components and precisized parts.									
	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
	1st Phase			2nd Phase				3rd phase		
Out come	Established advanced technologies and robust infrastructure to streamline the fabrication of diverse prototypes.									
❑Additive Manufacturing	- Introducing and implementing AM technologies - Am Lab establishment			- Full filament of AM facilities - Conducting capacity building & development of training programs		Development and implementing AM technologies on complicated parts and components for different applications		maximization the efficiency and effectiveness of the AM tech.		Scale-up and transfer of AM technologies in various sectors for different applications
❑Robot-Assisted Fabrication (RAF) Technologies	Establish RAF supported lab for specific application (welding, machining and assembly & related operations)			Conducting training and skill development in robotics programming (ROS, CAD/CAM, PLCs). Creating collaborative relationship				Running Pilot Small-Scale Projects with the aid of RAF Utilization of RAF for different application		Design and fabricate Robot components such as grippers, sensors, and controllers
❑Hybrid Manufacturing	Development of appropriate infrastructure and capacity development.			Integration of additive manufacturing with subtractive processes.		Maximizing the efficiency of hybrid manufacturing		fully integrated hybrid manufacturing platforms for advanced research and production system.		scale-up and advancing hybrid manufacturing systems.
❑Automation & Internet of Things integration	Fulfillment of infrastructure for automation and capacity development.			Initiation of semi-automation of machine		Conducting semi-automation & integrate IoT systems		Scale-up of semi - automation & integrate IoT systems		full automation of machine & integration of IOT
R&D Strategies	Reversing of technologies, Modeling and designing, Manufacturing, Adopting, Customizing, Licensing, Patenting, and Innovation									
Key Infrastructure	3D coordinate measuring machineries, High performance computers, and related software's, including Ansysis, abacus, LAB facilities									
Human Resource	Mechanical Engineers, Electrical and electronics engineers, mechatronics engineers, Technicians and related fields									

Figure 4-32 Smart manufacturing roadmap and implementation strategy.

- *Additive Manufacturing Technologies (ADM):* For the implementation of this, the first phase focuses on introducing and implementing ADM technologies in selected application areas, such as manufacturing, aerospace, healthcare and automotive industries. Key activities include assessing industry needs, procuring entry-level 3D printers e.g., FDM and Stereolithography (SLA) machines, and setting up dedicated ADM labs in research institutions and manufacturing hubs. Early applications may involve rapid prototyping, custom tooling and low-volume production of simple components. For example, medical labs may begin producing patient-specific surgical guides, while automotive firms adopt ADM for lightweight jigs and fixtures. Establishing partnerships with ADM machine suppliers. By the second phase, the focus shifts

to scaling up ADM capabilities by deploying industrial-grade 3D printers e.g., Selective Laser Sintering - SLS, Direct Metal Laser Sintering (DMLS), and expanding material options (polymers, metals, and composites). A full-fledged ADM facility is established, integrating post-processing equipment (CNC finishing, heat treatment) for higher-quality outputs. Concurrently, capacity-building programs are launched including technical workshops, certification courses and workforce training in collaboration with universities and industry leaders. This phase ensures that engineers and technicians gain expertise in design for additive manufacturing, process optimization and quality control. In the third phase, ADM technology is leveraged for high-complexity and high-performance applications. Advanced techniques such as multi-material 3D Printing, Binder Jetting, and Electron Beam Melting (EBM) are introduced, enabling the production of intricate geometries, embedded sensors and hybrid structures. Industries transition from prototyping to full-scale production, with applications including turbine blades with internal cooling channels (aerospace), lattice-structured medical implants (healthcare) and topology-optimized automotive components. Research institutions collaborate with manufacturers to develop new ADM-compatible alloys and high-temperature polymers, pushing the boundaries of material science. The third phase focuses on optimizing ADM processes for maximum efficiency, cost-effectiveness and sustainability. Automated ADM production lines with robotic part handling and AI-based quality inspection systems are implemented, reducing lead times and human intervention. Closed-loop recycling systems for metal powders and polymers are introduced to minimize waste. Industries achieve mass customization at scale, producing on-demand spare parts, smart structures with embedded electronics, and bio-printed tissues for medical applications. Furthermore, digital twin technology is fully integrated, allowing real-time simulation and predictive maintenance of ADM systems. By the end of this phase, ADM became a mainstream manufacturing method, fully embedded in smart factories and Industry 4.0 ecosystems, revolutionizing production across sectors.

- *Robot assisted fabrication technologies*: Over the next ten years, the country will implement a structured roadmap to establish and advance Robot-Assisted Fabrication (RAF) technologies, supporting R&D activities in bioengineering and emerging technologies. The phased approach ensures gradual capability development, skill enhancement and practical implementation. The first milestone involves setting up a dedicated Robot RAF laboratory equipped with industrial

robotic arms, collaborative robots, and necessary peripherals for targeted applications such as welding, machining, and assembly operations. This phase includes procuring robotic systems compatible with biomedical device manufacturing, precision machining, and automated assembly processes. The lab will serve as a foundational hub for research, allowing scientists and engineers to explore RAF's potential in bio-fabrication, tissue engineering scaffolds, and customized medical device production. Once the RAF lab is operational, the country will prioritize training and capacity-building in robotics programming, focusing on Robot Operating System (ROS), CAD/CAM integration, and Programmable Logic Controllers (PLCs). Workshops and certification programs will be conducted in collaboration with robotics manufacturers and academic partners to equip researchers with hands-on expertise. Additionally, the country will establish collaborative relationships with industry leaders, robotics research centers and biomedical engineering firms to facilitate knowledge exchange, joint research initiatives, and access to advanced robotic technologies. With trained personnel and industry collaborations in place, the country will initiate pilot projects to demonstrate RAF's viability in real-world R&D scenarios. Small-scale experiments will include automated bio-assembly, robotic precision machining of biocompatible materials, and automated quality inspection systems. Success in these pilot projects will lead to broader applications, such as high-throughput screening in drug discovery, robotic-assisted surgical device fabrication, and automated tissue engineering processes. The third phase focuses on in-house development of robotic components, including specialized grippers, force/tactile sensors and adaptive controllers tailored for biomedical and precision engineering applications. Researchers will explore soft robotics for delicate bio-handling, AI-driven vision systems for real-time adjustments, and modular robotic attachments for diverse fabrication tasks. By designing and fabricating these components, the country will reduce dependency on commercial suppliers and foster innovation in robotic mechanisms. This phase will culminate in the integration of these custom components into the RAF lab, enabling fully autonomous and adaptive fabrication systems for advanced R&D.

- *Hybrid manufacturing technologies:* The first phase focuses on establishing the necessary infrastructure and building technical expertise. This includes procuring additive manufacturing and subtractive manufacturing equipment, setting up dedicated labs and training researchers in both technologies. Collaborations with industry partners and academic institutions will facilitate

knowledge transfer, while workshops and certification programs will enhance workforce competency. Simultaneously, the country will develop a digital framework for data integration, ensuring seamless connectivity between future hybrid systems. This foundational phase is important for creating a skilled workforce and a robust technological base for subsequent integration efforts. With infrastructure in place, the country will begin integrating ADM and SMT into a cohesive hybrid manufacturing system. Research will focus on optimizing material compatibility, process sequencing, and machine interoperability. Key activities include developing hybrid machining centers, refining post-processing techniques and establishing quality control protocols. Pilot projects will test hybrid fabrication for specific applications, such as aerospace components or medical implants to validate process efficiency and precision. This phase will also involve software integration for real-time monitoring and adaptive manufacturing, ensuring smooth transitions between additive and subtractive stages. The third phase aims to refine hybrid manufacturing processes for maximum efficiency and scalability. Advanced research will explore AI-driven process optimization, in-situ inspection systems, and energy-efficient hybrid techniques. The institute will develop fully integrated hybrid manufacturing platforms that combine multi-axis machining with laser-based or directed energy deposition additive methods. These platforms will support advanced R&D in high-performance materials, complex geometries, and functional graded structures.

- *Automation and internet of things integration*: The first phase focuses on establishing the necessary physical and digital infrastructure to support automation. This includes procuring programmable logic controllers (PLCs), sensors and industrial communication networks while setting up a dedicated lab for automation experiments. Simultaneously, capacity development through training programs, workshops and collaborations with industry experts will equip researchers with foundational knowledge in automation systems, robotics and IoT fundamentals. By the end of this phase, the institute will have a functional automation-ready environment and a skilled workforce capable of advancing further. With infrastructure in place, the institute will begin semi-automating existing machinery to reduce manual intervention in repetitive tasks.

b) Predictive engineering

Predictive engineering represents a data-driven approach to product development that integrates advanced design technologies, simulation tools, and artificial intelligence to optimize product performance prior to physical realization. As indicated in Figure 4.33, the strategic roadmap and

implementation plan which will be executed over the next ten years is presented based on the selected technology implementation phases. The plan has been prepared in accommodating advanced CAD, CAE and AI product design as main components.

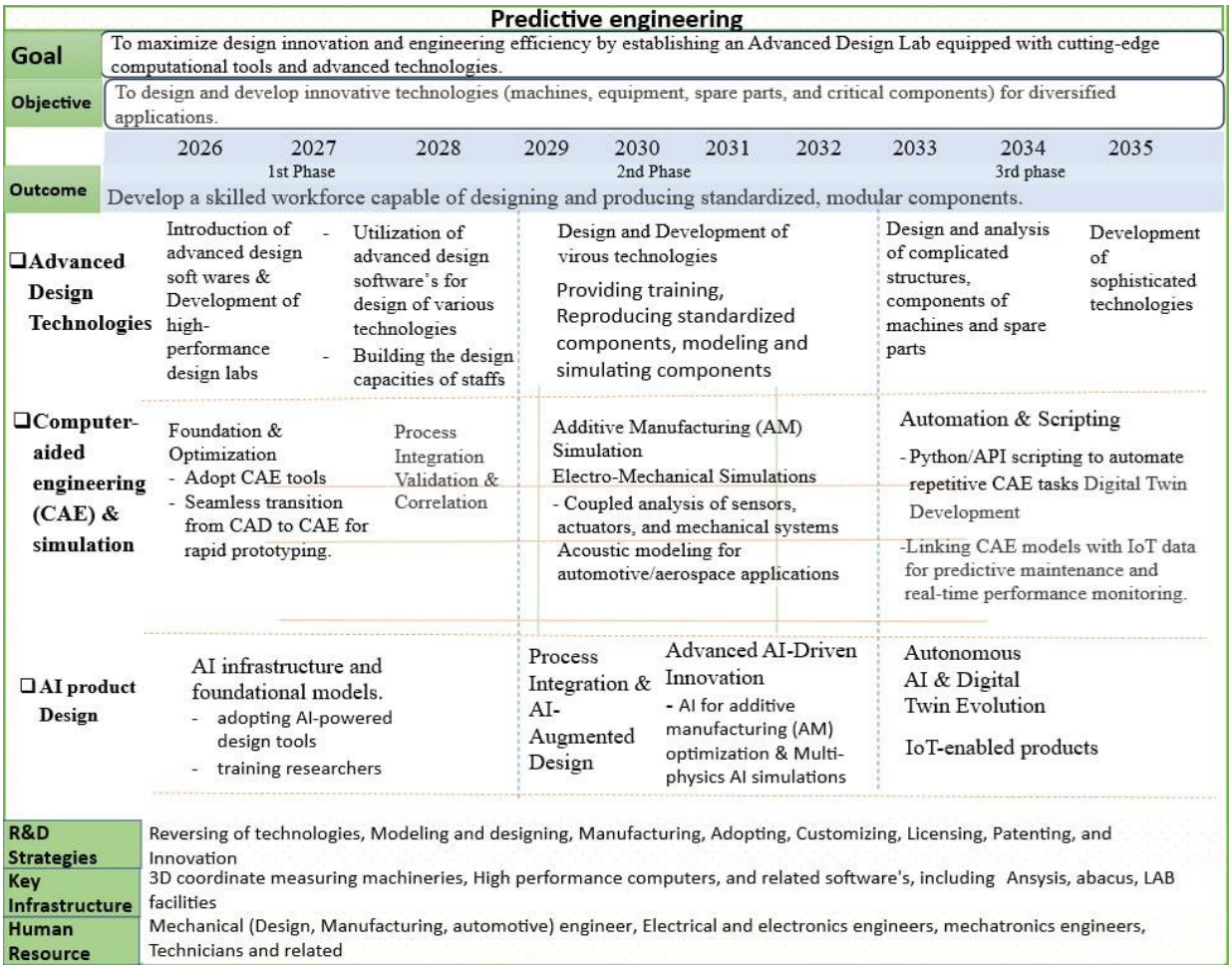


Figure 4-33 Predictive engineering roadmap and implementation strategy.

- *Advanced Design Technologies* form the foundation of predictive engineering by enabling the creation of high-fidelity digital models using Computer-Aided Design (CAD) tools. These technologies support detailed 3D modeling and early-stage simulation of structural, thermal, and fluid behaviors, allowing engineers to evaluate and refine concepts before physical production. As a result, they significantly reduce the need for multiple prototypes, accelerate innovation, and improve design accuracy in the initial stages of product development. In addition, Computer-Aided Advanced Design (CAAD) allows engineers to create highly detailed 3D models with simulations that test structural integrity, thermal properties and fluid dynamics. This reduces the need for multiple physical prototypes.

- *Computer-Aided Engineering (CAE)* extends the capabilities of digital design by incorporating advanced simulation and analytical tools. Through methods such as Finite Element Analysis (FEA), Computational Fluid Dynamics (CFD), and multibody dynamics, CAE enables the evaluation of product performance under realistic operating conditions. This ensures that designs meet safety, durability, and functional requirements prior to manufacturing, thereby reducing development risks and enhancing product reliability.
- *AI-Based Product Design methods* integrates artificial intelligence and machine learning into the engineering process to automate and optimize design generation. Using techniques such as generative design and data-driven modeling, AI systems can produce multiple optimized design alternatives based on predefined constraints, including weight, cost, strength, and material efficiency. When combined with simulation feedback from CAE tools, AI establishes a closed-loop system that continuously refines and improves design outcomes, leading to more innovative and efficient solutions.

Overall, predictive engineering is a data-driven approach that optimizes product performance prior to physical production by integrating advanced CAD, CAE, and AI-based design tools. For effective adoption and innovation on these technologies, this roadmap outlines a ten-year implementation strategy divided into three phases: At phase 1, the roadmap aims to establishing core infrastructure and human capacity through software deployment, high-performance lab setup, and engineer training, while also integrating design and simulation platforms to enable early-stage digital prototyping. Then it proceeds to unifying predictive engineering tools within a Product Lifecycle Management (PLM) environment to support iterative design and validation, applies AI-driven optimization to real-world industrial challenges, enhances simulation accuracy using material databases, and extends training to industries, particularly SMEs to encourage broader adoption. At final phase, the roadmap aims at achieving full digital transformation by expanding into multi-physics and specialized simulation domains, developing autonomous AI-driven design systems, and integrating digital twin technologies with real-time data for predictive maintenance and performance optimization, ultimately enabling complex applications in robotics, renewable energy, and smart manufacturing to build a fully intelligent and data-driven R&D ecosystem.

GOVERNANCE AND REGULATION STRATEGY

The successful integration of emerging technologies into Ethiopia's development agenda requires a robust governance and regulatory framework. This framework ensures that the development and deployment of technologies such as advanced materials, nanotechnology, synthetic and systems biology, AI, IoT, robotics, and advanced manufacturing technologies are safe, responsible, and aligned with the country's socio-economic goals. This chapter outlines the key components of the governance and regulatory framework necessary for responsible implementation of emerging technologies in Ethiopia.

5.1 Emerging Technology Governance Framework

Ethiopia has made notable progress in developing policies and governance frameworks to support emerging technologies, including the Digital Ethiopia 2025 strategy, Digital Ethiopia 2030 strategy, the national AI policy, gene editing and biosafety guidelines, and data protection proclamations. However, the country's governance landscape for emerging technologies faces various challenges. For example, emerging technologies are overseen by disparate institutions due to the absence of a unified body that oversees cross-cutting technologies. This results in duplication of efforts and exacerbates AI ethics, nano-safety, and other emerging technology-specific risks. Additionally, existing policies have implementation lags due to coordination and capacity constraints among responsible institutions. These governance challenges collectively hinder effective adoption, scaling, and responsible deployment of emerging technologies across different sectors in Ethiopia.

5.1.1 *National Emerging Technology Council (NETC)*

To address the aforementioned emerging technology governance challenges in a unified manner, Ethiopia shall establish a National Emerging Technology Council (NETC) that consolidates governance oversight of advanced materials, AI, advanced materials, nanotechnology, synthetic and systems biology, IoT, robotics, and advanced manufacturing technologies.

As highlighted in Figure 5.1 and Table 5.1, the NETC comprises the NETC Council Chairperson, Minister of Innovation and Technology as Vice Chairperson, Director General of BETin as

Member and Secretary, supported by five core ministers, two agency heads, two academic representatives, and two private sector representatives each with defined primary responsibilities spanning strategic direction, cross-ministerial coordination, daily operations, sectoral advisory, AI and IP governance, academic input, and private sector engagement.

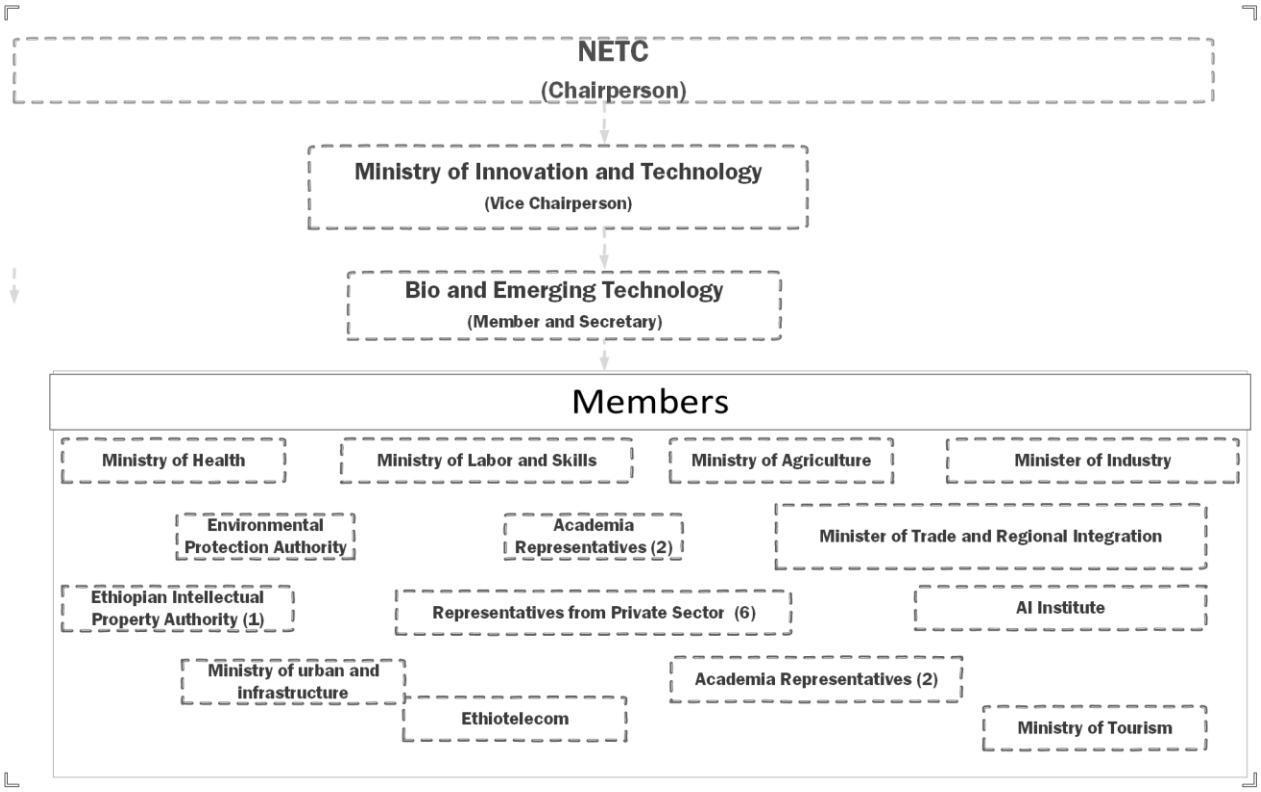


Figure 5-1 National emerging technology council organogram

NETC's roles and responsibilities include governance, coordination, and implementation of emerging technologies to ensure socio-economic transformation. In order to achieve this, the council has the following main governance functions:

- Provides unified oversight by consolidating governance of all emerging technologies under a single council, thereby eliminating fragmentation and ensuring coherent policy application across sectors.
- Facilitates policy coordination by aligning technology policies across key ministries including health, agriculture, industry, trade, and environment.
- Enables stakeholder coordination by facilitating collaboration among government agencies, academic institutions, private sector entities, and international partners to create a cohesive innovation ecosystem.

- Oversees ethics and safety issues by establishing specialized bodies including AI ethics review committees to audit algorithmic fairness, nano-biotech safety desks to monitor lab-grown materials and enforce waste disposal protocols.
- Promotes public awareness and indigenous knowledge integration by launching digital industry collaboration platforms.
- Drives collaboration development by strengthening existing local and international partnerships and establishing new wide-ranging collaborations with research institutions, industry leaders, and multilateral organizations.

Table 5-1 NETC members, role and key responsibilities

Member	Role	Responsibility
NETC Council	Chairperson	Provide strategic direction; preside over council meetings; approve major decisions
Minister of Innovation and Technology	Vice Chairperson	Deputize for chairperson; coordinate activities
Bio and Emerging Technology Institute	Member and Secretary	Manage daily operations; convene meetings; maintain records; implement council decisions
Minister of Health	Member	Advise on health-related emerging technologies; ensure biosafety and healthcare innovation
Minister of Agriculture	Member	Advise on agri-tech, gene editing, and agricultural AI applications
Minister of Industry	Member	Advise on advanced manufacturing, industrial automation, and materials innovation
Minister of Trade and Regional Integration	Member	Advise on technology transfer, trade agreements, and regional integration

Environmental Protection Authority	Member	Advise on environmental impact, climate tech, and sustainable materials
Artificial Intelligence Institute & AI University	Member	Advise on HR Development, AI policy, research, and ethical issues
Ethiopian Intellectual Property Authority	Member	Advise on intellectual property protection, patenting, and technology licensing
Representatives from Academia (2)	Member	Provide academic and research perspectives; advise on education and training
Representatives from Private Sector (Industry, startups, small and medium enterprises, etc.) (3)	Member	Provide industry perspectives; advise on commercialization and market needs
Ministry of Labor and Skills		Provide industry perspectives; advise on commercialization and market needs
Ministry of Tourism		Provide industry perspectives; advise on commercialization and its needs
Ministry of Transport and Logistics		Provide perspectives/ advise on transport and logistics and its needs
Ministry of urban and infrastructure	member	Provide perspectives/ advise on urban and infrastructure and its needs.
Ethiotelecom	member	Provide its perspectives and computational infrastructure /R&D ecosystem

5.1.2 Stakeholder engagement and communication

Stakeholder engagement ensures key actors to have a voice in decision-making and to enable transparency and accountability in emerging technology governance. Table 5.2 summarizes key

stakeholder engagement and role categorized based on associated roadmaps of emerging technologies.

Table 5-2 Key stakeholders and engagements on implementation of the roadmap.

Tech Category	Sub-Category	Key Stakeholder	Roles of Stakeholders
ACIS	Advanced computational ecosystem and AI	MiNT, BETIn, AI institutes, SSGI, Universities, IT service providers (e.g., ICT park, Ethiotelecom, etc.), and NGOs	Develop policies and regulations; establish, computational resource and data sharing standards, set implementation and safety guidelines, funding and resource allocation and training
	IoT and Big data analytic	MiNT, BETIn, AI institute, SSGI, Universities and other IT service providers e.g., Ethio telecom, EtherNet, ICT park, etc	Establish IoT and Big data analytic platforms/ecosystem, fund and conduct R&D as well as provide workforce training
	Robotics and Intelligent Systems	MiNT, BETIn, AI institute, ATA, Ministry of transport and logistics, MoH, Ministry of construction, Ministry of Mine and Petroleum, Ministry of Tourism and Culture, Universities, CT Companies and NGOs	Collaboratively conduct and fund Robotics and Intelligent system R&D, implement technologies, provide workforce training; provide and engagement as well as public awareness creation.
Synthetic and System Biology	System Biology, Gene Editing, Medical Innovation, Agriculture & Environmental	Ministry of Innovation and Technology (MInT) Ministry of Health (MOH), Ministry of Agriculture (MOA) and Ministry of Education (MOE), Bio- and Emerging Technology Institute	Develop policies and regulations, implementation and safety guidelines, establishing funding and resources sharing schemes, conduct research, and training

	Solutions, Manufacturing & Industrial Biotechnology	(BETin), Ethiopian Public Health Institute (EPHI), Armauer Hansen Research Institute (AHRI) and Universities (AAU, HrU), Ethiopia Institute of Agricultural Research (EIAR), Regional Agricultural Research Institutes (RARIs), Ethiopian Biodiversity Institute (EBI), National Agricultural Biotechnology Research Institute (NABRC), CDT-Africa, Africa-CDC, Public and private hospitals, Entrepreneurship Development Institute (EDI), Environment Protection Authority (EPA), Ethiopian Intellectual Property Authority (EIPA), National Veterinary Institute (NVI); Ethiopian Chamber of Commerce and Ethiopian National Industry Association.	
Nanotechnology	Nanotechnology	(e.g., Nanotechnology	Develop policies and regulations, implementation and safety guidelines, establishing funding and resources sharing schemes, conduct research, and training

Advanced Materials	Advanced Energy Materials, Advanced Construction Materials, Advanced Green Materials and Mineral-Based Advanced Materials	resource-sharing	Resource-sharing
Advanced Manufacturing Technology	Additive Manufacturing, Intelligent and Connected System	Ministry of Industry, Ministry of Trade, Universities (e.g., Addis Ababa University), Manufacturing Companies, Tech Companies, Ethiopian Manufacturing Institute and International Manufacturing Companies	Develop policies and regulations, implementation and safety guidelines, establishing funding and resources sharing schemes, conduct research, and trainings

To effectively engage stakeholders, communication strategy of this roadmap involves:

- Provide stakeholders with regular updates on the progress of each technology roadmap.
- Establish feedback mechanisms to ensure stakeholders' concerns and suggestions are addressed.
- Conduct public awareness campaigns to educate the public about the benefits and risks of each technology.
- Organize networking events to facilitate collaboration and knowledge sharing among stakeholders.
- Organize forums to discuss ethical, legal, and social implications (ELSI) issues and involve stakeholders in policy development. The emerging technology council shall implement the following communication strategies:

Table 5-3 Key stakeholders and engagements strategies

Activity	Description	Frequency
Regular progress updates	Provide stakeholders with timely updates on the progress of each technology roadmap, including milestones achieved, challenges encountered, and next steps	Quarterly
Feedback mechanisms	Establish formal channels (e.g., surveys, public comments, advisory groups, etc.) to ensure stakeholder concerns and suggestions are addressed	Continuous
Public awareness campaigns	Conduct nationwide campaigns to educate the public about the benefits, risks, and responsible use of each emerging technology	Biannually
Networking events	Organize workshops, conferences, and matchmaking events to facilitate collaboration and knowledge sharing among stakeholders	Annually

5.1.3 Tech startups support

Implementing an emerging technology roadmap requires continuous tech startup support and technology incubations. In this regard, the Ethiopian government has launched several initiatives, including the Ethiopian IT Park, which offers a collaborative ecosystem for technology startup support and incubation. Recently, on July 17, 2025, the House of People's Representatives also unanimously approved the Ethiopian Startup Proclamation, a law designed to transform Ethiopia into a global competitor in innovation, entrepreneurship, and technology-driven development, which is part of the National Startup and Incubation Initiative under the Ministry of Innovation and

Technology. This provides support to startups working on various technologies, including training, funding, mentorship, and access to markets, especially applications related to healthcare, agriculture, smart cities, intelligent transport and logistics, and industrial automation. Despite these efforts, the country's tech startup ecosystem and financial support for emerging technologies remain limited. To address this, the roadmap suggests the following strategies that aim to strengthen tech startups and emerging technology incubation.

- Introduce targeted grants, tax incentives, and a dedicated emerging tech fund with tax waivers.
- Strengthen university-industry partnerships, integrate student talent into startups, and simplify regulatory pathways for compliance, market entry, and scaling.
- Establish incubators and accelerators with co-working spaces, labs, and mentorship programs.
- Organize workshops and networking events
- Create online platforms connecting innovators with investors and global markets.
- Highlight success stories and economic potential to inspire talent and attract investment, while advocating for policies that support grassroots innovation.

5.1.4 Funding strategy

Successful implementation of this national emerging technology roadmap requires a diverse, sustainable, and well-structured funding strategy. While Ethiopia's current R&D spending stands at approximately 0.61% of GDP (ETB 5.24 billion), this falls significantly short of the resources needed to realize the roadmap's ambitious goals. Traditional government allocations and unpredictable foreign aid are insufficient to sustain long-term technology adoption and commercialization. Therefore, this roadmap proposes a comprehensive funding ecosystem with clear targets, dedicated instruments, and innovative financing mechanisms that de-risk investment and ensure predictable, sustainable resource flow across all phases of implementation.

The cornerstone of the funding strategy is the establishment of a dedicated National Emerging Technology Fund (NETF) with a defined initial capitalization and clear operational framework. Table highlights Capitalization structure of NETF.

Table 5-4 NETF Capitalization structure

Source	Contribution (USD)	Mechanism
Government Seed Capital	150 million	Direct budget allocation from Ministry of Finance
World Bank Digital Foundations Project	100 million	IDA financing allocation for technology innovation
EU Investment Package	75 million	Grant funding for digital ecosystem development
Private Sector Co-investment	50 million	Tax-incentivized contributions from industry partners
Total Initial Capitalization	375 million	

The NETF will be governed by a dedicated Board comprising representatives from the Ministry of Innovation and Technology, Ministry of Finance, BETin, private sector representatives, and international development partners. The fund will operate under the following principles:

- Blended Finance Approach: Combining grants, concessional loans, and equity investments to de-risk private sector participation.
- Competitive Grant Mechanisms: Open calls for proposals with rigorous peer review for research and innovation projects.
- Matched Funding Requirements: Private sector co-investment requirements of 20-30% for commercialization-stage projects.
- Performance-Based Disbursement: Milestone-linked funding release with clear deliverables and KPIs.
- Independent Oversight: External audits and annual performance reviews to ensure transparency and accountability.

Budget estimation by Phase: The following budget estimates are based on phased implementation across the five technology domains, considering infrastructure requirements, human resource development, research activities, and pilot deployment costs. Table shows total Estimated Budget by Phase (2026–2035).

Table 5-5 Total Estimated Budget by Phase

Phase	Period	Estimated Budget (USD)	Key Activities
Phase 1	2026–2028	4.0 – 5.5 billion	Foundational infrastructure, human capacity development, policy establishment, pilot research projects
Phase 2	2029–2031	5.0 – 6.5 billion	Infrastructure and technology scaling and optimization, technology deployment, industry partnerships, semi-commercialization
Phase 3	2032–2035	5.0 – 7.0 billion	Full commercialization, technology transfer, ecosystem sustainability
Total	2026–2035	14.0 – 19.0 billion	

Funding contribution targets: To achieve the roadmap's objectives, contributions from various funding sources must be systematically mobilized. Table 5.6 highlights proposed funding contribution targets.

Table 5-6 Funding mobilization Targets (2026–2035), (B= Billion USD)*

Year	Gov.	Multilateral	Private	Diaspora	Green/ Climate	Annual Total
2026	0.4B	0.3B	0.2B	0.1B	0.1B	1.1B
2027	0.5B	0.3B	0.2B	0.1B	0.1B	1.2B
2028	0.5B	0.4B	0.3B	0.1B	0.1B	1.4B
2029	0.6B	0.4B	0.3B	0.1B	0.1B	1.5B
2030	0.6B	0.5B	0.4B	0.2B	0.2B	1.9B
2031	0.7B	0.5B	0.4B	0.2B	0.2B	2.0B
2032	0.7B	0.6B	0.4B	0.2B	0.2B	2.1B
2033	0.8B	0.6B	0.5B	0.2B	0.2B	2.3B
2034	0.8B	0.7B	0.5B	0.2B	0.2B	2.4B
2035	0.9B	0.7B	0.6B	0.3B	0.3B	2.8B
Total	6.5B	5.0B	3.8B	1.7B	1.7B	18.7B

5.2 Regulatory Strategy and Implementation Mechanisms

To create an effective technology roadmap, both regulatory strategy and implementation mechanisms are essential. The regulatory strategy establishes a clear and supportive environment for innovation, while implementation mechanisms ensure that the roadmap is translated into practical actions and measurable results. This section details the regulatory strategy and implementation mechanism of the roadmap: monitoring and Evaluation (M&E) mechanisms as well as risk assessment and mitigation mechanisms.

5.2.1 Monitoring and Evaluation (M&E) mechanism

Emerging technologies often become outdated rapidly or may become obsolete within a relatively short period. Therefore, it is recommended that this roadmap be reviewed and updated every two to three years to ensure it remains current and relevant. M&E mechanisms provide a framework for tracking progress against defined goals, enabling organizations to identify whether technologies, products, or services are on track and make timely adjustments to improve outcomes. M&E also generates data for evidence-based decision-making and enhances accountability by setting clear performance expectations, fostering a culture of responsibility. The main M&E strategies of this roadmap are to:

- Establish structured planning strategies outlining project goals, objectives, activities, and success indicators.
- Define specific, quantifiable Key Performance Indicators (KPIs) to evaluate project success against objectives.
- Conduct baseline studies before project implementation to gather comparative data and measure changes over time.
- Provide regular progress updates documenting project activities, outputs, and outcomes to help stakeholders assess progress.
- Deploy surveys to collect quantitative and qualitative data from stakeholders, beneficiaries, and participants to gauge project effectiveness.
- Conduct field visits and on-site observations for direct assessment of project activities and outcomes, including mid-term assessments to review progress, identify challenges, and recommend adjustments.
- Perform comprehensive evaluations at project conclusion to assess overall effectiveness, impact, and lessons learned.
- Form stakeholder feedback mechanisms to collect input from beneficiaries and stakeholders, informing project adjustments and enhancing accountability.

5.2.2 Risk Assessment and mitigation mechanism

Risk assessment enables early challenge identification, optimized resource allocation, and informed decision-making, while strong mitigation fosters resilience, stakeholder confidence, and

maximized R&D impact across all emerging technology domains. Risk assessment and mitigation strategies of the roadmap involves:

- Establish an integrated M&E and risk assessment framework to track progress, identify potential risks, and develop proactive mitigation or management strategies.
- Develop and regularly update risk mitigation plans to reduce the likelihood or impact of identified risks, with bi-annual reviews to ensure ongoing effectiveness and identify emerging risks.
- Foster multi-stakeholder collaboration among researchers, industry partners, and government agencies to share knowledge, expertise, and resources for effective risk mitigation.
- Provide continuous risk awareness training for researchers, stakeholders, and collaborators to ensure understanding of potential risks and corresponding mitigation measures.
- Implement graduated enforcement mechanisms, including warnings, fines, suspension, and revocation, based on the severity and recurrence of non-compliance.

Table 5.3 outlines emerging technology risks across including human resource, infrastructure, funding, legal and safety, collaborations and communication, and awareness and commitment with corresponding risk mitigation activities.

Table 5-7 Emerging technology potential risk and mitigation mechanisms

Risk Area	Risk Type	*Risk Level	Risk Mitigation Activities
Human Resource	Insufficient budget for training	Medium	Implement proper knowledge transfer platform, design training plans, leverage free education and collaboration opportunities
	Turnover/brain drain	Medium	Initiate retention mechanisms, income generation, and revenue sharing guidelines
	Ineffective capacity building plan	Medium	Institutional training, revise human capacity development plan, commit to conducting human capacity development
	Irregularity of knowledge management/transfer	High	Proper implementation and follow-up of knowledge management platform

Infrastructure	Procurement and purchasing process issues	High	Effective planning and implementation of purchasing activities, audit and assess suppliers, develop new procurement system
	Inflation	High	Generate internal income/revenue, effective utilization of available budget, budget adjustment request
	Lack of permanently set laboratories	Medium	Collaborate with other institutions, facilitate permanent offices/laboratories for researchers
	Inadequacy of suppliers	High	Consult with public and property administration
	Delay in procurement and delivery	High	Initiate new procurement system, install guidelines for direct purchase, work closely with public and property administration
Funding	Financial limitations for research	Low	Implement appropriate program budget, plan and prioritize financial investment, collaborate and hunt for grants
	Budget limitation for infrastructure	Low	Effective utilization of available budget, generate internal income/revenue
	Budget limitation due to inflation	Medium	Keep up regular forecasting
	Shortage of foreign currency	Medium	Grant and donation hunting, effective utilization of nationally available resources through collaboration
	Ontime projects un-accomplishment	High	Strong and continuous follow-up (M&E system)
Legal and Safety	Environmental: pollution/waste/contamination	Medium	Set laboratory infrastructure safety and management standards, establish proper waste disposal mechanism
	Unintended effect of new products/services	Low	Implement effective functionality, compatibility, and pre-release tests of products/services
	Health and Safety	High	Provide proper laboratory safety equipment, planned inspection and maintenance of lab equipment and machineries
	Emerging technology ethical/privacy/confidentiality risks	Medium	Prepare and implement research code of conduct, pay strong attention to obtaining, handling, securing, and storing data
	Violation of copyright	Medium	Prepare IP and research code of conduct, proper implementation and follow-up of research code of conduct

Collaborations and Communication	Inconvenient national procurement system	Medium	Initiate new procurement system, install guidelines for direct purchase, work closely with public and property administration
	Collaboration's sustainability	Low	Strengthen existing collaborations, search for new collaborations, establish wide-ranging collaborations
Awareness and Commitment	Resistance to new technologies	Medium	Strengthen awareness creation and demonstration
	Political decisions	Medium	Plan employee transfer, effective utilization of existing human resources, promote collaborative works
	Lack of interest/commitment to attending events	Medium	Strengthen technical supports, set appropriate time and place for attendants' convenience, create awareness regarding institute's mandates
	Lack of commitment of collaborators	High	Initiate technology transfer linkage guideline, establish binding agreements, develop enforcing rules and regulations

Note: *Risk levels are based on the reviewer's evaluation and judgments.

6. Summary

The National Emerging Technology Roadmap for Ethiopia outlines the significant potential of integrating emerging technologies into the national development agenda. After an overview of emerging technologies in the introductory section, the roadmap confirms the rapid growth of selected emerging technologies such as nanotechnology, advanced computational and intelligent systems, advanced materials, synthetic and systems biology, and advanced manufacturing, based on global trend analysis. The national situation analysis also reveals strong political commitment from the government to adopt these technologies. The PESTEL and SWOT analyses highlight enabling factors and structural constraints.

Using a purposive sampling approach and structured questionnaires from universities, research institutes, private sector actors and industries, the situational analysis identifies Ethiopia's strengths and opportunities, including human capital and a growing network of research institutions. However, the gap analysis underscores existing challenges such as limited R&D infrastructure, regulatory hurdles, and the need for public engagement and awareness.

As outlined in Chapter 4, the roadmap presents a phase-by-phase R&D approach and clear strategies for the selected technologies. This aims to achieve significant advancements, including improved agricultural productivity, healthcare services and environmental sustainability. These innovations address pressing socio-economic challenges across agriculture, healthcare, industry, and environmental management.

To ensure effective implementation, the roadmap proposes a governance and regulatory framework, including the establishment of the National Emerging Technology Council (NETC), supported by monitoring and evaluation systems and risk mitigation mechanisms. It also emphasizes the importance of enabling policies, capacity building, infrastructure development, sustainable funding, and multi-stakeholder collaboration through different partnership mechanisms. Overall, the implementation strategies outlined in the roadmap offer a clear and cohesive pathway for translating technological potential into transformative impacts across key sectors, ultimately delivering tangible socio-economic benefits.

While the roadmap's methodological framework; integrating global trend analysis, stakeholder consultations, and structured surveys; provides a robust strategic foundation, certain limitations warrant acknowledgment. The survey data, critical to identifying gaps in human resources, infrastructure, and stakeholder engagement, may be subject to self-selection bias. Given the voluntary and purposive recruitment approach, the findings may disproportionately reflect the views of stakeholders with a strong pre-existing interest in emerging technologies, while potentially underrepresenting less-engaged sectors or institutions facing the most acute constraints. Acknowledging this limitation underscores the need for continued inclusive stakeholder engagement and periodic validation of findings as the roadmap transitions from planning to implementation, ensuring that subsequent phases remain responsive to Ethiopia's full spectrum of national needs and realities.

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APPENDICES

I. Roadmap study committee members.

•	Dr. Minbale Aschale	Chairman
•	Dr. Eng. Melese Ayalew	Secretary
•	Dr. Wondimagegne Mamo	Member
•	Dr. Endalkachew Gashawtena	Member
•	Dr. Abiy Lolasa	Member
•	Dr. Yohannes Gedamu	Member
•	Mrs. Tinsae Fikru	Member
•	Mr. Zerihun Kedida	Member
•	Ms. Bethelhem Haile	Member
•	Mr. Tekalign Abdissa	Member

II. Validation Workshop Participants:



Picture taken during Validation Workshop

III. Consultative workshop participant institutions/organizations during development of the National Emerging Technology Roadmap.

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S. No.	Name of Institution/Organization Proposed
1.	FDRE Ministry of Innovation and Technology
2.	FDRE Ministry of Health (MOH)
3.	FDRE Ministry of Agriculture (MOA)
4.	Ethiopian Institute of Agricultural Research (EIAR)
5.	FDRE Ministry of Industry (MoI)
6.	FDRE Ministry of Mines and Petroleum
7.	Manufacturing Industry Development Institute
8.	National Agricultural Biotechnology Research Center (NABRC)
9.	Ethiopian Food and Drug Authority
10.	Space Science and Geospatial Institute
11.	iCog Labs
12.	Ethiopian Federal Police Commission
13.	Ethio telecom
14.	FDRE Ministry of Education (MOE)
15.	Ethiopian Technology Authority
16.	Mineral Industry Development Institute
17.	FDRE Environment Protection Authority (EPA)
18.	Ethiopian Standards Institute (ESI)
19.	Oromia Science and Technology Authority
20.	Ethiopian Intellectual Property Authority/EIPA
21.	Entrepreneurship Development Institute (EDI)
22.	Ethiopian Policy Institute (EPI)
23.	FDRE Ministry of Transport and Logistics
24.	Information Network Security Agency (INSA)
25.	Ethiopian Artificial Intelligence Institute (AII)
26.	Ethiopian Public Health Institute (EPHI)
27.	Armauer Hansen Research Institute (AHRI)
28.	National Veterinary Institute, Ethiopia (NVI)
29.	Addis Ababa University
30.	Addis Ababa Science and Technology University
31.	Adama Science and Technology University
32.	Haramaya University
33.	Chemical and Construction Inputs Industry Research and Development Center
34.	Chemical Industry Corporation
35.	Ethio Engineering Group, Ethiopia Plastic Industry
36.	FDRE Technical and Vocational Education and Training Institute
37.	Metal Technology and Engineering Industry
38.	Defense University, Engineering College
39.	Debirebrihan University
40.	Automotive Spare Part Manufactures, Bishoftu Automotive
41.	Oromia Job Creation and Vocational Bureau



Pictures taken during the consultative workshop.

IV. Technical/Expert-workshop participants for the development of National Emerging Technology Roadmap.

Technology area	**Name of Expert proposed**	**Institution/Organization**
Advanced Computing and Intelligent Systems	Dr. Yaregal Asabie	Addis Ababa University
	Dr. Getinet Yilma	ASTU
Advanced Materials	Dr. Temesgen Debelo	AASTU
	Dr. Anteneh Marilign	AAiT AAU
	Dr Fekadu Ashine	Manufacturing Industry Development Institute
Nanotechnology	Prof. Abi Taddesse	Haramaya University

	Mr. Demelie Yimer Mulatu	Chemical and Construction Inputs Industry Research and Development Center
	Dr. Tesfaye Eshete	Addis ASTU
Synthetic and System Biology	Dr. Solomon Tebeje	AAU
	Dr. Tilahun Mekonnon	AAU
	Dr. Yemisrach Melkie	BETin
Advanced Manufacturing	Dr. Kassu Jilcha	AaiT
	Dr. Belete Sirahbizu	Addis AASTU
	Mr. Benga Chala	Metal Technology and Engineering Industry



Pictures taken during the expert level-workshop.

V. BETin senior staff workshop.



Pictures taken during group work