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Technology Predictions 2025

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Executive Summary

Technology Predictions: From Hypothetical Exercise to Strategic Advantage

IEEE Computer Society technology experts have unveiled 22 breakthrough technologies set to redefine industries and shape the future of our world for decades to come.

The 53-member 2025 Technology Predictions Team foresees:

- accelerated growth in many AI facets, requiring reskilling of workforce
- US-centric reduction in interest in sustainability, due to new economic and socio-political pressures (not globally, though)
- ever-increasing automation in many dimensions, setting stage for additional AI opportunities
- biotechnology's rapid development under the radar (e.g. "AI-assisted drug discovery", "AI-based medical diagnostics")

The 22 technology predictions (see next slide) were:

- made in 6 categories: verticals (6); applied AI (4); user interfaces (2); non-functional characteristics (4); applied computing (3); and energy-related (3)
- evaluated for likelihood of success in 2025, impact to humanity, maturity, market adoption, adoption horizon (The most likely to succeed & adopted is LLM deployment; the most impact to humanity is AI-assisted drug discovery)
- correlated and confidence interpreted as a standard deviation
- mapped to the IEEE Future Direction Committee's (FDC's) Megatrends as a guiding principles for technology trends

2025 Technology Predictions - Ordered by Technology Development Grade

1. **Large Language Model (LLM) deployment (A-):** We will see deployments of new types of language models, such as Small Language Models and exotic special-purpose models.
2. **Drone adoption (A/B):** Drone-as-a-Service (DaaS) will redefine logistics, agriculture, and disaster response, offering reliable, low-cost solutions with quick turnarounds across diverse industries.
3. **AI agents (A/B):** AI agents combining LLMs, machine learning (ML) models, and rule-based systems will provide autonomous, highly specialized solutions for finance, manufacturing, and retail operations.
4. **AI-enhanced robotics (B+):** Embodied intelligence will enable robots to perceive, learn, and collaborate in dynamic environments, achieving unprecedented autonomy and human-like adaptability.
5. **Wearables/biomarkers in medicine/wellness (B+):** Wearables will track biomarkers for early disease detection and proactive wellness, expanding beyond fitness tracking to medical-grade monitoring for chronic conditions.
6. **IT/energy convergence (B+):** Energy's digital transformation will mirror IT's evolution, enabling sustainable grids, renewable integration, and exponential AI growth for efficient power delivery.
7. **Augmented artificial intelligence (B+):** Augmented AI will redefine human-machine collaboration, blending machine precision with human oversight for inclusive, ethical solutions in healthcare, finance, and education.
8. **Autonomous driving (B+):** Autonomous vehicles will reduce emissions, enhance safety, and transform urban logistics, but widespread adoption hinges on regulatory approvals and public trust.
9. **SmartAg (B+):** AI-driven systems will improve crop yields, resource management, and sustainability, addressing food security through real-time soil and climate monitoring.
10. **Functional safety / autonomous vehicles (B):** Advanced safety frameworks will ensure autonomous vehicles operate reliably in public and commercial sectors, gaining trust for broader adoption.
11. **AI-assisted drug discovery (B):** Advances in AI will speed up drug discovery, identifying novel compounds and treatments, though data quality and regulatory hurdles remain.
12. **Sustainable computing (B):** Data centers will adopt energy-efficient hardware, intelligent resource management, and renewable energy, though scaling sustainability practices remains a challenge.
13. **Mis/Disinformation (B):** AI tools will detect and mitigate misinformation, countering its rapid dissemination on social networks to protect public opinion and trust.
14. **AI-based medical diagnosis (B):** AI will enhance diagnostic precision, particularly in radiology and pathology, improving patient outcomes while reducing clinician workloads.

Please see backup slides for more detailed description (One-slide summary of Problems/Demand, Opportunities, Impact, and Sustainable Solution/Business Opportunity, including Enablers/Inhibitors, for each prediction.*)*

2025 Technology Predictions - Ordered by Technology Development Grade (continued)

15. **AI-optimized green HPC (B-):** AI will optimize HPC workflows, reducing energy consumption. Challenges include high costs and developing reliable energy measurement and allocation methods.

16. **Next-gen cyberwarfare (B-):** AI-driven cyber defenses will counter evolving threats. Challenges include international collaboration, response speed, and defending against increasingly AI-enhanced attacks.

17. **New battery chemistries (B-):** Solid-state and sodium-ion batteries will enhance energy density and safety. Challenges include scaling production and managing supply chain dependencies.

18. **Data feudalism (B-):** New tools will empower users to regain control over data. Challenges include enforcing equitable access and aligning global regulatory frameworks.

19. **Nuclear-powered data centers (B/C):** Small Modular Reactors (SMRs) will provide steady, carbon-neutral energy for data centers. Regulatory approvals, scalability, and public acceptance remain significant hurdles.

20. **Tools and policies for AI regulation (B/C):** Frameworks for AI ethics and governance will emerge. Challenges include harmonizing global standards and ensuring effective enforcement mechanisms.

21. **Brain Computer Interfaces (BCIs) (C+):** BCIs will assist individuals with disabilities and enhance communication. High costs, safety concerns, and scalability hinder broader use cases.

22. **Space computing (C+):** Reliable, autonomous computing will support deep-space missions. Challenges include radiation hardening, limited power supply, and extreme environmental conditions.

Please see backup slides for more detailed description (One-slide summary of Problems/Demand, Opportunities, Impact, and Sustainable Solution/Business Opportunity, including Enablers/Inhibitors, for each prediction.)

Landscape of Predicted Technologies

verticals
- SmartAg
- Next-gen cyberwarfare
- AI-based medical diagnosis
- AI-assisted drug discovery
- Drone adoption
- AI-enhanced robotics

applied AI
- LLM deployment
- AI agents
- Augmented AI
- Tools and policies for AI regulation

user interfaces
- Wearables/biomarkers in medicine/wellness
- Brain Computer Interfaces (BCIs)

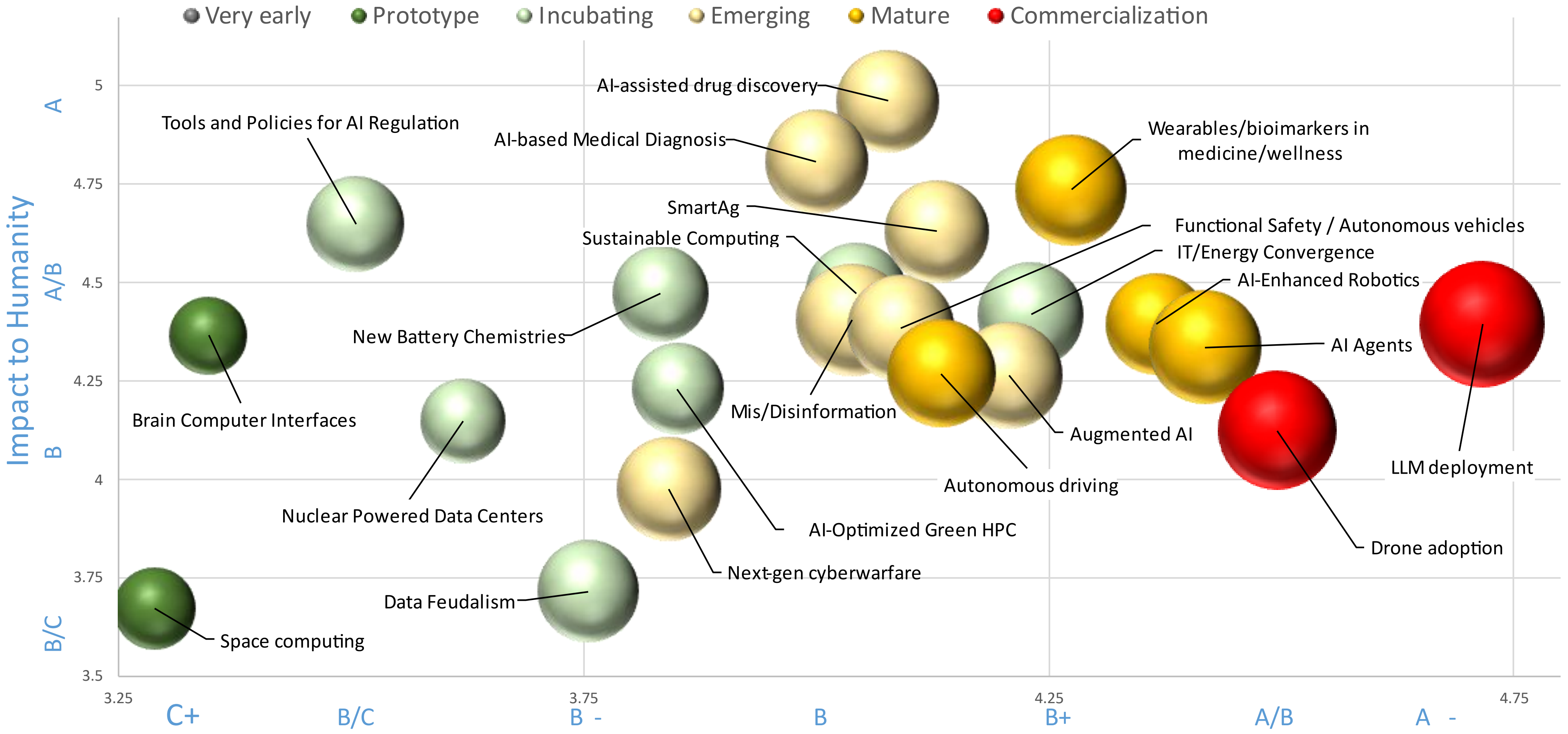
non-functional characteristics
- Autonomous driving
- Functional safety / autonomous vehicles
- Mis/Disinformation
- Data feudalism

applied computing
- Space computing
- Sustainable computing
- AI-optimized green HPC

energy
- IT/energy convergence
- New battery chemistries
- Nuclear-powered data centers

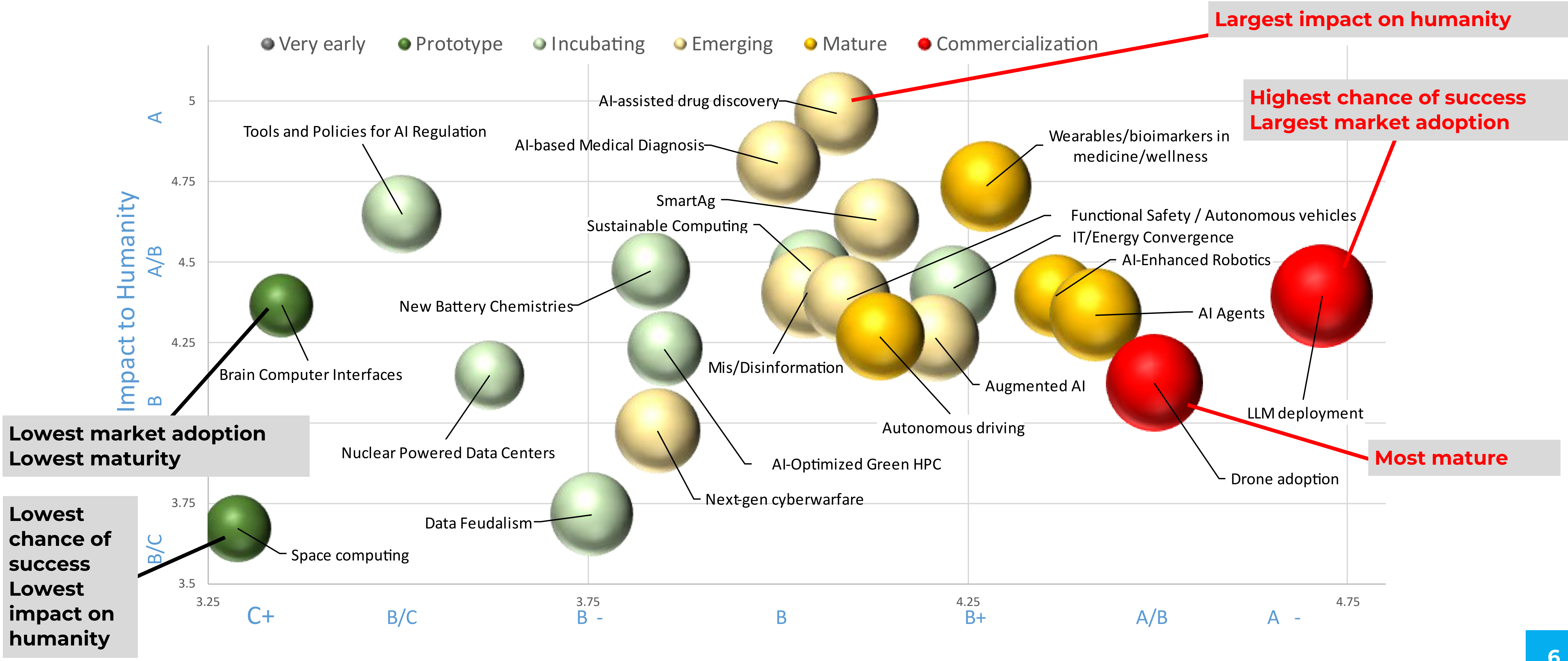
2025 Technology Predictions

Prediction: Tech. Development in 2025 (x – axis) vs Impact to Humanity (y – axis) (size of bubble proportional to relative market adoption)



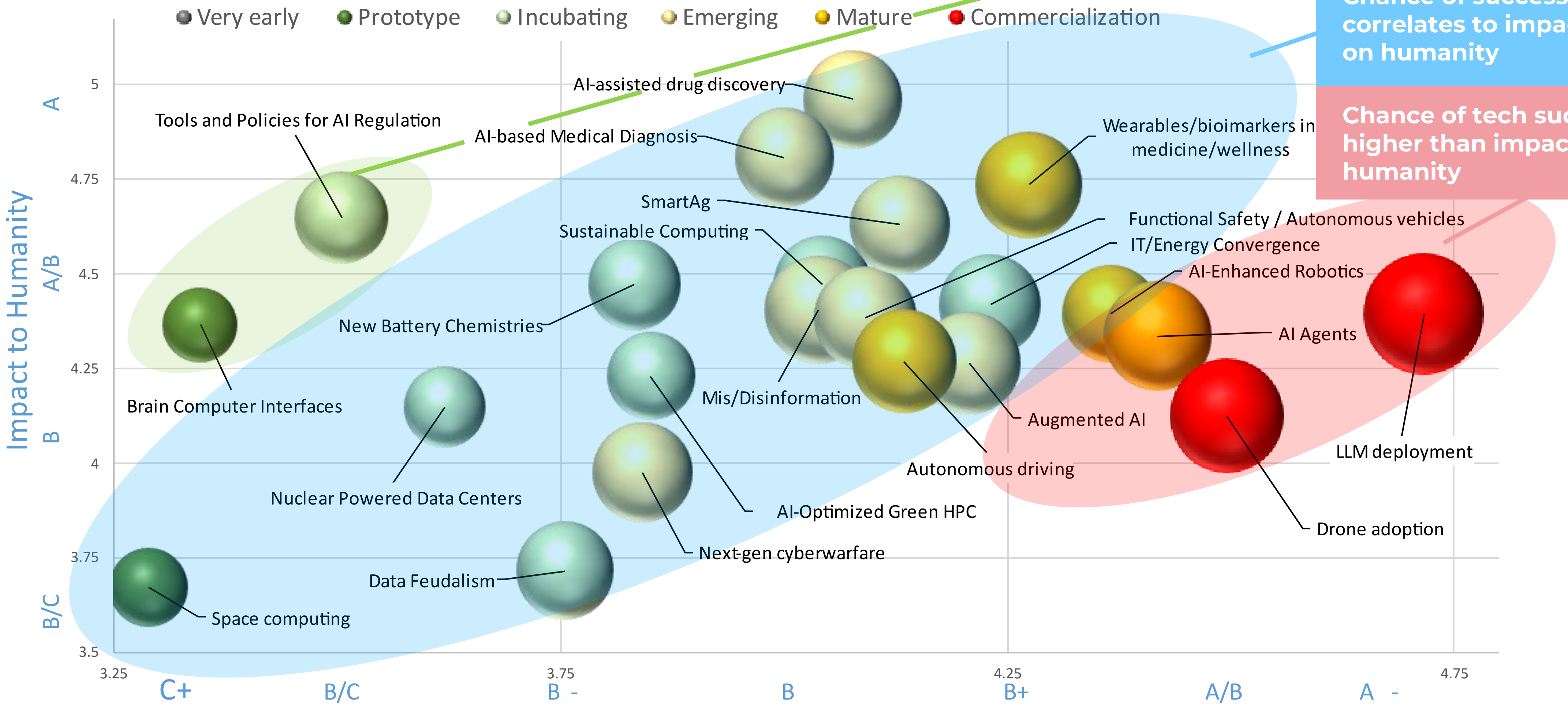
2025 Technology Predictions (Lowest/Highest)

Prediction: Tech. Development in 2025 (x – axis) vs Impact to Humanity (y – axis) (size of bubble proportional to relative market adoption)



Comparing 2025 Technology Predictions, Outliers

Prediction: Tech. Development in 2025 (x – axis) vs Impact to Humanity (y – axis) (size of bubble proportional to relative market adoption)



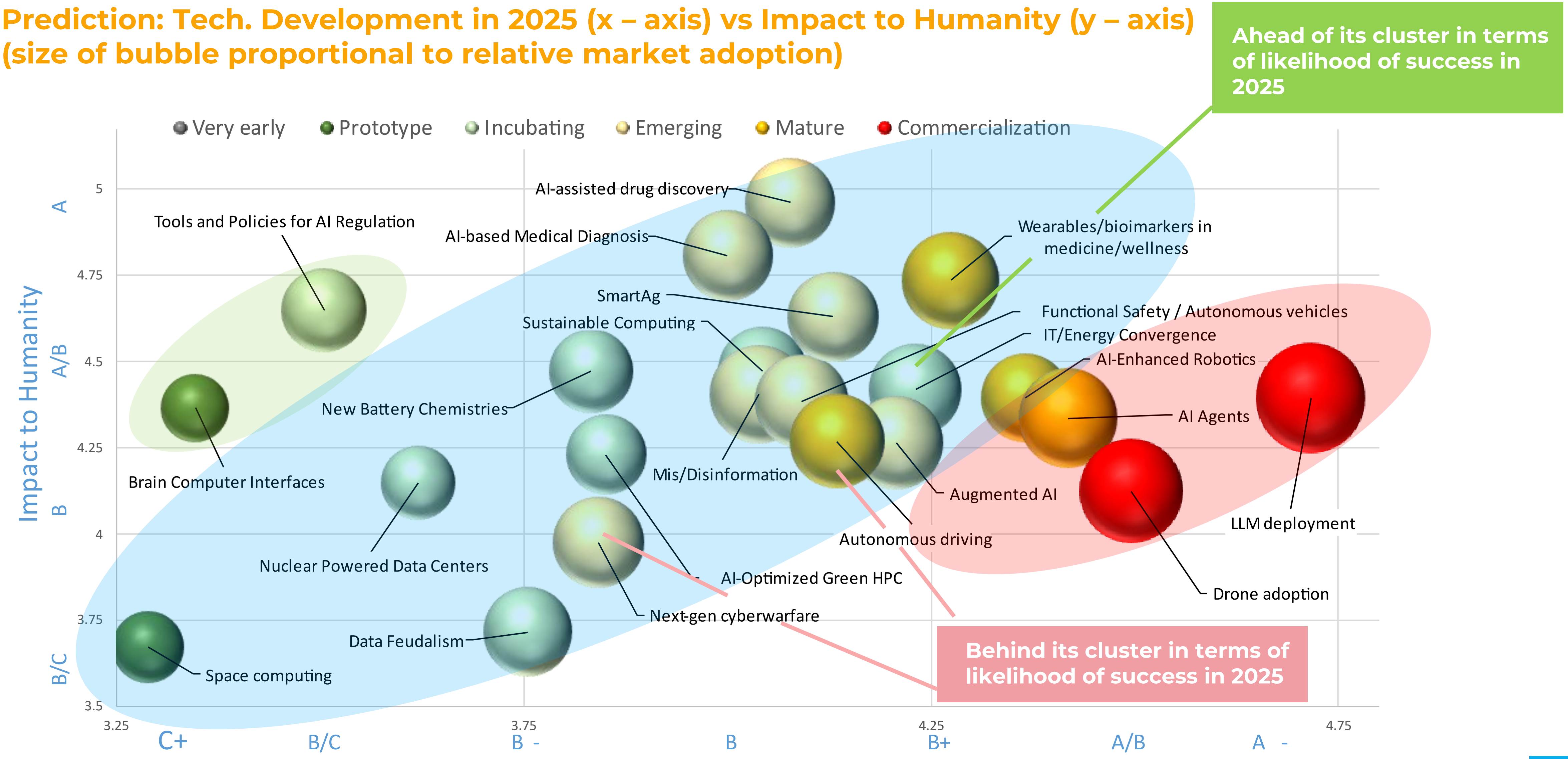
Impact on humanity higher than chance of tech success (worth investing in)

Chance of success correlates to impact on humanity

Chance of tech success higher than impact on humanity

Comparing 2025 Technology Predictions, Outliers *(continued)*

Prediction: Tech. Development in 2025 (x – axis) vs Impact to Humanity (y – axis) (size of bubble proportional to relative market adoption)



2025 Technology Predictions Detailed Comparison

Rank	Success in 2025		Impact to Humanity		Maturity in 2025		Market Adoption (2025)		Commercial Adoption Horizon	
	Technology	Grade	Technology	Grade	Technology	Grade	Technology	Grade	Technology	#Years
1	LLM deployment	A-	AI-assisted drug discovery	A	Drone adoption	B	LLM deployment	A/B	Brain Computer Interfaces	9.60
2	Drone adoption	A/B	AI-based Medical Diagnosis	A-	LLM deployment	B	Drone adoption	B+	Space computing	9.48
3	AI Agents	A/B	Wearables/biomarkers	A-	Wearables/biomarkers	B-	AI Agents	B+	Nucl. Powered Data Centers	6.54
4	AI-Enhanced Robotics	B+	Tools and Policies for AI	A-	Autonomous driving	B-	Mis/Disinformation	B	New Battery Chemistries	6.50
5	Wearables/biomarkers	B+	SmartAg	A-	AI Agents	B-	Wearables/biomarkers	B	AI-Optimized Green HPC	5.83
6	IT/Energy Convergence	B+	Sustainable Computing	A/B	AI-Enhanced Robotics	B-	Autonomous driving	B	Sustainable Computing	5.60
7	Augmented AI	B+	New Battery Chemistries	A/B	Mis/Disinformation	B/C	Funct. Safety / Autonomous	B	AI-assisted drug discovery	5.21
8	Autonomous driving	B+	IT/Energy Convergence	A/B	AI-based Medical Diagnosis	B/C	Augmented AI	B	IT/Energy Convergence	5.06
9	SmartAg	B+	Mis/Disinformation	A/B	SmartAg	B/C	IT/Energy Convergence	B-	Data Feudalism	4.90
10	Funct. Safety / Autonomous	B	AI-Enhanced Robotics	A/B	Funct. Safety / Autonomous	B/C	Next-gen cyberwarfare	B-	Autonomous driving	4.83
11	AI-assisted drug discovery	B	LLM deployment	A/B	Augmented AI	B/C	SmartAg	B-	Tools and Policies for AI	4.79
12	Sustainable Computing	B	Funct. Safety / Autonomous	A/B	Next-gen cyberwarfare	B/C	AI-based Medical Diagnosis	B-	SmartAg	4.77
13	Mis/Disinformation	B	Brain Computer Interfaces	B+	AI-assisted drug discovery	B/C	AI-assisted drug discovery	B-	AI-based Medical Diagnosis	4.75
14	AI-based Medical Diagnosis	B	AI Agents	B+	Sustainable Computing	C+	Data Feudalism	B-	Funct. Safety / Autonomous	4.73
15	AI-Optimized Green HPC	B-	Autonomous driving	B+	IT/Energy Convergence	C+	Sustainable Computing	B-	Next-gen cyberwarfare	4.58
16	Next-gen cyberwarfare	B-	Augmented AI	B+	Data Feudalism	C+	AI-Enhanced Robotics	B-	AI-Enhanced Robotics	4.25
17	New Battery Chemistries	B-	AI-Optimized Green HPC	B+	Tools and Policies for AI	C+	Tools and Policies for AI	B/C	Augmented AI	4.06
18	Data Feudalism	B-	Nucl. Powered Data Centers	B+	Nucl. Powered Data Centers	C+	New Battery Chemistries	B/C	Wearables/biomarkers	3.75
19	Nucl. Powered Data Centers	B/C	Drone adoption	B+	New Battery Chemistries	C+	AI-Optimized Green HPC	C+	Mis/Disinformation	3.69
20	Tools/Policies for AI	B/C	Next-gen cyberwarfare	B	AI-Optimized Green HPC	C+	Nucl. Powered Data Centers	C	AI Agents	3.15
21	Brain Computer Interfaces	C+	Data Feudalism	B-	Space computing	C	Space computing	C	Drone adoption	2.83
22	Space computing	C+	Space computing	B-	Brain Computer Interfaces	C	Brain Computer Interfaces	C-	LLM deployment	2.54

Correlation, Average, Range across Technologies, '23-'25

	Success in 2025	Impact to Humanity	Maturity in 2025	Market Adoption'25
Success in 2025	1	0.30 (↓)	0.90 (→)	0.89 (↓)
Impact to Humanity	0.30 (↓)	1	0.22 (↓)	0.21 (↓)
Maturity in 2025	0.90 (→)	0.22	1	0.93 (→)
Market Adoption in 2025	0.89 (↓)	0.21 (↓)	0.93 (→)	1

Success in 2025		Impact to Humanity		Maturity in 2025		Market Adoption in 2025		Horizon to Commercial Adoption (#years)	
Average	Range	Average	Range	Average	Range	Average	Range	Average	Range
B (↑↑)	[A-, C+]	B+ (↑↑)	[A, B-]	B/C (↑↑)	[B,C]	B- (↑↑)	[A-, C-]	4.81 (↑→)	[2. 49-9.69]

This year (2025)

	Success in 2025	Impact to Humanity	Maturity in 2025	Market Adoption'24
Success in 2025	1	0.47	0.90	0.96
Impact to Humanity	0.47	1	0.36	0.44
Maturity in 2025	0.90	0.36	1	0.93
Market Adoption in 2025	0.96	0.44	0.93	1

Success in 2025		Impact to Humanity		Maturity in 2025		Market Adoption in 2025		Horizon to Commercial Adoption (#years)	
Average	Range	Average	Range	Average	Range	Average	Range	Average	Range
B- (↑)	[A/B, C/D]	B (→)	[A-, C]	C+ (→)	[B+,C/D]	C+ (→)	[B+, D]	4.81 (↑)	[2. 29-9.66]

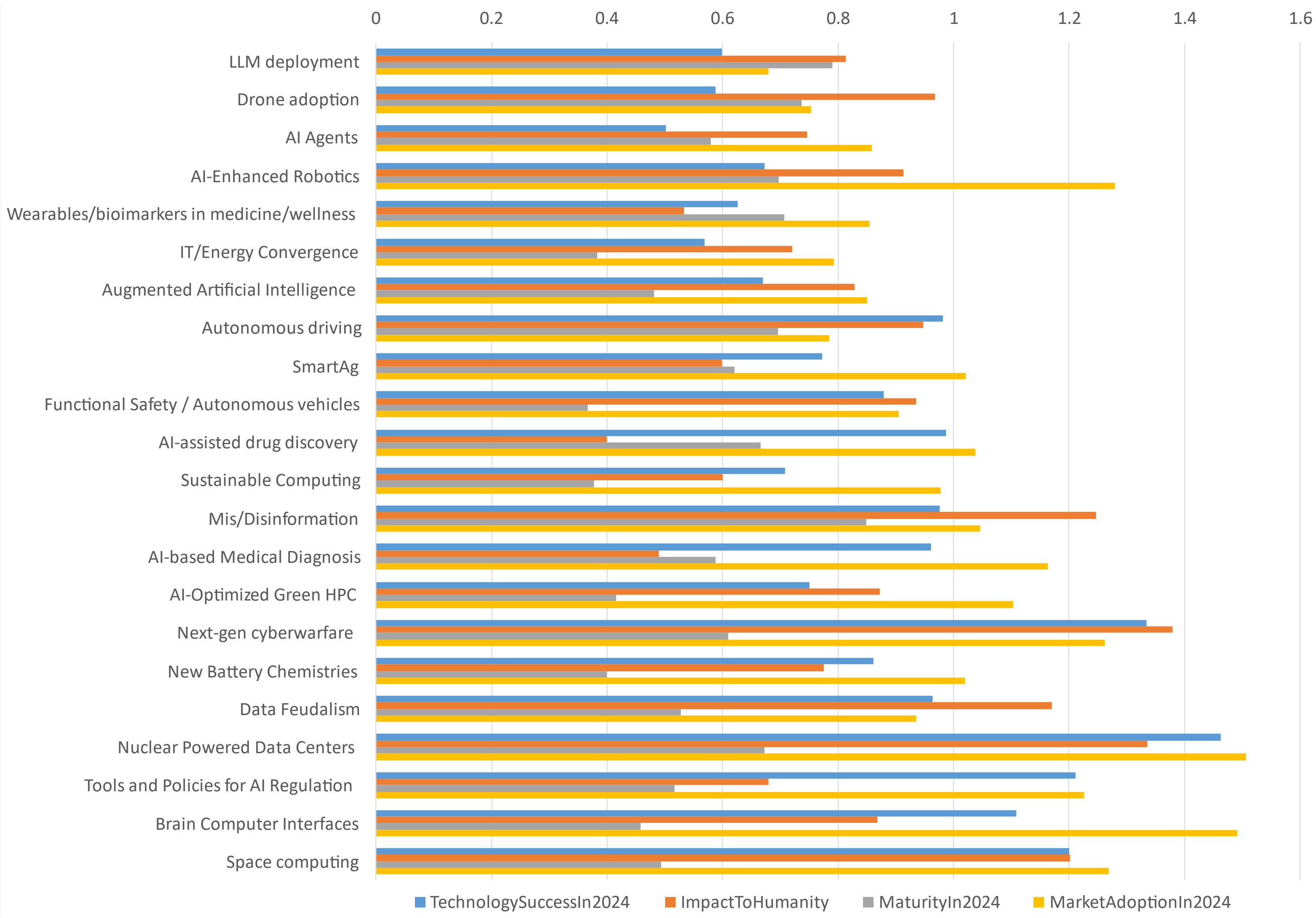
Last year (2024)

	Success in 2023	Impact to Humanity	Maturity in 2023	Market Adoption '23
Success in 2023	1	0.09	0.92	0.88
Impact to Humanity	0.09	1	0.13	0.28
Maturity in 2023	0.92	0.13	1	0.94
Market Adoption in 2023	0.88	0.28	0.94	1

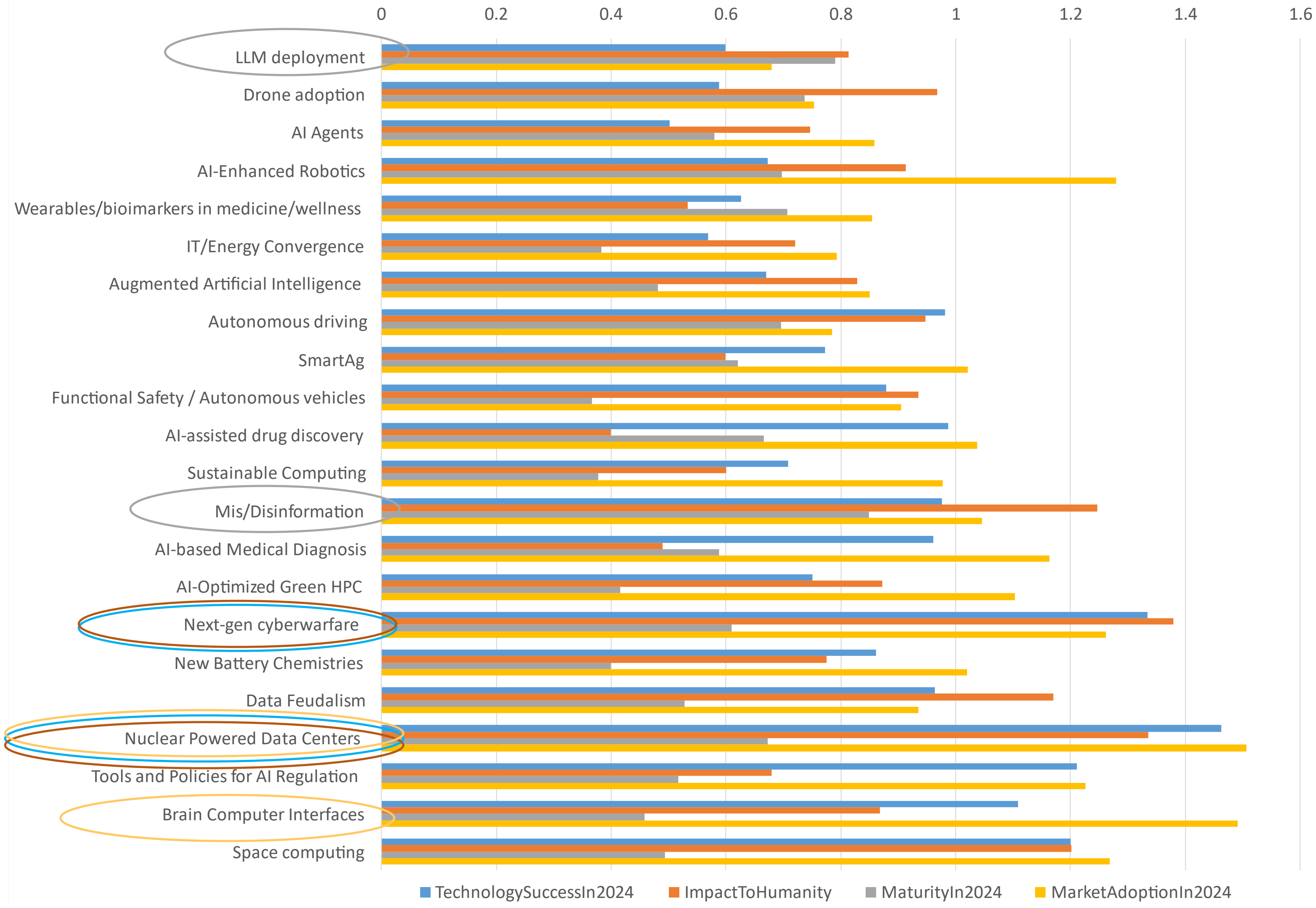
Success in 2023		Impact to Humanity		Maturity in 2023		Market Adoption in 2023		Horizon to Commercial Adoption (#years)	
Average	Range	Average	Range	Average	Range	Average	Range	Average	Range
B/C	[B+, C/D]	B	[A, B/C]	C+	[B,D+]	C+	[B+, D]	5.54	[2.4-11.1]

Two years ago (2023)

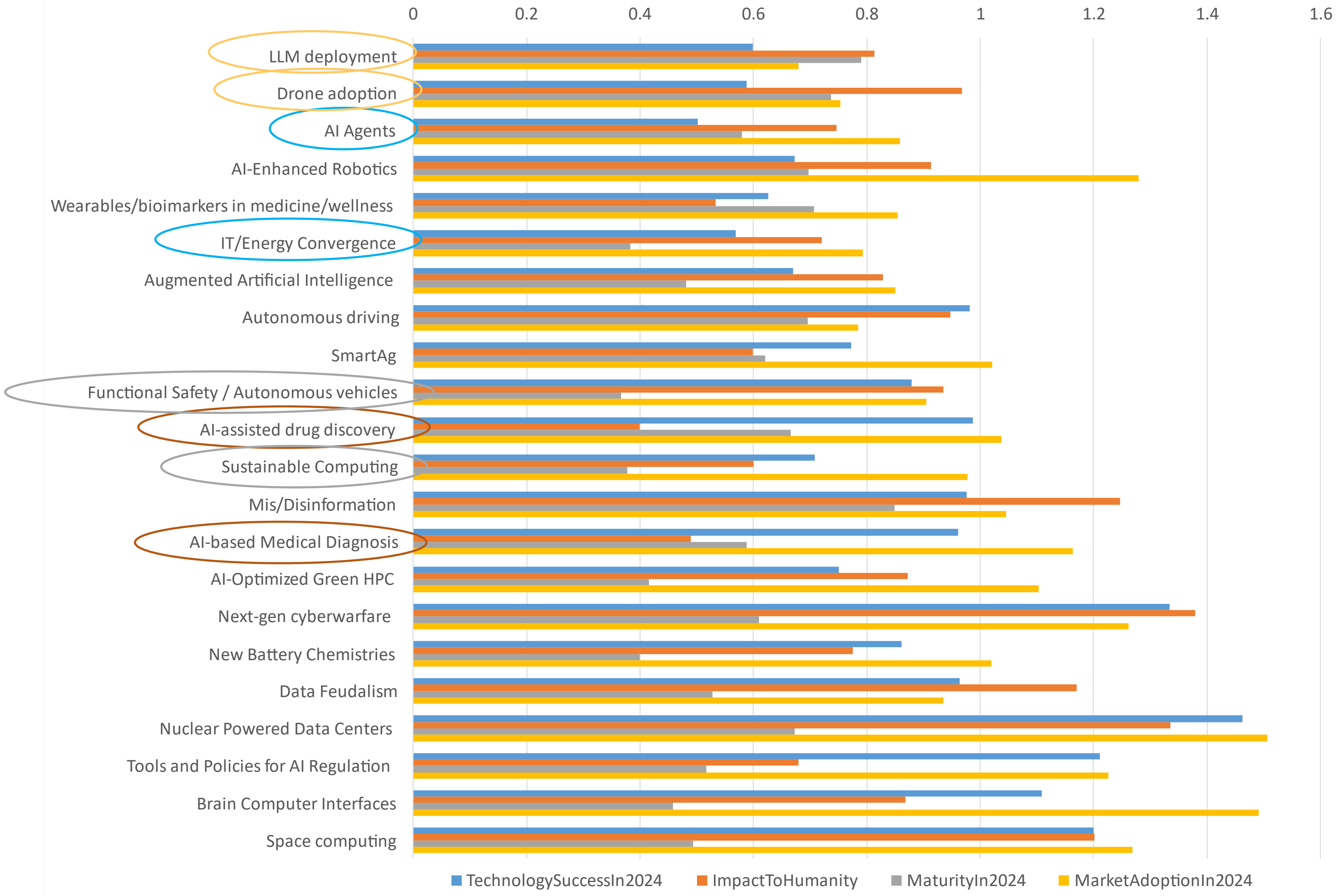
Standard Deviation



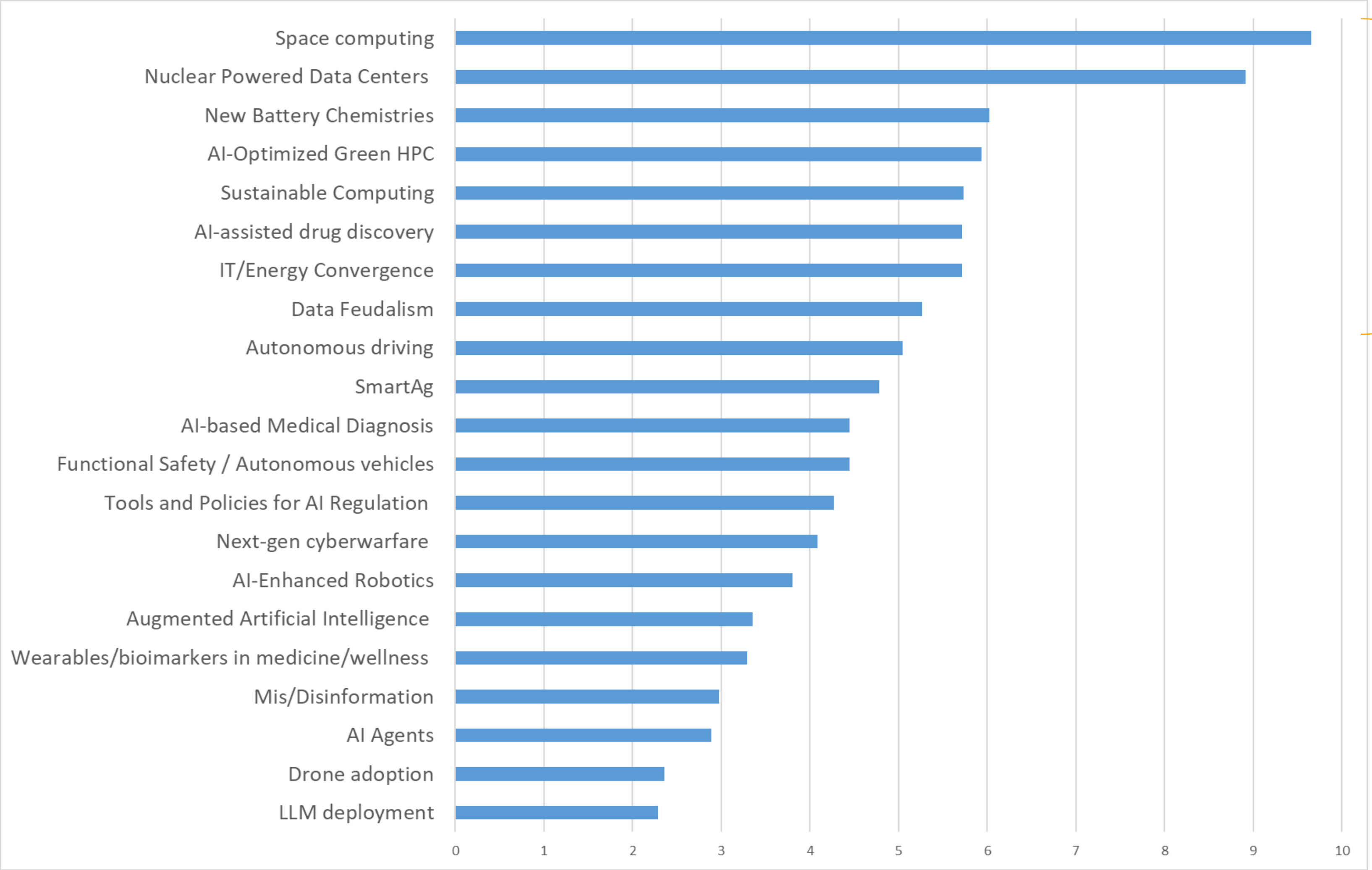
Standard Deviation, Largest (Least Confidence, 2 top)



Standard Deviation, Largest (Most Confidence, 2 top)



Horizons to Commercial Adoption



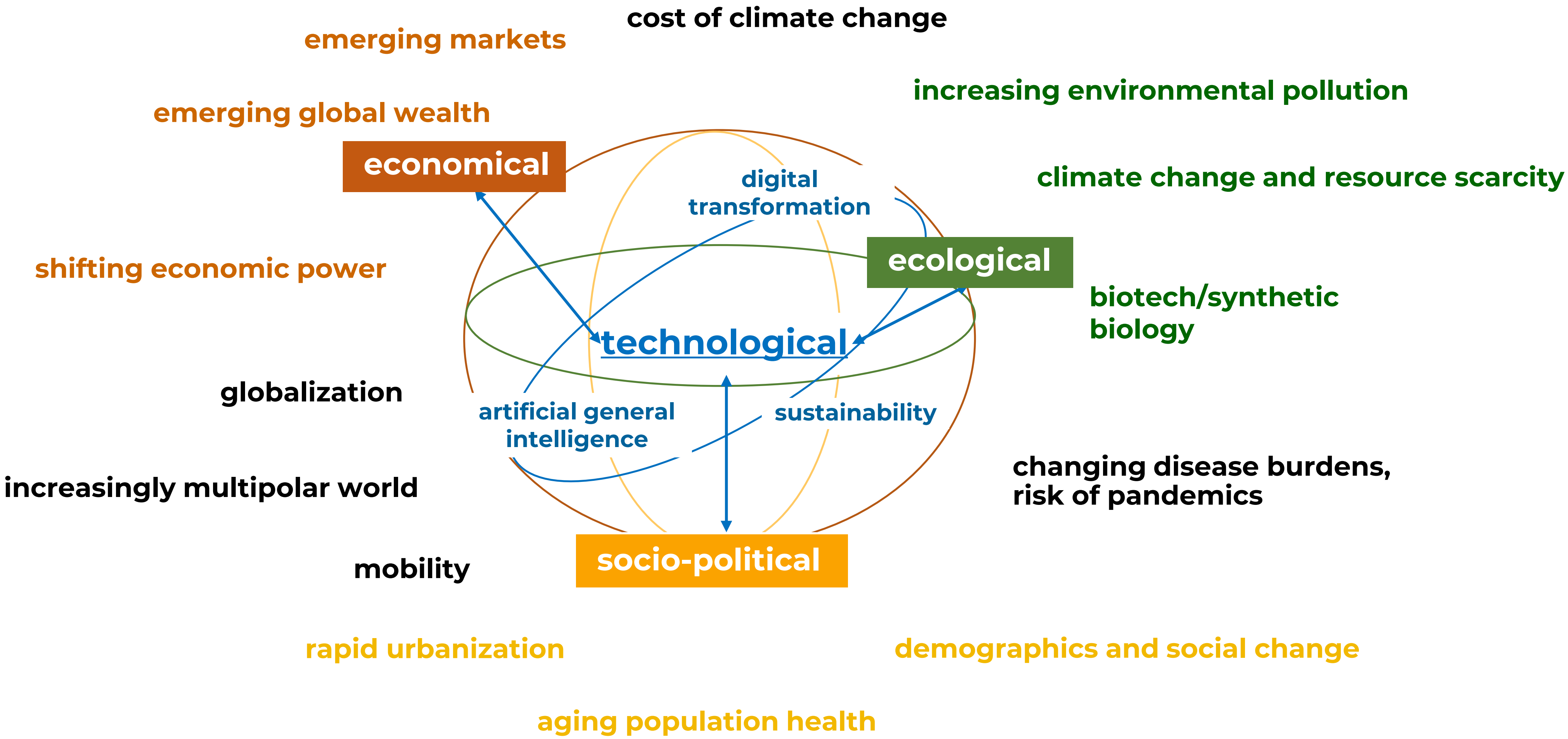
Opportunity for **academia (out-of-box thinking, innovations)**

Opportunity for **governments (funding, regulations)**

Opportunity for **professional organizations (standards, future directions, roadmaps)**

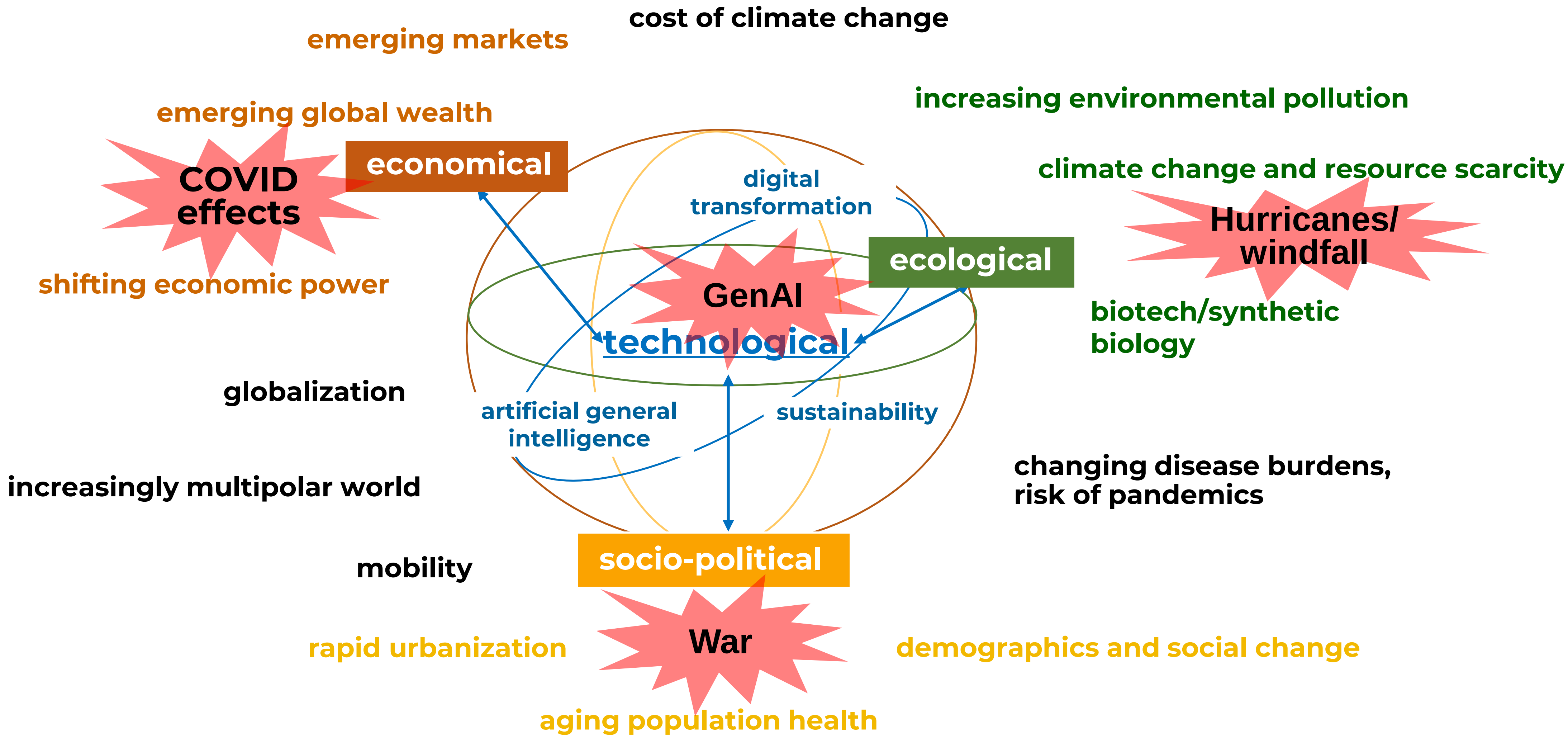
Opportunity for **industry (inventions, productization, new markets)**

Technology vs General-Megatrends



This Figure was originally published in C. Bash, K. Bresniker, P. Faraboschi, T. Jarnigan, D. Milojicic and P. Wood, "Ethics in Sustainability," in IEEE Design & Test, vol. 41, no. 1, pp. 25-32, Feb. 2024

Disruption and Megatrends, Impact on 2025



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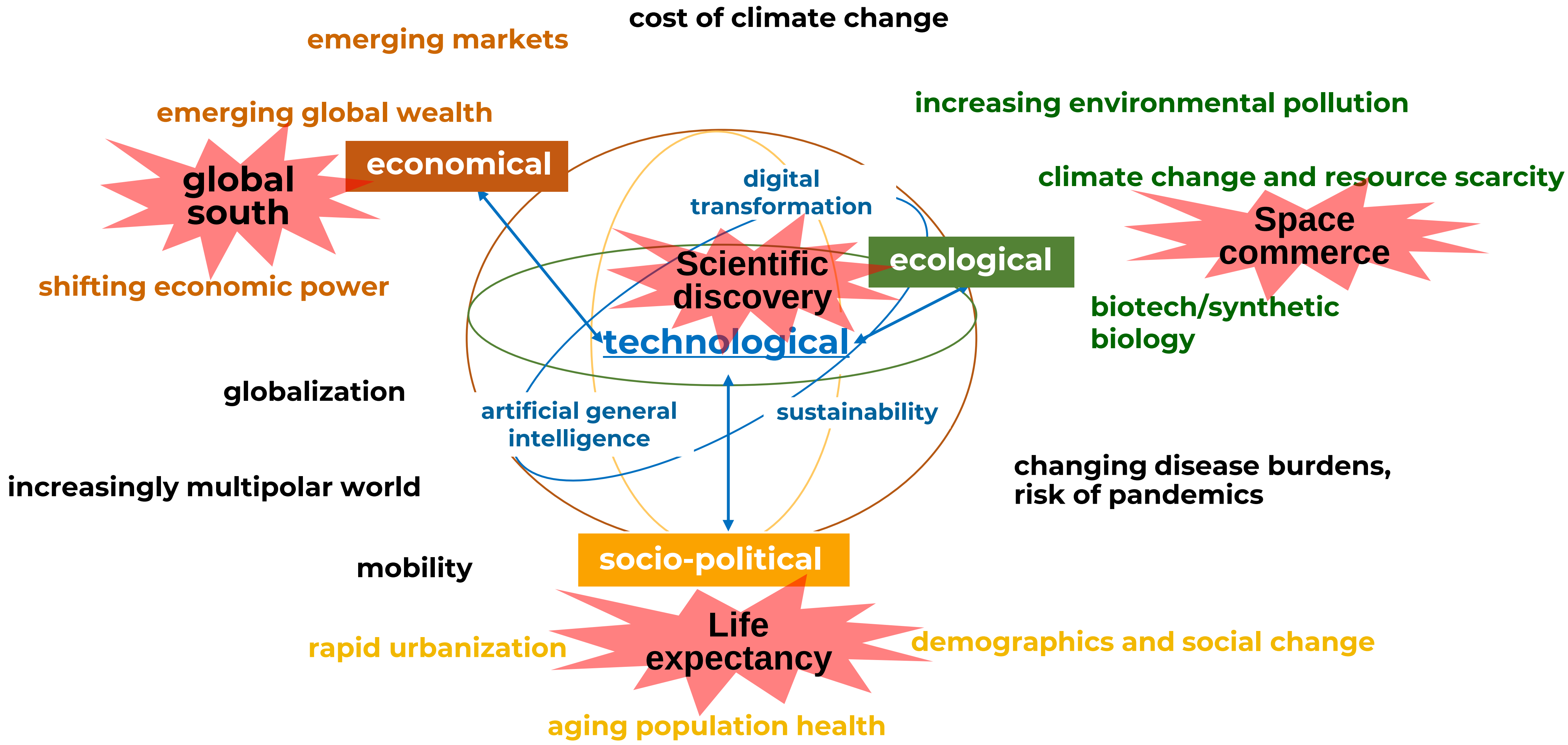
Disruption and Megatrends, Impact Beyond 2025



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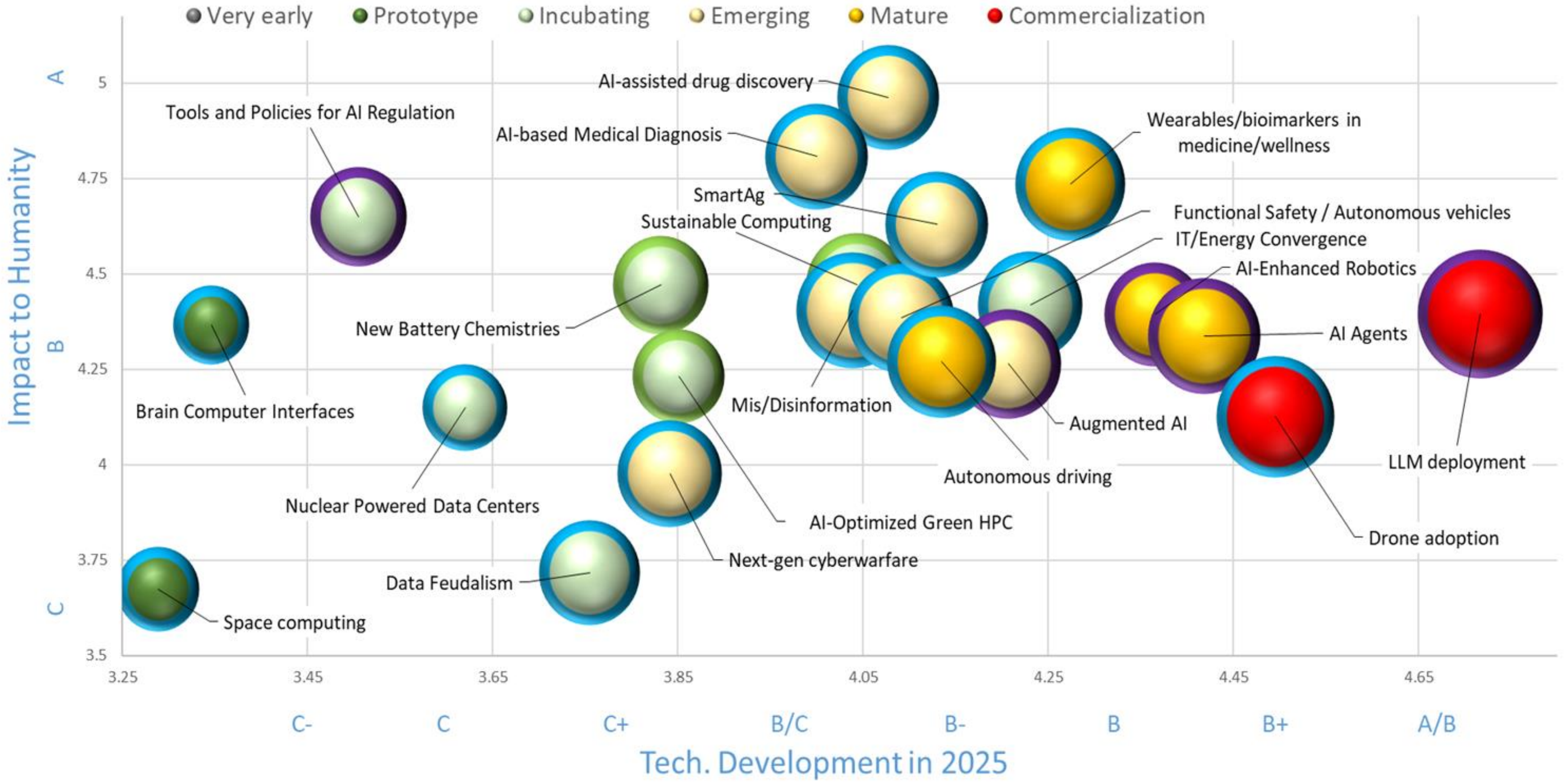
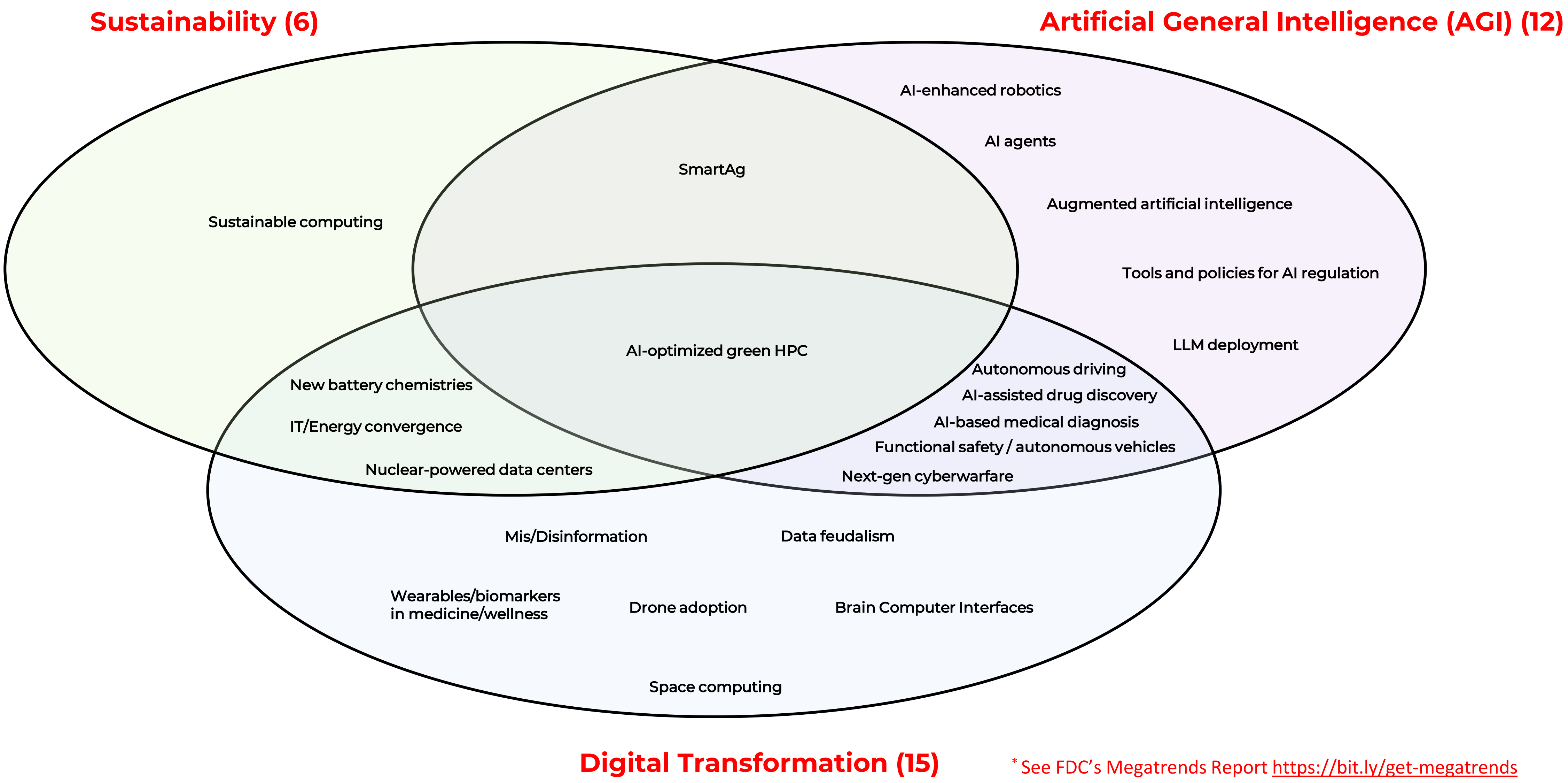
2025 Technology Predictions and Megatrends

Prediction: Tech. Development in 2025 (x – axis) vs Impact to Humanity (y – axis) (size of bubble proportional to relative market adoption)

- Artificial General Intelligence
- Sustainability
- Digital Transformation



2025 Technology Predictions and Megatrends*



* See FDC's Megatrends Report https://bit.ly/get-megatrends

Megatrends-related Insights*

From megatrends perspective, we have:

- 15 digital transformation-related predictions (6 exclusive) and most overlap with other megatrends (9)
- 12 AGI technology predictions (5 exclusive)
- 6 sustainability-related (1 exclusive)

There is a lot of overlap across megatrends:

- Digital transformation has most overlap in terms of the number of technologies
- Sustainability has most overlap in terms of percentage, making it most applied megatrend (in percentages)
- AGI is increasingly more applied to almost any other technology

Socio-political, economic, and ecological aspects are deeply entangled, e.g.:

- The ethical aspects of using drones, Brain Computer Interfaces, and LLM deployment
- Copyright and right-to-use issues are being heavily addressed: e.g., how to differentiate derivative from new intellectual properties
- Explainability and trustworthiness of AI solutions are still too nascent to be of sufficient use for regulatory needs

* See 2024 FDC's Megatrends Report **https://bit.ly/get-megatrends**

Insights and Opportunities

Insights for 2025

- Technology with most advancement, largest market adoption and market maturity is LLM deployment (A-)
- Technology with highest potential for impact on humanity is AI-assisted drug discovery (A)
- Technologies with large impact to humanity but fewer chances for technological success (tools and policies for AI regulation and Brain Computer Interfaces) may require government assistance
- Long-term opportunity is in space computing

Insights across years

- AI strengthened its dominance compared to previous years
- We see continued controversy around mis-information
- Compared to last year, we see some decline in sustainability-related tech

Longer-term broader opportunities

- Small Modular Reactors (SMRs) offer a breakthrough solution for a sustainable, reliable data center energy supply
- Wearables/biomarkers will continue innovations in sensor accuracy, energy efficiency, real-time analytics, and medical applications
- The development of tools and policies for AI regulation is making good progress
- Next-gen cyberwarfare is emerging as a key area due to rising concerns around data integrity and AI vulnerabilities
- Biotechnology rapidly advancing under the radar in the shadow of AI, with opportunity of working together with AI
- Convergence of technologies through systems approaches (e.g. IT/energy sectors)

* See 2024 FDC's Megatrends Report **https://bit.ly/get-megatrends**

Targeted Recommendations

Industry

- Explore new facets of **LLM deployment**, e.g. Small LM
- Validate **drone use cases** in select settings, business models
- Start delivering **AI agents** in areas where they can complement human labor
- Develop products and services to detect and prevent **mis/disinformation**
- Enforce end-to-end **sustainable computing** for all products services and most industries
- Factory production strategies with higher quality/economic benefits of **SMRs**
- Professional development curricula for **working engineers** ready to move into technical management

Government

- Regulate, sponsor, and encourage **smart agriculture**
- Invest in tools and policies for AI regulation in broad domains
- Regulate **autonomous driving** in road/air/water vessels
- Understand, define, and prevent data feudalism and data poisoning
- Invest in **IT/energy convergence** in main industry sectors
- Foster industry to drive **AI-assisted drug discovery**
- Address security & waste challenges in distributed **SMR** infrastructures
- Foster addressing technology challenges in **convergence of ICT, energy, AI, space, robotics**

Academia

- Research and prototype **AI-optimized green HPC**
- Explore **new battery chemistries** and their use in diverse use cases and settings
- Conduct research for safety of **SMR-powered data centers**
- Explore the near-/medium-term opportunities in **space computing**
- Prototype **Brain Computer Interfaces** for a select set of ethically approved use cases
- Create/strengthen curricula and departments in **systems engineering**
- Develop **AI-based medical diagnosis** for existing/new diseases
- Increase cross-technology curricula in **sustainable computing**

Professional Organization

- Define standards and best practices for **wearables/biomarkers in medicine/wellness**
- Foster safe and ethically aligned **Augmented artificial intelligence**
- Arrange for competition and events in **AI-enhanced robotics**
- Help drive industry/government coalitions to evaluate and **next-gen cyberwarfare**
- Introduce standards and best practices in **functional safety / autonomous vehicles**
- Encourage **AI-based medical diagnosis** for existing/new diseases
- **Plug-and-play standards** that induce competitive economies of scale and reliability possible with large statistics

Targeted Recommendations *(continued)*

End user

- Implications of AI evolution how to interact with AI agents
- Upskill for the AI age
- Be mindful of sustainability in daily use
- Be prepared for new UIs including brain-computer interfaces and wearables

Developer

- Heavy AI adoption in DevOps
- Increased automation will require new programming models, and new DevOps
- Understanding energy consumption propagates into code development, not just operations
- Address mis/disinformation, new cyberwarfare, and data feudalism across the stack

CxO

- Modernize enterprise using AI agents, new types of LLMs
- AI-assisted-* (drug discovery, medical diagnosis, robotics, HPC, etc.)
- Re-evaluate realistic sustainability goals
- Automate with new approaches, such as robotics

Investor

- Unlimited opportunities with AI
- Promise of new energy materials (batteries) and sources (Small Modular Reactors)
- Substantial opportunities in smart agriculture
- New transportation models with drones and in space
- AI and biotechnology working together

Direction of Individual Skills Evolution

Skills Impact Trending

Digital Transformation	Sustainability	AI	Regulatory Compliance
Autonomous driving ↘	Nuclear-powered data centers ↑	AI-enhanced robotics ↑	Mis/Disinformation ↗
Wearables/biomarkers in medicine/wellness ↑	IT/energy convergence ↑↑	AI agents ↓↑	Data feudalism ↗
Drone adoption →	SmartAg ↑↑	LLM deployment ↓↑	Tools and policies for AI regulation ↑
Brain Computer Interfaces →	Sustainable computing ↑	Augmented artificial intelligence ↓↑	Functional safety / autonomous vehicles →
Space computing ↗	New battery chemistries ↑	AI-assisted drug discovery ↑	Next-gen cyberwarfare →
		AI-based medical diagnosis ↑	
		AI-optimized green HPC →	

Skills Needed

↑↑ *Substantial growth*
↑ *Growth*
↗ *Some growth*
→ *Stay the same*
↘ *Some decline*
↓ *Decline*
↓↓ *Substantial decline*
↓↑ *Skills change, some decline, some growth*

Portfolio of Predictions

- Archive of annual IEEE CS Tech Predictions & scorecards
- IEEE Future Directions Megatrends Report: https://bit.ly/get-megatrends (over 3250 downloads)
- Special issues of IEEE Computer (2024, 2023, 2022, 2021, 2019), 6th year special issue to appear in Oct 2025
- IEEE Computer "Predictions" Columns (...., Sustainability, Digital Transformation, Megatrends, AGI, Heterogeneity/Serverless, Performance, Energy4DataCenters, DigitalTwins, Convergence of IT & Energy Sector), entering 5th year
- IEEE SCVS Industry Spotlights (Megatrends, AI, Sustainability, Digital Twins, Convergence of IT and Energy Sectors), co-sponsored by FDC, IEEE CS, IEC
- Special Features
  - The IEEE Institute article on Megatrends https://spectrum.ieee.org/preieee-2024-technology-megatrends-report
  - IEEE SSE, "The Art of Prediction"
  - IEEE Design and Test, "Ethics in Sustainability"
  - IT Professional "What Gets You Hired Now Will Not Get You Hired Then"
- Many webinars, podcasts, keynotes, invited talks, panels, etc.
  - E.g. SXSW panel: "AI: Prosperity or Doom for Human Workforce?"
- Course "High Performance Computing: Use of AI and Emerging Technologies in Science"
- Decadal reports: Computer Society Report 2022 (issued in 2015); Future of Workforce (issued in 2023)

Summary

Outlook

- Technologies will continue to be critical in addressing and preventing pandemics and consequences of natural disasters, while promoting innovative, sustainable, and socially responsible enhancements to quality of life

Predictions

- We made twenty-two predictions in six broad areas (applied computing, energy, applied AI, non-functional characteristics, user-interfaces, and verticals)
- We graded our predictions in terms of likelihood technology success, impact to humanity, maturity in 2025, market adoption in 2025, and horizon to commercial adoption
- Predicted technologies show a degree of correlation, but with a more diverse roster we got less correlation this year

Honorable mentions—technologies that barely did not make a cut

- Cybersecurity of data centers; machine unlearning; recycling of clean energy solutions; quantum-HPC fusion

Future work

- We continue to eliminate bias, as demonstrated by correlation and standard deviation
- At the end of the year, we will prepare a scorecard on how technologies succeeded against our predictions
- To improve the depth and accuracy of future predictions, we aim to increase collaboration with industry experts, academic institutions, and regulatory bodies

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Additional Materials

2025 Technology Predictions Team

Statements in this slideset express opinions of authors themselves only and not of their employers

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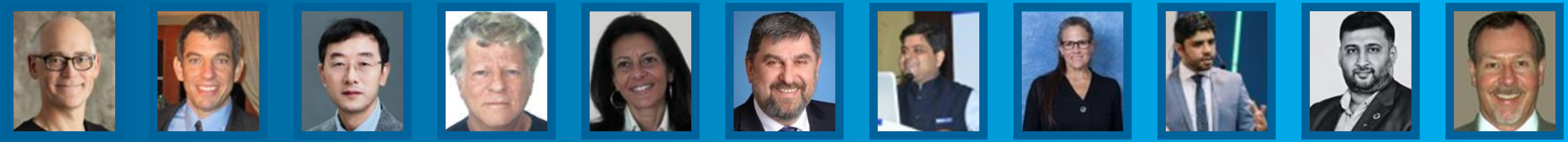

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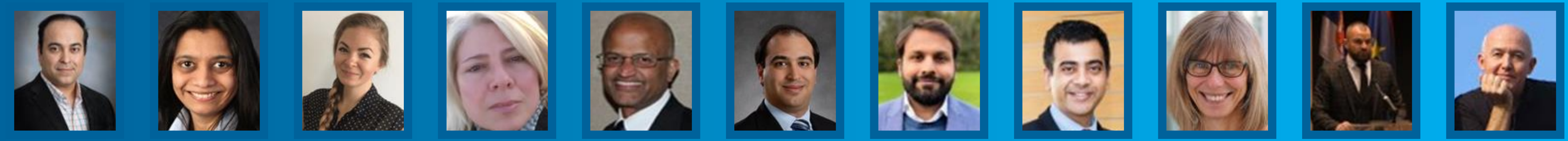

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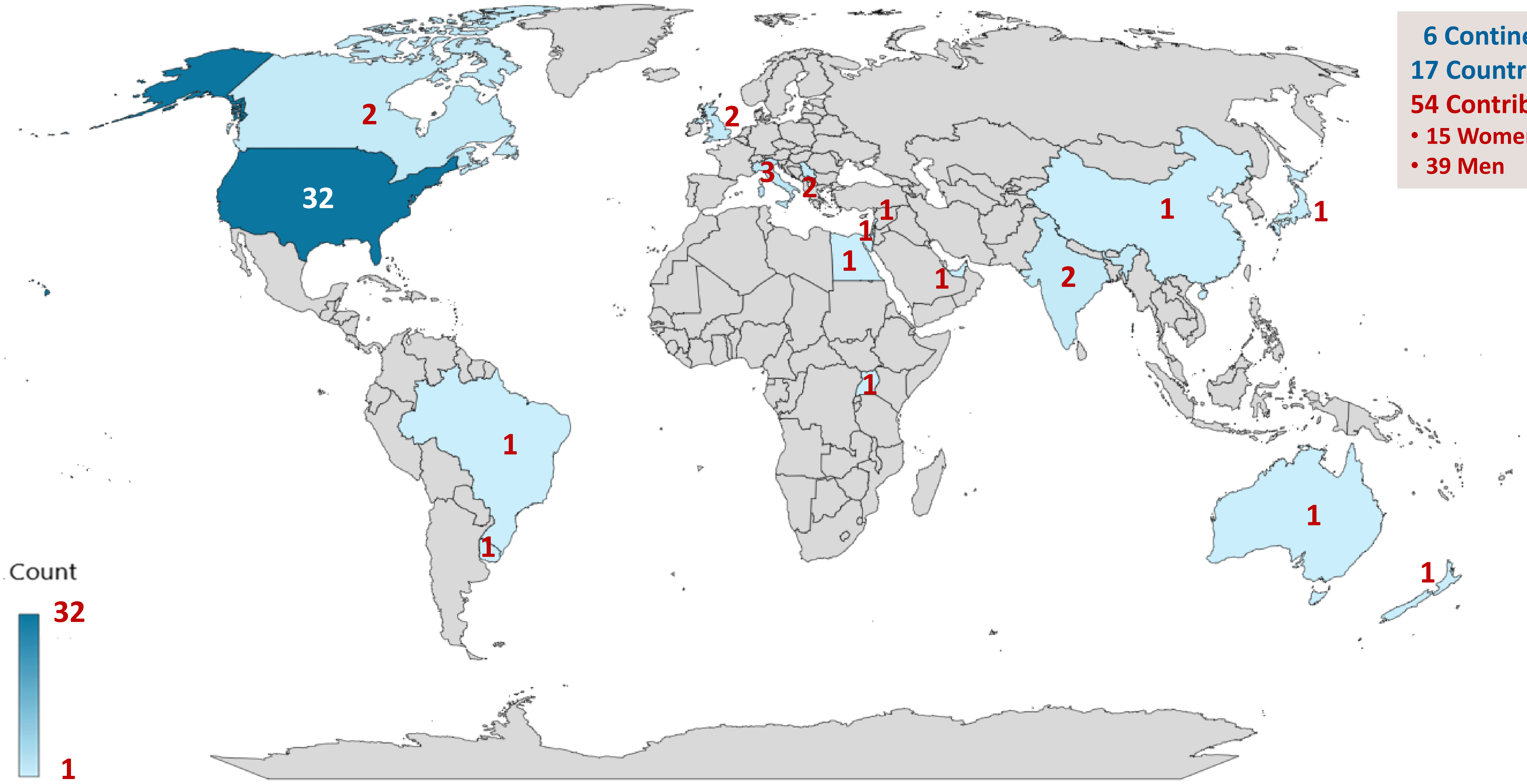
2025 Technology Predictions Team - Where They Live



6 Continents
17 Countries
54 Contributors
- 15 Women
- 39 Men

2025 Technology Predictions Team - What They Do

Academia
23

Industry
25

Government
5

Professional Organization
1

Process: Continued Improvements

Identification

- This year we expanded our team from 12 (2021), 16 (2022), 35 (2023), and 46 members (2024) to 54 (2025)
- We further improved our diversity in terms of gender (16 female) and technology areas (HPC, architecture)
- Authors made up to two predictions, resulting in 88 predictions
- We then down-selected to 22, by each author giving one of 16 votes to 16 technologies
- We then did another careful merging of some predictions

Grading: In the second round we graded each technology

- We assigned a grade of:
  - [A+ to F-] for: Technology Success in 2025; Impact to Humanity; and Predicted Market Adoption in 2025
  - [Very early, prototype, incubating, emerging, mature, and commercialization] for Maturity
  - [1 year, 3y, 5y, 10y, 15y] for Horizon to Commercial Adoption
- We express impact to humanity as a function of technology advancement; we quantify maturity, market adoption, and time-to-adoption
- We calculated our confidence as standard deviation in voting; and bias as a correlation between individual grades
- Finally, we tweaked and optimized

Qualifying

- For each of the down-selected 22 technologies, we wrote a slide on problem/demand, opportunity, impact, & sustainable solution/business opportunity

LLM Deployment (A-)

1

We will see deployments of Small Language Models and exotic, special-purpose models, transforming industries through more domain-specific and efficient AI applications.

Problems/Demand

- Still few and only localized initiatives on sustainable IT
- The increasing cost of IT on global energy consumption
- Limited understanding of how to use computing resources efficiently
- Lack of tools and techniques for carbon-responsive computing
- Limited understanding of how to measure sustainability
- Electronic waste
- Disposable devices/planned obsolescence
- Growing reliance on LLMs for advanced tasks in specific industry needs
- Privacy-preserving LLM model designs

Opportunities

- Provide effective Small Language Models
- Argument detection and analysis with LLMs
- Solve computer tasks with language models from text descriptions
- Use of LLMs for recommendation
- Open-source Small Language Models bring opportunities to fine tune models and use them for a specific purposes
- Companies concerned about data privacy and proprietary information will be able to deploy their own local models

Impact

- Language models become more accessible, which brings opportunities for innovative ideas and specific use cases
- Companies will be able to protect their data
- Improved hallucination detection using model cross validation
- Increased opportunity for AI agent development
- Use of LLMs as a source of truth
- Loss of skills, mainly for the younger generation
- Loss of creative content if new models feed on results of previous ones

Sustainable solutions / business opportunity

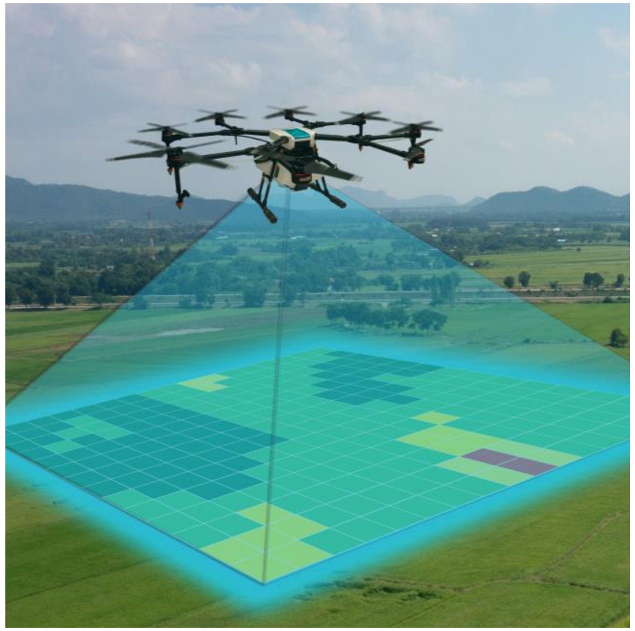
- New innovative applications for lightweight and highly specialized LLMs
- Custom language models will no longer be restricted to large companies
- Cost to train and fine tune models will decrease
- Development of energy-efficient architectures
- Industry-specific LLMs for fields like healthcare, finance, and law can improve accuracy and reduce computational overhead

- **Enablers:** open-source communities such as Hugging Face; cloud services providing LLM solutions with integrated prompt engineering; hardware evolution to specifically accommodate for optimal run of LLMs; model compression, cloud/AI infrastructure, emerging MLOps

- **Inhibitors:** training models will still require carefully curated data sets; significant hardware requirements remain for running the latest LLMs; computational and energy requirements to develop custom LLMs; privacy/copyright issues; high costs, data scarcity, ethical/security risks

2 Drone Adoption (A/B)

Drone-as-a-Service (DaaS) will redefine logistics, agriculture, and disaster response, offering reliable, low-cost solutions with quick turnarounds across diverse industries.



Problems/Demand

- Enhanced demand for drone-enabled AgriTech solutions (crop managements, livestock monitoring, spraying of fertilizers and pesticides, capturing data of crop health, nutrient level and irrigation needs, supporting precision forming)
- Enhanced demand for drone-assisted fire fighting (providing real time situational awareness, mapping the fire perimeter, & identifying hotspots)
- Enhanced demand for drone-born (microwave/optical/hyperspectral) remote sensing/ground penetrating radar data for precise cartographic, urban planning, resource mapping, IED detection, environmental study applications
- Enhanced demand for drone assisted formation flying for entertainment, cinematic and strategic applications
- Enhanced demand for drone assisted delivery in urban and rural areas
- Regulatory hurdles, privacy and ethical concerns, limited battery life and flight range

Opportunities

- AI-powered drone choreography, geospatial analysis
- Advanced drone motion compensation algorithms
- Size, Weight, and Power optimization for drone-born payloads
- Advanced drone swarm technologies
- Advanced electric vertical takeoff and landing technologies
- Fully autonomous drones & refueling on fly technologies
- Revolutionizing last-mile delivery, enhanced disaster response and recovery, military and intelligence gathering will push the technology

Impact

- Extensive drone adoption in search and rescue, reshaping wars, delivering time sensitive medical supplies
- Fully autonomous drones will circumvent the problems raised by hamming and unavailability of GPS signals and provide 24x7 services in critical situations
- Advanced electric vertical takeoff and landing technologies will change the landscape of urban mobility

Sustainable solutions / business opportunity

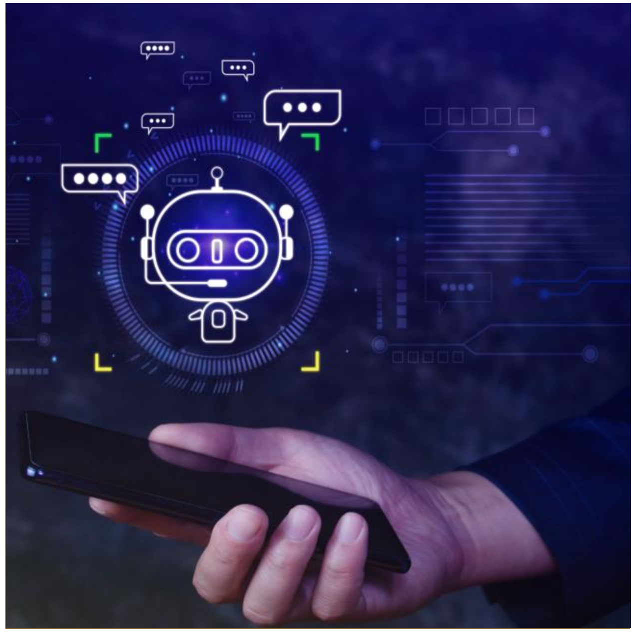
- Extensive drone adoption will create a Drone-as-a-service (Daas) industry growing exponentially

- **Enablers:** continuous size, weight and power optimization; AI /ML adoption in all possible domains; advanced Swarma, eVTOL technologies will boost adoption of drones in several domains; fully autonomous drones will reshape wars; higher volume production and larger markets; improved battery technology; public acceptance

- **Inhibitors:** limited payload carrying capability; limited continuous flying time; limited autonomy; regulatory hurdles; privacy and ethical concerns

3 AI Agents (A/B)

AI agents combining LLMs, ML models, and rule-based systems will provide autonomous, highly specialized solutions for finance, manufacturing, and retail operations.



Problems/Demand

- Repetitive task requiring low level of expert knowledge and/or creativity, can be performed by AI agent
- Challenges to scale up small business due to inability to hire skilled workers to perform specific tasks
- Users should be able to interact with AI agents in their preferred human language, including flexible or informal expression
- Enabling AI agents to automatically generate and deliver relevant content based on a given context or subject

Opportunities

- AI agents will enable automation of more complex tasks with minimal human input, requiring only task descriptions
- Work efficiency will increase as some tasks will be performed faster by AI agents than humans with less error
- Enabling small businesses to scale up without the need to hire more skilled workers
- AI agents will create new job opportunities centered around their development and maintenance.
- Guidance of AI agent development of their own logic in suitable directions
- Have AI agents as allies and even drivers in the development of sustainable activities
- Education can become more accessible and personalized through AI agent tutors

Impact

- Jobs will evolve as AI agents take on certain specialized tasks, creating opportunities for new roles
- The need for upskilling will grow as some jobs fade, while others evolve into active collaborations with AI agents to achieve desired outcomes
- Increased training for workers on effectively collaborating with AI agents
- Small businesses will scale faster by deploying AI agents, reducing the need for extensive labor investments

Sustainable solutions / business opportunity

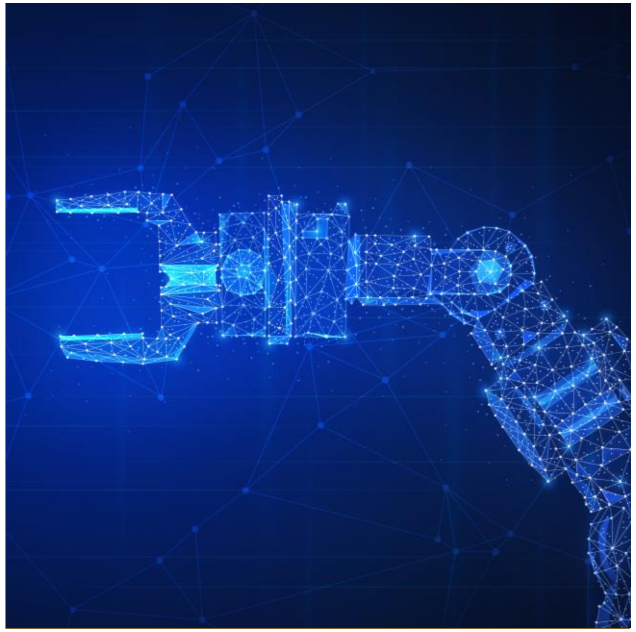
- Solutions with a friendly user interface to interact with AI agents
- AI agents will enable sustainable solutions by performing specific roles or assisting humans, promoting efficient and responsible practices
- AI agents to drive trends to sustainability

- **Enablers:** advancement of small language models will lower hardware requirements and enable easier fine-tuning; open-source AI libraries and models will allow for model and data ownership; cloud solutions with friendly user interface and low code approach will increase the accessibility of AI agent solutions

- **Inhibitors:** data quality and preparation will remain important for quality solutions; limited computational resources and energy costs can hinder progress; challenge from LLM hallucinations generating inaccurate information; potential loss of employment; risks related to AI agents developing their own logic

4 AI-Enhanced Robotics (B+): Embodied intelligence for seamless human-robot interaction

Embodied intelligence will enable robots to perceive, learn, and collaborate in dynamic environments, achieving unprecedented autonomy and human-like adaptability.



Problems/Demand

- Critical labor shortages in high-risk, repetitive, and skilled manufacturing roles
- Growing aging population requiring advanced healthcare and caregiving assistance
- Increasing complexity in supply chain and manufacturing requiring adaptive automation
- Growing consumer expectations for intelligent, and personalized interactive devices
- Safety and reliability concerns in human-robot interactions

Opportunities

- Development of advanced collaborative robots (cobots) with enhanced perception and safety features for diverse industrial applications
- Innovations in healthcare robotics for surgery, rehabilitation, and personal care assistance
- Enhanced productivity and safety in hazardous environments
- Integration in smart cities for improved infrastructure management
- Potential for consumer robotics in education, household, and entertainment

Impact

- Significant reduction in workplace injuries and errors
- Improved quality of life through assistive care and rehabilitation
- Cost savings and operational efficiency across industries
- Acceleration of human-AI synergy in the workplace and home
- Enhanced disaster response and risk mitigation

Sustainable solutions / business opportunity

- Energy-efficient robotic systems with optimized AI processing
- Subscription and as-a-service models for commercial and consumer robots, enabling accessibility for SMEs
- Collaboration with renewable energy for sustainable operation
- Customizable, modular robotic systems for diverse applications
- Robotics-enabled circular economy (e.g., waste management, recycling)

- **Enablers:** advances in large language models and multimodal AI, and computer vision; advanced edge computing and 5G/6G networks; next-generation battery technology, wireless charging, and energy storage; integrated sensors with advanced fusion capabilities and real-time analytics to enable enhanced perception and seamless interaction; robust data integration from IoT for real-time adaptability, with standardized protocols for robot-to-robot communication to ensure seamless interaction and collaboration

- **Inhibitors:** : high capital investment for robotics and AI systems; complex regulatory and compliance for autonomous systems; limitations in current AI models' adaptability and autonomy, and technical challenges in generalizing robot cross-application learning; workforce skill gap in robotics operation and maintenance; public resistance to widespread robotics adoption due to ethical concerns about privacy, safety, and job displacement

5 Wearables/Biomarkers in Medicine/Wellness (B+)

Wearables will track biomarkers for early disease detection and proactive wellness, expanding beyond fitness tracking to medical-grade monitoring for chronic conditions.

Problems/Demand

- Detection of early signs of health issues
- Tracking of disease progression
- Reducing cost for health and wellness interventions and inpatient visits
- Need for remote and continuous monitoring
- Comprehensive analysis of individuals' health data and history is needed to optimize diagnosis and treatment
- Determination of disease subtypes in pathologically and clinically heterogeneous diseases
- Management of chronic conditions (e.g., diabetes, heart conditions)

Opportunities

- Enabling effective preventive medicine and optimized drug delivery
- Support chronic disease management
- Track health status by targeted monitoring of specific disease-related risk factors
- Government and insurance company R&D investments will help advance sensors, research, and remote medical infrastructure.
- New classes of machine learning algorithms coupled with new technologies/accurate patient history allow physicians to improve diagnosis, enhance personalized treatment and efficiency
- ML algorithm can be used to address patient management at a health care delivery-systems level, thus optimizing patient flow resulting in increased efficiency and lower costs
- Richer and better-informed data sets will enable more accurate design of digital twins

Impact

- Broader access to customized solutions, medical assistance, health care specialists and preventative interventions
- More efficient health care monitoring and improved outcomes for a larger fraction of the population
- Increased feasibility and benefits of personalized medicine/more efficient use of medical resources/more accurate and efficient triaging
- Positive impact on individuals' quality of life, overall social productivity and health care costs
- Collection of rich data sets to catalyze further research

Sustainable solutions / business opportunity

- Improved reliability and accuracy of sensor data & information analytics.
- Integration of wireless charging, energy harvesting, make-on-demand sensors, real-time data analytics.
- Development and delivery of risk mitigating interventions
- Expansion of the application & use of wearables/sensors/medical devices
- Development and distribution of effective low-cost biomarkers

- **Enablers:** identification of low-cost, specific biomarkers, data bandwidth, storage, and access; new ML algorithms and new accelerators to perform sophisticated computations; electronics miniaturization, battery efficiency, advanced sensors, advances in biotechnology and commercial IoT market, data harmonization, new IC technologies like Plastic ICs

- **Inhibitors:** cost, health insurance models/infrastructure, regulatory requirements (e.g., HIPAA, FDA, pre-market approval, biocompatibility testing), data privacy & categorization, parts obsolescence / life-cycle, data processing, limited interaction between technology developers and 'end users', lack of a 'systems' approach in healthcare.

6 IT/Energy Convergence (B+)

Energy's digital transformation will mirror IT's evolution, enabling sustainable grids, renewable integration, and exponential AI growth for efficient power delivery.

Problems/Demand

- Slower evolution of energy sector not keeping up with demands of AI expansive adoption
- Sustainability demands imposed by climate change
- Distributed energy resources introducing uneven supply lacking to provide guaranteed demands
- Complexity in managing and securing diverse energy sources
- SMR safety and security

Opportunities

- Digital transformation of energy sector, modernized for changing circumstances on both demand and supply
- Deeply integrating IT practices into energy sector from edge to Cloud
- Guaranteed sustainable and economically viable energy supply for increasingly demanding AI-driven IT
- Passive feature innovation for enhancing SMR safety
- Factory production strategies to achieve higher quality and economic benefits of mass production versus distributed custom-built reactors.
- Develop plug and play standards that induce competitive economies of scale and reliability possible with large statistics.
- Address security and waste challenges inherent in a more distributed nuclear power infrastructure through standardized modular solutions.

Impact

- Sufficient energy supply for industry growth, especially AI training
- More sustainable generation and consumption of energy
- Modernized energy management and optimization
- Applying IT security, reliability, QoS, (auto-)scale, and forecast best practices to the domain of energy
- Lifecycle, sustainability, refresh and other economic measures could be cross-applied and cross-leveraged
- Adopting increased (direct and indirect) transfer of energy across geo- domains complemented with transferring IT workload

Sustainable solutions / business opportunity

- Nuclear energy generation
- Energy generation close to consumption
- AI-driven energy management with multi-objective reinforcement learning

- **Enablers:** Distributed energy resources; revived use of nuclear energy; modernized energy supply and demand management; improved security of DERs and cyber-physical energy supply-demand chain.

- **Inhibitors:** Regulatory compliance; fragmented world in power and energy--lack of energy Internet; enhanced safety and security attack surface; economies of scale

7 Augmented Artificial Intelligence, A^2I (B+)

Augmented AI will redefine human-machine collaboration, blending machine precision with human oversight for inclusive, ethical solutions in healthcare, finance, and education.

Problems/Demand

- Current AI deployments often lack contextual adaptability, making them insufficient for scenarios requiring nuanced human understanding
- AI data training and processing require substantial energy resources, raising sustainability and scalability issues
- Aligning with evolving regulations and ensuring ethical standards remains a challenge; broadly classified as "colonization by algorithms"
- The focus on technology-driven solutions may overlook broader societal impacts, particularly on underrepresented communities
- AI integrations can be siloed, leading to inefficiencies and difficulties in cross-platform communication
- The lack of comprehensive frameworks incorporating non-technology facets limits human-centered and ethically aligned innovation

Opportunities

- Combining human understanding with AI's computational strengths creates an adaptable, ethically aligned intelligence system
- AI in A^2I can enable dynamic resource allocation, optimizing network usage and responsiveness in real-time
- New frameworks can ensure AI tools align with societal values, fostering inclusivity, fairness, and accessibility
- A^2I offers the potential for proactive alignment with global regulatory standards, reducing compliance complexities
- A^2I fosters innovation while aligning business models with societal values, enabling sustainable, community-centered growth
- Through A^2I, communications ecosystems can adjust to evolving technology and societal demands, maintaining adaptability across shifts
- A^2I modalities can also encompass machine unlearning, offering a complementary, reactive approach alongside traditional ML techniques

Impact

- A^2I supports efficient, adaptive resource allocation and real-time optimization, crucial for meeting future wireless demands
- Integrating A^2I ensures AI applications align with ethical guidelines, building public trust and supporting regulatory compliance
- A^2I-driven solutions promote accessibility, offering adaptable technologies that cater to diverse user needs
- A^2I helps manage energy use in AI operations, promoting eco-friendly protocols within data-intensive systems
- By blending AI with human oversight, A^2I minimizes risks in critical areas, encouraging safe, ethical automation

Sustainable solutions / business opportunity

- A^2I supports cost-effective scaling of wireless communication by optimizing resource allocation, reducing infrastructure strain
- By integrating AI, A^2I can predict and prevent network failures, lowering operational costs and increasing system longevity
- A^2I can facilitate energy-efficient AI models, reducing the carbon footprint of data centers and communication networks
- A^2I's integration of human expertise and AI enables adaptive business strategies that respond to evolving market demands
- A^2I's cross-sector adaptability promotes partnerships across telecos, healthcare, and energy, leading to innovative, sustainable solutions

- **Enablers:** Advances in interpretive AI, ethically aligned design and standards thereof, and human-AI collaboration drive A^2I's development

- **Inhibitors:** Regulatory gaps, societal misalignment, and limited access restrict A^2I's potential

8 Autonomous Driving (B+)

Autonomous vehicles will reduce emissions, enhance safety, and transform urban logistics, but widespread adoption hinges on regulatory approvals and public trust.

Problems/Demand

- Autonomous, Connected, Electric, Shared (ACES) vehicles are disrupting the transportation market
- SAE International classifies autonomous driving levels 0 to 5. We are between 3 and 4; by 2030, vehicles will be L2 or above
- Most accidents are a result of human driver error
- Traffic congestion and parking are major problems
- Self-driving, consumer vehicles in everyday traffic are still in test phase and must overcome many challenges

Opportunities

- Controlled environments (behind closed gates, such as airports, factories, warehouses, etc.) are likely the first adopters of L4-L5 autonomous vehicles
- Commercial trucks on highways are the next large opportunity, followed by robo-taxis and shuttles
- Self-driving can reduce driver related accidents, increase vehicle density, reduce operational costs

Impact

- Reduce traffic deaths, improved vehicular safety
- Increase efficiency (road utilization, occupancy, parking)
- Reduce carbon emissions and travel time
- Reduce operational expenses of commercial operations

Sustainable solutions / business opportunity

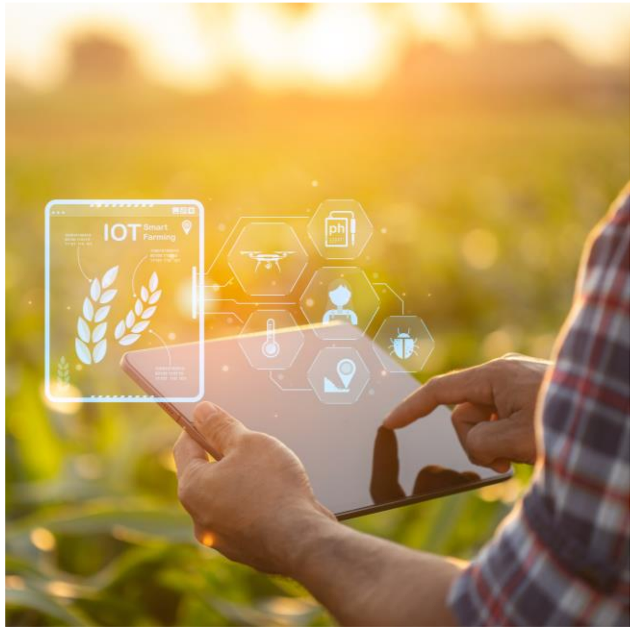
- The business case behind self-driving in controlled environments is strong, scalable, and fast to commercialize.
- Software is likely to remain a key control point and large business opportunity
- Improved sensors and component reliability, including error free software, are necessary
- Infrastructure and regulatory changes are needed to fully implement everyday autonomous driving

- **Enablers:** AI, data science, edge computing, electric and connected vehicles, shared economy

- **Inhibitors:** social acceptance, regulations, large investments, at-scale commercialization

9 SmartAg (B+)

AI-driven systems will improve crop yields, resource management, and sustainability, addressing food security through real-time soil and climate monitoring.



Problems/Demand

- Food security and waste for global population drives energy/water needs
- Food safety demands transparency and accountability at digital speed
- Loss of arable land to climate change and competing uses (bio-fuels, industrialization) drives need for efficiency
- Equity in socio-economically challenged areas drives wide disparity in outcomes in health
- Environment threats demands targeted use of fertilizers and x-cides (x = herbi/pesti/fungi)

Opportunities

- Food systems engineering of supply chain and metrics
- Sensors + AI: from soil to plant to packaging to wholesale/retail to pantry applied from field to drones to appliances to handheld devices
- Global digital food passport (standards) providing nutrition, interactions, and provisioning enabling smart menu construction to reduce waste and improve absorption/efficacy of nutrients while incentivizing sound production
- Food manufacturing and menus for personalized nutrition and health
- Food sterilization technologies from pulsed power to cold plasmas to gammas
- Decarbonization of Haber-Bosch process for fertilize production which enabled the present global population expansion creating an ammonia-hydrogen economy
- Smart agrifood systems to reduce global food waste via AI-managed consumer pantries

Impact

- Most fundamental ingredient for life and health for 7B+ humans
- Food supply chain consumes over 30% of produced fresh water and energy, including logistics
- Improve equity in caloric and nutrient availability
- Improve individual outcomes with personalized menu recommendations
- System-wide supply chain optimization

Sustainable solutions / business opportunity

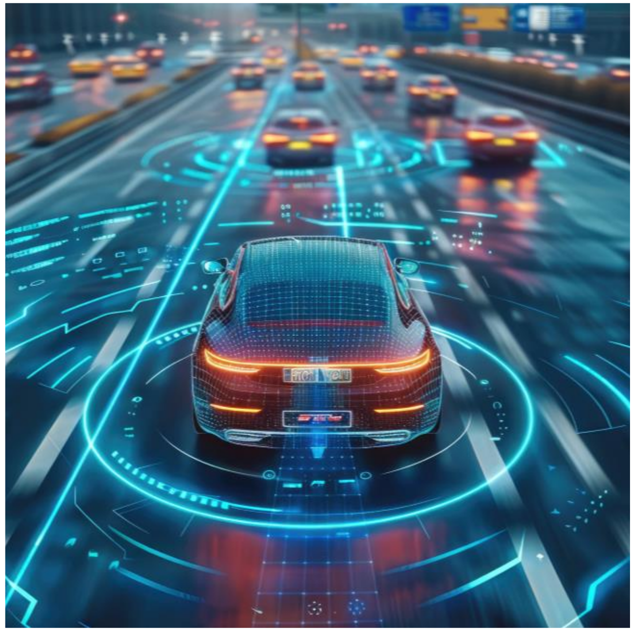
- Standards and sensors for global digital food passport for tracking and transparency throughout supply chain
- IOT inventory managing systems throughout food supply chain right out to consumer with mobile RFID + apps to manage menus and inventory to reduce waste
- Lab on a chip + blockchain for secure verification of livestock health
- Edge- and cloud-based IOT to manage application of agricultural amendments from water/fertilizers to x-cides connected to local environmental management systems

- **Enablers:** Food IOT: AI, sensors, robotics, cloud-based data, personalized nutrition all connected via data, apps, and education; consumer-level AI supported personalized nutrition and menus; standardized digital food labels; implanted sensors

- **Inhibitors:** status quo culture, limited access to (low-cost!) technologies, inertia in global policy, contrary economic interests, nationalism inhibiting global standards and data sharing; nutrient absorption impacted by food combinations

10 Functional Safety / Autonomous Vehicles (B)

Advanced safety frameworks will ensure autonomous vehicles operate reliably in public and commercial sectors, gaining trust for broader adoption.



Problems/Demand

- The higher the level of autonomy of autonomous vehicles, the higher becomes the amount of electronics adopted to drive them, and the more critical becomes their role
- Electronic components in safety critical systems may be impacted by faults and degradation during their operation in the field, possibly compromising their correct operation, thereby increasing functional safety risks with potential catastrophic consequences on the environment and users
- High safety integrity levels are required for trustworthy systems such as autonomous vehicles with an increasingly higher level of autonomy
- The push for performance and adoption of AI workloads is driving a higher challenge for meeting functional safety requirements and the needed optimizations with other dependable technologies
- Multi-die/chiplet based systems and increased integration, coupled with zonal architectures in autonomous systems, pose new challenges for complying with functional safety requirements

Opportunities

- Facilitate advancement in mobility capabilities.
- Assist people with disabilities and compromised driving abilities
- Sustainability benefits via beneficial impact on the environment (e.g., reduction of carbon emissions, reduction of traffic congestion, etc.)

Impact

- Functionally safe autonomous vehicles with a high level of autonomy will pave the way to a more inclusive society for people with disabilities (visual, hearing, movement, etc.)
- Functionally safe autonomous vehicles with a high level of autonomy will eliminate the need for certain professions, with an impact on employment and required professional skills

Sustainable solutions / business opportunity

- Functionally safe hardware components: adoption of hardware fault tolerance and dedicated solutions to drive autonomous vehicles into a safe state in case of faults, aging, or hazardous conditions occurring during their operation in the field
- Reliable AI hardware: adoption of hardware fault tolerance and dedicated solutions to guarantee the correct execution of AI algorithms for image recognition, etc.

- **Enablers:** New low-cost, fault-tolerant approaches for the hardware components driving autonomous vehicles. Addressing new challenges such as SDC and growing extrinsic defects in silicon components which compromise reliability performance. Innovation in silicon health monitoring and predictive maintenance capabilities for systems in the field

- **Inhibitors:** possible unpredictability of some hazardous conditions; need for standards in the field; need for international regulations clarifying liability in case of accidents

11 AI-Assisted Drug Discovery (B)

Advances in AI will speed up drug discovery, identifying novel compounds and treatments, though data quality and regulatory hurdles remain.

Problems/Demand

- The drug discovery process is lengthy, in part due to the time in takes to screen a large search space of potential drug candidates for their toxicity, binding affinity, etc. There is a demand to make this process faster
- New types of diseases introduced from animals, human experiments and due to climate change
- Viruses and bacteria becoming resistant to existing drugs

Opportunities

- AI can help screen a larger number of potential drug candidates at a faster rate and prioritize the screened drugs for later stages
- Generative AI can even propose new drug candidates to include in the search space
- AI can also help discover new drug targets for different diseases
- Advances in explainable AI can help make the process of AI-assisted drug discovery more transparent, leading to more insights
- The orders of magnitude improvement in complexity and scale enabled by AI methods versus deterministic methods
- Determining granularity of science included as well as in drug interactions, and perhaps in the future precision drug discovery based on individual genomes
- Improved models might mean less animal testing as well

Impact

- Better insight in humankind help and imminent diseases
- Discovering new drugs faster
- Discovering more effective drugs due to the ability to screen a larger search space
- More effective drugs through personalization

Sustainable solutions / business opportunity

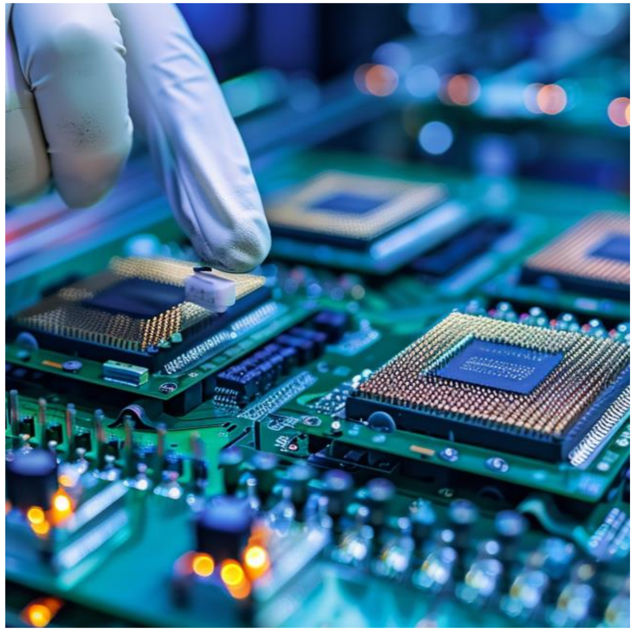
- Reduced cost of drug discovery with faster time to market
- Opportunities for just-in-time drug production and delivery

- **Enablers:** Rapid advances in AI; Investment from government and pharmaceutical companies

- **Inhibitors:** Availability of training data; regulations; lack of worldwide standards

12 Sustainable Computing (B)

Data centers will adopt energy-efficient hardware, intelligent resource management, and renewable energy, though scaling sustainability practices remains a challenge.



Problems/Demand

- Lack of end-to-end sustainability management
- Developers unaware of how sustainable their code and hardware is
- Still few and localized initiatives in sustainable IT
- The increasing cost of IT related to the energy consumption
- Using computing resources in a more efficient way
- Traditional computing was for general purpose solutions while AI may not need all the precision

Opportunities

- Rely on clean energy for data centers
- Consider sustainability on new approaches: software development, software maintenance, etc.
- Use heterogeneous hardware, more energy efficient for specific computations
- Look for sustainable supply chain for building hardware
- More efficient power (e.g. SMRs) and cooling solutions (e.g. liquid)
- Understand where data uncertainties do not justify high precision

Impact

- Reduce the energy cost of the IT industry
- Reduce the environmental impact of the computing equipment
- Improved algorithm efficiency by operating at lower precision in edge compute and AI in general
- Assuming hardware can linearly reduce energy cost with bits, this offers factors of 2-8 in many cases
- Heterogeneous hardware might also include federated computing to distribute compute closer to the source, resulting in reduction of data transmitted and stored

Sustainable solutions / business opportunity

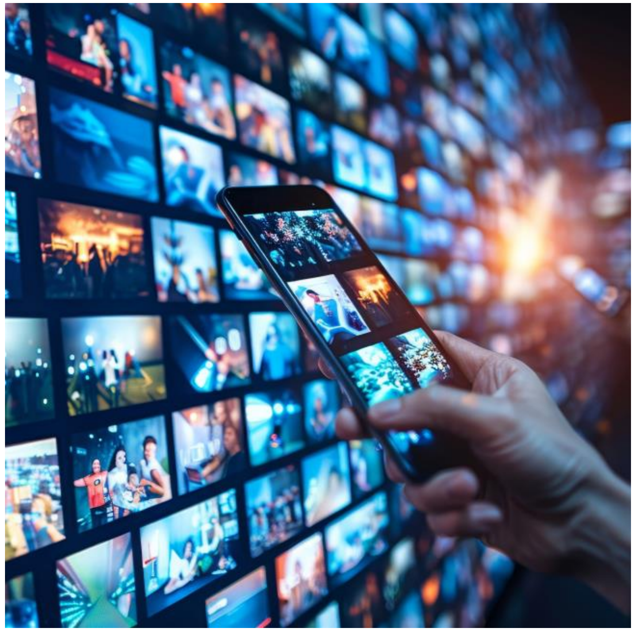
- Provide sustainable certifications
- Competitive advantage over those without sustainable solutions
- Financial savings

- **Enablers:** many sustainable initiatives around the world; people are more engaged towards sustainability; pledges made by CxOs; government regulations

- **Inhibitors:** possible increase in price; difficulties in changing the mindset; complexity in managing

13 Misinformation/Disinformation (B)

AI tools will detect and mitigate misinformation, countering its rapid dissemination on social networks to protect public opinion and trust.



Problems/Demand

- Accidental or deliberately produced, factually incorrect information propagating throughout all media
- Negatively affects human behavior and computer algorithms
- Adverse effects to government and corporate policy, public opinion
- Perversion of AI/ML algorithm results
- Disinformation created by AI co-mingles with correct information
- Promotes/propagates societal distrust and confusion

Opportunities

- Agenda free adjudication entities, groups, tools
- Creation of mis/disinformation free spaces
- Tools for identification, filtering and removal can be developed
- Using AI to verify information
- Trustworthy elections

Impact

- Eliminate/attenuate harm to the public, industrial sectors, certain groups
- Discourage unsafe/bad behaviors, protect open opinions
- Managing/regulating government reach to combat mis/disinformation

Sustainable solutions / business opportunity

- Embed trustworthy algorithms to monitor information sources
- Data lineage

- **Enablers:** distrust of existing institutions (e.g. the press, government, academia); AI tools for generation; social networks for easy production and rapid propagation

- **Inhibitors:** formal methods; epistemological approaches; review boards / wisdom of crowds; new tools for identification and removal; malicious actors, whether geopolitical or economic in motivation

14 AI-Based Medical Diagnosis (B)

AI will enhance diagnostic precision, particularly in radiology and pathology, improving patient outcomes while reducing clinician workloads.

Problems/Demand

- Growing healthcare needs
- Demand for faster and more accurate diagnosis
- Personalized medicine
- Accessibility to quality care
- Human error reduction
- Early detection
- Burnout reduction

Opportunities

- Earlier and faster diagnosis with enhanced accuracy
- Predictive analytics (predict patient outcomes, potential complications, proactive management of health conditions, better resource allocation)
- Integration with wearables (analyze data from wearables, monitor health in real-time, continuous insights, early warnings)
- Remote access to care and better use of complex patient data
- Advanced R&D (accelerate medical research by analyzing large datasets to identify new disease patterns, potential treatments, drug discovery)
- AI is often better at granular image analysis than humans, especially considering human fatigue
- Advances in multispectral imaging is an opportunity for AI based data fusion to see details difficult for humans to visualize
- Potential to distribute expertise via AI improves energy, bandwidth, and accessibility

Impact

- Improved accuracy and efficiency
- Enhanced patient care
- Cost reduction
- Early disease detection
- Accessibility: AI tools can provide diagnostic support in remote or underserved areas, helping to bridge the gap in healthcare access and ensuring that more people receive timely and accurate diagnoses

Sustainable solutions / business opportunity

- AI-powered diagnostic tools
- AI-enabled telehealth solutions
- AI-driven healthcare IT solutions
- AI-based medical devices
- AI-driven healthcare data analytics
- Integration with digital health platforms, including telemedicine and wearable devices, offers new business opportunities.
- Real-time health monitoring and diagnostics, enhancing remote patient care and chronic disease management

- **Enablers:** advancements in AI/ML; increasing computational power; growth of medical data; government and industry support; collaboration between healthcare professionals and AI experts; global reach of deploying solutions in underserved regions; big data availability: public and professional acceptance

- **Inhibitors:** data privacy and security concerns; ethical considerations; regulatory hurdles; lack of standardization; resistance to change; bias and fairness; cost and investment; legal and liability issues; data quality and availability

15 AI-Optimized Green HPC (B-)

AI will optimize HPC workflows, reducing energy consumption. Challenges include high costs and developing reliable energy measurement and allocation methods.

Problems/Demand

- Growing computational demands coupled with diminishing returns in traditional silicon technology's performance-per-watt pose urgent need for energy-efficient HPC solutions
- Limited power budgets (typically 20MW per facility) constrain the ability to scale up computational capabilities while meeting scientific demands in post-exascale era
- Current AI-HPC workflows lack comprehensive energy consumption metrics and tools for near real-time optimization of computational resources
- Competing demands between AI/ML and traditional HPC workloads strain limited energy resources
- Lack of tools and incentives for developers to optimize applications for energy efficiency

Opportunities

- AI-driven optimization systems can dynamically balance computational performance with power consumption in real-time
- End-to-end telemetry and operational analytics enable data-driven decisions for energy efficiency across HPC systems
- Integration of specialized accelerators and purpose-built architectures for specific workloads improves energy efficiency
- Development of new energy-aware benchmarks and metrics can drive sustainable HPC practices and innovation

Impact

- 30-40% reduction in data center energy consumption while maintaining computational performance
- Enhanced scientific output per watt through intelligent workload management and resource allocation
- More sustainable HPC operations through optimized power usage and reduced environmental footprint
- Shift in HPC culture towards energy-conscious application development and deployment
- Improved resource utilization through energy-aware scheduling and workload distribution

Sustainable solutions / business opportunity

- Development of energy-aware HPC training programs and curricula to build workforce expertise in sustainable computing practices
- Creation of new tools, frameworks and APIs for energy optimization, provenance, and automation of AI-HPC workflows
- Establishment of industry standards and benchmarks for measuring and certifying energy efficiency in AI-HPC workflow applications

- **Enablers:** Advanced data analytics, AI optimization, workflow orchestration, energy-aware software, efficiency standards

- **Inhibitors:** Legacy infrastructure, skill gaps, limited power budgets, technical complexity, resistance to change

16 Next-Generation Cyberwarfare (B-)

AI-driven cyber defenses will counter evolving threats. Challenges include international collaboration, response speed, and defending against increasingly AI-enhanced attacks.

Problems/Demand

- Critical intelligence decisions nowadays are delegated to AI, which combs through millions and billions of inputs and weights to make predictions
- This "black box" modelling means that understanding of what goes into a particular prediction is intractable for humans, making AI ripe for exploitation; by inserting judiciously misleading inputs to the model (which are themselves computed with AI), the predictive model can produce subtly different predictions
- Next-gen cyberwarfare will aim to foil AI models with poisoned data. Conversely, next-generation counter-warfare will aim to use AI to detect data poisoning and maintain model integrity

Opportunities

- Counter-warfare: Develop technologies to track and attest to data's integrity
- Develop advanced technologies & statistical techniques to detect data tampering
- Promote effective regulation and monitoring of business and state-actor participation in data pipelines, including both production and consumption of data
- electronic warfare (projecting battlefield superiority via electromagnetic energy)

Impact

- Next-gen cyberwarfare may shift the focus from hacking systems to misleading them into reaching wrong conclusions by subtly altering their inputs
- The enormous input sizes make this hard to detect and may in turn require training specialized anti-AI AIs, and so forth

Sustainable solutions / business opportunity

- An arms race of data poisoning and poisoning detection; this prediction is negative, so it doesn't provide sustainable solutions or opportunities, only risks to plan for

- **Enablers:** Advances in AI/ML to create poisoning; increasing size of input sets; Increasing adoption of AI in decision-support tool

- **Inhibitors:** Advances in AI/ML to detect poisoning; increased human vigilance and supervision of decision support tools; effective regulation

17

New Battery Chemistries (B-)

Solid-state and sodium-ion batteries will enhance energy density and safety. Challenges include scaling production and managing supply chain dependencies.

Problems/Demand

- Current Li-ion batteries have the following issues:
  - Mining of Li consumes a lot of energy and potentially pollutes environment
  - Li-ion are not easily to recycle raising issues in terms of sustainability
  - Li-ion batteries can cause fire pausing hazard in operation and transportation.
- There is also demand for batteries that have better charge/discharge rates and have much longer lifetime.

Opportunities

- The opportunity is to come up with multiple chemistries that:
  - Are made up of materials that are abundantly available and easier to source/mine
  - Are easier to manufacture with more sustainable lifecycle
  - Are easier to recycle
  - Are safer to use and have a lower risk of causing fire
  - Last longer
  - Charge more quickly
  - Discharge as appropriate faster or slower based on a given application

Impact

- Every day we have more and more consumer electronics which have batteries; better batteries mean better consumer electronics
- Every day we are moving closer to electrifying our transportation systems; better batteries will enable / accelerate this
- Every day we are moving towards using more and more renewable energies, which are available to us at times that we may not need them the most; we need better batteries to help us balance supply and demand

Sustainable solutions / business opportunity

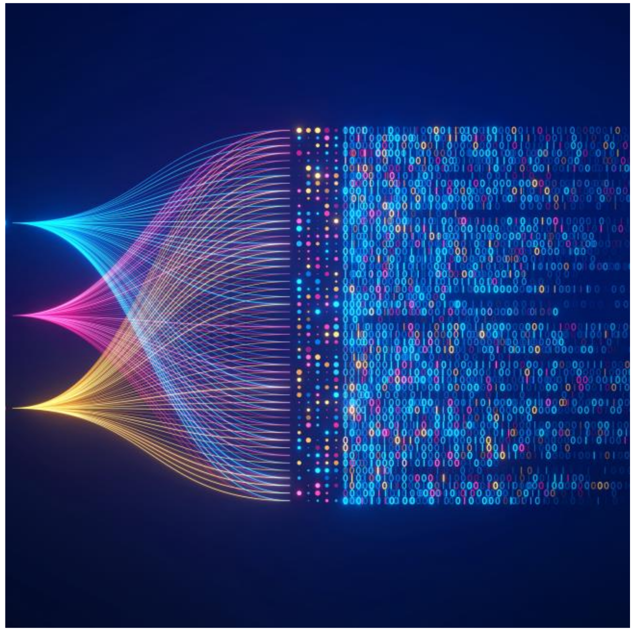
- Extended battery lifetime for edge devices leading to breakthrough missions not possible earlier as well as reducing cost of existing ones
- Similarly, at the cloud side, ability to store energy in an efficient and scalable way can complement fluctuation of distributed energy resources

- **Enablers:** venture capital; government funding; research and academic organizations

- **Inhibitors:** those who have heavily invested in the Li-ion supply chain

18 Data Feudalism (B-)

New tools will empower users to regain control over data. Challenges include enforcing equitable access and aligning global regulatory frameworks.



Problems/Demand

- Datafication of human online activities by big tech
- The creation of digital fiefdoms by different platform and service providers
- Control of modern societies by big tech
- The inability of individuals to easily leave digital fiefdoms without major life disruptions
- Control of users by non-transparent algorithms that trap users into big tech fiefdoms
- Internet may devolve into a feudalized space
- A few digital giants are amassing so much money and power that they are increasingly independent of meaningful control by government and political entities

Opportunities

- The opportunity to create regulations on user surveillance by big tech
- The opportunity of platform providers to better explain their algorithms and policies that entice users into using their services
- The opportunity for the private sector to address this issue without government intervention

Impact

- Greater user trust that they are not being spied on by big tech
- Fewer demands for legislation to address this problem if the algorithms and policies applied for user surveillance are transparent
- Users can more easily move from fiefdom to fiefdom
- Users will feel less like digital serfs to big tech
- A public conversation about ethics concerns of data feudalism can begin

Sustainable solutions / business opportunity

- The solution here is for transparency on what information is being collected on individuals, how it is aggregated, and how it is used or sold

- **Enablers:** Both big tech and governments can work together to agree on what is the proper usage of the big datasets that are created by surveillance on users' online activities

- **Inhibitors:** Big tech is a major inhibitor; user apathy about surveillance being placed on them--the greater the apathy the fewer incentives that big-tech will modify this business model/practice

19 Nuclear-Powered Data Centers (B/C)

Small Modular Reactors (SMRs) will provide steady, carbon-neutral energy for data centers. Regulatory approvals, scalability, and public acceptance remain significant hurdles.

Problems/Demand

- High energy consumption: Data centers consume vast amounts of energy, leading to increased demand for reliable power sources
- Heat management: Excess heat generated by data centers requires efficient cooling solutions, impacting operational efficiency and costs
- Regulatory challenges: Nuclear energy faces stringent regulations and public scrutiny, complicating implementation in data centers
- Public perception: Concerns about safety and environmental impact of nuclear energy can hinder acceptance

Opportunities

- Increase in the AI services demand & emerging cloud technologies, leading to the huge need of powerful, highly functional & operational data centers
- Stable power supply: Nuclear power can provide a consistent and reliable energy source, crucial for 24/7 data center operations
- Lower carbon footprint: Utilizing nuclear energy can drastically reduce the carbon footprint of data centers, aligning with sustainability goals
- Cost-effective energy: Over the long term, nuclear energy may offer competitive pricing compared to volatile fossil fuel markets
- Innovative cooling solutions: Developing advanced cooling technologies that utilize waste heat from nuclear reactors can enhance efficiency

Impact

- Sustainability: Nuclear energy offers a carbon-free alternative to fossil fuels, aligning with global climate targets
- Reliability: Unlike solar and wind, nuclear energy provides a continuous base load, ensuring data centers can function without interruptions or needing massive battery storage
- Efficiency: SMRs can be located in areas where large power grids may not be accessible, supporting localized, high-performance computing hubs
- Energy density: Nuclear fuel has a high energy density, meaning a small amount of fuel can power a large facility for extended periods

Sustainable solutions / business opportunity

- Waste heat utilization, partnerships with tech firms, carbon credits trading, microgrid
- **Enablers:** Advancements in nuclear technology, government support, public-private partnerships, technological integration, skilled workforce
- **Inhibitors:** Regulatory hurdles, high initial investment, public opposition, safety concerns, competition from renewables

20 Tools and Policies for AI Regulation (B/C)

Frameworks for AI ethics and governance will emerge. Challenges include harmonizing global standards and ensuring effective enforcement mechanisms.

Problems/Demand

- Ethical concerns: Rising issues around privacy, bias, and transparency
- Safety and security: Need for safeguards against AI misuse, such as deep fakes
- Data quality and reliability: Bias in large datasets and lack of explainable models
- Legal compliance: Complex regulatory environments across jurisdictions
- High computational costs: Limits AI capabilities to only a few large players

Opportunities

- Innovation in policy frameworks: New models for AI governance and ethical standards
- Cross-border collaboration: Potential for international AI standards to streamline compliance
- Enhanced public trust: Improved transparency can lead to broader AI acceptance
- AI-driven compliance tools: Automating regulatory tasks to reduce costs
- Inclusive AI development: Creating AI that addresses the needs of underserved populations

Impact

- Boosts public confidence: Safer AI systems may increase user trust
- Market growth for AI governance tools: Growing need for tech solutions to regulatory challenges
- Reduced legal risks: Clearer guidelines help mitigate potential liabilities
- Environmental sustainability: Incentives to reduce data center energy usage
- Enables responsible innovation: Frameworks ensure ethical considerations in development

Sustainable solutions / business opportunity

- Public-private partnerships: Collaboration on best practices and ethical norms
- AI policy frameworks: Unified standards for transparency, fairness, and safety
- Low-code/no-code compliance solutions: Tools for rapid compliance deployment
- Training for ethical AI: Upskilling for responsible AI management and use
- With stringent AI regulations coming into force, many enterprises will unify their data and AI governance frameworks

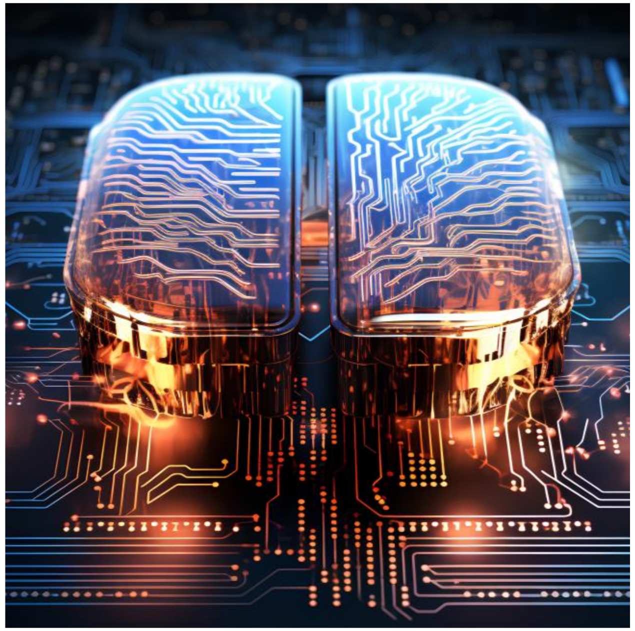
- **Enablers**: Affordable AI tools, AI-integrated compliance platforms, open models and curated datasets, government AI task forces, growing public awareness

- **Inhibitors**: Closed models, bias in training data, high implementation costs, limited interoperability across regions and nations, resistance to regulation

21

Brain Computer Interfaces (BCIs) (C+)

BCIs will assist individuals with disabilities and enhance communication. High costs, safety concerns, and scalability hinder broader use cases.



Problems/Demand

- Current Interfaces between humans and computers are clunky and inefficient
- Many interfaces are inaccessible for people with disabilities
- Short and long-term side effects are not fully understood
- Brain function may not be sufficiently understood to enable effective design of BCI
- BCIs are designed for limited number of applications – there are many other potential ones.
- Extraction of meaningful signals from BCIs and optimal integration with clinical and other patient specific information

Opportunities

- Using recorded brain signals (e.g., EEG) to control computers and other smart systems is a more seamless interface between humans and machines
- Development of advanced combination of BCI and neuro stimulation approaches can form effective disease managing feedback loops
- Development of highly personalized control of prosthetic limbs, wheelchairs and communication through computers
- Development of precise brain stimulation devices
- Can be used to treat neurological disorders and enhance cognitive functions
- Large scale production of demonstrated effective devices mitigating motor, speech, sensory deficits
- Development of AI based algorithms to optimize data interpretation as well as use BCI information to inform development of AI algorithms

Impact

- Can revolutionize treatments for neurological disorders (Parkinson's, epilepsy, and depression etc.) by providing precise and targeted therapies
- Can enhance cognitive functions, such as memory and learning
- Can be instrumental in restoring function for people with spinal cord injuries
- Can enable more seamless interactions between humans and AI, potentially leading to smarter and more intuitive AI system
- For individuals with disabilities, BCIs can offer greater independence and control over their environment, improving their overall quality of life

Sustainable solutions / business opportunity

- Improved reliability and accuracy of sensor data & information analytics
- Integration of wireless charging, energy harvesting, make-on-demand sensors, real-time data analytics.
- Increasing useful life of the devices' power source/identification of new types of power sources
- Reducing invasiveness of the interfaces
- Development of AI systems and high data rate processing
- Non-invasive BCIs will become more accessible, enabling individuals with neurological conditions to regain communication and mobility functions

- **Enablers:** invasiveness minimization, understanding of optimal device operating regime, safety demonstration, high data rate transfer protocols, effective signal processing

- **Inhibitors:** brain surgery associated risk, risk of attacks on implantable devices; safety and privacy concerns, lack of comprehensive ethical and regulatory guidelines, lack of FDG approvals and knowledge of long-term health and psychological effects

22 Space Cmputing (C+)

Reliable, autonomous computing will support deep-space missions. Challenges include radiation hardening, limited power supply, and extreme environmental conditions.

Problems/Demand

- Although optical fiber-based terrestrial communications networks (TCN) can provide large data rates, their reach into remote areas of the world as well as developing countries is limited. This is largely due to the cost of installation
- We are experiencing the great 'Digital Divide,' where the few have access to massive amounts of information and the majority of the world does not
- The development of Smart Cities/Communities require networks that not fixed, agile, federated and cognitive
- We need to develop a complementary symbiotic federated communication network linking the terrestrial fiber optic-based network with the Non-Terrestrial Network (NTN) consisting of satellites (GEOs, MEOs, LEOs) and HAPs (High Aerial Platforms) and terrestrial ground stations
- This also calls for solving space sustainability of mega constellations

Opportunities

- A high data-rate low-latency NTN will enable efficient remote tele-operations from anywhere in the world
- The TN combined with the NTN is an enabling technology for remote healthcare, intelligent agriculture, mIoT, as well as providing experiential education to developed and underdeveloped areas of the world
- Multi-layer multi-dimensional multi-band topology
- Flexible systems through Space Software Defined approach
- AI-driven space and ground segment design

Impact

- Will redefine our communities in terms of allowing access to all, independent of location
- Will create smarter, more efficient cities/communities
- Real-time teleoperations, including digital twins
- Improved network resiliency and increasing availability
- Increased interest in relevant space education

Sustainable solutions / business opportunity

- Resolving the great digital divide
- A new 3D wireless network architecture
- The federated TN/NTN system needs not only the current technology but requires new technologies in the overall scheme of space compute

- **Enablers:** Advanced antenna technology (phased arrays); direct EHF/Optical inter-satellite links; intelligent networks; AI and machine learning; edge computing; alternative energy sources; small satellite constellations; software defined approaches

- **Inhibitors** Government regulation and coordination Initial CAPEX (although some large companies are investing already); government buy-in; limited workforce; new standards required for network security, timing and causality

To Learn More

Written by our Team Members

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