IEEE COMPUTER SOCIETY

2024 Technology Predictions

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In This Report

SECTION 01

Introduction

Technology Predictions—from Hypothetical Exercise to Enabling Prosperity

- Predicting the future can be useful, powerful, and fun.
- Predictions are essential in business, military, healthcare, and many other areas, particularly when it comes to critical infrastructures.
- Predicting ahead of others can provide a strategic advantage.
- Technologies play an increasingly crucial role and are becoming essential in predictions.
- Predictions go beyond a hypothetical exercise to enable survival and prosperity of humanity.

SECTION 02

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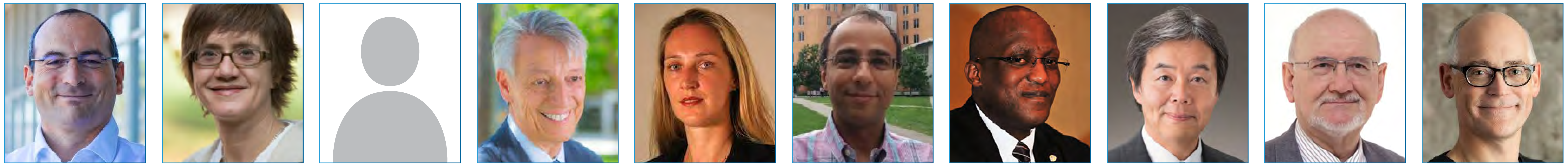

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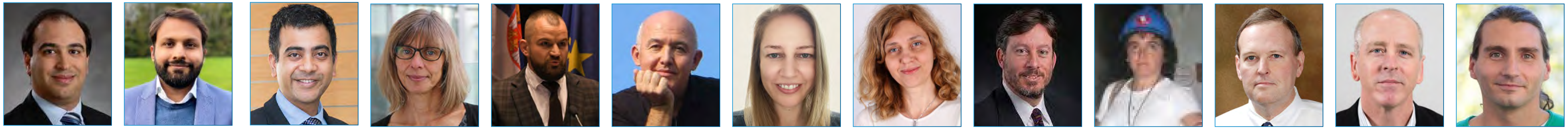

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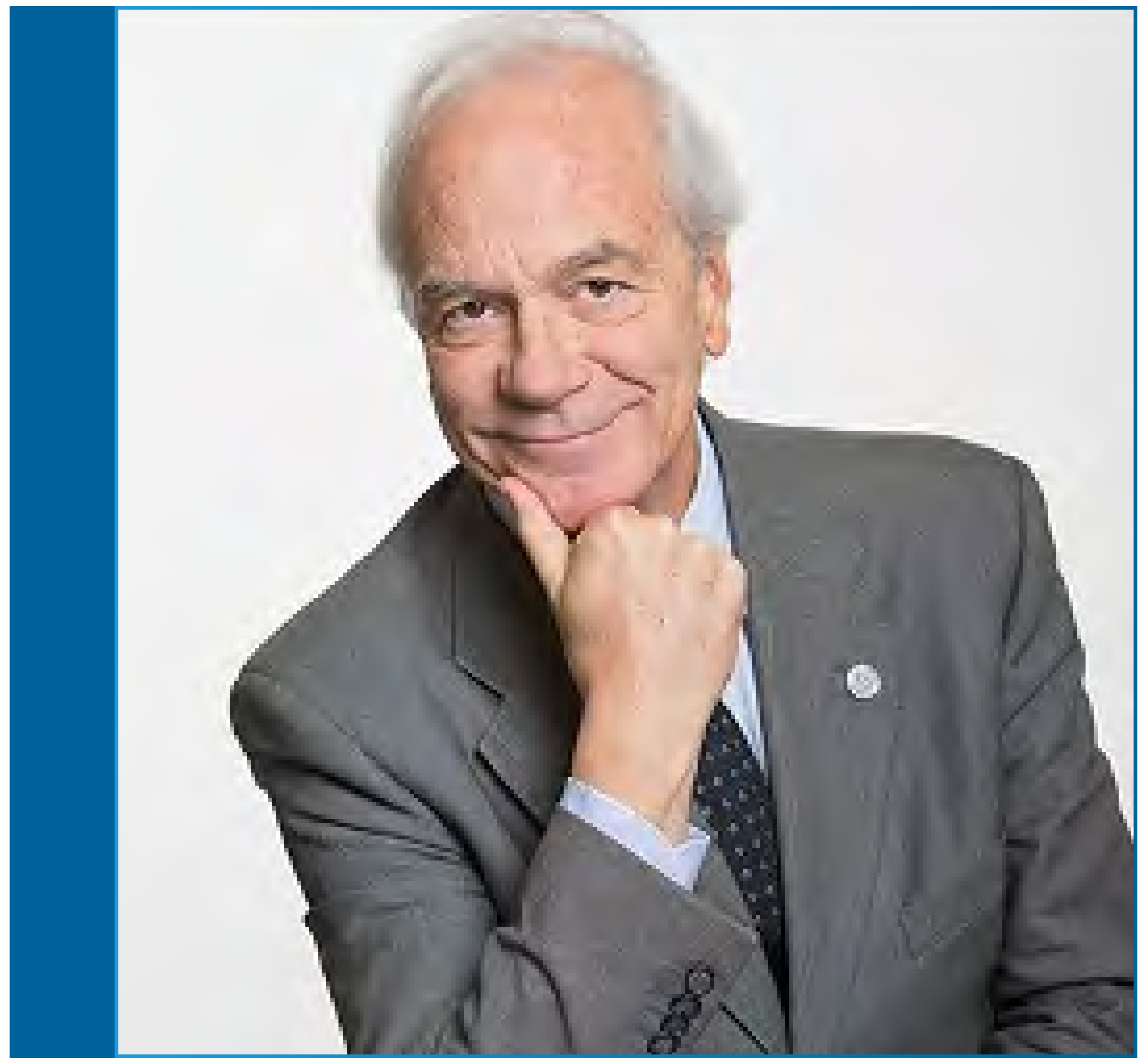
In Memoriam
Roberto Saracco



This year we have lost our regular contributor and the leader in predictions, Roberto Saracco.

His kind nature, visionary perspectives, and collaborative, can-do attitude will never be replaced.

He has shown us the path from early days till predictions scorecard for 2023.

Over the years he tried to convince us that Digital Twins are already here, and now that they finally appeared in our predictions, we do not have Roberto with us anymore.

You will always be remembered by your colleagues.

—*2024 Technology Predictions Team*

Process

Continued Improvements

Identification

- This year we expanded our team from 35 (2023), 16 (2022) and 12 (2021) to 46 members (3 left, 14 joined).
- We further improved our diversity in terms of gender and the technology areas with specific focus on power and energy.
- Authors made up to two predictions, resulting in 87 predictions.
- We then down-selected to 21, 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–F for: Technology Success in 2024; Impact to Humanity; Predicted Maturity in 2024; Predicted Market Adoption in 2024 and (1 year, 3y, 5y, 10y, 15y) for Horizon to Commercial Adoption.
- We express impact to humanity as a function of technology advancement, and we also qualify 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 21 technologies, we wrote a slide discussing problem/demand, opportunity, impact, & sustainable solution/business opportunity.

Technology Predictions for 2024

Sorted by Tech. Development

1. **Generative AI Applications (A/B):** Generative AI use will increase with rapidly expanding efficiency and new applications and services both beneficial and detrimental. Ethical and societal issues will continue to rise. Expect strong short-term impacts on business, education and society.
2. **Next Generation AI (B+):** The evolving advancements and developments in the field of artificial intelligence that push the boundaries beyond current capabilities. It is the next generation of Artificial Intelligence (AI) that is expected to be more advanced and sophisticated than the current AI systems.
3. **Advances in Cybersecurity (B)** will enhance public confidence and will enable reliance on the cyber infrastructure for large scale applications including energy production and distribution.
4. **Managing Misinformation (B)**: AI deepfakes (text, audio, visual) will become regular tools that will require careful management.
5. **Remote Healthcare (B)**, monitoring sensors and system-level data integration will enable patients to obtain remote medical assistance, physicians to improve diagnosis and treatment, optimal utilization of individuals' medical history, and efficient health care delivery protocols.
6. **Digital Twins for Vertical Applications (B)** will advance state of the art of predictions, what-if-analysis and oversight in a number of industries, such as data centers, medicine, geo-physical hazards, manufacturing, agriculture, transportation, and many others.
7. **New 3D Printing Applications (B)** will evolve towards customized and automated solutions in many domains.
8. **New Programming Models (B-)**. Advances in AI, broader adoption of script-based languages, and further digital transformation into non-programmers' world will further increase ease of development and require new programming models and DevOps, such as serverless, from the Edge to Cloud.
9. **Reliability (B-)** will emerge as a major concern in a widespread set of application fields.
10. **Autonomic Autonomous and Hybrid Systems (B-)** will see increased development and adoption in areas, such as driving, laboratory work, agriculture, and many others.
11. **Distributed Energy Resources for Powering Data Centers (B-)** Engaging renewable energy based on distributed energy resources for powering data centers will have a high impact on clean energy requirements for data centers.
12. **Sustainable ICT (B-)**: will evolve by designing, manufacturing, using, and disposing of electronic systems efficiently and effectively for new use cases, with minimal or no impact on the environment.
13. **Regenerative AgriTech (B/C)** is a holistic, circular approach to farming that strives to improve the health of agroecosystems and the natural ecosystems that support them.
14. **Non-Terrestrial-Networks (B/C)** involving satellites and high-altitude platforms (HAPs) expand and augment the capabilities of terrestrial networks (TN) involving wireless and cabled communications in the quest to connect everything to everything (E2E) in real time (RT).
15. **New Battery Chemistry and Architecture (B/C)** will replace Lithium and will make it possible to make batteries that are cheaper and more sustainable.
16. **Low Power AI Accelerators (B/C)** will be key-components for practical, compact, cost-effective, long-term reliable computation units for Self-driving vehicles and AI robots, data-centers, LLM, systems, smart phones, games.
17. **Alternate Materials for Electro Machines (EV motors) (C+):** Inadequate raw materials for conventional high-performance electro machines motivates discovery and engineering.
18. **Cost Effective Recycling of Batteries (e.g. Lithium) (C+)** to recover materials for reuse will reduce the need for mining and increase the general sustainability of battery technology.
19. **Metaverse (C+)** will bridge the gap between the real and the digital worlds, by solving real world industrial problems digitally.
20. **Accessible Quantum Computing (C-)** will improve public understanding and access to the power of quantum computing, increasing 'conventional' computing efficacy exponentially.
21. **Satellite (Constellation) Recycling (C/D)** will enable circular economy in space ensuring long term sustainability. We expect an initial success in 2024 with increasing awareness of the tremendous impact on Humanity.

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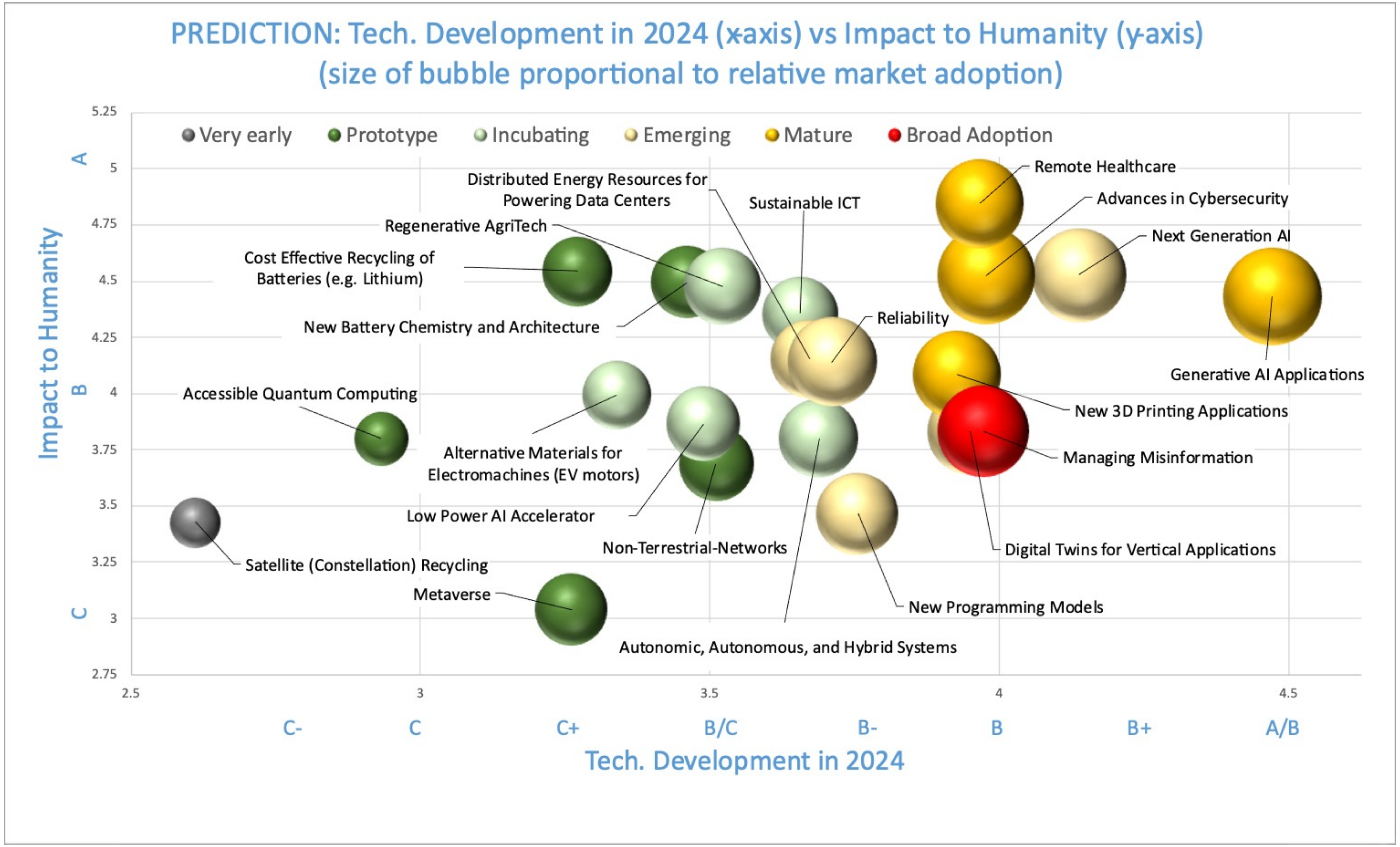
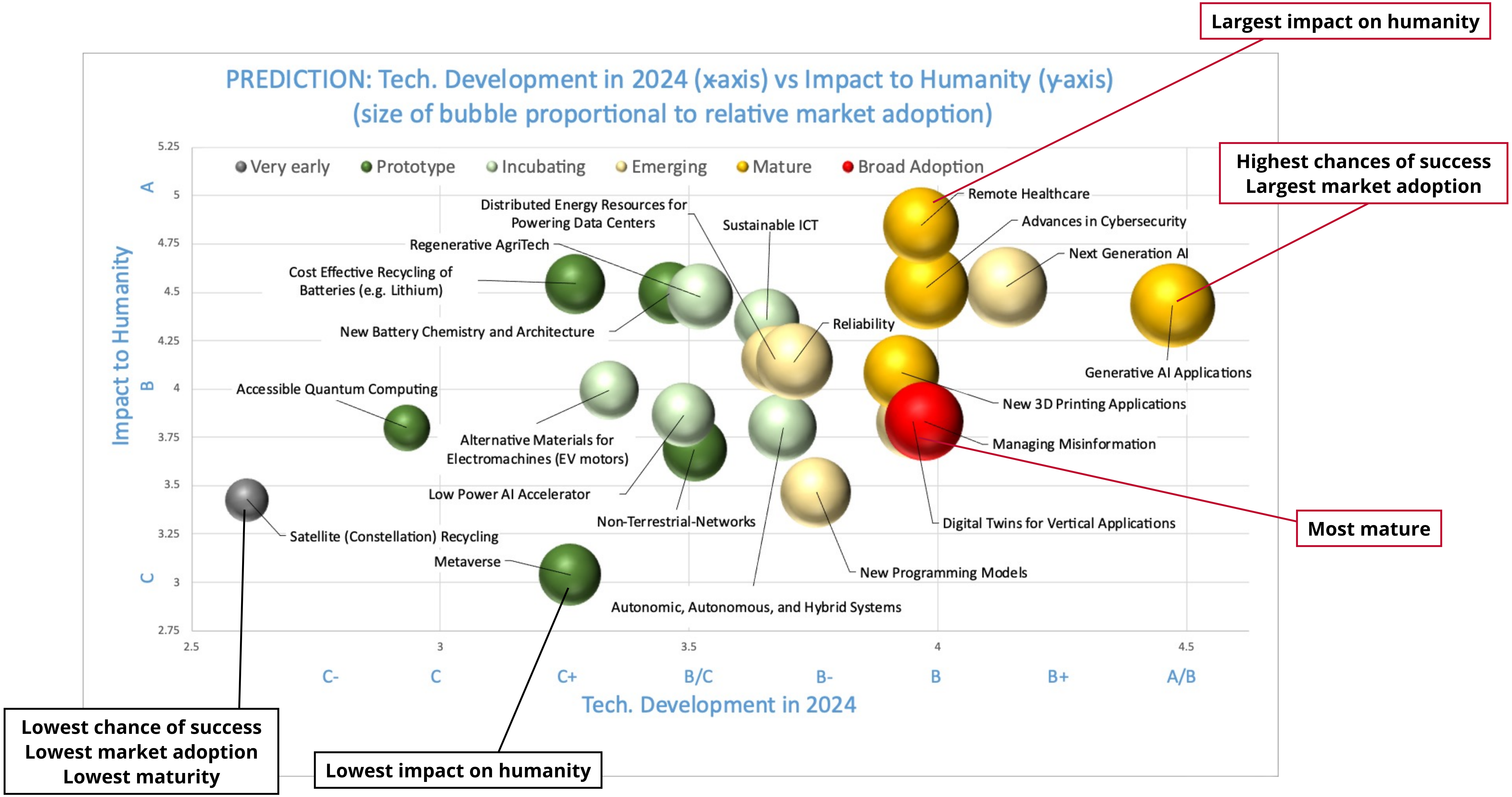
Comparisons

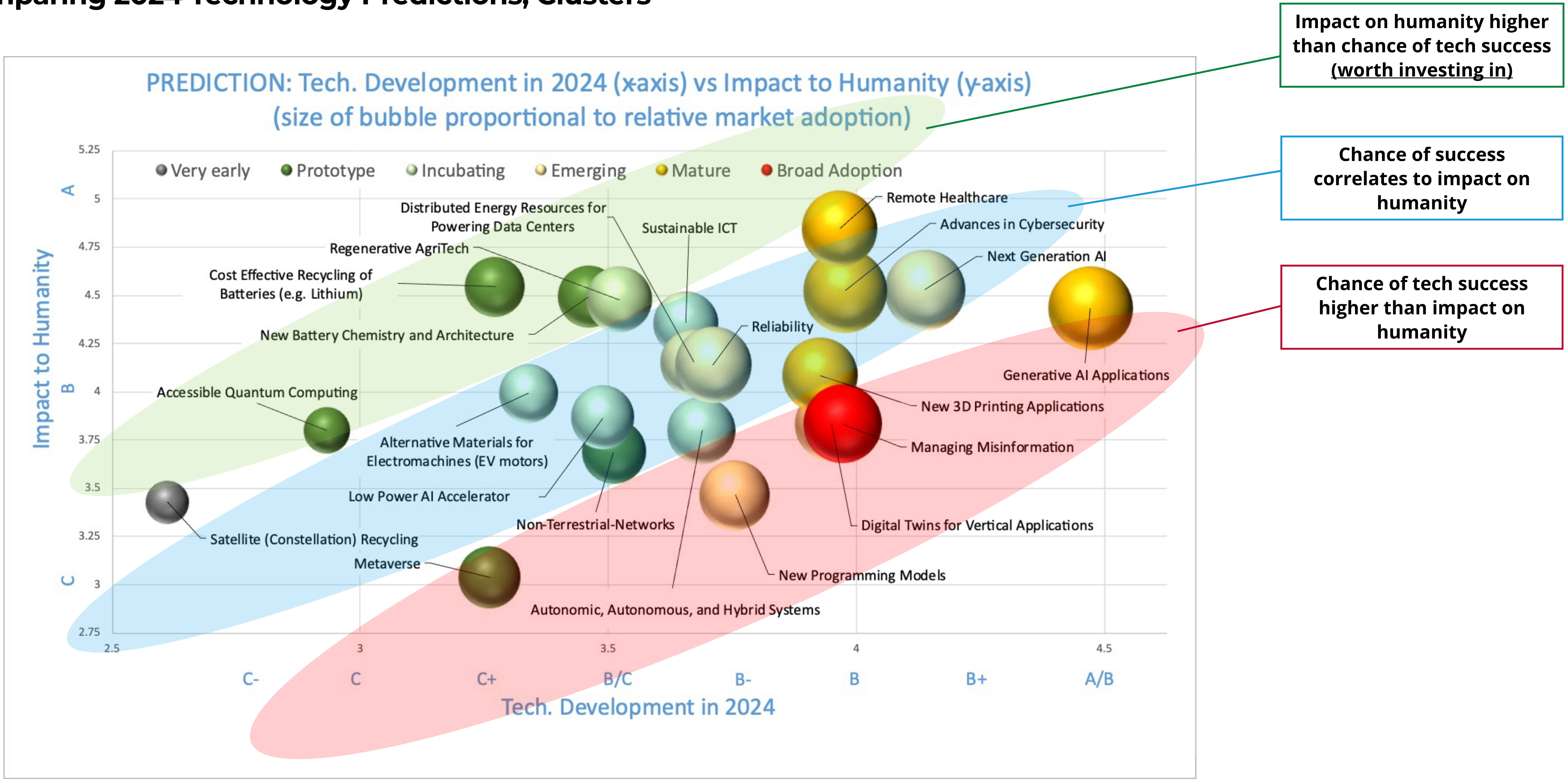
Comparing 2024 Technology Predictions, Four Ways



Comparing 2024 Technology Predictions, Lowest/Highest



Comparing 2024 Technology Predictions, Clusters



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Technology Predictions, Comparison

	Technology	Success in 2024		Impact to Humanity		Maturity in 2024		Market Adoption (2024)		Commercial Adoption Horizon	
		rank	grade	rank	grade	rank	grade	rank	grade	rank	# years
1	Digital Twins for Vertical Applications	6	B	14	B-	7	B/C	8	B/C	17	3.29
2	Autonomic, Autonomous, and Hybrid Systems	10	B-	16	B-	13	C+	10	C+	13	4.27
3	Next Generation AI	2	B+	3	A/B	8	B/C	3	B	16	3.36
4	New Programming Models	8	B-	19	B/C	9	B/C	9	B/C	14	4.09
5	Generative AI Applications	1	A/B	7	A/B	2	B	1	B+	21	2.29
6	Advances in Cybersecurity	3	B	4	A/B	5	B-	2	B	19	2.89
7	Distributed Energy Resources for Powering Data Centers	11	B-	9	B+	10	B/C	11	C+	11	4.44
8	Metaverse	19	C+	21	C	18	C	17	C	6	5.71
9	New Battery Chemistry and Architecture	16	B/C	5	A/B	17	C	16	C	6	5.71
10	Sustainable ICT	12	B-	8	B+	14	C+	13	C+	9	5.04
11	Remote Healthcare	5	B	1	A-	4	B-	6	B-	15	3.80
12	Accessible Quantum Computing	20	C	16	B-	20	C/D	20	D+	1	9.66
13	Low Power AI Accelerator	15	B/C	13	B-	11	C+	15	C	10	4.78
14	Satellite (Constellation) Recycling	21	C/D	20	B/C	21	C/D	21	D	2	8.91
15	Cost Effective Recycling of Batteries (e.g. Lithium)	18	C+	2	A/B	19	C	18	C	8	5.27
16	Managing Misinformation	4	B	14	B-	1	B+	4	B	20	2.36
17	New 3D Printing Applications	7	B	11	B	3	B	7	B-	18	2.98
18	Non-Terrestrial-Networks	14	B/C	18	B-	16	C	14	C+	3	6.02
19	Reliability	9	B-	10	B+	6	B-	5	B-	11	4.44
20	Alternative Materials for Electro Machines (EV motors)	17	C+	12	B	15	C+	19	C	4	5.93
21	Regenerative AgriTech	13	B/C	6	A/B	12	C+	12	C+	5	5.73

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Correlation and Average & Range (Across Technologies)

This Year, 2024

	Success in 2024	Impact to Humanity	Maturity in 2024	Market Adoption in 2024
Success in 2024	1	0.47	0.90	0.96
Impact to Humanity	0.47	1	0.36	0.44
Maturity in 2024	0.90	0.36	1	0.93
Market Adoption in 2024	0.96	0.44	0.93	1

Success in 2024		Impact to Humanity		Maturity in 2024		Market Adoption in 2024		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, 2023

	Success in 2023	Impact to Humanity	Maturity in 2023	Market Adoption in 2023
Success in 2023	1	0.09	0.90	0.96
Impact to Humanity	0.09	1	0.36	0.44
Maturity in 2023	0.92	0.13	1	0.93
Market Adoption in 2023	0.88	0.28	0.93	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]

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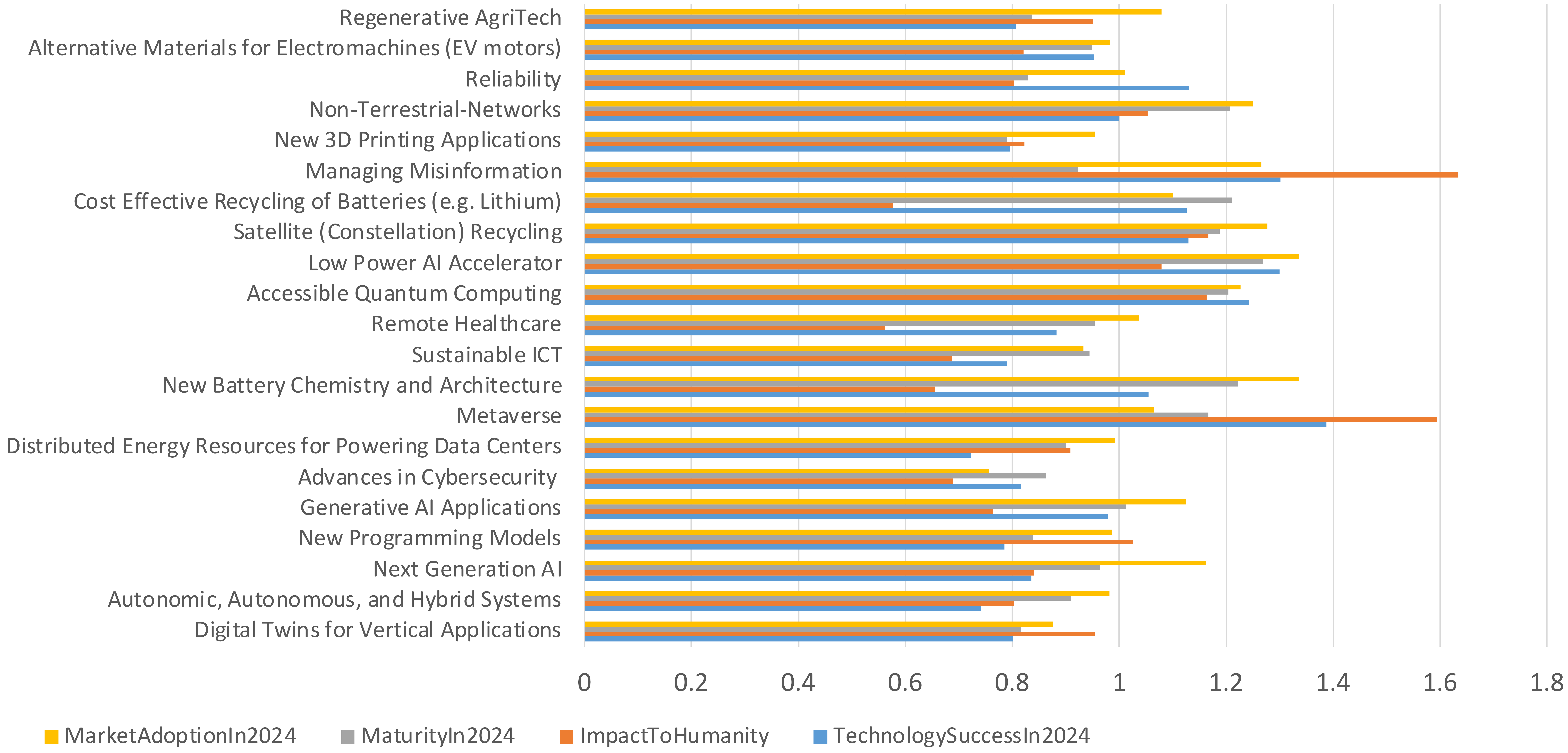
Standard Deviation



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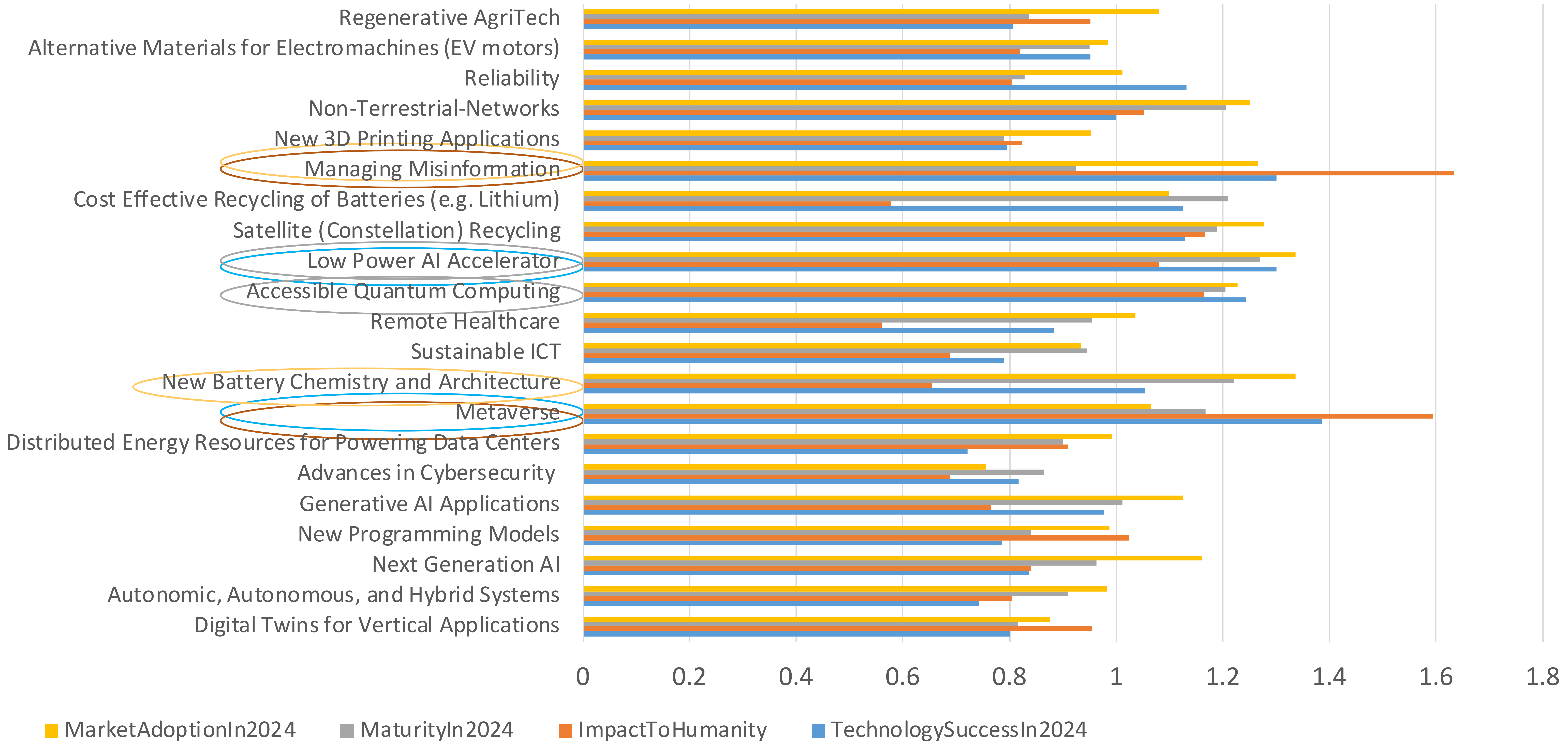
Standard Deviation, Largest (Least Confidence)



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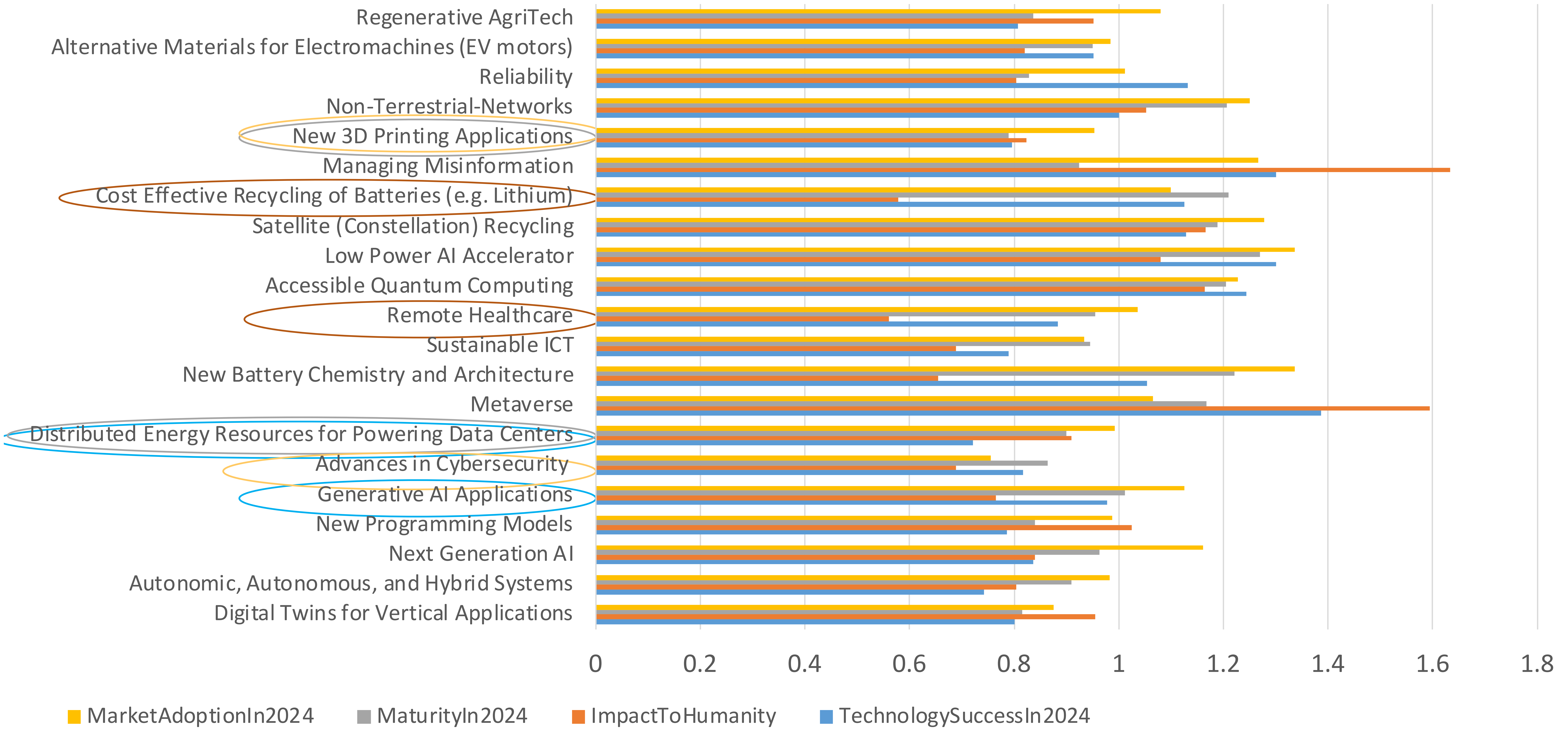
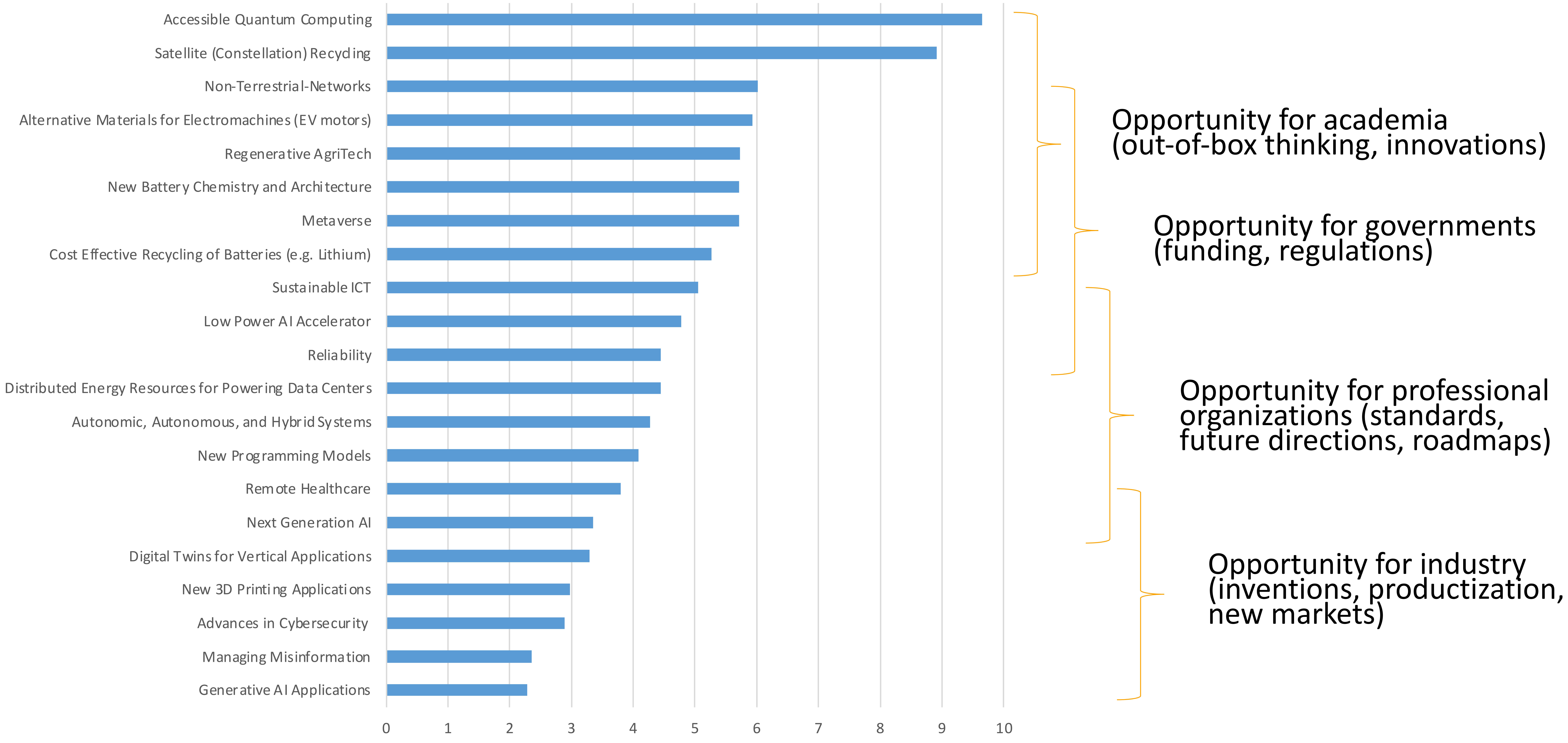
Standard Deviation, Smallest (Most Confidence)



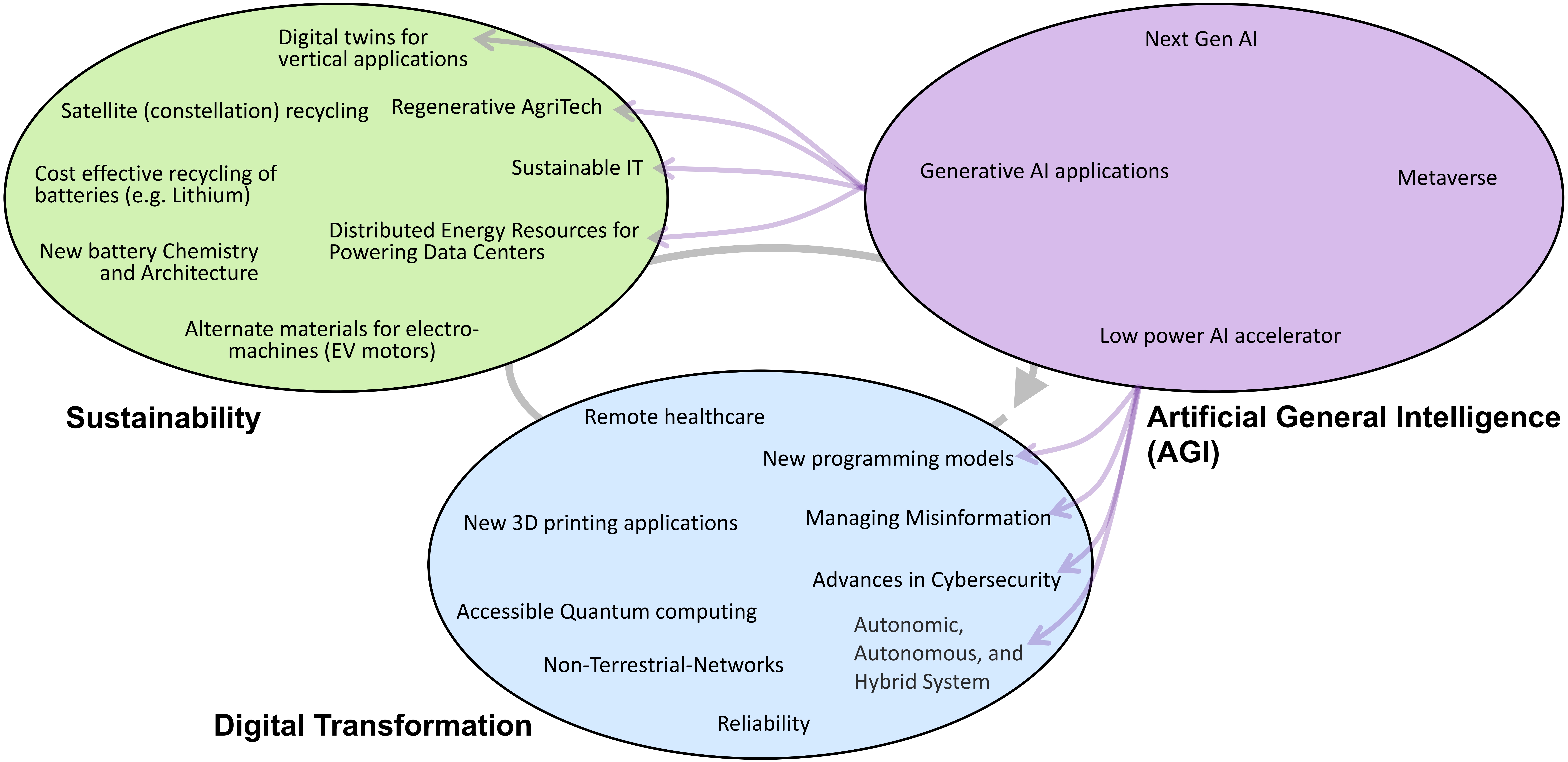
SECTION 05

How to Use Results, Horizons to Commercial Adoption



SECTION 05

Technology Predictions and Megatrends*



* See forthcoming IEEE Future Directions Committee Report on Megatrends

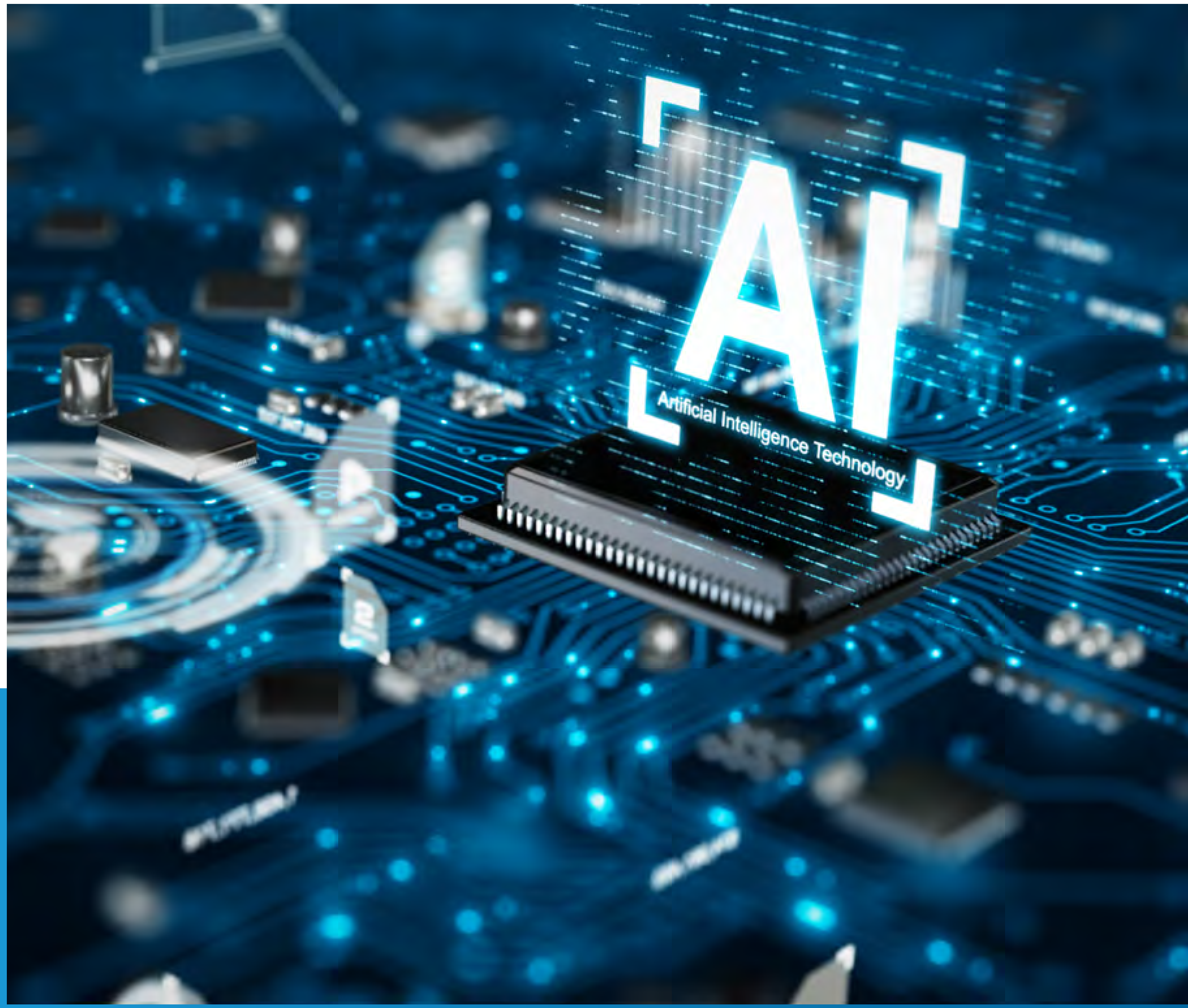
AI-related Megatrends Insights*

From a megatrends perspective, we have four core AGI technology predictions compared to eight sustainability-related and nine digital-transformation-related predictions.

- While there are only four core AGI technologies, there are at least 8 AGI-applied technologies that fall under two other megatrends (see previous slide).
- AGI is a more recent megatrend than the other two and less mature.

AGI technologies are deeply entangled with socio, economic, and ecological aspects, e.g.:

- The ethical and legal aspects are being formalized. For instance, the EU AI Act (December 2023). For individuals or organizations striving to further AI, it's advisable to prioritize these aspects.
- 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.



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Insights and Opportunities

- Technology with most advancement, largest market adoption and market maturity is *Generative AI Applications*.
- Technology with highest potential for impact on humanity is *Remote Healthcare*.
- Concern are technologies with large impact to humanity but fewer chances for technological success (Cost Effective Recycling of Batteries (e.g. Lithium), Regenerative AgriTech, and New Battery Chemistry and Architecture).
- Long-term opportunities are *Satellite (Constellation) Recycling* and *Accessible Quantum Computing.*
- AI continued the dominance from previous years, even more so.
    - Two most advanced technologies are *Generative AI Applications* and *Next Gen AI.*
    - Many other technologies are substantially enabled by AI (almost all).
    - Compared to past year, most benefit from AI are advances in cybersecurity and managing misinformation.
- Managing misinformation and advancing cybersecurity were both heavily influenced by elections across the world and in US.
    - They were both ranked much lower in previous year.
    - Managing misinformation was ranked highest in terms of maturity, but much lower on technology advancement, reflecting on attention it draws.

Opportunities for Industry

- Generative AI applications
- Managing Misinformation
- Advances in Cybersecurity
- New 3D printing applications

Opportunities for Governments

- Digital twins for vertical applications
- Next Gen AI
- Remote healthcare
- Autonomic systems

Opportunities for Professional Organizations

- Reliability
- Cost effective recycling of batteries (e.g. Lithium)
- New battery Chemistry and Architecture
- Metaverse

Opportunities for Academia

- Regenerative AgriTech
- Alternate materials for electro machines (EV motors)
- Non-Terrestrial-Networks
- Satellite (constellation) recycling
- Accessible Quantum computing

SECTION 07

Summary

Outlook

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

Predictions

- We made twenty-one predictions aligned with three megatrends (digital transformation, sustainability, and artificial general intelligence).
- We graded our predictions in terms of likelihood of technology success, impact to humanity, maturity in 2024, market adoption in 2024, and horizon to commercial adoption.
- Predicted technologies show a degree of correlation, but with more diverse roster we got less correlation this year.

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.

Generative AI Applications

Generative AI use will increase with rapidly expanding efficiency and new applications and services both beneficial and detrimental. Ethical and societal issues will continue to rise. Expect strong short-term impacts on business, education and society.

Problems/Demand

- Provides flexibility for new challenges and adaptive responses demand.
- Safety and security: Need to build safeguards against misuses and generated harmful content, such as deep fakes.
- Lacking Robustness, Reliability, Control, and Explainability, necessitating transparent techniques and consistent AI models. This is a major issue for agents and trusted apps.
- Bias and data quality issues in large datasets call for better curation.
- High computational costs limit model training to an oligarchy of very few players who can afford to train a foundation model.
- Evolving regulatory landscapes, especially regarding data privacy and use, demand for ensuring legal and ethical compliance.

Opportunities

- Enhanced creativity in arts and design, accelerated design. processes and collaborative human-AI creative processes.
- Generative AI-based revolutionized personalized medicine, from drug discovery to tailored treatment plans.
- Personalized education and marketing boost productivity.
- Improved customer support through natural interactions-conversation, problem solving, detailed product knowledge.
- Accelerated scientific discovery and 3D modeling.

Impact

- Helps content creators and designers to be more productive.
- Helps businesses improve their digital channels and marketing.
- Time-To-Market significantly decreased.
- Better accessibility: image-to-text, audio transcripts, translations (including to sign language).
- Personalized assistants (coding, editing, teaching, etc.) increase productivity and efficiency.
- Displacement of repetitive jobs requires reskilling/upskilling.
- Spreading of much higher quality misinformation requires source checking and critical thinking.
- More environmentally sustainable practices in various industries through optimization of resources and reduction of waste.
- Significantly changing traditional Industries—like manufacturing, agriculture, and transportation.

Sustainable Solution/Business Opportunity

- Generative AI may decrease the need for processing-intensive training.
- Support for no/low-code.
- Generative AI will increase AI adoption and create new revenue streams.
- Global cooperation in standardization and best practices to address challenges like intellectual property, cybersecurity, and ethical norms.
- Public-Private Partnerships: tighter collaborations between government, academia, and industry.
- Increased significance of Edge Computing in processing data closer to the source, reducing latency, and improving response times.
- **Enablers:** New ML approaches, affordable AI tools, open models, access to large curated datasets, AI-integrated agents for automation.
- **Inhibitors:** Threat to content creators and IP holders, difficulty in distinguishing human created content versus machine created, adversarial applications, Ethical questions of GAI versus human content generation, lack of interoperability, closed models, low-quality and biased datasets, high compute costs, lack of trust in AI, regulatory burdens and resistance to change.

Next Generation AI

The evolving advancements and developments in the field of artificial intelligence that push the boundaries beyond current capabilities. It is the next generation of Artificial Intelligence (AI) that is expected to be more advanced and sophisticated than the current AI systems.

Problems/Demand

- General Intelligence: current AI systems are specialized and narrow. Evolving towards AGI requires an interdisciplinary collaboration across computer science, engineering, ethics and even philosophy.
- Trust and explainability: the black-box nature of AI can cause a reduction in interpersonal trust. We need technology that prevents deriving secrets from large language models, and takes into account ethical consideration and data privacy.
- AI sustainability: as AI models keep growing, the excessive data center loading causes concern on environmental impact. Increased model efficiency, improved accuracy and greater flexibility are key.
- Human-centered AI: next gen AI should focus on enhancing human capabilities, for example by increasing the empathy level.

Opportunities

- Assuming the above demands are met, the technology has an opportunity to add $4.4 trillion to the global economy annually.
- Next gen AI can target a broad set of domains, ranging from healthcare (precision medicine), to education (personalized teachers), transportation (autonomous vehicles), manufacturing (AI robots), and even scientific discovery (AI surrogates).
- Significant impact on knowledge work, decision making, and collaboration.

Impact

- Positive impact include enhanced productivity, better healthcare, easier transportation, improved energy sector, faster science, breaking language barriers, and in general enhancing human capabilities.
- Democratization of content creation, helping content creators and designers to be more productive.
- Negative impact include the danger of job displacements and need for reskilling, broadening of inequality and worse bias, potential loss of control to AI agents, lack of data privacy.

Sustainable Solution/Business Opportunity

- Healthcare: Improve patient outcomes, reduce costs, and increase efficiency.
- Finance: Fraud detection, risk management, customer service.
- Retail: Optimize supply chain, personalized marketing, service.
- Manufacturing: Improve quality control, reduce downtime, optimize production.
- Transportation: Improve safety, reduce congestion, optimize logistics.
- **Enablers:** Widespread dataset availability, efficiency while driving down the costs, advances in AI hardware, new generative AI algorithms, multi-modal beyond language (image, video).
- **Inhibitors:** Lack of data privacy, lack of transparency, ethical concerns, lack of regulations and standards, fear of the unknown, inability to differentiate between human-created and AI-generated content, including content in training datasets.

03

Advances in Cybersecurity

Advances in Cybersecurity will enhance public confidence and will enable reliance on the cyber infrastructure for large scale applications including energy production and distribution

Problems/Demand

- Innumerable instances of hackers attacking utilities companies, major infrastructure organizations, and government agencies.
- Rising number of cyber attacks and increasing complexity of enterprise networks.
- Ransomware attacks on hospitals, schools, etc. on the increase.
- Privacy concerns, phishing attacks, misinformation and disinformation.
- Everyday applications such as Autonomous Driving Systems demand high levels of security.

Opportunities

- Cyber-Physical Security of Electrical Power and Energy Systems.
- Cybersecurity job opportunities are increasing
- Emerging availability of AI tools for detection of and response to attacks.
- Sharing of cyber threats across organizations allowing anticipation and proactive defense against emerging threats.
- Institutional investors have deemed cybersecurity investment a top-tier priority.

Impact

- Broader access to safe and reliable computing resources.
- Increased reliability on infrastructure (e.g., utility companies), public institutions (e.g., government, emergency services), financial organizations (e.g., banks), and shared datacenters.
- Reliance on cyber devices which require high degrees of safe availability (such as embedded systems, autonomous vehicles, critical life sustaining applications, etc.).

Sustainable Solution/Business Opportunity

- Hardware-based security.
- Privacy-enhancing technologies for multi-party computations.
- Permissioned blockchain solutions such as Hyperledge Fabric will be deployed to secure distributed access control to resources.
- IoT will benefit from the decentralized, tamper-proof nature of distributed ledger technology.
- **Enablers:** Availability of AI tools, awareness of the issues at the levels of governments.
- **Inhibitors:** Cybersecurity is often an afterthought in the design of complex systems. Defenses must be flexible to adapt to new threats constantly. Keeping defenses up on a near daily basis is simply too inconvenient to ask of the average user.

04

Managing Misinformation

AI deepfakes (text, audio, visual) will become a regular electioneering tool that will require careful management

Problems/Demand

- Social media is a collection of unregulated media platforms that are prone to distributing misinformation and disinformation.
- There are various actors with malicious intent to offer information that is harmful to the reader if they opt to believe it.
- There are nation states that wish to affect elections or disrupt society in other nations by targeting specific disinformation to specific voters in specific geographic regions.
- Demand for regulation of social media platforms faces the challenges associated with limiting free speech which is available in most but not all nations.
- The difficulty is "how to not create a Ministry of Truth." Also, the sheer amount of information to be monitored is daunting and only increasing.

Opportunities

- Social media is the largest information disseminator.
- The opportunity is to convince platform providers to censor certain types of speech such as hate speech.
- The opportunity is how do this within the private sector without governments doing it.

Impact

- Creating an Internet with increased believability concerning the information found on social media platforms.
- Creating a "safer" Internet.

Sustainable Solution/Business Opportunity

- Enhanced reliability and accuracy of the information found on social media platforms
- Reduced concern from parents concerning what their minor children are reading
- Reduced concern about cybersecurity threats such as phishing.
- For social media providers the opportunity is the ability to argue and advertise that their platform is "well-moderated" and that the content is safer to trust than other competing platforms.
- **Enablers:** Trusted moderators that can discern truth from fake information, and in particular, disinformation that is malicious, platform providers that take this challenge seriously.
- **Inhibitors:** Arguments that censoring or moderating content is an attack on free speech, government intervention to moderate content that is purely political in terms of its goals, once disinformation goes viral it is difficult to control and more difficult to undo, some people do not want to see the truth--they want to see only their own viewpoints.

Remote Healthcare/ Monitoring Sensors/ Systems

Remote healthcare, monitoring sensors and system-level data integration will enable patients to obtain remote medical assistance, physicians to improve diagnosis and treatment, optimal utilization of individuals' medical history, and efficient health care delivery protocols.

Problems/Demand

- Access to healthcare in remote areas is limited.
- General demand is growing in response to increasing healthcare costs, aging population, increased life span, and chronic diseases.
- There is lack of general and specialized medical teams, while health conditions often require continuous and objective monitoring for diagnosis and treatment efficacy assessment.
- Comprehensive analysis of individuals' health data and history is needed to optimize diagnosis and treatment.
- Biomed, remote diagnosis and treatment technologies are rapidly advancing; dissemination and implementation need accelerating.

Opportunities

- Connectivity improvements, additional type/scope of sensors and further miniaturization to reduce cost and expand usefulness.
- Increased reliability of sensors/wearable devices.
- Cloud computing allows small medical centers to perform computations that require vast compute power.
- 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 can be used to optimize patient management at a health care delivery-systems level, increasing efficiency and lowering costs.
- Richer data sets will enable more accurate design of digital twins.

Impact

- Broader access to customized solutions, medical assistance and health care specialists.
- Better health care 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 quality of life and overall social productivity.
- Collection of rich data sets to catalyze further research.

Sustainable Solution/Business Opportunity

- Integration of wireless charging, energy harvesting, make-on-demand sensors, real-time data analytics.
- Improved reliability and accuracy of sensor data & information analytics.
- Decrease of health care delivery costs.
- Expansion of the application & use of wearables/sensors/ medical devices.
- The unfortunate likelihood of continuing and future global health crises.
- **Enablers:** Data bandwidth, storage, and access; new ML algorithms and new accelerators for sophisticated computations, including at the edge; electronics miniaturization, battery efficiency, advanced sensors, microfluidics, advances in biotechnology and commercial IoT market.
- **Inhibitors:** Cost, the need for explainable ML algorithms, health insurance models/infrastructure, regulatory requirements (e.g., HIPAA, FDA, pre-market approval, biocompatibility testing), data privacy & categorization, parts obsolescence / life-cycle, data processing, still limited interaction between technology developers and 'end users.'

Digital Twins for Vertical Applications

Digital Twin technology will advance state of the art of predictions, what-if-analysis and oversight, in a number of industry verticals, such as data centers, medicine, geo-physical hazards, manufacturing, agriculture, transportation, and many others.

Problems/Demand

- Deployed systems are becoming increasingly complex to understand, manage, and support, they need:
  - Uncertainty Quantification.
  - Multi-X (scale, resolution, modality).
- Reliability and robustness require real-time reaction to attacks, anomalies, and systematic failures of the infrastructure.
- Increased relevance/need of personalized medicine in recognition of individuals' diversity.
- Remote crop and animal health monitoring at disparate agricultural production locations.
- Physical or siloed prototyping/testing of products or solutions result in increased costs, time and complexity.

Opportunities

- Digital Twin technology can provide a systematic way to collect all information from the working systems and processes.
- Digital twin can conveniently integrate AI tools, such as reinforcement learning to observe trends.
- While connected to live systems and processes, it can perform what-if analysis.
- Treatments and control decisions can be optimized/tested on digital twin.
- Reducing cost of HW and emerging low-power long-range public networks is opening opportunities in agriculture applications.
- Digital Twins can bring together disparate sources of data into a unified model to assess the development, delivery, and operation, of an asset or an environment.

Impact

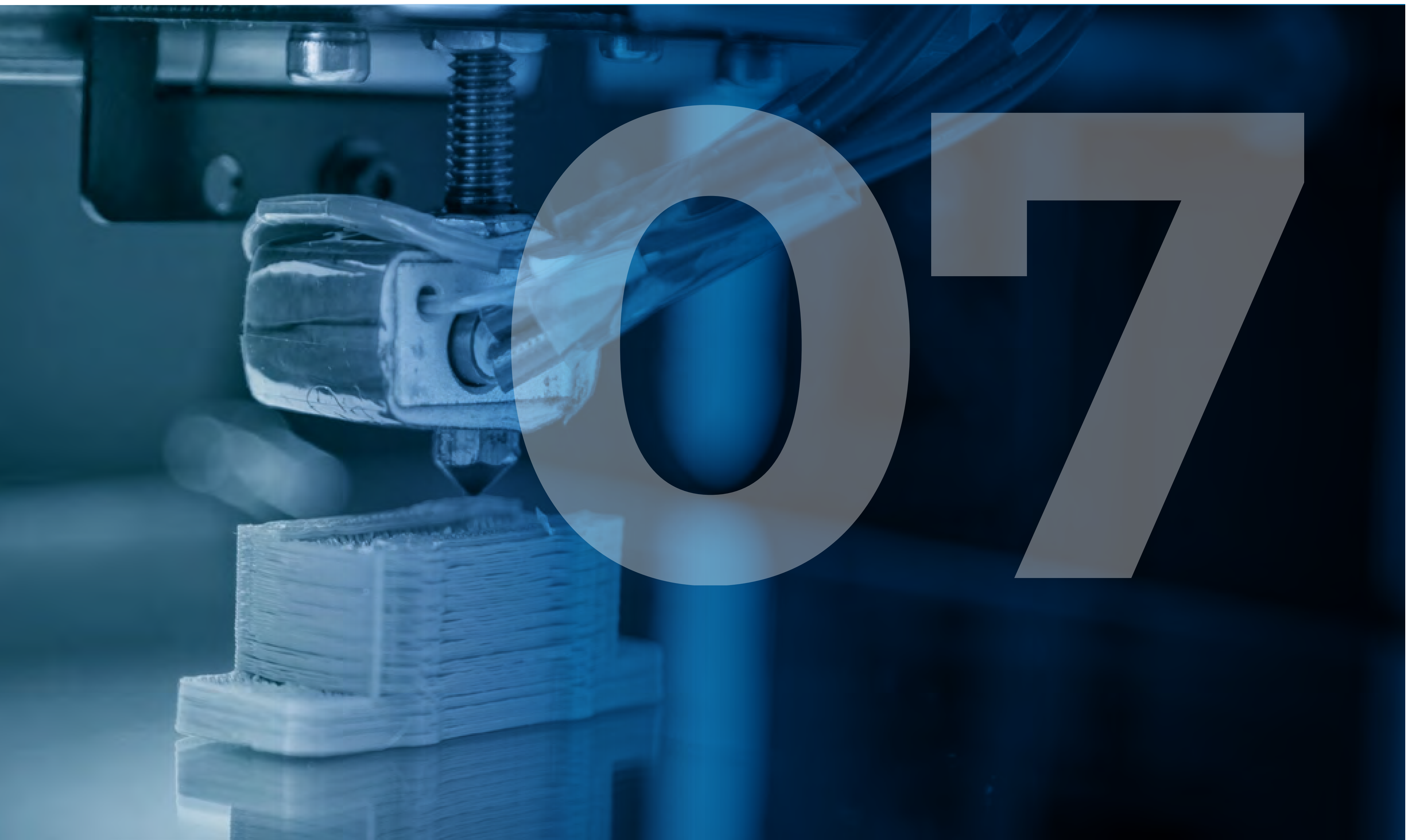
- Improved reliability, security, planning processes.
- Reduced cost from failures.
- Optimization of health care delivery/better health outcomes.
- Real-time modeling of the state of the object.
- Improved crop and animal health, improved food security.
- Improved safety, workforce productivity, maintenance and optimized usage of materials in construction, manufacturing and building operations.
- Improved quality of manufacturing.

Sustainable Solution/Business Opportunity

- Deploying in various sectors and adoption.
- Integration of health care data to produce digital twins.
- **Enablers:** AI integration; connection to cyber-physical systems and processes, health related technological advances; heterogeneous computers that support mixed workload (traditional computing and AI), network providers exploring technologies like LoRa, support from an increasing number of governmental and inter-governmental bodies across the world.
- **Inhibitors:** Regulatory compliance; increased complexity, privacy regulations, data standardization, lack of generic interfaces to/from physical systems to digital (HPC) systems.

New 3D Printing Applications and Solutions

3D printing in many domains will evolve towards customized and automated solutions.



Problems/Demand

- One-size-fits-all products can be inefficient, only partially meet needs, and have unwanted side-effects, e.g., prostheses.
- Centralized manufacturing of critical parts leads to fragile supply chains.
- Centralized production of customized products suffers bottlenecks.
- Low-volume/high-mix manufacturing is very expensive.
- Traditional design tools cannot create new very complex geometries.

Opportunities

- New/improved and sustainable materials and processes.
- Mass customization.
- Design workflows / software for automated customization and complex geometries.
- Democratization of manufacturing (low cost and localization).
- Reliability (dimensions, warping, surface quality, etc.) through hardware and software.
- Applications for unique parts in medical, space, structures, homes, and other fields.
- Digital twins (applications using digital 3D models).
- Unforeseen applications will unfold rapidly.

Impact

- Better availability.
- Improved supply chains.
- Better fit to solve needs.
- Availability of otherwise hard to manufacture/costly products.

Sustainable Solution/Business Opportunity

- Reduced transportation costs enabled by distributed manufacturing.
- New manufacturing markets (printers, materials, etc.).
- New 3D design tools.
- New scanning technologies.
- Education
- **Enablers:** Open Access/Source community; new approaches to highly complex, highly customized 3D design.
- **Inhibitors:** Environment sustainability, cost, access to power, internet and materials in remote locations, lack of suitable design tools.

New Programming Models and DevOps

Advances in AI, broader adoption of script-based languages, and further digital transformation into non-programmers' world will further increase ease of development and require new programming models and DevOps, such as serverless, from the Edge to Cloud.

Problems/Demand

- Ease of Development and Operations.
- AI models require different approaches compared to traditional Web Services, HPC, or general-purpose coding.
- Complexity of the underlying accelerators need to be hidden from programmers, yet enable well-performing code.
- Extreme scale systems deployed from edge to Cloud.
- Novice users have hard time understanding increasingly complex code, configurations, debugging, and support.

Opportunities

- Stateless, serverless, Function-as-a-Service, simplify state mgmt, enable redirection in support of improved performance and energy.
- Low-code/No-code solutions, broaden programming to wide masses.
- Same programming models from edge to Cloud simplify support, management, and maintenance.
- Just like writing, AI can support coding simple snippets, debugging, formatting, etc.
- Observability can be built-in into the new programming models and DevOps.
- Support for new programming paradigms, i.e. swarm.

Impact

- The world undoubtedly depends on digital transformation and the number of people who can program it is limited. Broadening the number of programmers and developers will accelerate digital transformation.
- Scale of solutions grows both absolutely and relatively (largest to lowest). New DevOps will enlarge the scope of adoption of digital transformation.
- New systematic approaches to exposing energy management will improve overall sustainability.
- Interoperability will increase if standard simplified coding is utilized.
- Integrated solutions will enable better QoS, QoE delivery.

Sustainable Solution/Business Opportunity

- Open-source tools, such as OpenFaaS, Knative make for more sustainable solutions and improved interoperability and manageability.
- Faster time-to-market of software apps built on top of complex edge-to-cloud environments.
- **Enablers:** Open source, best practices, new de facto standards, patterns, broader use of AI.
- **Inhibitors:** Proprietary solutions, unverifiable (unexplainable) source of AI models, requirement for legacy solutions, some limiting regulatory governance requirements.

Reliability

Reliability will emerge as a major concern in a widespread set of application fields.

Problems/Demand

- Enhanced adoption of AI powered systems to support human decisions (e.g., medical safety critical applications), with consequent need for reliable operation.
- Increasing demand for highly autonomous systems capable of interacting with humans, with consequent reliability requirements.
- High reliability needs in hyperscalers with increased scale, complexity, multi-die evolution and workload expansion.

Opportunities

- **Make AI trustworthy:** reliable systems implementing AI algorithms can make AI trustworthy, thus possibly being adopted to support human decisions in several application fields (medical, highly autonomous systems, etc.).
- **Increase autonomous systems' safety:** reliable systems can move highly autonomous systems into a safe state in case of hazardous conditions, and extend remaining useful life.
- **Improve availability for hyperscalers:** reliable systems can decrease downtime and prevent SDC occurrences.

Impact

- Reliable systems will enhance the adoption of trustworthy AI to support and benefit humans' activities.
- Reliable systems will speed up the evolution towards highly autonomous systems to replace humans in harsh environments and to guarantee inclusive accessibility to technology.
- With adoption of Silicon Lifecycle Management, reliable systems will reduce risk for downtime and catastrophic hazards.

Sustainable Solution/Business Opportunity

- **Reliable hardware implementation of AI:** adoption of hardware fault tolerance and dedicated solutions.
- **Reliable systems for safety:** adoption of self-checking and fault tolerance approaches to drive autonomous systems into a safe state in case of occurrence of hazardous conditions.
- **Enablers:** Dedicated low-cost approaches for fault tolerance for the hardware implementing the AI and for the hardware driving an autonomous system into a safe state.
- **Inhibitors:** Unpredictability of hazardous conditions and possible faults affecting the hardware; need for international regulations and standards constraining the realization of reliable systems.

Autonomic, Autonomous, and Hybrid Systems

Evolution of autonomous systems will require a failsafe hybrid mode with autonomic response to urgent stimuli and human in the loop.

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Problems/Demand

- Autonomic systems provide a discrete response to a discrete stimulus, such as a hand pulling back from heat.
- Autonomous systems must make decisions to proceed independently, such as determining a path around an obstacle.
  - Unknown conditions can result in confusion in how to proceed, resulting in inefficiency and safety challenges.
- Hybrid systems provide general autonomy but can revert to an autonomic response to an unknown condition and a failsafe mode to await further instructions.
- Public demand for autonomous systems to provide much higher safety margins while operating in general situations has led to a need for hybrid operation when uncertain.
- The need for hybrid systems scales with the number of unknown conditions and risk.
- Requires updated legal framework on responsibility disclaimers.

Opportunities

- AI can be used to generate hypothesis and robot systems can perform experiments. (Lather, rinse, repeat).
- Use hybrid mode to gradually transfer responsibility to autonomous systems as experience and confidence increase.
- User input as learning tool to increase autonomy.
- Increased human-autonomous system interaction with autonomic protection protocols, e.g. in manufacturing, agriculture, mining, etc.

Impact

- Decrease time for innovation.
- Automated driving has the potential to decrease energy costs, reduce traffic congestion and increase safety.
- Autonomous agriculture can increase yields, decrease use of pesticides and herbicides, optimize land use.
- Automated labs can streamline processes, save resources, and accelerate the pace of discovery.
- Improved autonomy and human-machine collaboration can alleviate labor shortages, de-risk dangerous jobs.
- Potential lower threshold for autonomous warfare.

Sustainable Solution/Business Opportunity

- Improved hybrid autonomous systems with autonomic safety protection can broaden application in a safer environment while collecting more data to reduce risk.
- Hybrid systems for dangerous or undesirable jobs.
- Force multiplier for productivity.
- Efficiency support such as in aerial drone small package delivery.
- **Enablers:** AI integration; sensor fusion, faster computation enables better learning and faster decisions.
- **Inhibitors:** Safety, reliability, public expectations for much higher safety levels, workforce and user training to program or operate.

Distributed Energy Resources for Powering Data Centers

Engaging renewable energy based distributed energy resources (DERs) for powering data centers will have a high impact on clean energy requirements for data centers.

Problems/Demand

- Data centers are mostly powered by diesel generators, thus they are considerable air polluters.
- New legislations demand clean energy requirements from data centers.
- Oregon and Washington have already introduced measures that require data center operators to reduce their greenhouse gas emissions per megawatt hour under a standard baseline in set increments, leading to 100% reduction in 2040. Other states will most likely follow.
- Data center operators are under pressure to demonstrate that their facilities will be sustainable enough to satisfy the local community, self-sufficient enough not to burden local grids, and resilient enough to provide the reliability their customers require.
- Finally, another issue with traditional, diesel-powered data centers is stranded capacity. This can also be managed through an intelligent usage of the flexibility of DERs.

Opportunities

- Renewable DERs as well as Battery Energy Storage Systems for powering Data Centers.
- Intelligent usage of DER flexibility to lower stranded capacity.
- Evolving Data Centers into DER-powered Microgrids.

Impact

- Substantial reduction in pollution caused by Data Centers.
- Available generation capacity fully utilized.
- Less available power needed—overall more cost-effective solution.

Sustainable Solution/Business Opportunity

- Appropriate software solutions for design, planning, operation and analysis of emerging Data Centers are required
- There is much data available from data centers and/or, in future, DERs. Data fusion and artificial intelligence (deep learning) could augment developmental approach and implementation.
- Real-time management tools for utilizing flexible DERs for powering Data Centers are required.
- **Enablers:** High global awareness of the pollution and stranded capacity issues.
- **Inhibitors:** Completely novel paradigm, it will take time to persuade decision makers and other stakeholders.

Sustainable ICT

Sustainable ICT is the study and practice of designing, manufacturing, using, and disposing of computers, servers, and associated devices and subsystems efficiently and effectively, with minimal or no impact on the environment.

Problems/Demand

- Only 43% of executives are even aware of their organization's ICT footprint.
- Half of organizations have an enterprise-wide sustainability strategy in place, only 18% have a comprehensive one, with well-defined goals and target timelines.
- 49% lack the tools to adopt and deploy solutions and 53% lack the expertise.
- Energy consumption of ICT is growing, attaining approximately 10% of the worldwide electricity consumption.

Opportunities

- Impact on the environment, especially given the digital acceleration triggered by the COVID-19 pandemic.
- Reaching net zero by 2050 could entail a 60 percent increase in capital spending on physical assets, compared with current levels.
- Transition to sustainable ICT will create massive opportunities to build entirely new businesses.
- E.g: Optimization and trading of surplus energy produced in microgrids could be done via blockchain technology. These innovations aid in the creation of new jobs, cheaper energy, and energy security.

Impact

- Can help organizations increase efficiencies while creating more motivated, inspired employees and more satisfied, loyal customers.
- Growing demand for net-zero offerings could generate more than $12 trillion of annual sales by 2030 across 11 value pools, including transport, power, and hydrogen.

Sustainable Solution/Business Opportunity

- Early leaders in enterprise sustainability are applying digital technologies such as AI, IoT data, blockchain, computer vision, big data, and hybrid cloud to help operationalize sustainability at scale.
- Green Building Initiative: An international effort toward creating sustainable, resource-efficient buildings.
- LED Lighting: LED lights are more energy-efficient than traditional incandescent bulbs and can last up to 25 times longer.
- Smart Power Management Systems: These systems can help reduce energy consumption by automatically turning off devices when they are not in use.
- From optimizing the location of scooter-sharing stations to better predictions of shipping-container timings to non-invasive methods for tracking songbirds in Brazil, AI plays an increasing role to ensure an ongoing balance between humans and their surroundings.
- **Enablers:** Edge computing, AI, and IoT can enable sustainable digital transition and a circular economy, raising awareness.
- **Inhibitors:** High cost, lack of legislative guidance, incentives, and broad sustainability culture.

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Regenerative AgriTech

Regenerative agriculture is a holistic, circular approach to farming that strives to improve the health of agroecosystems and the natural ecosystems that support them.

Problems/Demand

- Soil Health Decline: Soil erosion, compaction, and loss of organic matter due to intensive farming practices, affecting crop productivity.
- Water Scarcity: Increasingly stressed water resources due to inefficient irrigation methods and climate change impact, leading to reduced crop yields.
- Chemical Dependency: Heavy reliance on synthetic fertilizers and pesticides causing environmental pollution and health hazards.
- Climate Volatility: Agriculture being vulnerable to extreme weather events impacting harvests and threatening food security.
- Consumer Consciousness: Growing consumer interest in ethically sourced, organic, and sustainably produced food, driving market demand.
- Investor Pressure: Investors seeking opportunities in environmentally friendly and socially responsible agricultural ventures.
- Policy Imperatives: Governments and regulatory bodies emphasizing sustainable farming practices to combat environmental degradation.

Opportunities

- Advanced Technology Integration: Adoption of precision agriculture, drones, AI, and IoT for efficient resource utilization and yield optimization.
- Market Expansion: Access to niche markets and premium prices for organically and sustainably grown produce.
- Ecosystem Services: Capitalizing on carbon credits, biodiversity preservation, and ecosystem restoration initiatives.
- Knowledge Exchange: Collaboration platforms and educational programs facilitating the dissemination of regenerative farming practices.

Impact

- Environmental Restoration: Soil regeneration, increased carbon sequestration, and biodiversity preservation.
- Economic Prosperity: Improved soil fertility leading to higher crop yields, cost savings from reduced chemical inputs, and access to high-value markets.
- Socioeconomic Development: Enhanced food security, rural employment opportunities, and healthier communities through nutritious produce.

Sustainable Solution/Business Opportunity

- The world is becoming digital, and all solutions will need some amount of programming, configuration, and maintenance.
- **Enablers:** Innovations in data-driven agriculture, such as sensor technologies and AI algorithms for precise resource management. Collaborative Ecosystem: Partnerships between farmers, agribusinesses, tech firms, and research institutions fostering innovation and knowledge sharing. **Consumer Education:** Awareness campaigns promoting the benefits of regenerative agriculture, encouraging demand for sustainable products.
- **Inhibitors: Initial Investment:** High upfront costs for technology implementation and transitioning to new farming methods. **Policy Frameworks:** Inconsistent or insufficient government policies and regulations supporting regenerative practices. **Behavioral Shift**: Resistance among farmers to change traditional practices without visible short-term benefits or adequate support.

Non-Terrestrial Networks

Non-terrestrial networks (NTN) involving satellites and high-altitude platforms (HAPs) expand and augment the capabilities of terrestrial networks (TN) involving wireless and cabled communications in the quest to connect everything to everything (E2E) in real time (RT).

Problems/Demand

- There is an urgent need to connect everything to everything at high speed, while Unpredictable latencies in terrestrial networks (TN) prevent real-time operations.
- The installation of mega-constellations of low-Earth orbit (LEO) satellites has provided dense coverage of the Earth and reduced the latency time.
- Telecommunications and teleoperations.
- With NTN, all mobile devices can be connected to both terrestrial and satellite networks as part of one ecosystem.
- Digital twins (turbines, platforms, power grids).

Opportunities

- Moving from 5G to 6G and beyond and using the available spectrum for high-speed data communications.
- Direct optical and terahertz communications.
- Connectivity and control of IoT devices.
- Automotive industry transformations (telematics, autonomy, safety).
- Healthcare transformations (monitoring, responses, teleoperations).
- Multi-layer multi-dimensional multi-band topology.
- Global and extended communications.

Impact

- NTN is a fundamental enabler of global coverage to a wide range of applications requiring high availability and high resilience.
- Improved mobile communications.
- Real-time teleoperations, including digital twins.
- Improved network resiliency and increasing availability.
- Increased interest in relevant space education.

Sustainable Solution/Business Opportunity.

- Global and augmented connectivity.
- New real-time teleoperations.
- Low-power and cost-effective solutions.
- Enhanced mobile edge compute infrastructure.
- A new 3D wireless network architecture.
- **Enablers:** A growing market of digital assets popularizing NFTs in certain markets, like art; perhaps space- and time-based blockchains could reduce the energy consumption for NFT blockchains.
- **Inhibitors:** Fraud and trustworthiness problems; legal ownership deficits/uncertain legality—copyright, TM, rights of publicity; energy consumption of current blockchain technologies used for NFTs, security issues in NFT marketplaces, wallets, and with the tokens themselves.

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New Battery Chemistry and Architecture

New materials will replace Lithium and they will make it possible to make batteries that are cheaper and more sustainable.

Problems/Demand

- More batteries needed every day for:
  - Consumer Electronics.
  - Electric Vehicles.
  - Homes.
  - Power Grid.
  - Climate legislation increasing demand.

Opportunities

- Find new chemistries and/or architectures that include:
  - Materials that are more accessible.
  - Materials that are easier to mine.
  - Materials that are easier to recycle.
  - Materials that have higher power density.

Impact

- Higher production rate of electronics.
- More affordable prices.
- Transition to electrification.

Sustainable Solution/Business Opportunity

- Sustainability: Current Li-ion batteries do not have a very sustainable lifecycle from the mine to recycling; reducing fire hazard.
- Charge: the amount of charge a battery can hold as well as the charge time are opportunities.
- Cost: finding alternate, less-expensive materials will be essential to advance EV adoption and to support the energy grid.
- Capacity: We need a lot more storage capacity for the Grid of the future; packing more energy in smaller space.
- **Enablers:** Advances in battery chemistry; Advances in recycling technology, government funding.
- **Inhibitors:** Availability of Metals, manufacturing processes.

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Low Power AI Accelerator

Low power AI accelerators will be key-components for practical, compact, cost-effective, long-term reliable computation units for self-driving vehicles and AI robots, data-centers, LLM, systems, smart phones, games.

Problems/Demand

- AI processing units for autonomous driving vehicles and AI robots have needed big power-consuming AI servers and cooling units. For practical systems with long-term reliability and fewer battery recharging, next-generation low-power, high-performance AI accelerators will be essential.
- Big data centers with LLM processing will consume enormous power, over 100 MW. Next-generation low-power AI accelerators will be required for cost-effective services of ChatGPT and so on, considering power receiving capacity.
- Everyday devices, including games and smartphones, will need stronger AI processing. Compact and low-power AI accelerators requiring no cooling units will be necessary to have a bigger market.

Opportunities

- Power reduction of IT apparatus using AI, including smartphones, games, PCs, autonomous vehicles, AI robots, and data servers, is significant for sustainability and carbon neutrality.
- Autonomous systems related to human lives, like automobiles and robots at home, need long-term reliability. Low-power processing units, not requiring water cooling or cooling fans, will be essential to develop those products.

Impact

- Make long-term reliable self-driving cars and AI robots used at home practical.
- Dramatically reduce IT power consumption from smartphones, games, PCs, servers, autonomous vehicles, AI robots.

Sustainable Solution/Business Opportunity

- Power consumption of IT apparatus from smartphones, games, and PCs to data centers will be dramatically reduced. It significantly contributes to sustainability and will open up new business models.
- Market acquisition of self-driving vehicles needs low-power high-performance AI accelerators that work reliably without liquid cooling for many years or more than 5 and 10 years.
- **Enablers:** Power control by co-design of architecture and compiler. Hardware knows past behavior though a compiler knows the behavior of the whole program, or future operation of cores, memory modules, and so on. With compiler control clock- and power-gating and frequency and voltage control, power consumption will be dramatically reduced.
- **Inhibitors:** A limited number of researchers and engineers have a good knowledge of co-design, parallelizing- and power-reducing compilers in industry and academia.

Alternative Materials for Electro Machines

Inadequate raw materials for conventional high-performance electro machines motivates discovery and engineering.

Problems/Demand

- Transportation market is converting from internal combustion engines (ICE) to hybrid and EV, requiring efficient heat tolerant motors.
- Known or geopolitically available global supplies are adequate for less than 25% conversion of vehicles.
- Wind and hydro turbines as well as many other energy converters also require efficient generators. Critical for microturbines.

Opportunities

- Discovery of new materials, including temperature tolerant ceramics as well as new alloys holds promise.
- Early engineered materials are showing up in high end electromachine applications.
- Magnet geometries (optimize field and thermal management).
- Systems performance.
- Economic scaling required.

Impact

- Enable global hybrid and electric vehicle fleet conversion.
- Enable continued cost-effective proliferation of distributed turbo-machinery power sources, including wind, hydro, geothermal, nuclear.

Sustainable Solution/Business Opportunity

- The business opportunity is conversion of global vehicle fleet and proliferation of small-turbine energy conversation systems.
- **Enablers:** Materials genome (AI, data science), climate change policy, additive manufacturing, EM and thermal modeling, digital twins.
- **Inhibitors:** Social acceptance, regulations, large investments, at-scale commercialization, cheap hydrocarbons.

Cost Effective Recycling of Batteries (e.g. Lithium)

Recycling of batteries to recover materials for reuse will reduce the need for mining and increase the general sustainability of battery technology.

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Problems/Demand

- By 2025 the International Energy Agency (IEA) estimates 4 TWh of battery production.
- Currently, there is very little recycling of lithium batteries (the most widely used rechargeable memory technology).

Opportunities

- **Reduce landfill danger:** Many batteries are put into landfalls despite efforts to curb this. This can cause contamination and possible fire danger.
- **Decrease mining:** If battery recycling becomes mainstream it could reduce the need for mining of materials for new batteries.
- **Reduce environmental impact:** Besides damage to ecoysystems from mining, processing to extract elements like Lithium involve dangerous chemicals.

Impact

- Cost effective battery recycling could reduce the costs of batteries, reduce environmental impact and encourage electrification of more products as well as enable energy storage for renewable energy sources.

Sustainable Solution/Business Opportunity

- **New battery recycling industry:** lower costs will result in higher demand for recycling and encourage electrification and sustainability
- **Enablers:** New recycling processes that can increase recycling with lower costs. It may be that recycled batteries are better than new ones.
- **Inhibitors:** Scaling new battery recycling processes including how to bring in batteries for recycling at scale could inhibit an otherwise cost-effective battery recycling technology.

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Metaverse for Industrial Applications

Metaverse will bridge the gap between the real and the digital worlds, by solving real world industrial problems digitally.

Problems/Demand

- Enhance production speed and quality (e.g., faster design and prototyping, reduction of fails at test, etc)
- Reduce maintenance costs (e.g., adoption of predictive maintenance, remote monitoring)
- Increase safety at work (e.g., through synchronized digital twins, remote monitoring)

Opportunities

- Enhance production speed and quality: adoption of accurate digital reality tools to speed up design and emulate the real world, thus increasing the likelihood of successful design and reducing the number of required prototypes and fails at test.
- Reduce maintenance costs: integration of remote sensing and AI tools to perform predictive maintenance, thus enabling maintenance's schedule optimization and reducing he likelihood of out-of-service occurrence.
- Increase safety at work: creation of a synchronized digital twin of the factory, to enable the real time monitoring of potential safety-risky conditions, and the prompt activation of counteractions.
- Improve competitiveness: improvement of productivity and the flexibility to adapt to markets needs faster and at reduced production cost

Impact

- Metaverse will make production more efficient in basically all industrial fields, reducing production costs and increasing product quality.
- Metaverse will make the production environment safer for workers.
- Enable sustainability and resilience.
- Enable fast and efficient testing at reduced cost.

Sustainable Solution/Business Opportunity

- Accurate and reliable digital reality tools: development of accurate and reliable digital reality tools.
- AI solutions for trustworthy predictive maintenance: adoption of fault tolerance approaches to increase the reliability of AI algorithms for predictive maintenance.
- Synchronized digital twins for safety improvement: development of synchronized digital twins of potentially dangerous production phases for continuous monitoring and countermeasures activation.
- **Enablers:** Tools for digital reality, remote monitoring, digital twins and AI.
- **Inhibitors: Initial Investment:** Occurrence of possible hazardous conditions in the real world; difficulty in modelling some physical phenomena; possible human unpredictable behaviors; AI explainability.

Accessible Quantum Computing

Improved public understanding and access to the power of quantum computing. Increasing 'conventional' computing efficacy exponentially.

Problems/Demand

- Conventional computing capability, particularly AI, creates an opportunity for a 'quantum' leap in delivering the 'quantum' dream—realizing the power of quantum mechanics.
- However, current quantum technologies require very low temperature at which quantum computers can work nowadays.

Opportunities

- Seamless computing: human-machine and machine-machine.
- Cloud/distributed-computing resourcing (open source, open access and otherwise).
- Solving unresolved complex science/engineering problems.
- Education, including thought leadership.

Impact

- AI capability at radically faster speeds
- Significant societal impact of technology—both positive and negative.
- Many unique or customized combinations, e.g. personalized healthcare (genomics), new materials, etc.

Sustainable Solution/Business Opportunity

- At this point, technology realization is still far from reality (cost-effective) however there are many education and research opportunities.
- Thought leadership in the discipline.
- **Enablers:** Enhanced power of computing, collaboration and communication means that scientists around the world can work closer towards a 'quantum leap.'
- **Inhibitors:** Centered towards first-world economies; with growing societal awareness of both positives and negatives of technology – there will be significant public concern regarding a 'quantum' leap.

Satellite (Constellation) Recycling

Satellite (constellation) recycling will enable circular economy in space ensuring long term sustainability. We expect an initial success in 2024 with increasing awareness of the tremendous impact on Humanity.

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Problems/Demand

- Strong coordination among players.
- High penetration of SDE in space systems.
- Broad use of "ally" technologies, such as EHF/optical links and AI.

Opportunities

- Enhanced flexibility of space system missions and services.
- Longer lifetime through software-based architectures.
- Cost reduction through system coordination.
- Shorter time-to-deployment and time-to-operations.
- On-orbit manufacturing, assembly, refueling, and recycling.
- Next generation platforms, warehouse, intermediate stops for deep space missions.

Impact

- High integration level among space systems and services.
- Increase in verticals applications due to the SDE flexibility.
- Enhanced sustainability of space on the medium term
- Enhanced Earth sustainability, due to the holistic nature of the sustainability paradigm.
- Debris recycling and cost-effective space exploration.

Sustainable Solution/Business Opportunity

- Recycling sats and sat-nets is sustainable for both space and Earth.
- That recycling would open the way to a general approach to space that could be rewarded by Governments in the future.
- That recycling could become "The" business, when polluting space will become more costly that keeping it clean.
- Life Extension and rehabilitation of satellites.
- **Enablers:** SDE, EHF and optical links, AI.
- **Inhibitors:** Collision of hardware reduction with some space industry trends.

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