
2024
Technology Megatrends
IEEE FUTURE DIRECTIONS
IEEE

In This Report

IEEE FUTURE DIRECTIONS

SECTION 01

2024 Technology Megatrends Team


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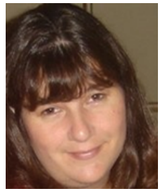
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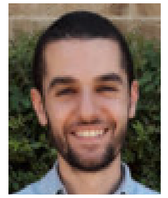
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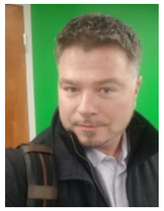
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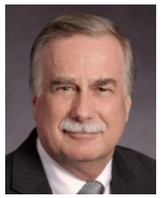
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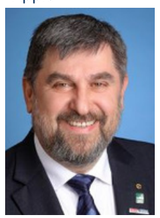
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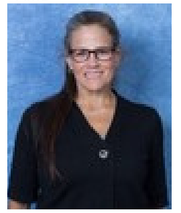
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IEEE FUTURE DIRECTIONS

SECTION 02

Executive Summary

- The IEEE Future Direction Committee released its 2024 Technology Megatrends for
  - Digital Transformation (DT); Sustainability; and Artificial General Intelligence (AGI)
    - see pages 41-53 for definition of these megatrends and more detailed descriptions
  - For each megatrend, we suggest our predictions for six technologies
- High-level observations
  - AGI will continue to dominantly support other megatrends and technologies
  - Sustainability support will penetrate all vertical and horizontal technologies
  - Digital transformation will affect all six technologies with a focus on those that could or may be automated
- Based on the ranking this report predicts
  - Technology most likely to succeed in Digital Transformation (DT) megatrend is ubiquitous connectivity and in AGI is generative AI
  - Technologies that will have the most impact on humanity, both in DT, are genomics and healthcare
- We compare our insights with those of the IEEE Computer Society (IEEE CS) Technology Predictions, and position our Technology Megatrends predictions with those of our predictions and analyze bias

IEEE FUTURE DIRECTIONS

SECTION 02

Introduction

- Megatrends influence humanity in many ways
- Technology megatrends are intertwined with economic, ecological & social megatrends
- The IEEE Future Directions Committee (FDC) Industry Advisory Board (IAB) members determined the following three technology megatrends
    - Digital Transformation; Sustainability; and Artificial General Intelligence (AGI)
- Because megatrends may evolve over a 20 year or longer timeframe, this report describes an ensemble of technologies within these three megatrends
- We provide insights about technologies and megatrends and their impact on humanity
- We compare our insights with those of the the IEEE Computer Society (IEEE CS) and position our predictions with those of Google Trends, IEEE Xplore and US Patents intellectual property

IEEE FUTURE DIRECTIONS

SECTION 02

What Constitutes a Megatrend?

- A megatrend has an impact on the evolution of multiple trends, hence the importance to understand megatrends
  - it is both the sum of individual trends and a guiding force since usually it leads to a perception that influences its components

- A megatrend impacts multiple factors, substantially
  - technological
  - economical
  - social
  - ecological

- A megatrend **is not**
  - temporary fashionable technology
  - coming from a single technical focus
  - of interest to a limited region or a group

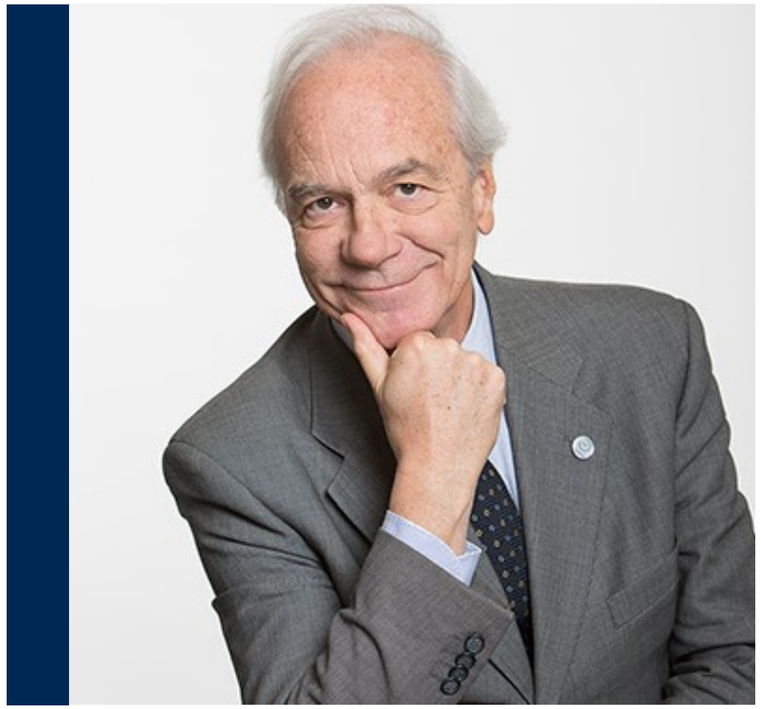
- A megatrend **is**
  - of global, world-wide importance
  - critical enough that will require regulation
  - encompassing multiple technologies
  - evolving over a few years if not decades

SECTION 02

Portfolio of Predictions

- IEEE Future Directions Megatrends (THIS REPORT)
- **Annual IEEE CS Technology Predictions (Jan)** and **Scorecard** (Dec), since 2010
- IEEE *Computer* magazine (July) (***2023, 2022, 2021, 2019***), 5th year special issue to appear in Jul 2024
- IEEE CS "Predictions" Column (…. **Jan'23, Apr'23, Jul'23, Oct'23, Jan'24**)
- IEEE Santa Clara Valley Section (IEEE SCVS) Industry Spotlights (**Megatrends, AI, Sustainability, Digital Twins**), co-sponsored by FDC, IEEE CS, IEC
- Special Features
  - IEEE International Conference on Software Services Engineering (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. South by Southwest (SXSW) pane: **"AI: Prosperity or Doom for Human Workforce?"**
- Course **"High Performance Computing: Use of AI and Emerging Technologies in Science"**
- Decadal reports: **IEEE CS Report 2022** (issued in 2015); **Future of Workforce** (issued in 2023)

In Memoriam
Roberto Saracco



In December of 2023 we 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 showed us the path from early days to Predictions Scorecard for 2023 and Megatrends 2024.

Over the years he tried to convince us that Digital Twins are already here. He was right all along, and now they are finally in our predictions. Sadly we do not have Roberto with us to see the benefits of his efforts.

Roberto, you will always be remembered by your colleagues..

-2023-2024 Megatrends Predictions Team

SECTION 03

Process

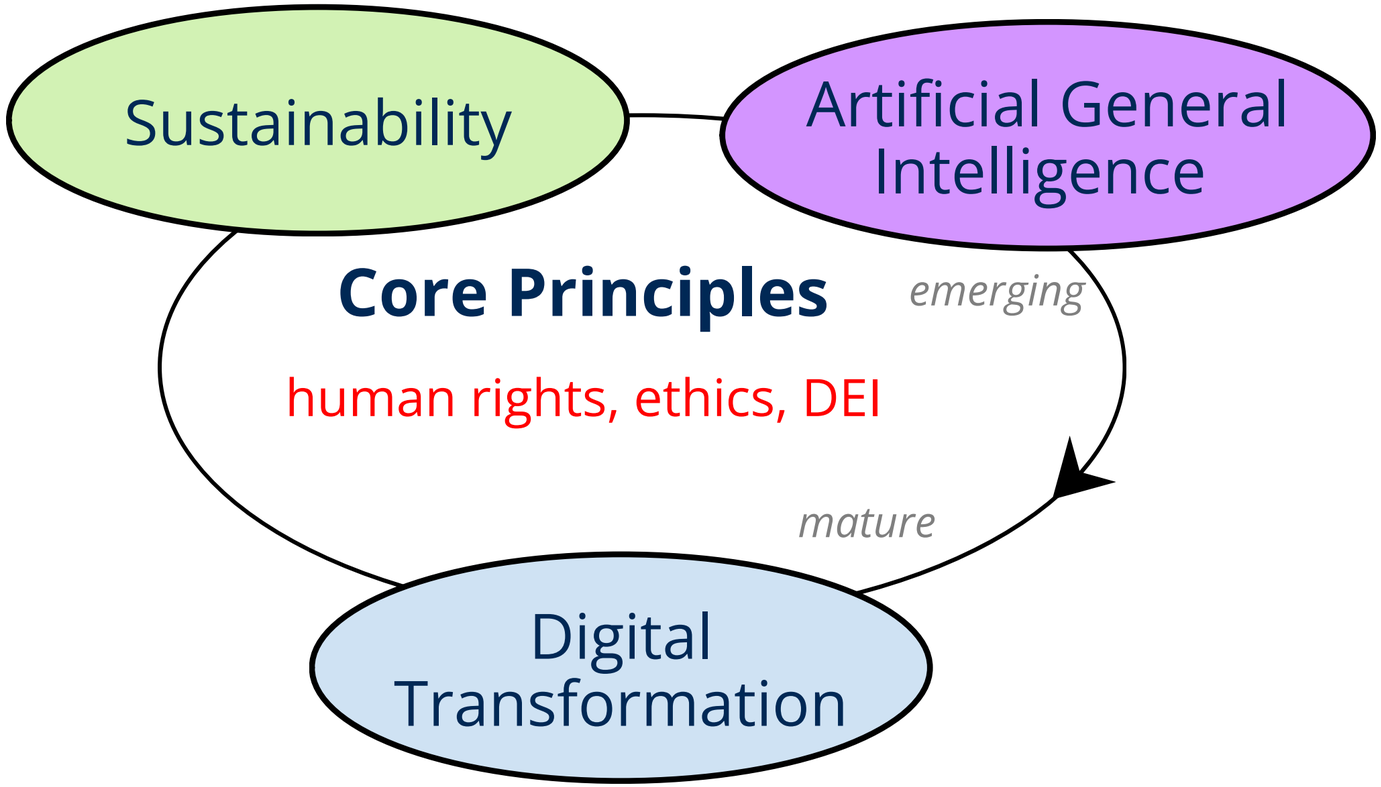
Team

- We formed the team of approximately 50 people who meet throughout the year
- Diversity
  - GEOGRAPHICAL: We have incorporated perspectives from the Middle East, Australia, Asia, Europe, and Latin America to US representation
  - GENDER: We have 16 women out of 54 team members
  - TECHNICAL FIELD OF INTEREST: We have members from across 47 IEEE technical fields of interest

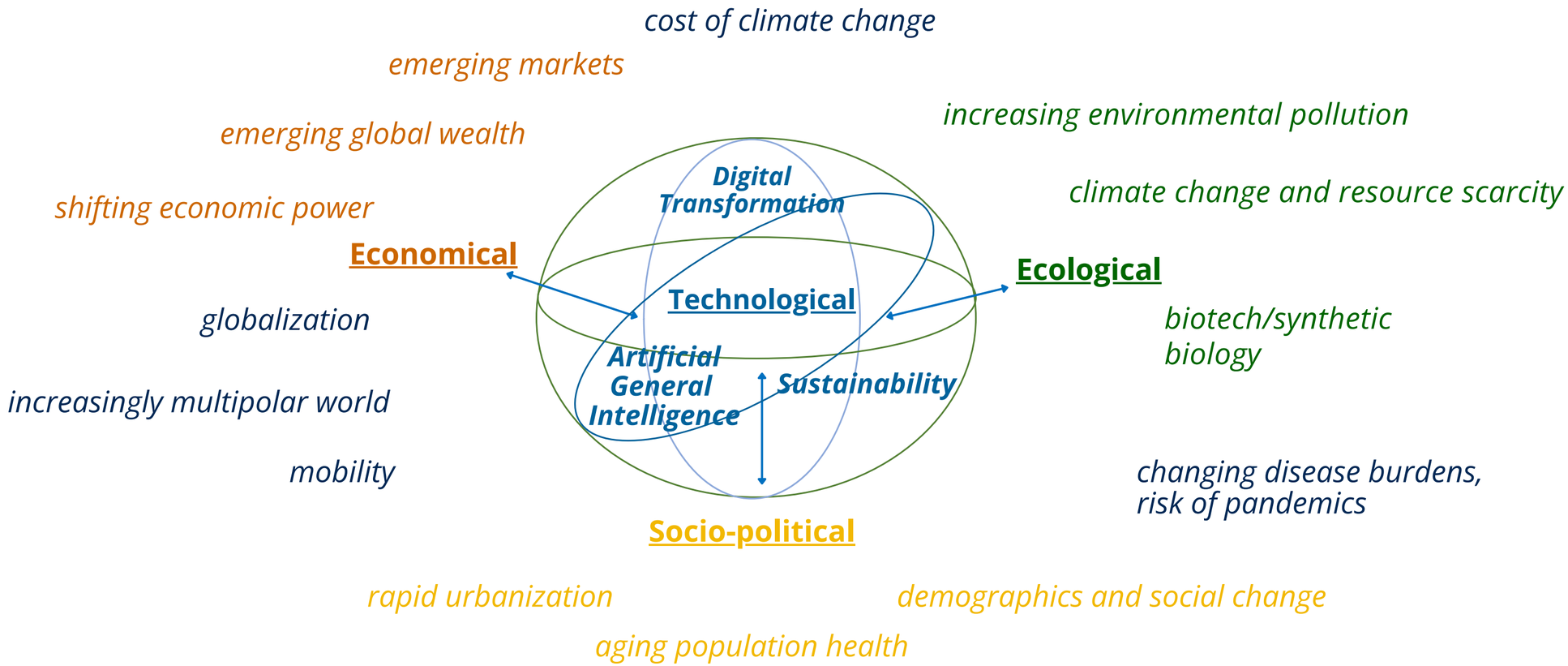
The process and criteria are similar to IEEE CS Technology Predictions process

- Selection of megatrends and associated technologies
  - During the inaugural year of 2023, we identified 3 megatrends: digital transformation, sustainability, and artificial general intelligence
  - For each megatrend, the team proposed approximately 20 technologies per megatrend
  - This was followed by down-selection to 6 technologies per megatrend, having each member at the time vote
- Criteria and grading scale used by the team members for predictions
  - (A-F) for Predicted Technology Success in 2023; (Potential for) Impact to Humanity; Predicted Maturity in 2023; Predicted Market Adoption in 2023
  - (1 year, 3y, 5y, 10y, 15y) Horizon view to Commercial Adoption
- Outcome of the process
  - Impact to humanity as a function of technology advancement, qualified by maturity, market adoption and time-to-adoption
  - We calculate and report our confidence levels as the standard deviation in voting, and bias as a correlation between individual grades
- Qualifying outcomes
  - We conclude with our insights derived from opportunities

Technology Megatrends



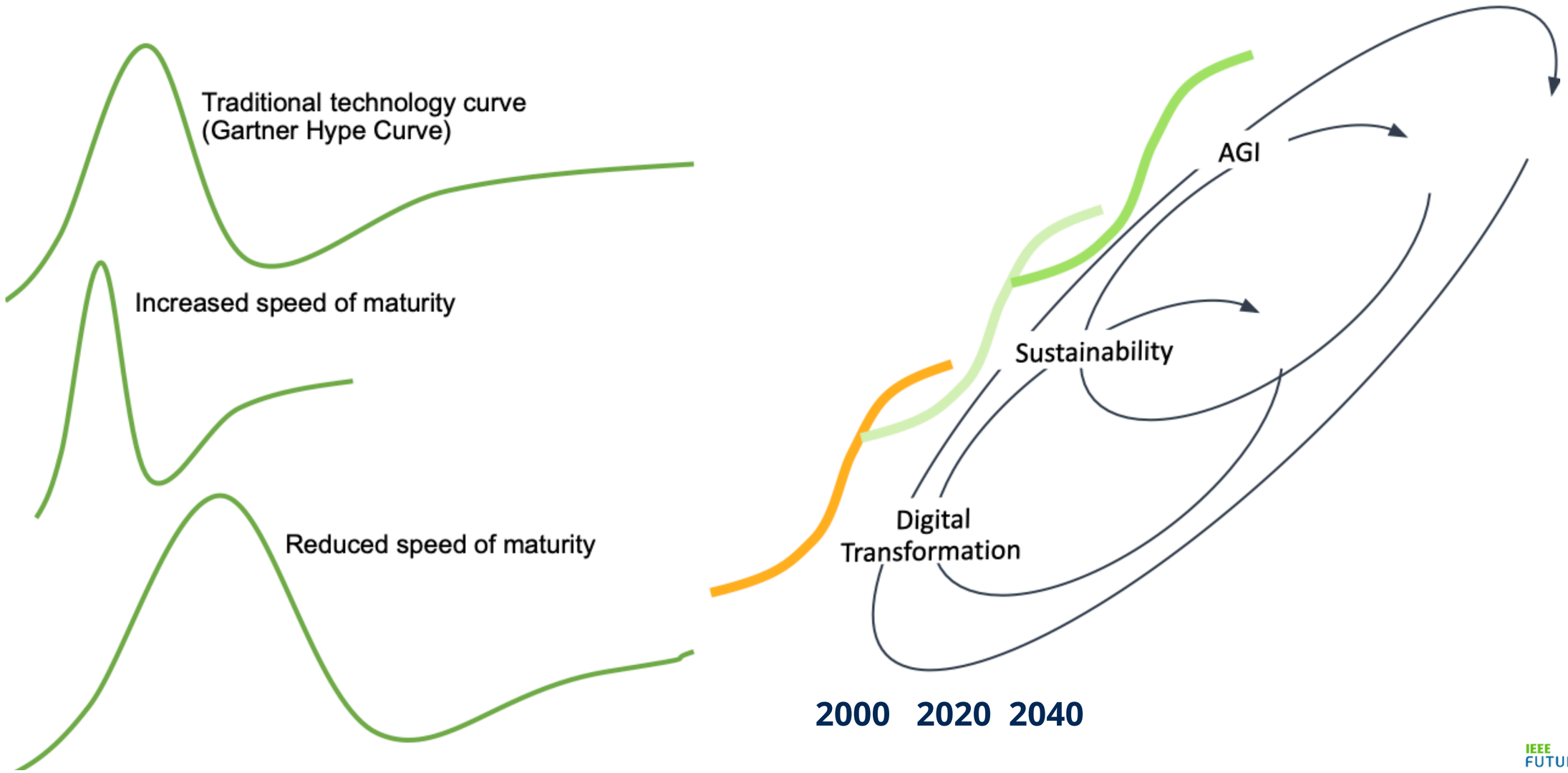
Technology vs General Megatrends



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

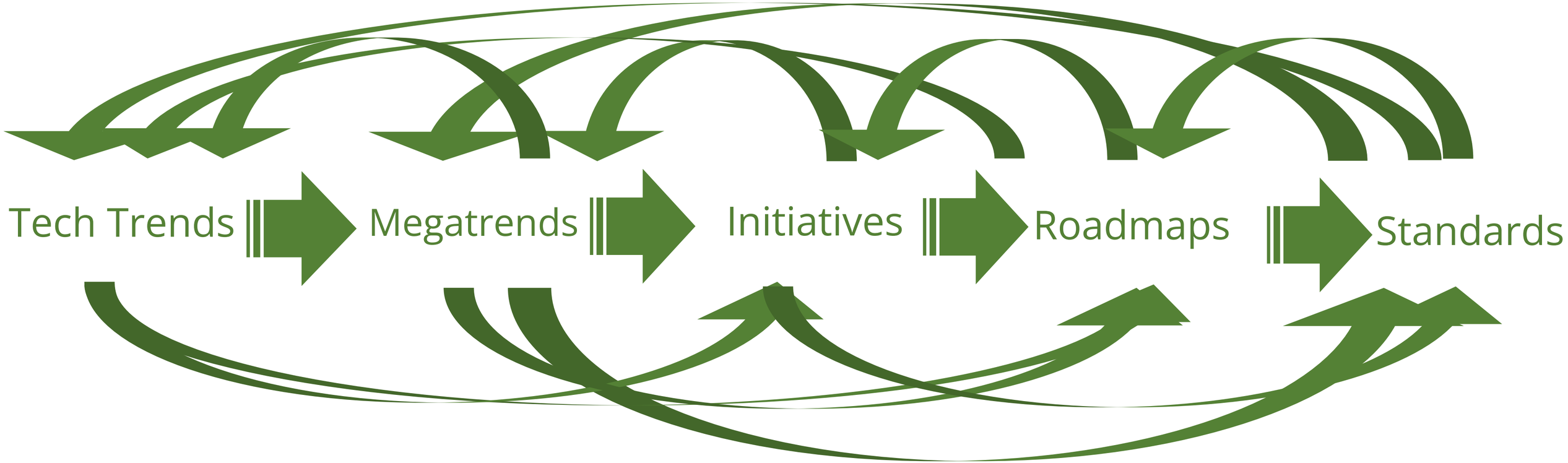
SECTION 04

Technology Trends vs Megatrend Curves



SECTION 04

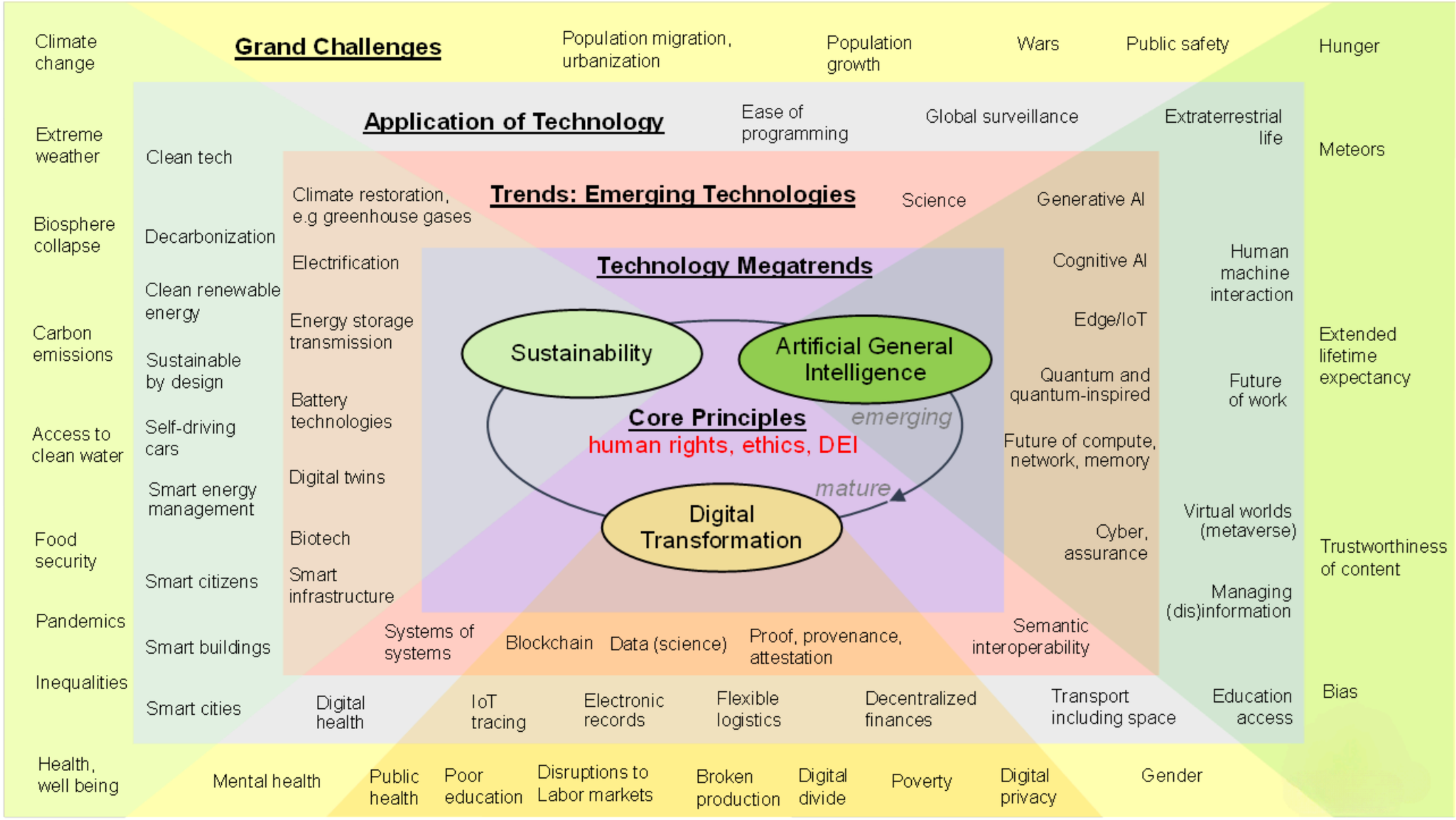
Trends in the Broader IEEE Context



- Technology trends collectively result in observations about megatrends
- Megatrends help formulate and inform important IEEE Future Directions Initiatives
- Some successful IEEE Future Direction Initiatives result in IEEE Roadmaps
- Some trends, megatrends, initiatives, and roadmaps lead to industry standards

IEEE FUTURE DIRECTIONS

SECTION 04



IEEE FUTURE DIRECTIONS

Megatrends Technologies

Generative AI, ChatGPT and other application domains of AGI

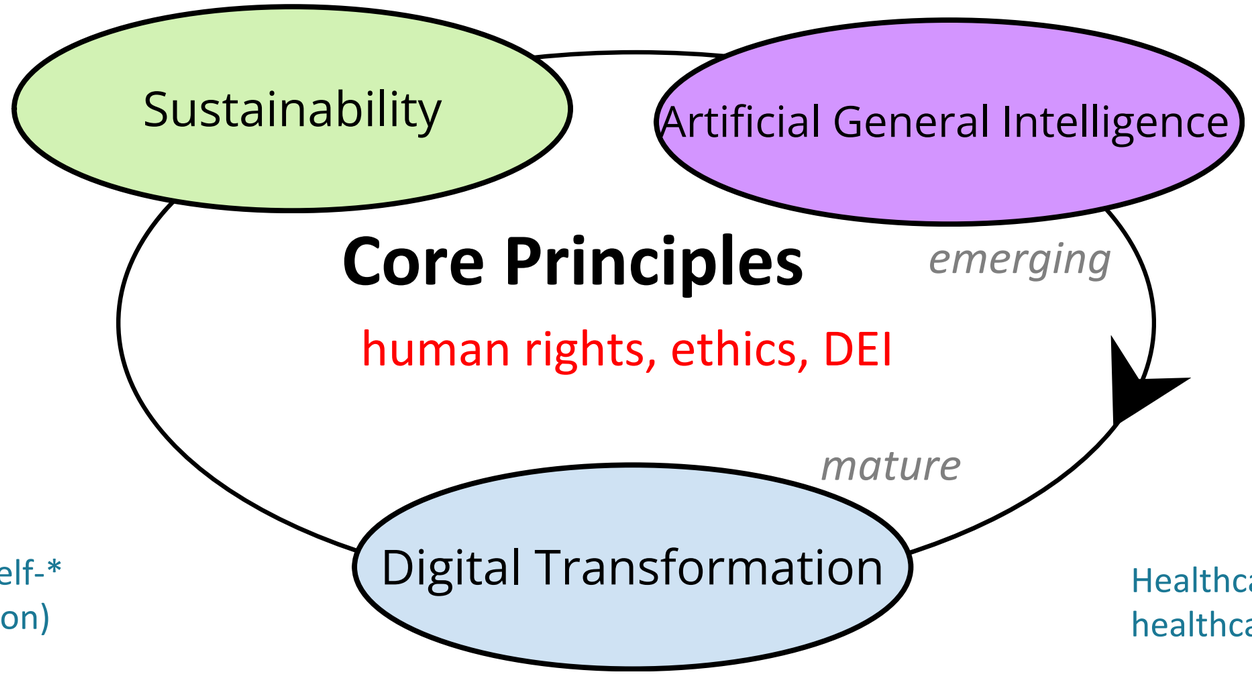
Electrification

Autonomous robots

Sustainable IT and IT for sustainability

Wearable and implantable technologies, and computer brain I/F

Sustainable manufacturing, recycling/Re-use



Digital twins

Energy storage

Space technologies

Decarbonization

Trusted computing (data protection/privacy/cybersecurity/ data verification, lineage, etc.)

Clean renewable energy

Autonomous technologies, self-* (e.g. Self-driving transportation)

Healthcare/digital health/remote healthcare/personalized medicine

Smart environments (city, home, lighting, …)

Genomics/gene repair/DNA medicine/molecular medicine

Ubiquitous connectivity/ communications/cellular

Power & energy digital transformation

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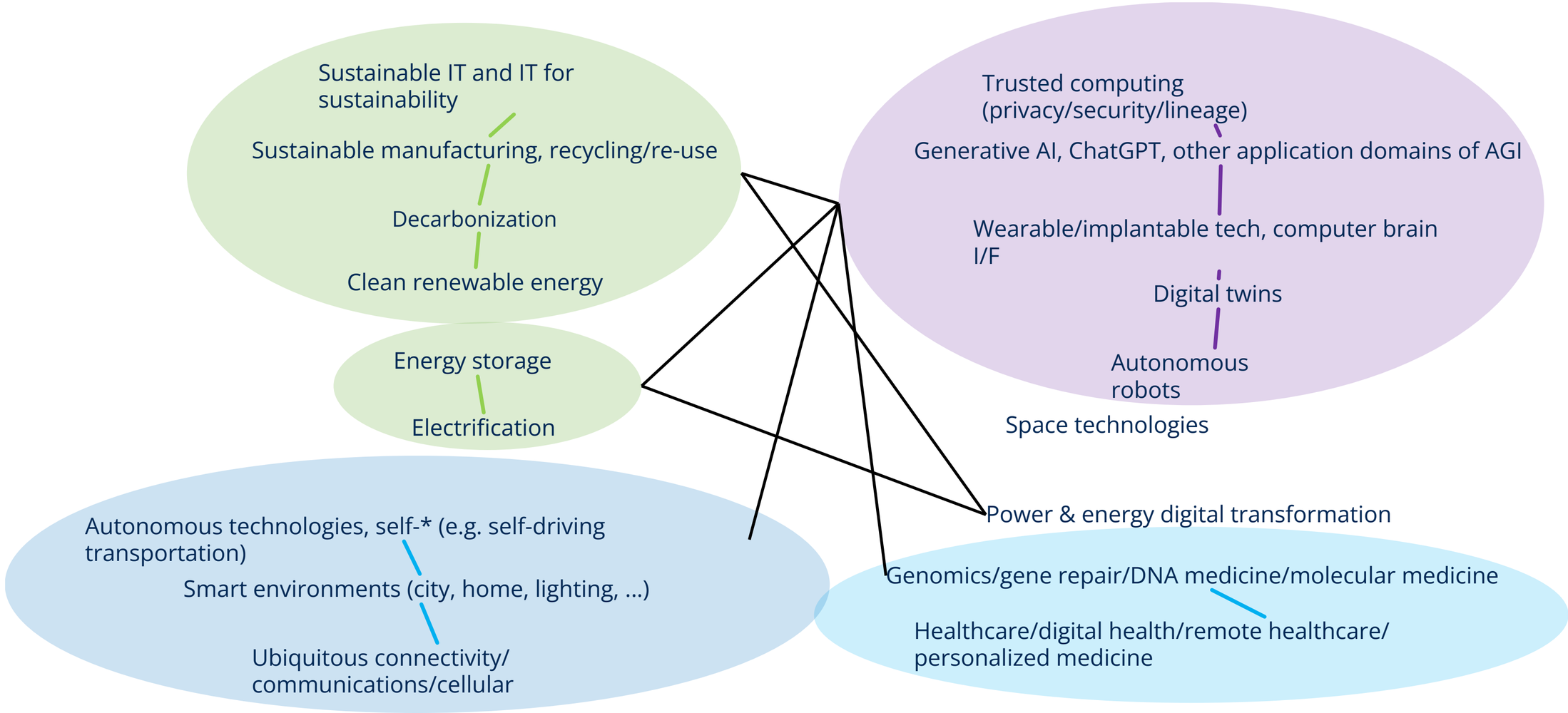
SECTION 04

Megatrends Technologies, Relationships



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SECTION 04

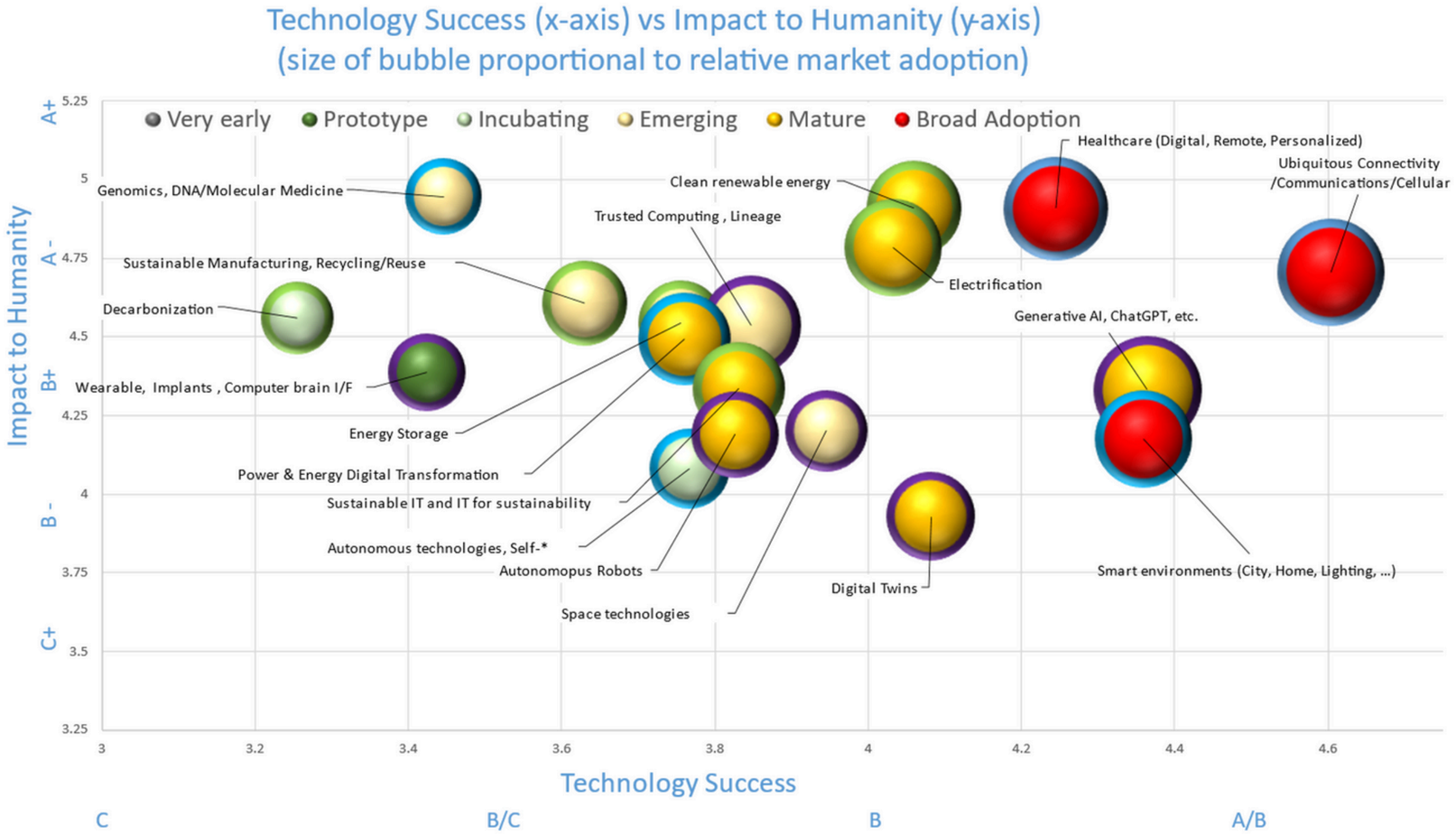
Relationship Between Megatrends

		How Megatrend Benefits		
		Digital Transformation	**Sustainability**	**AGI**
How megatrend contributes	**Digital Transformation**		• More control points • Clear separation and models • Opportunity to automate	• Broader set of applications • Edge-to-Cloud integration • Increases confidence
	Sustainability	• More incentives to transform • Reduced energy cost of transformation		• More powerful AGI • Broader adoption • Stretching limits
	AGI	• More effective transform • New ways of transform	• Innovating efficiency improvements • Improved anomaly detection	

This Table was modified from the table that originally appeared in P. Faraboschi, E. Frachtenberg, P. Laplante, D. Milojicic and R. Saracco, "Artificial General Intelligence: Humanity's Downturn or Unlimited Prosperity," in Computer, vol. 56, no. 10, pp. 93-101, Oct. 2023,

SECTION 04

Megatrends to Technologies Mapping



- Artificial General Intelligence
- Sustainability
- Digital Transformation

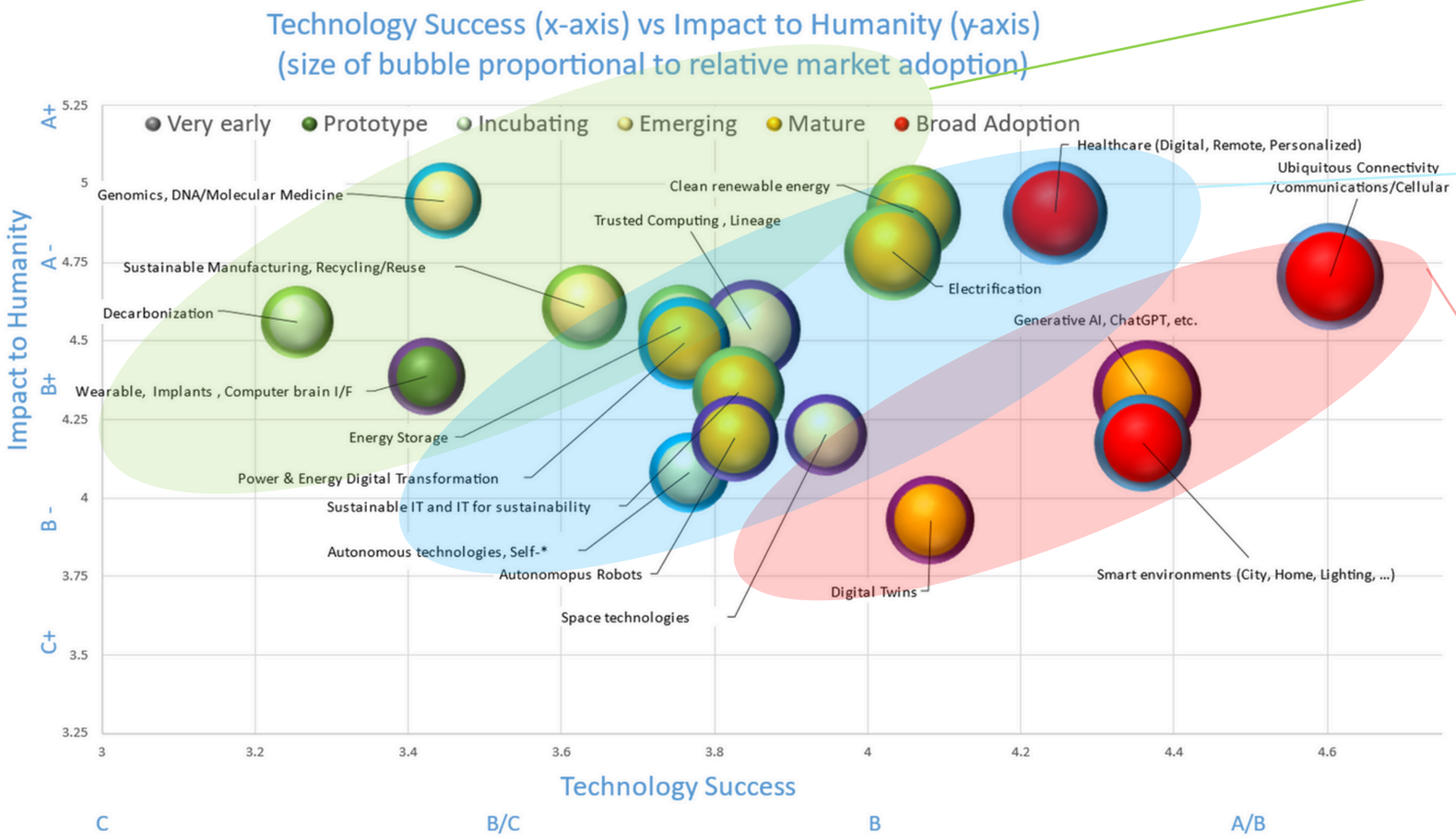
These are averaged assessments of 48 members of committee

IEEE FUTURE DIRECTIONS

SECTION 04

Insights

Artificial General Intelligence Sustainability Digital Transformation



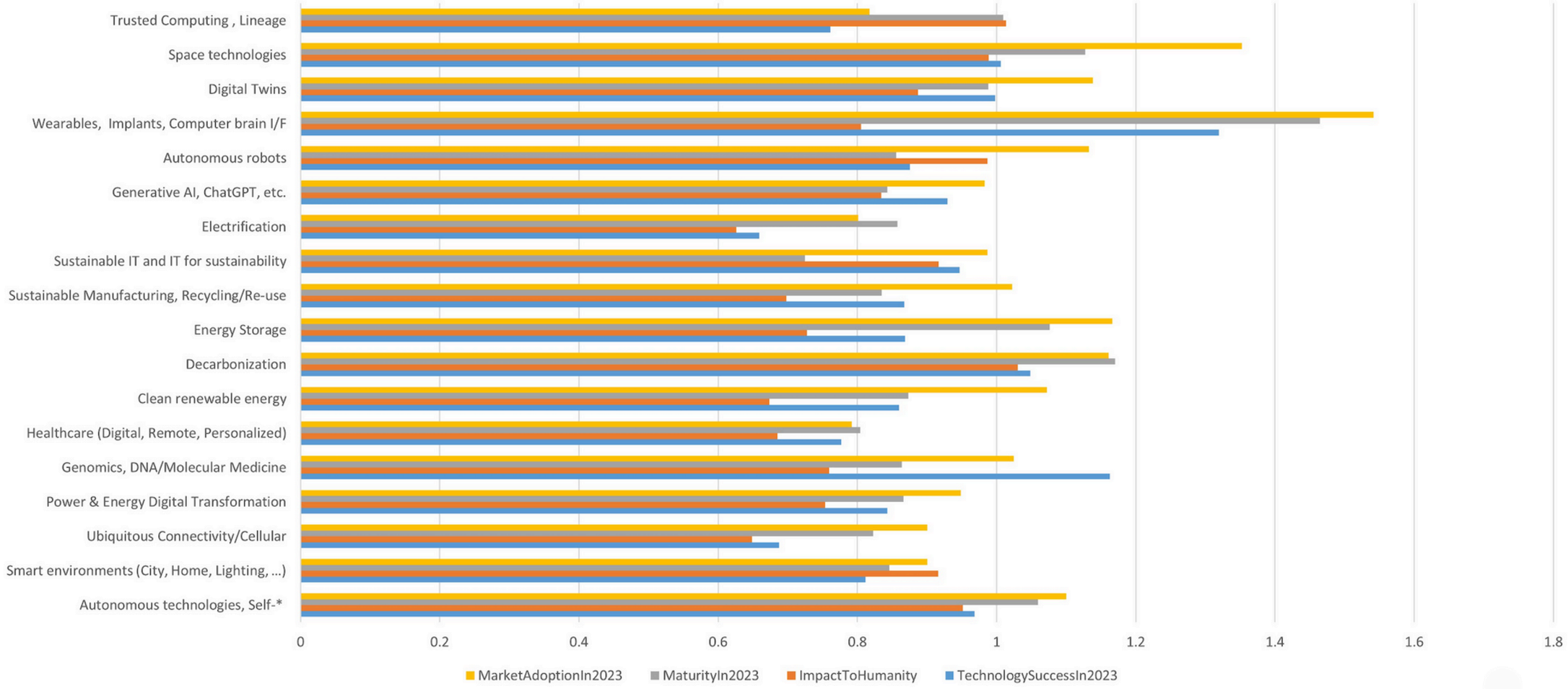
Impact on humanity higher than chance of tech success **(worth investing in)**

Chance of success correlates to impact on humanity

Chance of tech success higher than impact on humanity

IEEE FUTURE DIRECTIONS

Standard Deviation



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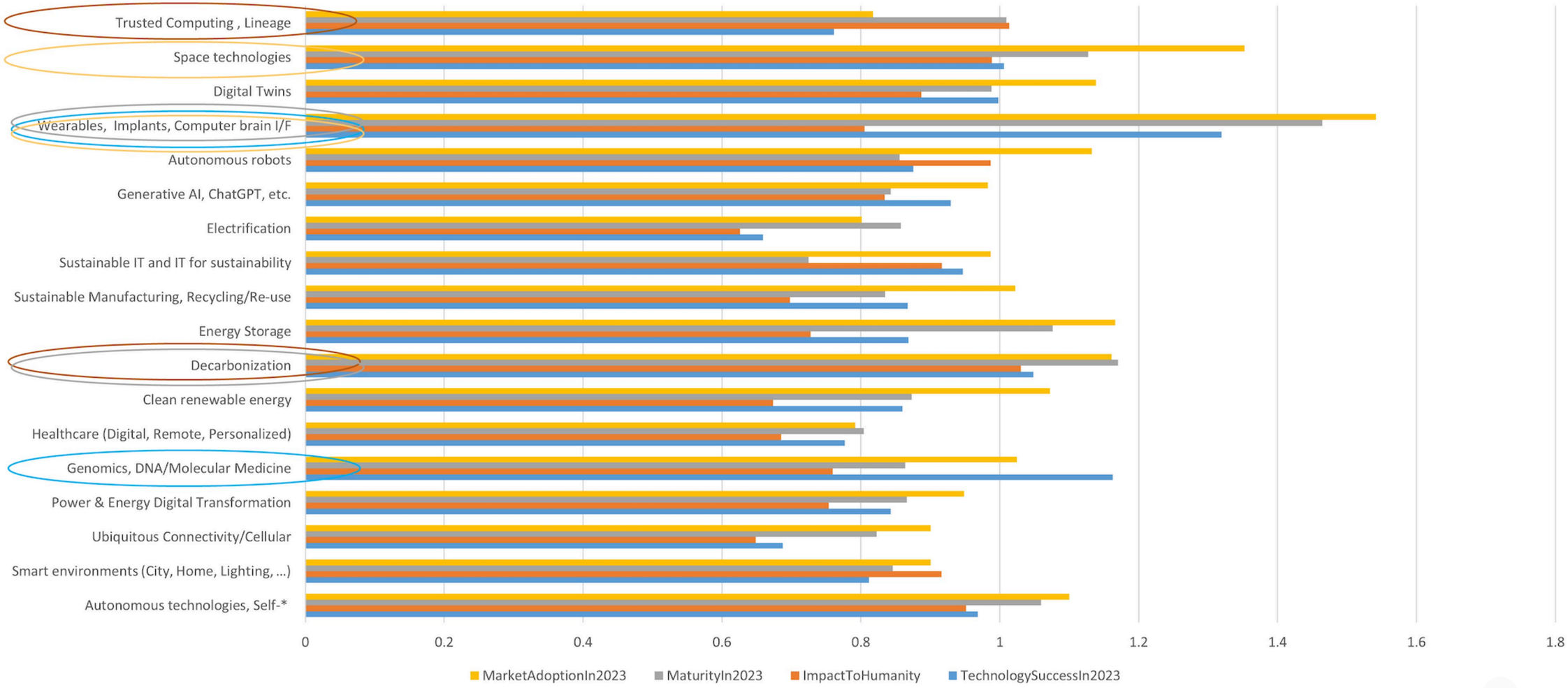
Standard Deviation, Largest (Least Confidence)



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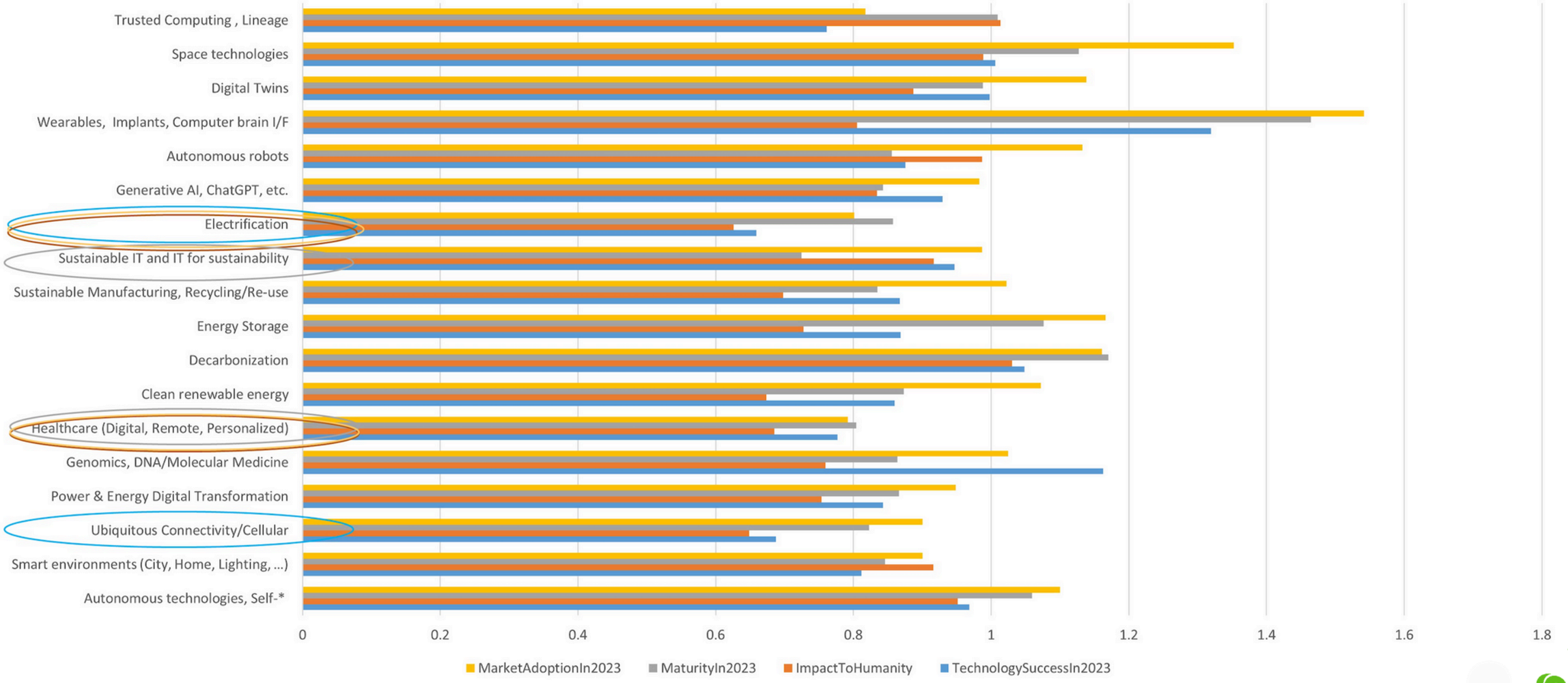
SECTION 04

Standard Deviation, Smallest (Most Confidence)



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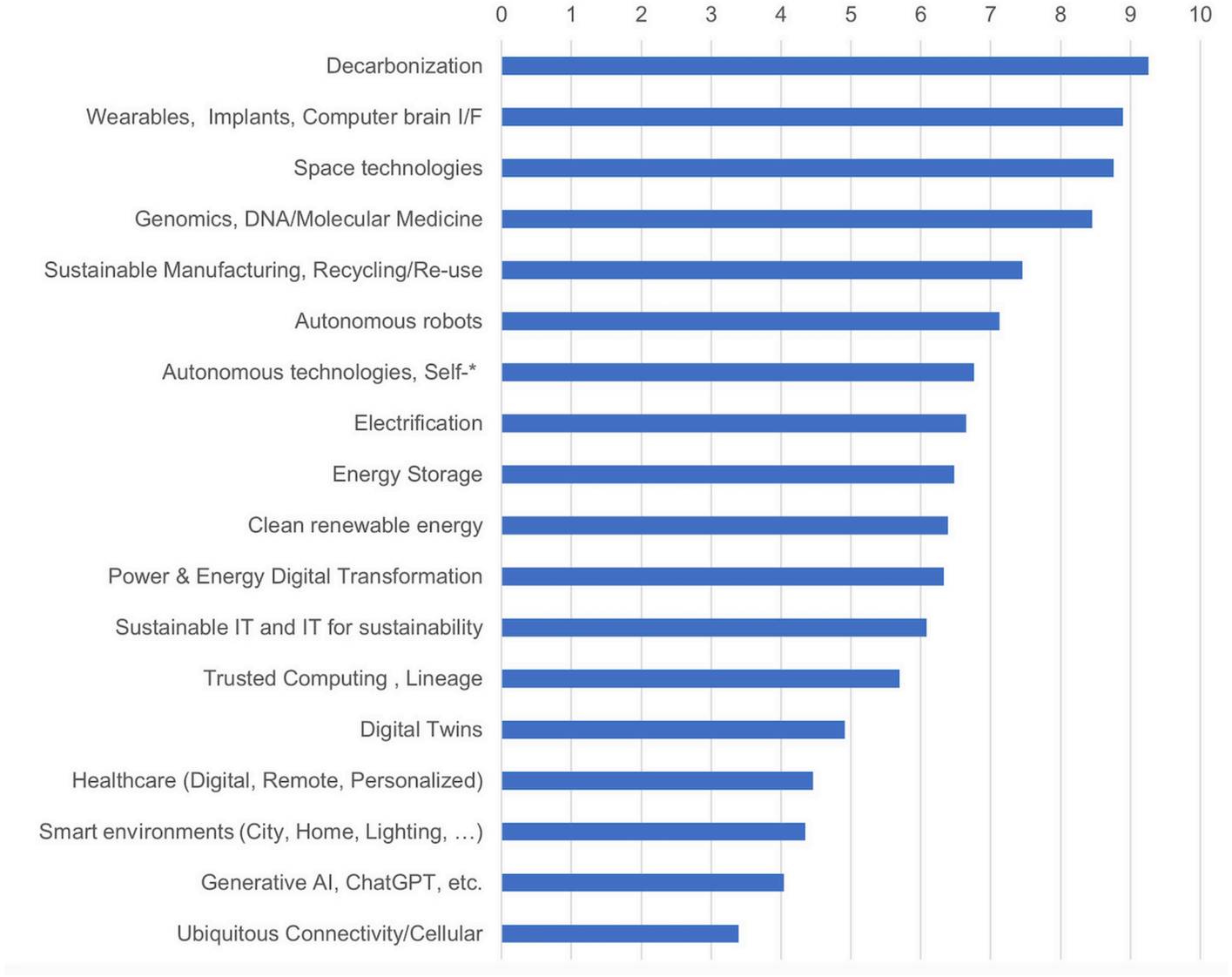
SECTION 04

Horizons to Broad Commercial Adoption (#years)



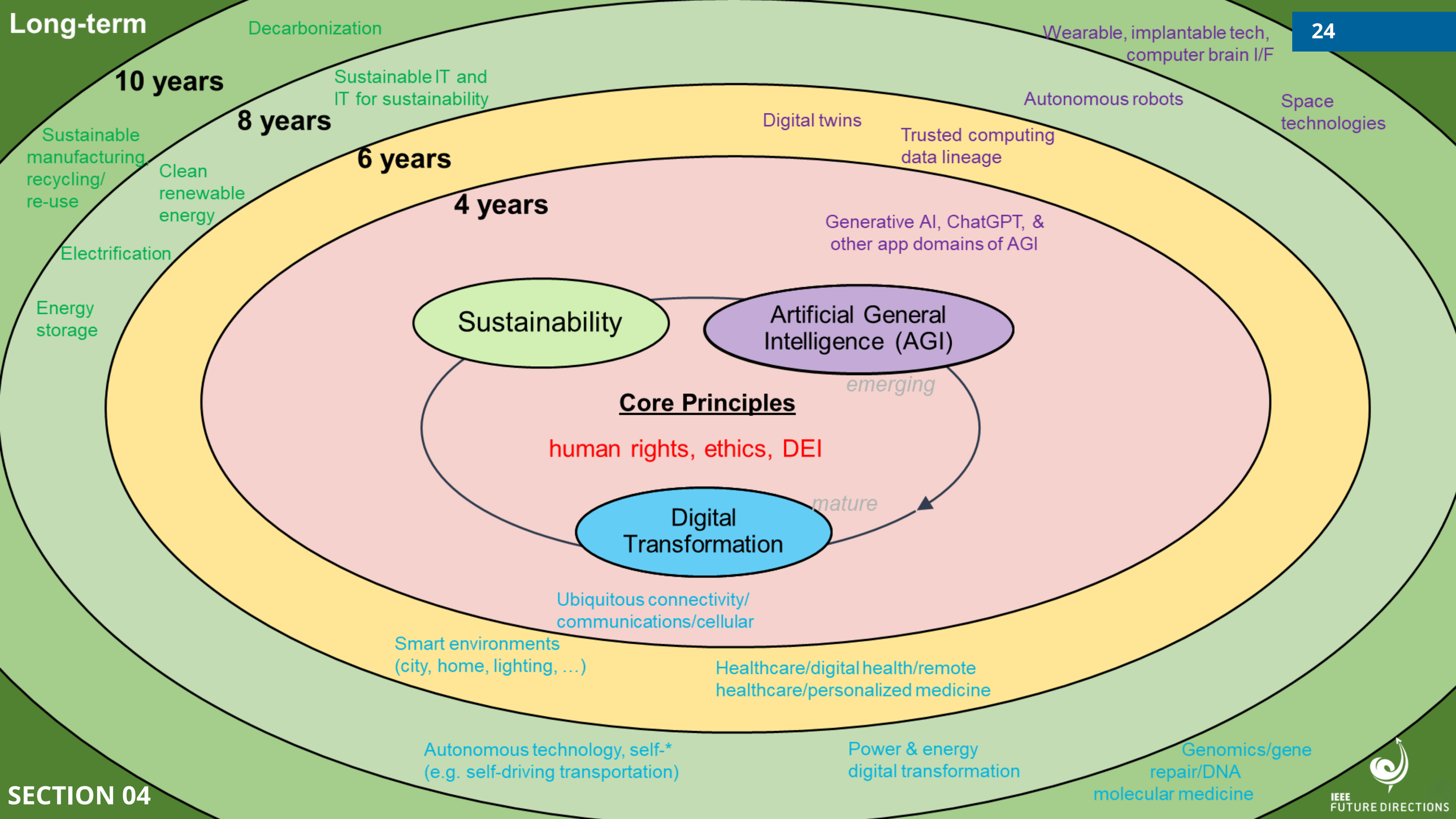
Opportunity for academia (out-of-box thinking, innovations)

Opportunity for governments (funding, regulations)

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

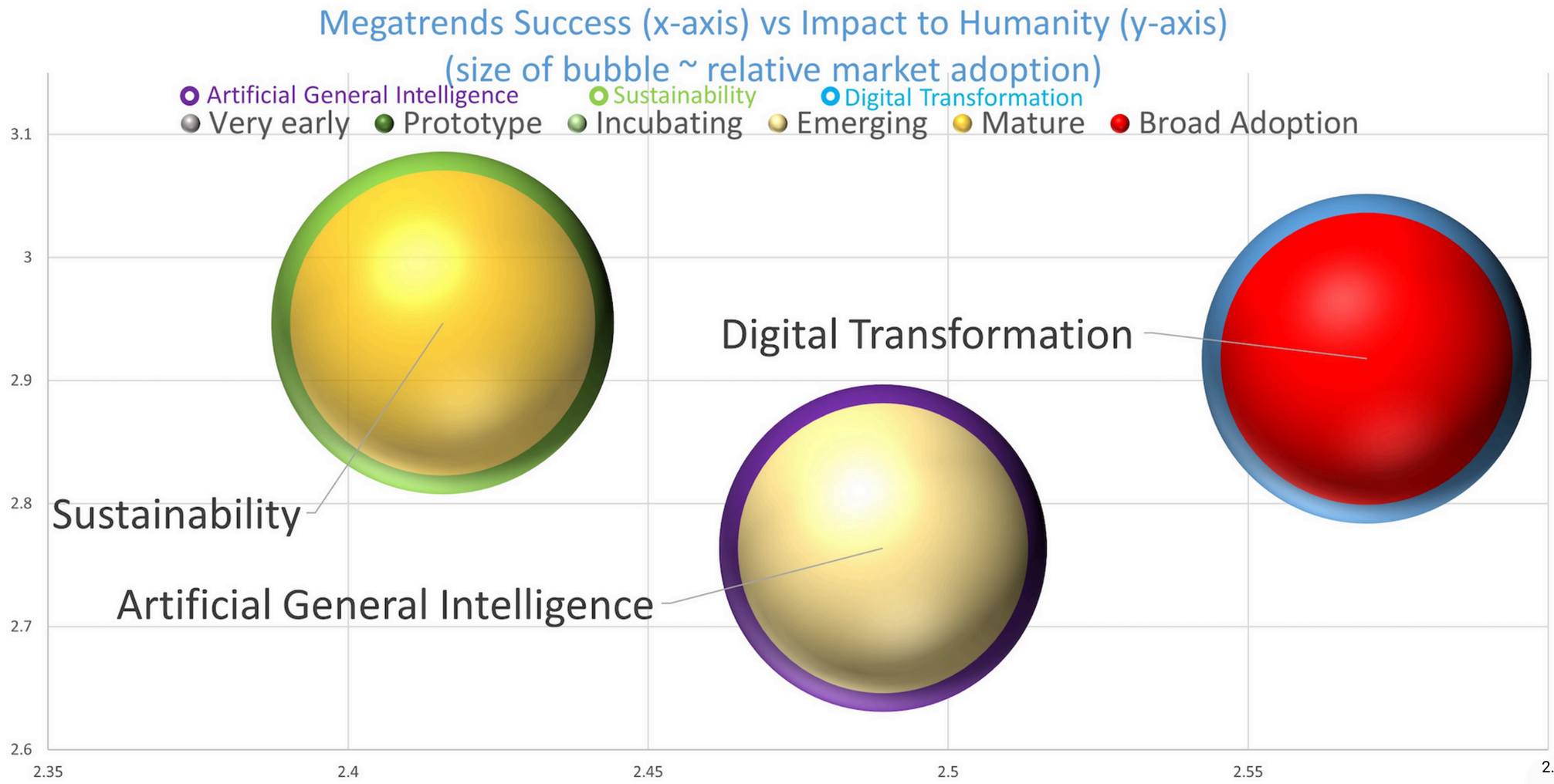
Opportunity for industry (inventions, productization, new markets)

IEEE FUTURE DIRECTIONS



SECTION 04

Megatrends Technology Predictions (Rolled Up)



SECTION 04

Megatrends Technologies Predictions Grades

Type	Technology	Success	Impact	Maturity	Adoption	Horizon
Digital Transformation	Autonomous technologies, Self-* (e.g. self-driving transportation)	B-	B	C+	C+	6.761
	Smart environments (city, home, lighting, …)	B+	B+	B	B-	4.348
	Ubiquitous connectivity/communications/cellular	A/B	A-	B+	B+	3.391
	Power & energy digital transformation	B-	A/B	B-	B/C	6.326
	Genomics/gene repair/DNA medicine/molecular medicine	B/C	A	C+	C	8.457
	Healthcare (digital, remote, personalized)	B+	A	B	B	4.457
Sustainability	Clean renewable energy	B	A	B-	B-	6.391
	Decarbonization	C+	A/B	C	C-	9.261
	Energy storage	B-	A/B	C+	C+	6.478
	Sustainable manufacturing, recycling/re-use	B-	A/B	B/C	C+	7.457
	Sustainable IT and IT for sustainability	B-	B+	B/C	B-	6.087
	Electrification	B	A-	B-	B-	6.652
AGI	Generative AI, ChatGPT and other application domains of AGI	B+	B+	B-	B+	4.043
	Autonomous robots	B-	B+	B/C	B/C	7.130
	Wearable and implantable technologies, and computer brain I/F	B/C	A/B	C-	C	8.891
	Digital twins	B	B	B-	B/C	4.913
	Space technologies	B	B+	C+	C+	8.761
	Trusted computing (data protection/privacy/ cybersecurity/data verification, lIneage, etc.)	B-	A/B	B/C	B	5.696

SECTION 04

Cross Technology Statistics

Correlation

	Success in 2024	Impact to Humanity	Maturity in 2024	Market Adoption in 2024
Success in 2024	1	-0.05	0.88	0.88
Impact to Humanity	-0.05	1	0.19	0.18
Maturity in 2024	0.88	0.19	1	0.86
Market Adoption in 2024	0.88	0.18	0.86	1

	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

Average & Range

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	[C+, A/B]	A/B	[B, A]	B/C	[C-,B+]	B/C	[C-, B+]	6.42	[3.39-9.26]

Megatrends, 2024

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]

Technology Predictions, 2024

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SECTION 04

Megatrends vs Technology Predictions

Evaluation of Technology Predictions from Megatrends Perspective

IEEE Future Directions Committee
Industry Advisory Board (IAB)

Megatrends

↓

Technology Predictions

Megatrends

↑

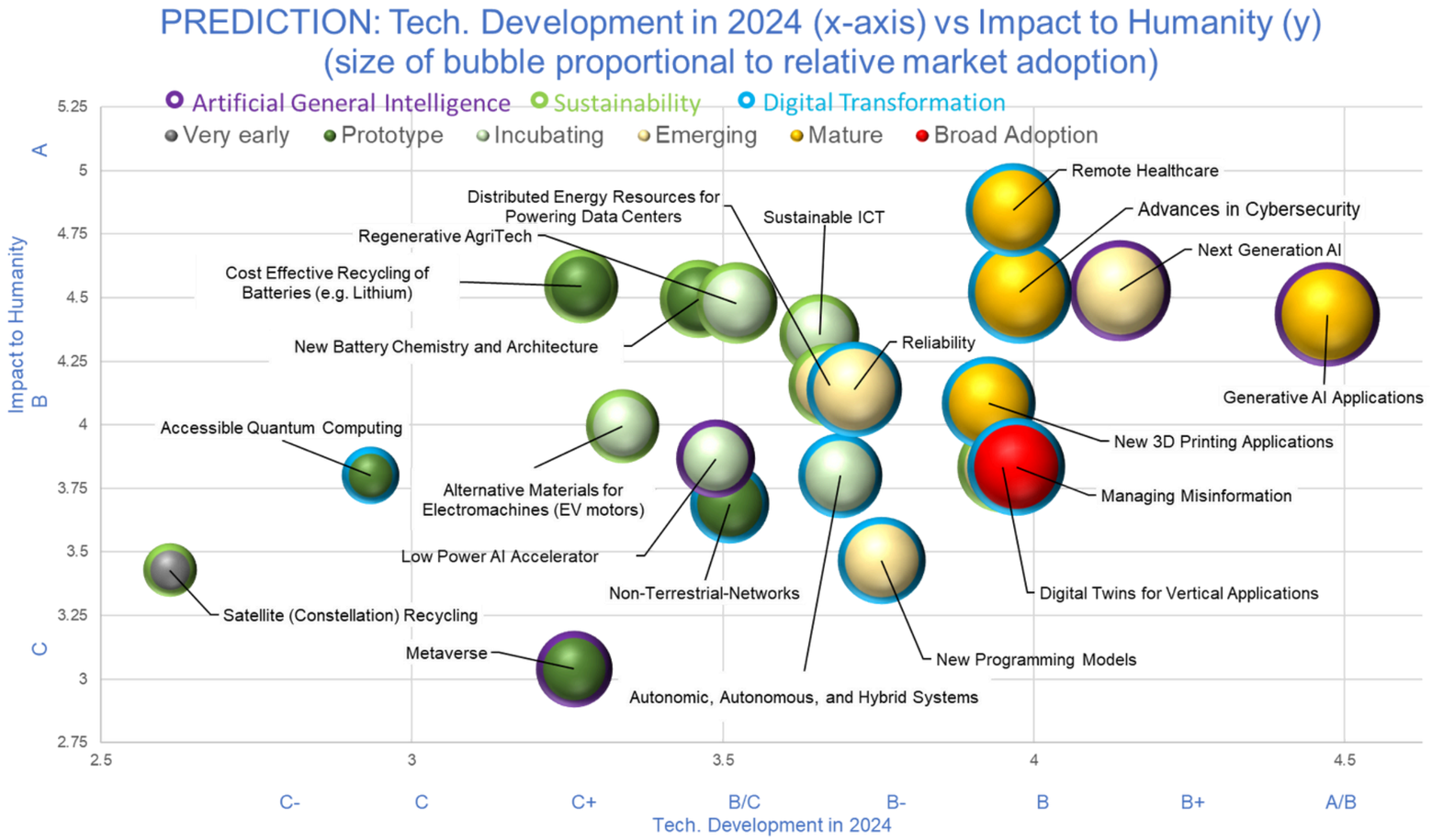
Technology Predictions

IEEE Computer Society

- IEEE CS started from Technology Predictions and came up with Mega trends observations
- Both approaches are valid and confirm each other. Differences arise from the process and people
- In the next slide we touch on Technology Predictions perspective, and we discuss differences and similarities

SECTION 04

Technology Predictions Mapped to Megatrends



These are averaged assessments of 46 members of committee

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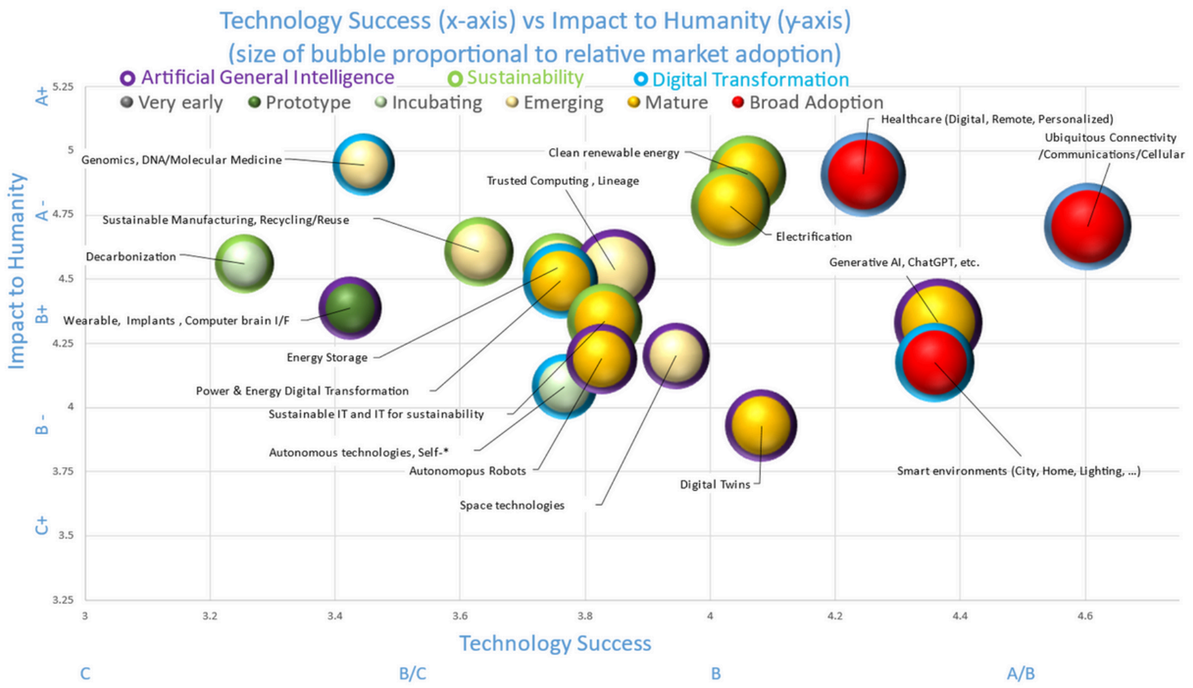
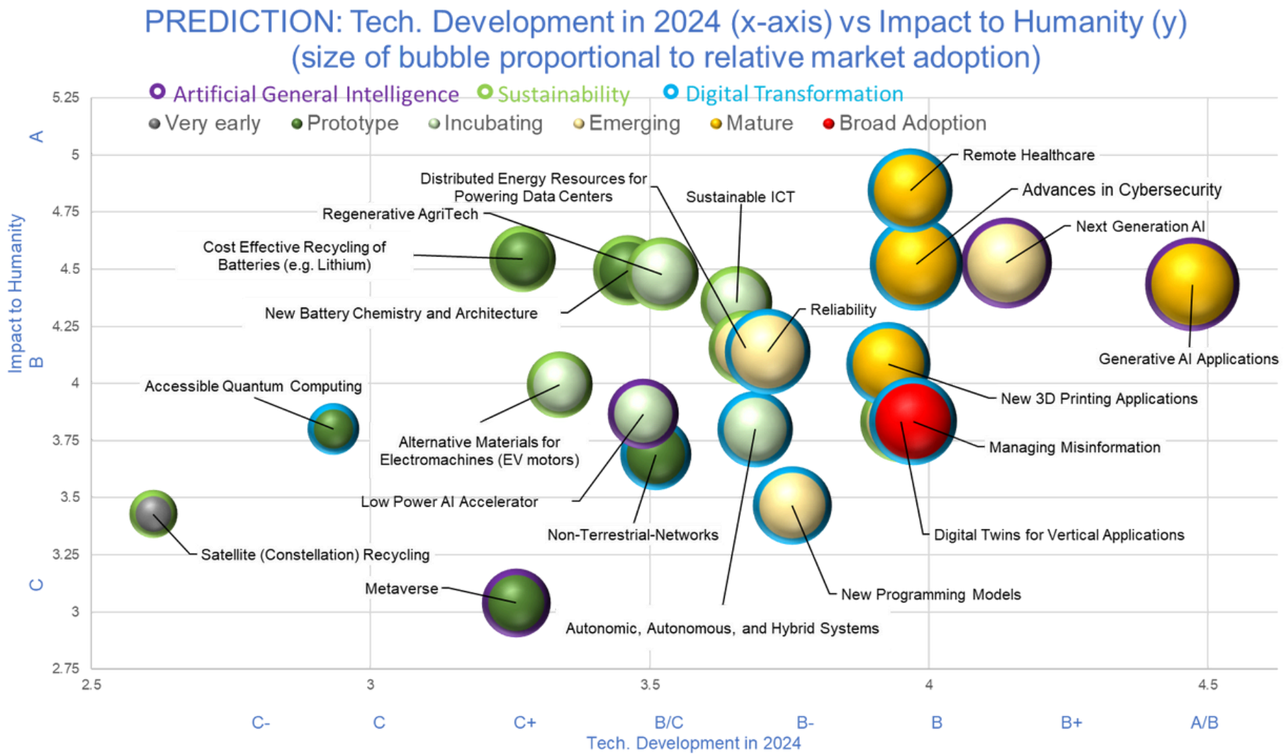
SECTION 04

Megatrends vs. Technology Predictions

Technology Megatrends



Technology Predictions



Insights

- Megatrends (on the left) have more mature technologies on both ends of maturity than Technology predictions (on the right)
- They also have both higher impact on humanity and likelihood of success (both reflect on the process) (selecting technologies for given 3 megatrends)
- Technologies (on the right) are more disruptive, again reflecting process, will be accounted for in future

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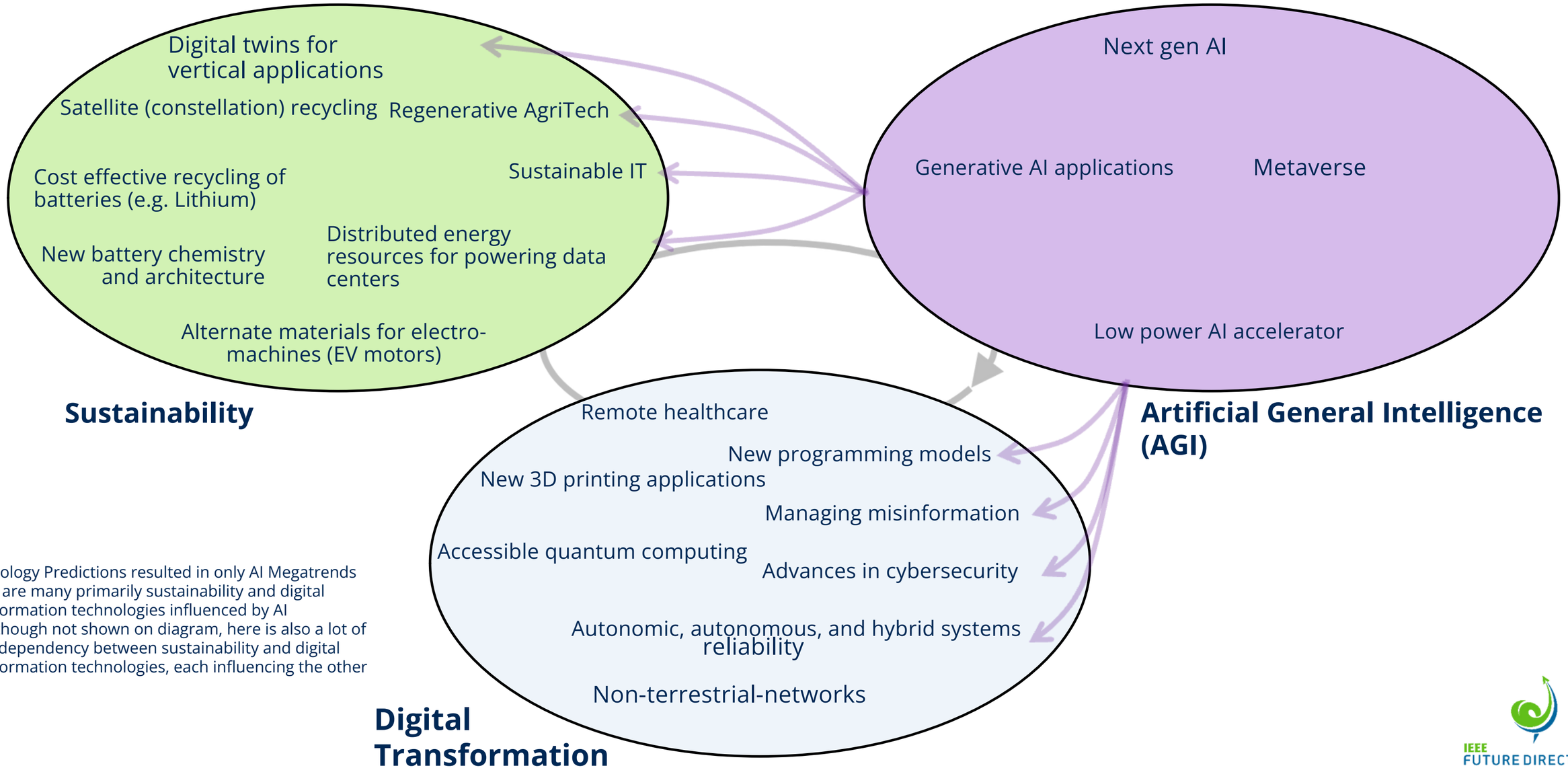
SECTION 04

Technology Predictions Mapped to Megatrends



- Technology Predictions resulted in only AI Megatrends
- There are many primarily sustainability and digital transformation technologies influenced by AI
- Even though not shown on diagram, here is also a lot of cross dependency between sustainability and digital transformation technologies, each influencing the other

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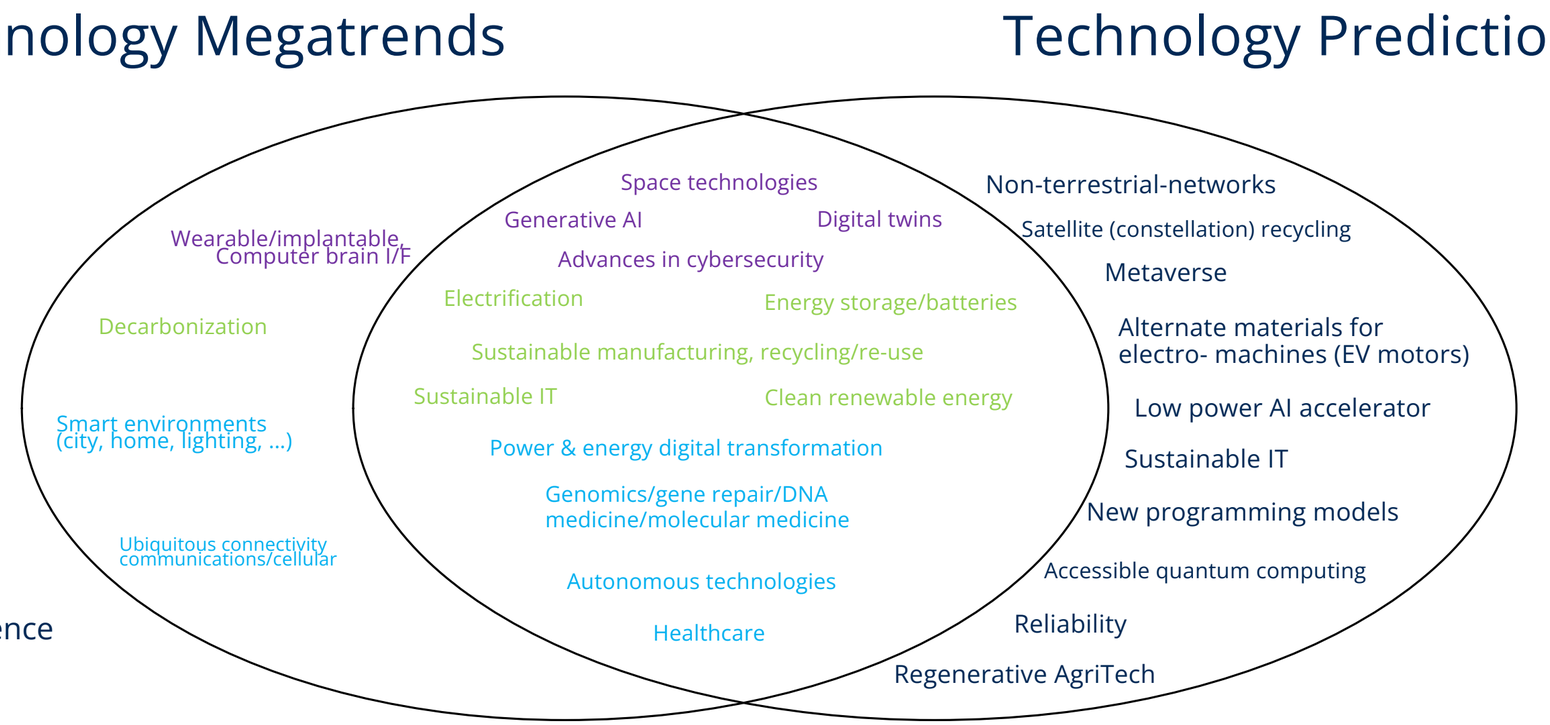
SECTION 04

Megatrends Technologies vs Technology Predictions

- There is substantial overlap between Megatrends-first and Technology-first prediction (intersection)
- Those only originating from Technology-first are disruptive in nature and there are more of them
- There are fewer Megatrends-first and they are longer-term (with further out horizons)



- Artificial General Intelligence
- Sustainability
- Digital Transformation

IEEE FUTURE DIRECTIONS

SECTION 05

Megatrends: Insights and Opportunities

Insights

- Technology with most likely advancement and market maturity is *Ubiquitous connectivity/communications/cellular*
- Technology with most likely largest market adoption is *Healthcare (digital, remote, personalized)*
- Technology with highest potential for impact on humanity is *Genomics, DNA/molecular medicine*
- Of concern are technologies with large impact to humanity but fewer chances for technological success (Genomics, DNA/molecular medicine; sustainable manufacturing, Recycling/re-use; and decarbonization)
- Digital transformation continues strong
- Sustainability is gaining momentum
- With Generative AI, the AGI megatrend is on fire, influencing all other technologies
- There is a lot of cross pollination among megatrends and underlying technologies

Opportunities

- Opportunities for industry
  - Ubiquitous connectivity/communications/cellular
  - Generative AI, ChatGPT, etc.
  - Healthcare (digital, remote, personalized)
  - Smart environments (city, home, lighting, …)
  - Digital twins
- Opportunities for governments
  - Trusted computing (protection/privacy/security/lineage, ..)
  - Sustainable IT and IT for sustainability
  - Electrification
  - Clean renewable energy
- Opportunities for professional organizations
  - Autonomous technologies, self-*
  - Energy storage
  - Power & energy digital transformation
  - Sustainable manufacturing, recycling/re-use
- Opportunities for academia
  - Autonomous robots
  - Genomics, DNA/molecular medicine
  - Space technologies
  - Wearables implants, computer brain interface
  - Decarbonization

SECTION 05

Direction of Individual Skills Evolution

Skills			Trending
Digital Transformation	**Sustainability**	**AGI**	
Supervision of automation	Multi-objective optimizations	AI programmers	↑
Analytics	Measure precursor to manage	Data scientists	↗
Presale, system integrators	Designers for sustainability	Solution architects	→
Maintenance	End-to-end lifecycle designers	Support	↘
Operators	Sustainability oversight	System administrators	↓

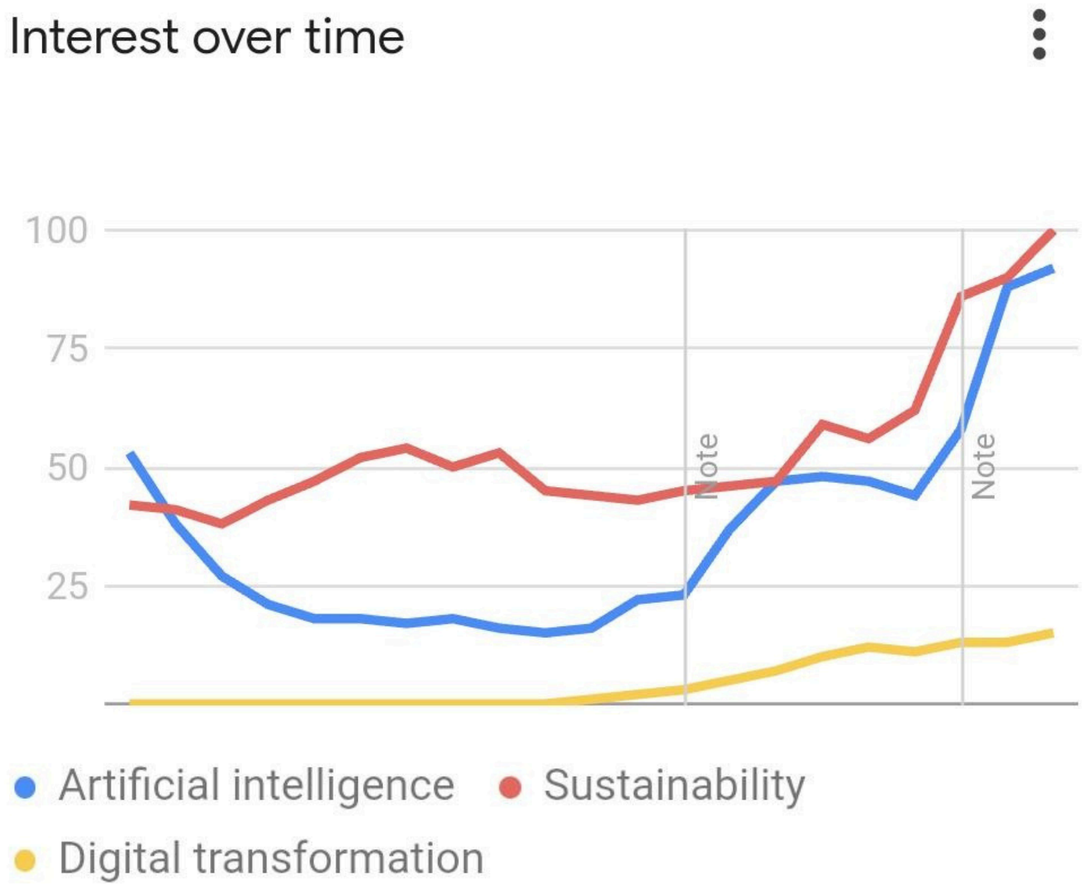
This Table was motivated by the table that appeared in K. Bresniker et al., "What Gets You Hired Now Will Not Get You Hired Then," in IT Professional, vol. 26, no. 1, pp. 26-31, Jan.-Feb. 2024. The subset there of, on AGI, was published in the article.

SECTION 05

Graphic Art from the AI & Workforce Panel Held at SXSW by Co-Authors of This Document

SECTION 05

Megatrends vs Google Trends



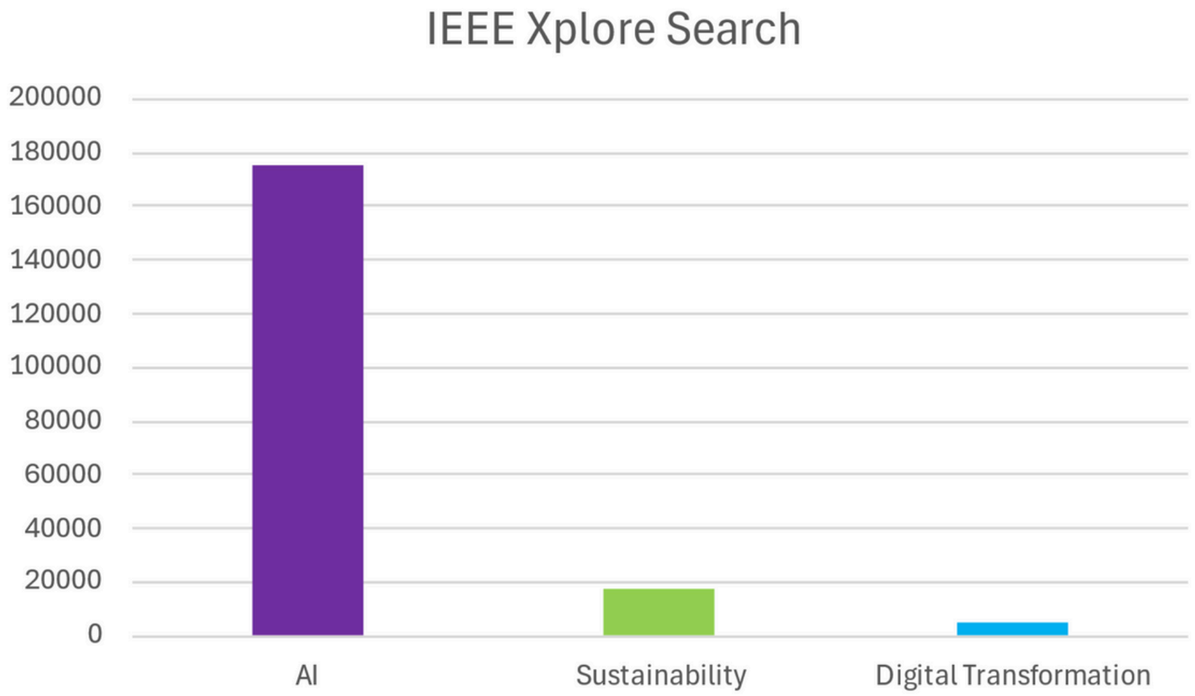
- Surprisingly, sustainability leads among three trends, contrary to AI popularity
- This means that sustainability is firmly on mind of community
- Digital transformation trails substantially which speaks to its maturity

January 2024

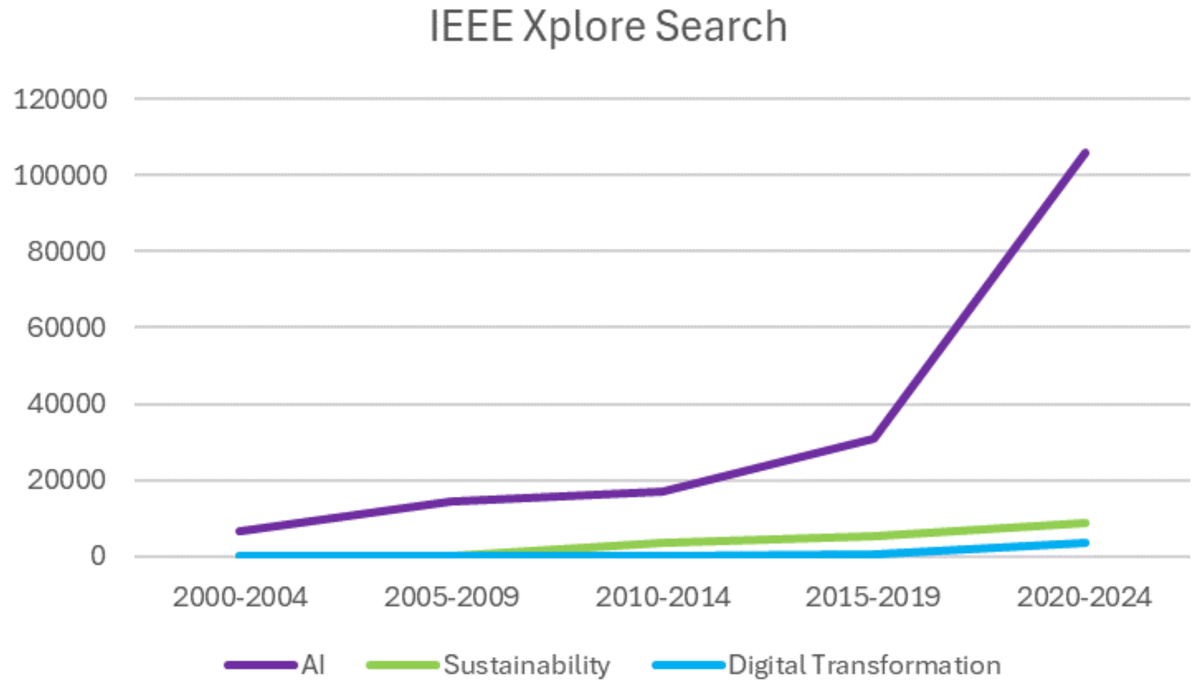
From Google Trends: *Numbers represent search interest relative to the highest point on the chart for the given region and time. A value of 100 is the peak popularity for the term. A value of 50 means that the term is half as popular. A score of 0 means there was not enough data for this term. (Notes denote dates when improvements to systems were made)*

SECTION 05

Megatrends vs IEEE Xplore Publications



(a) January 2024: Overall #documents in IEEE Explore



(b) January 2024: #documents in IEEE Explore, growth in each of 5-year segments. Sum of all points are the numbers in (a)

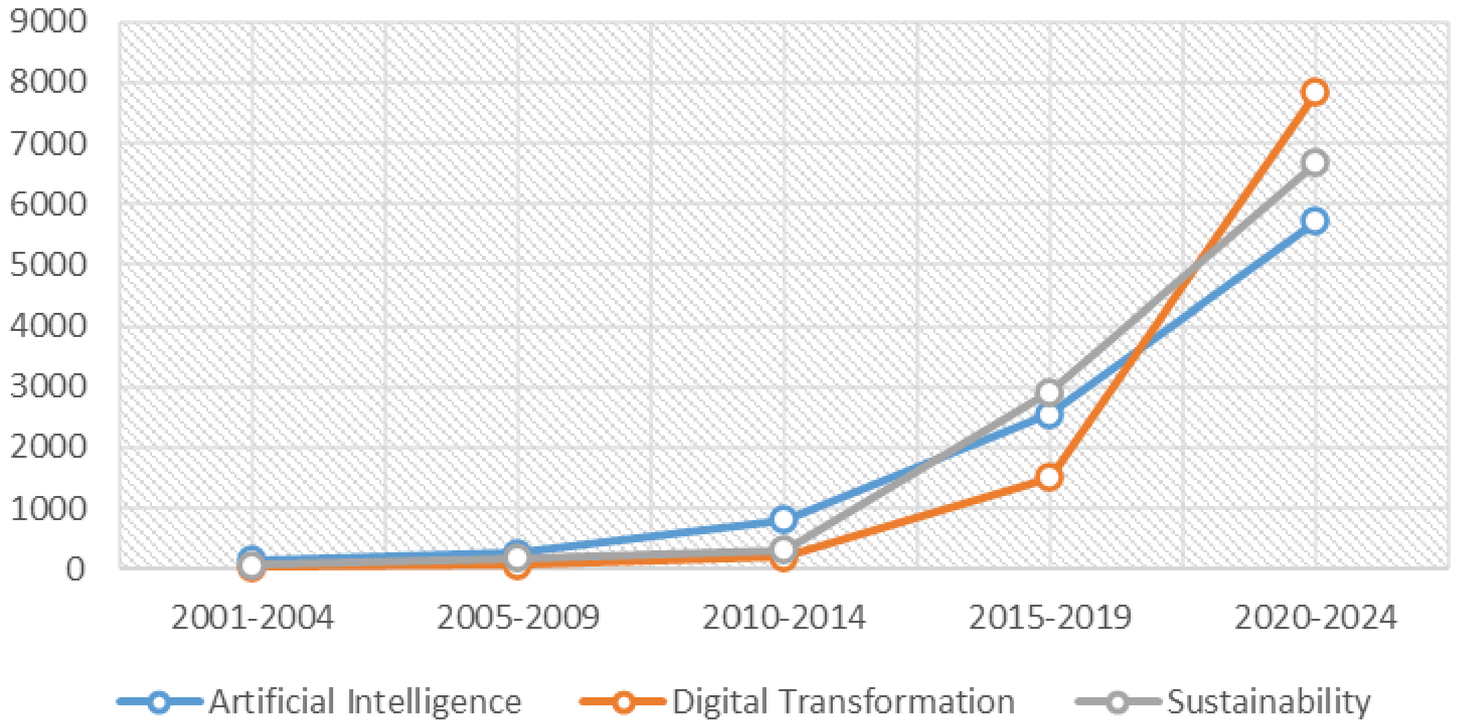
- In publications, AI clearly dominates other two megatrends, this is especially true for the past few years
- We expect this trend will continue in the foreseeable future

IEEE FUTURE DIRECTIONS

SECTION 05

Megatrends vs US Patents (USPTO)

Allowed US Patents from 2001 to 2024*



- AI: there is an upward trend in AI patent filings in recent years, especially from 2015-2019 to 2020-2024.
- Digital Transformation: these patents also show a consistent growth trend with an increase in from 2015-2019 to 2020-2024.
- Sustainability: these patents have witnessed substantial growth from 2010-2014 to 2015-2019.
- Overall, patents trail publications and Google trends. In a way they look backward
- Inherently there is >1.5 year delay from filing to allowing patents
- We expect that patents will catch up in AI domain within ~2 years

*Query conducted in January 2024

IEEE FUTURE DIRECTIONS

SECTION 05

General Recommendations

- All three megatrends need to be considered coherently and synergistically
  - A(G)I techniques could be readily applied to sustainable and digitally transformed technologies
  - Sustainability is key aspect of any technology, e.g. AGI requires substantial amounts of processing
  - Digital transformation needs to be continuously modernized taking into account AGI and sustainability
- All three technology megatrends are deeply intertwined with other megatrends and cannot be considered separately
- New Quality of Service (QoS) aspects are being introduced, such as bias, trustworthiness, misinformation, etc.
- Megatrends need to be supported with broad dissemination activity to avoid splitting the society into knowledgeable and left behind.
- One of the challenges is the speed of change being faster than the humans could adapt. This could create fear and aggression. Broad education is critical for technology adoption.

IEEE FUTURE DIRECTIONS

SECTION 05

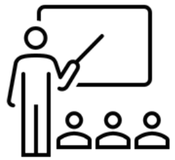
Targeted Recommendations

Industry

- Timely productization of near-horizon technologies
- Advance technologies with highest return on investment
- Take responsibility for green technologies
- Make realistic goals and achievable pledges
- Work with academia to educate workforce
- Offer advice to governments how to regulate technology

Government

- Early regulation of technologies that cause concern
- Enforce governance and lineage of data source for training
- Foster research by academia and non-for-profit organizations
- Institute processes and practices against misinformation
- Socialize the mega trends
- Dissemination information for acceptance and explaining risks



Academia

- Globally train trainers for key megatrends
- Work closely with industry to coherently advance science in support of megatrend technologies
- Achieve breakthroughs in fundamental technologies
- Help industry think outside of the box
- Educate (future) workforce of new (mega)trends
- Disseminate materials for all groups/ages for large acceptance

IEEE
Advancing Technology for Humanity

Professional Organization

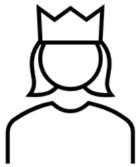
- Help develop standards suited for increased speed of tech introduction
- Foster communities and events that will address key research problems
- Introduce processes and practices for addressing ethics
- Develop roadmaps for some key technologies of 3 megatrends
- Introduce education, processes, and practices for addressing ethics
- Work closely with industry to better adjust to their needs

IEEE FUTURE DIRECTIONS

SECTION 05

Targeted Recommendations, Cont.

- Artificial General Intelligence
- Sustainability
- Digital Transformation



End user

- Get acquainted with AI use
- Set expectations correctly
- Green & planet awareness, every little bit helps
- Entertain remote participation instead of flying
- Adopt new devices and tools (that may consume less energy)
- Align with broader infrastructure

Developer

- Get acquainted with AI tools
- Adopt & practice principles of data lineage and trustworthiness
- Focus on sustainable e2e designs
- Make designs observable, verifiable, aligned with SLOs
- E2E Lifecycle awareness
- Minimize data movement
- Any new architecture should be suitable for digital transformation
- Adopt principles of DevOps

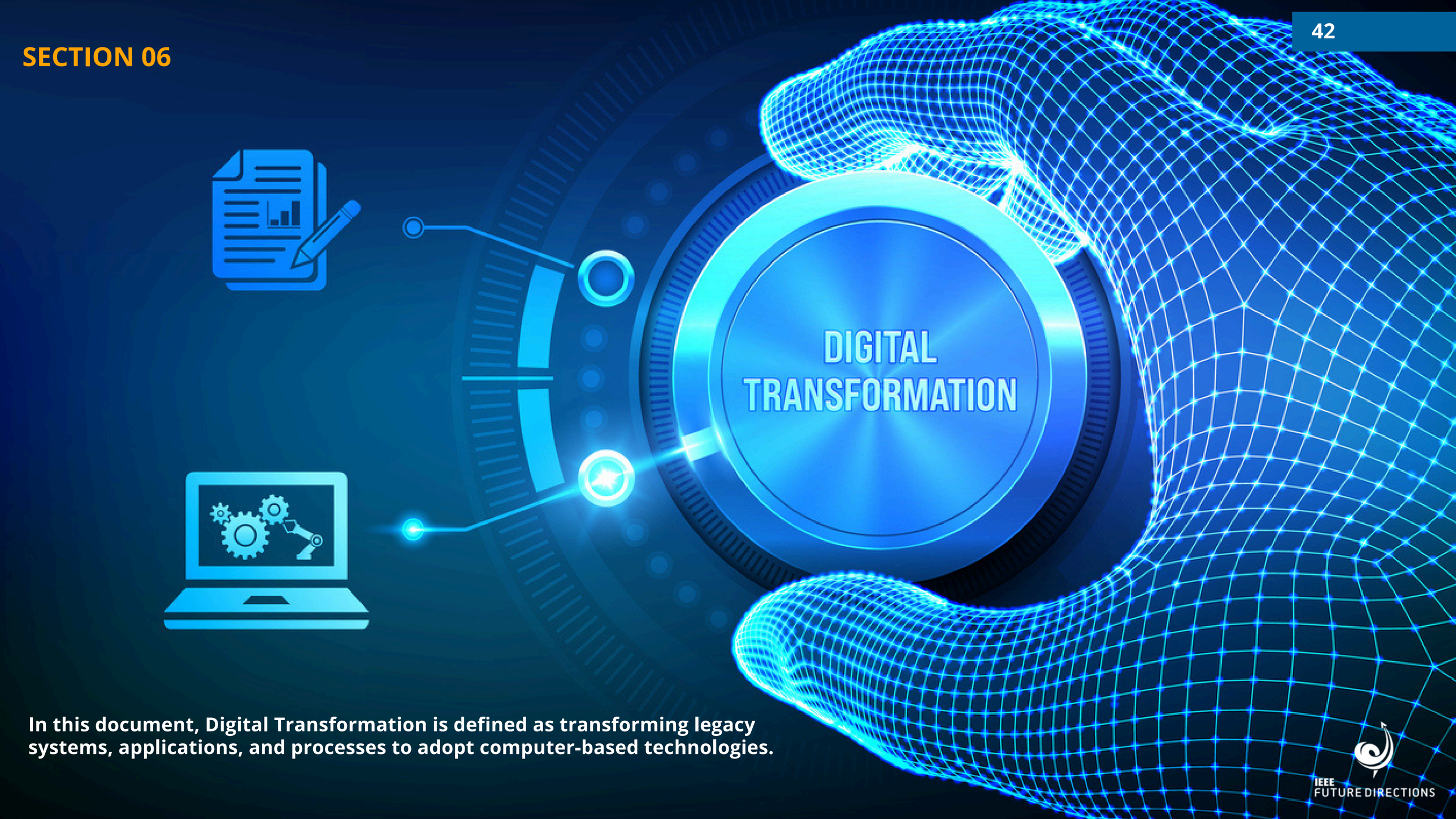
CxO

- Modernize enterprise using AI tools
- Understand AI business and technical risks and opportunities
- Set realistic sustainability expectations
- Carefully align resources to the needs/requirements
- Modernize organization and equipment

Investor

- Invest in balanced tech
- Require coverage of all aspects
- Foster sustainability cross-benefiting green and economy
- Application of AI but not at the expense of sustainability
- Consider new GPUs and new AI accelerators
- Address verticals that have not been digitally transformed

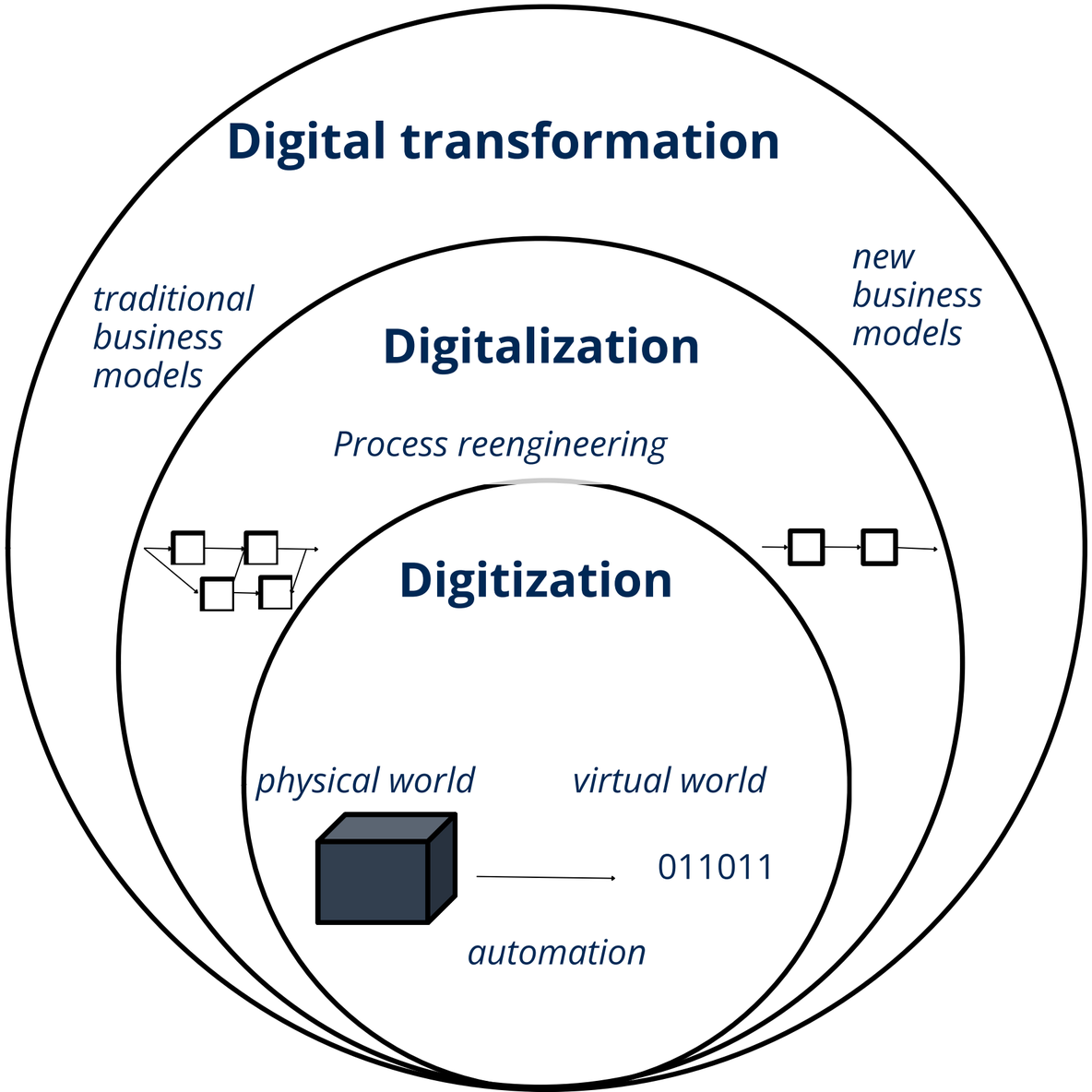
SECTION 06



In this document, Digital Transformation is defined as transforming legacy systems, applications, and processes to adopt computer-based technologies.

SECTION 06

The Three Steps towards Digital Transformation



This Figure was originally published in P. Faraboschi, E. Frachtenberg, P. Laplante, D. Milojicic and R. Saracco, "Digital Transformation: Lights and Shadows," in Computer, vol. 56, no. 4, pp. 123-130, April 2023

SECTION 06

Digital Transformation: Understanding to Influencing

WHAT?

WHY?

WHAT IF?

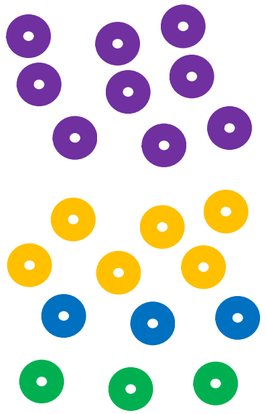
ACT

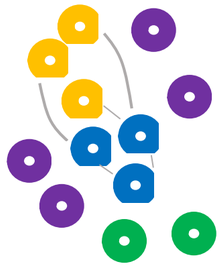
data

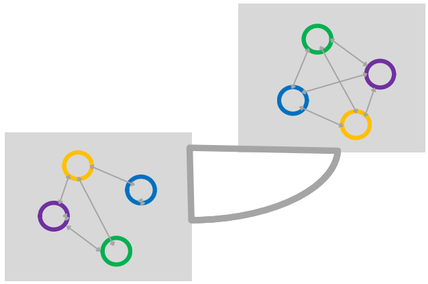
information

insights

actions







data collections

data processing

data analytics

data actuations

increasing value, intelligence

COMMODITY

VALUE-DIFFERENTIATION

This Figure was originally published in P. Faraboschi, E. Frachtenberg, P. Laplante, D. Milojicic and R. Saracco, "Digital Transformation: Lights and Shadows," in Computer, vol. 56, no. 4, pp. 123-130, April 2023

IEEE FUTURE DIRECTIONS

SECTION 06

Digital Transformation

Problems/Demand

- Technical – These are well known and discussed in many other places, they are easiest to address
- Resources – Sufficient materials (chips, batteries, etc.) to build all devices and systems needed. There are insufficient resources on the planet for equitable distribution of the technology.
- Understanding and acceptance -- Not everyone understands and can use the full capabilities of a digitally transformed object/environment. Does this exacerbate the digital divide?
- Awareness – In a full Digital Transformation, not everyone will know or be aware of its existence, the collection of data, etc.– is this ethical?
- Affordability -- Not every entity, state, jurisdiction, individual will be able to afford all of that is offered by the digital divide.
- Capability to be digitally transformed -- Not everyone will be able for a full digital transformation – there will always be remote, underdeveloped, underpowered, under networked areas.
- Willingness and inclusion -- Not everyone will want to participate digital transformation based on privacy, religion and lifestyle. Many people fear or distrust sophisticated technologies.
- Errors and mitigations – Smart devices make errors. Data analytics produce erroneous results.

Opportunities

- Manufacturing: The starting point for manufacturing is the use of computer-aided design (CAD)-generated data. CAD tools create a digital representation of the product that can be used as the digital model
- Construction: The starting point in the construction sector is using the Building Information Modelling (BIM) tool that generates (like the CAD for industry) the digital model of the construction (building, bridge, mall, etc.).
- Healthcare: This sector comprises the infrastructure (e.g. hospitals, equipment, drugs, prosthetics), processes, and the patient. For the former, the starting point for data accrual, and generation of the digital models, is a combination of CAD and BIM, for the latter the cornerstone is the EHR – Electronic Health Record.
- Education: The education sector is possibly the most reliant on digital content. However, it is the least advanced in leveraging it. Most education processes are the same as they were last century at a time when we need to change to more life-long learning!

Timeframe: Now-5 years out

Impact

- Potential for impacting whole industries in terms of substantial cost reduction, more reliable and higher scaling deployments
- Accelerating innovative product and process design
- Digital world has already taken place in many industries
- Broad scenario exploration to improve usability and safety
- Solving problems before they occur, predictive maintenance; Increased adoption of autonomous systems

Sustainable solutions / business opportunity

- Substantial impact in product/process quality improvement, reduced operation cost
- Improved VR/AR technologies help bridge physical distancing
- Gradual transformation commensurate to adoption and business growth
- Business opportunities are limited, but execution is not trivial
- Enablers: low-latency immersive VR; sensors for data collection; and networks to transport vast amounts of sensor data; reliable broadband. 3D virtual environments, machine learning. the emergence of open metadata platforms (like DVC) and a data-centric AI movement, improved data acquisition through IoT and 5G, data pipeline and simulation tools.
- Inhibitors: decreased personal privacy and freedom; insufficiently reliable broadband may lead to VR that causes physical harm; inadequate immersion technology/device fatigue getting in the way; cost to consumers; bridging the gap between the virtual world (simulation) and the real world - ability to accurately model physical property; proprietary platforms; slow adoption of AI de-facto incompatible standards; inability to define “unbiased”; synthetic data too expensive and removed from reality; lack of skilled “data workers”; lack of trust in synthetic training data

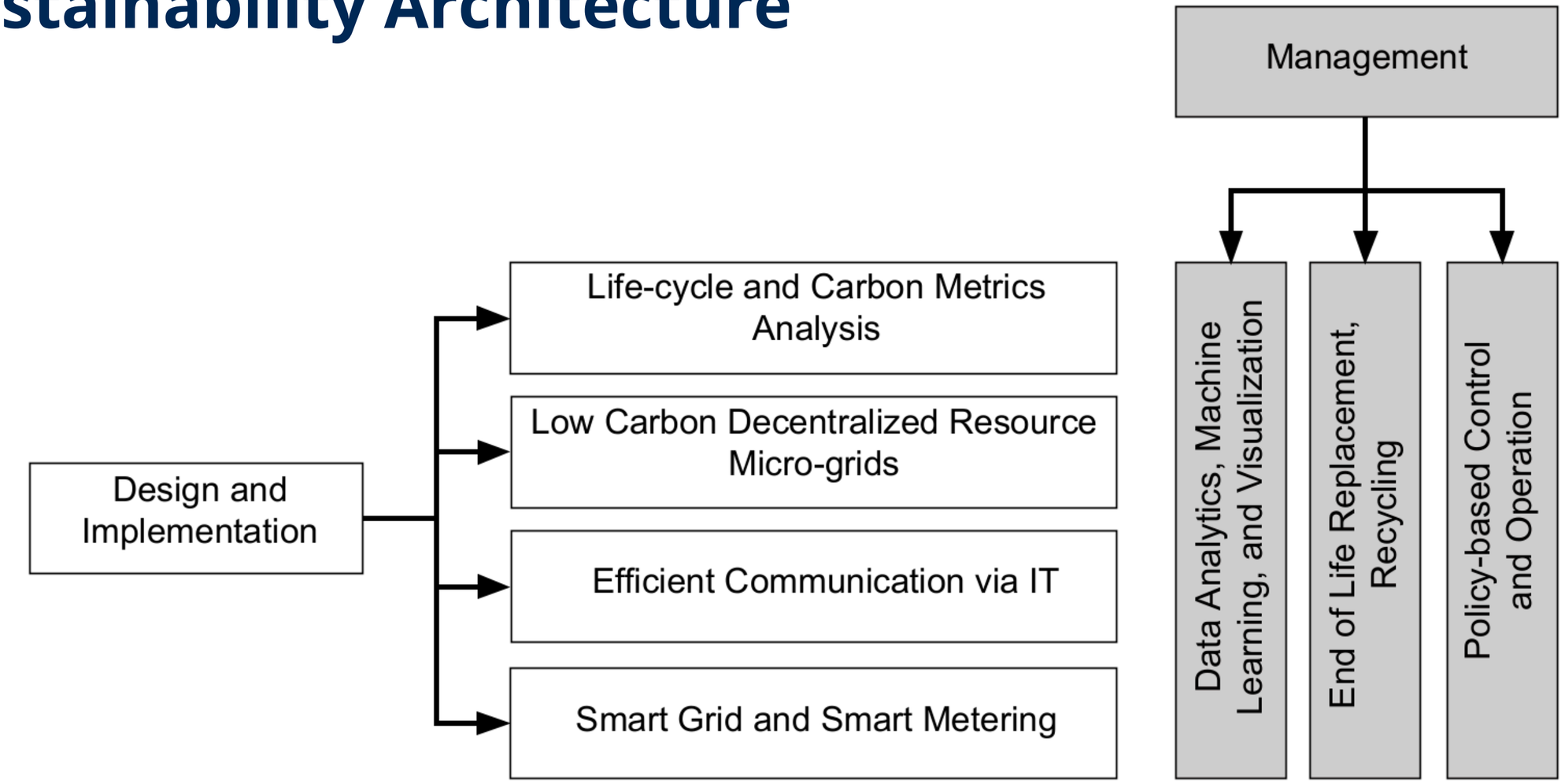
SECTION 06

Sustainability

In this document, Sustainability is defined as an ability to maintain resources or processes at a certain rate or level. The focus is on technical support and implications on ecological, economical and social impact.

SECTION 06

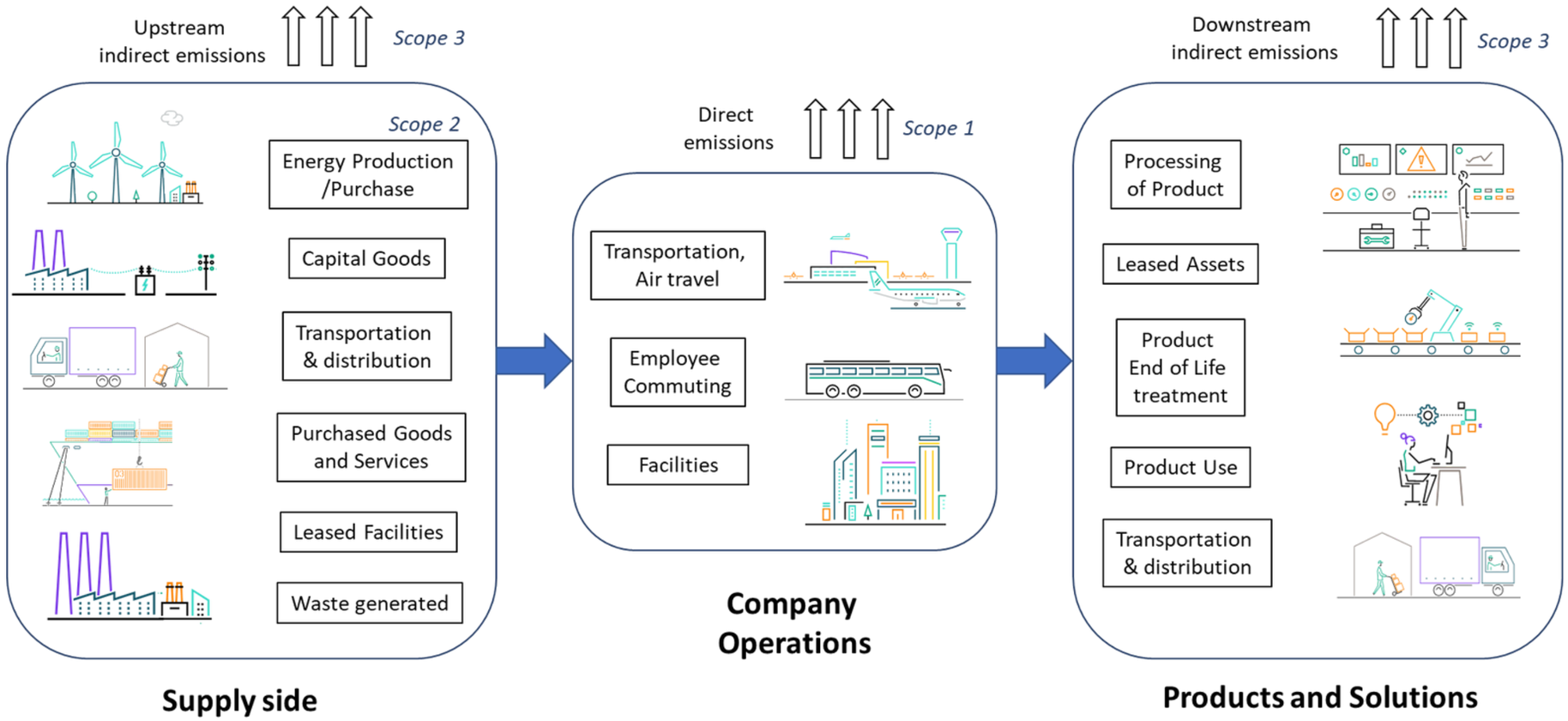
Sustainability Architecture



This Figure was originally published in C Bash, N Hogade, D Milojicic, CD Patel, "IT for Sustainable Smart Cities," NAE BRIDGE, Vol. 53, No. 1, Spring 2023, pp 30-37

SECTION 06

Sustainability, Corporate View



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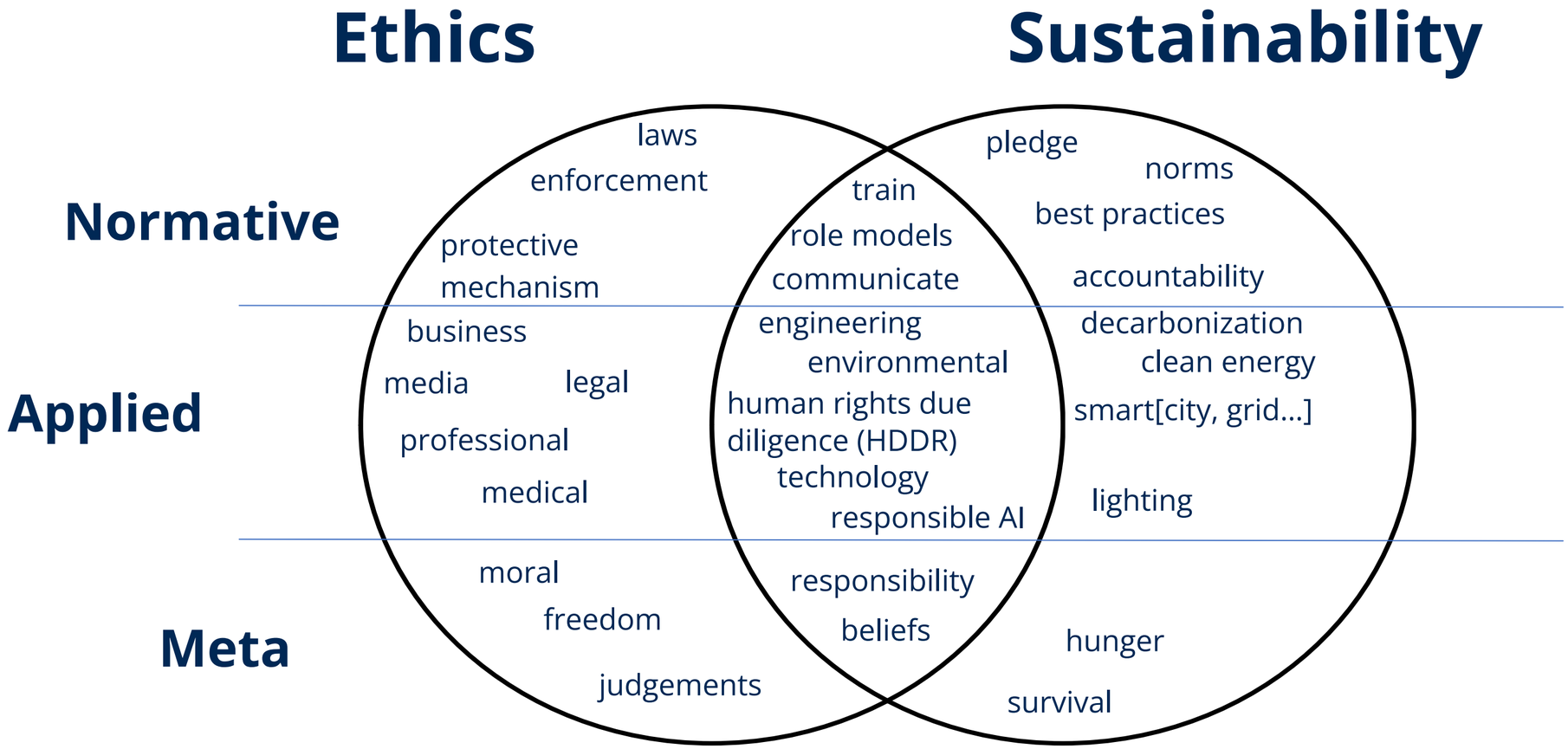
IEEE FUTURE DIRECTIONS

SECTION 06

Ethics in Sustainability



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

IEEE FUTURE DIRECTIONS

SECTION 06

Sustainability

Problems/Demand

- Grand challenges: Increased society decarbonization to address climate change; clean energy to support public health; Reliable and resilient energy delivery; affordable prices; Energy justice
- Economics: 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

- Energy and fuel transformation
- Electrification: transportation, buildings, industry, and agriculture
- Energy efficiency and demand response
- Impact on the environment, especially given the digital acceleration triggered by the COVID-19 pandemic
- Reaching net zero by 2050 could entail a 60% 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.

Timeframe: Now-15 years out

Impact

- Reduction in carbon emissions to combat climate change; clean environment; Increased resilience to natural disasters (hurricanes, fire, tsunamis, earthquakes, etc.); achieving affordability; quality of life equity
- More environmentally sustainable practices through optimization of resources and reduction of waste
- 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 solutions / business opportunity

- Engage various stakeholders in achieving goals
- Identify technology and business solutions to mitigate GHG emissions
- Adaptation strategies to address climate change
- Prioritize initiatives to reach targets and have most effective impact
- 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: international effort toward creating sustainable, resource-efficient buildings
- LED lighting 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 scooter-sharing stations to better predictions of shipping-container to non-invasive tracking of songbirds, AI ensures 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. Technology developments (electrical vehicles, solar, and wind generation, electrical storage, controls, communications, SW/HW tools). IEEE ability to communicate key technology solutions and connect key stakeholders global. Benefit from standardization. Energy storage solutions to bridge consumption and production cycles.
- Inhibitors: Business and politically biased environment promote self-interests. Use incorrect technology reasons to prevent progress. Inefficient battery energy storage solutions depending on rare earth metals resulting in environmentally harmful mining and geostrategic dependence on extraction monopolies. high cost, lack of legislative guidance, incentives, and broad sustainability culture

Artificial General Intelligence (AGI)

In this document, Artificial general intelligence (AGI) is defined as a type of AI that can perform equally or better than humans on a broad range of tasks.

SECTION 06

Types of Artificial Intelligence (AI)

Characteristic	Type of AI			
	Narrow AI	**AI**	**AGI***	**ASI***
Behavior	Carries certain intelligent behaviors	Can achieve different goals, solve different problems, and perform different tasks, in many contexts and environments	Resembles human intelligence in terms of analysis, thinking, decision-making, and creativity (see Section AGI opportunities later)	Surpasses human intelligence to superhuman omnipotence
Examples	Chess, Go, chatbots	ChatGPT, Gemini (Bard AI), Chatsonic, Natural Language Translation, Image recognition, Self-Driving Car, RPA	Has not been achieved as yet, Generative AI is getting closer	Sci-fi (e.g., HAL9000 from "2001: A Space Odyssey")

This Table was modified from the table that originally appeared in P. Faraboschi, E. Frachtenberg, P. Laplante, D. Milojicic and R. Saracco, "Artificial General Intelligence: Humanity's Downturn or Unlimited Prosperity," in Computer, vol. 56, no. 10, pp. 93-101, Oct. 2023,

**AGI: Artificial General Intelligence*
**ASI: Artificial Super Intelligence*

IEEE FUTURE DIRECTIONS

SECTION 06

Possible Future Scenarios for AGI

Characteristic	Future AGI Evolution Scenarios		
	AGI Adoption Fails	**AGI as a Superintelligence**	**AGI as a Tool**
Outlook	N/A	Pessimistic	Optimistic
Coexistence		Separated	Yes
Impact on humans		Harmful, AGI vastly superior	Positive
Outcome	Like it happened before, A(G)I failed in development and alternative technology approaches prevail	Humans develop a synthetic version of themselves. AGI either harms humans, ignores them, or transports itself to a separate physical/digital location	AGI remains a tool, through technology or governance. It helps humans understand technology, advances the discovery rate, and frees humans to excel

This Table was modified from the table that originally appeared in P. Faraboschi, E. Frachtenberg, P. Laplante, D. Milojicic and R. Saracco, "Artificial General Intelligence: Humanity's Downturn or Unlimited Prosperity," in Computer, vol. 56, no. 10, pp. 93-101, Oct. 2023,

SECTION 06

Artificial General Intelligence (AGI)

Problems/Demand

- 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 trust. Prevent secrets leak from large language models. Account for ethical consideration, data privacy
- AI sustainability: as AI models keep growing, the excessive data center loading causes concern on environmental impact. Increase model efficiency, improve accuracy and greater flexibility
- Human-centered AI: focus on enhancing human capabilities, e.g. increase empathy
- Cost of physical world is prohibitively expensive for many solutions
- Safety and security: safeguards against misuses and harmful content, such as deep fakes
- Lacking robustness, reliability, control and explainability: necessitate 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: regarding data privacy/use, ensurw legal and ethical compliance

Opportunities

- The technology has an opportunity to add $4.4 trillion to the global economy annually
- A broad set of domains: healthcare (precision medicine), transportation (autonomous vehicles), education (personalized teachers), manufacturing (AI robots), scientific discovery (AI surrogates)
- Significant impact on knowledge work, decision making, and collaboration
- Enhanced creativity in arts & design: accelerated design collaborative human-AI creative processes
- Generative AI-based revolutionized personalized medicine: drug discovery, tailored treatment plans
- Personalized education and marketing boost productivity
- Improved customer support: natural interactions, problem solving, detailed product knowledge
- Accelerated scientific discovery and 3D modeling
- Iterative improvements/optimizations by exchange between virtual and physical worlds
- Facilitate proximity-based or spontaneous collaboration, substituting office environment
- Technology to facilitate remote learning, substituting for the classroom environment
- Facilitate effective large-scale meetings, substituting for the conference environment
- Large increase in recreational and social time spent in the virtual world

Timeframe: Now-25 years out.

Impact

- 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 be more productive
- But: job displacements, need for reskilling, broadening of inequality and bias, potential loss of control to AI agents, lack of data privacy
- Helps businesses improve 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
- Spreading of much higher quality misinformation requires source checking and critical thinking
- Significantly changing traditional Industries - like manufacturing, agriculture, and transportation

Sustainable solutions / 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
- Substantial impact in product/process quality improvement, reduced operation cost
- 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
- Support and oversight: augmented intelligence in quality inspection
- **Enablers**: widespread curated dataset availability, efficiency while driving down the costs, advances in AI hardware, new generative AI algorithms, multi-modal beyond language (image, video); New ML approaches, affordable AI tools, open models, AI-integrated agents for automation; The emergence of open metadata platforms (like DVC) and a data-centric AI movement
- **Inhibitors**: lack of data privacy, transparency, regulations and standards; ethical concerns; fear of the unknown; inability to differentiate between human-created and AI-generated content, including content in training datasets; threat to content creators and IP holders; adversarial applications, ethical questions of AGI 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; decreased personal privacy and freedom; lack of skilled “data workers”; lack of trust in synthetic training data

SECTION 06

Megatrends Define Future of Humanity

SECTION 07

To Learn More

Written by our Team Members

- C. Bash, P. Faraboschi, E. Frachtenberg, P. Laplante, D. Milojicic, R. Saracco, “Megatrends,” Computer 56 (07), 93-100, 2023.
- D. Milojicic, P. Laplante, “Predicting technology and its impact on humanity,” Computer 56 (7), 17-20, 2023
- P. Faraboschi, E Frachtenberg, P Laplante, D. Milojicic, R Saracco, “Digital transformation: Lights and shadows,” Computer 56 (4), 123-130. 2023.
- C. Bash, N. Hogade, D. Milojicic, G. Rattihalli, CD Patel, “Sustainability: Fundamentals-Based Approach to Paying It Forward,” Computer 56 (1), 125-132. 2023.
- P. Faraboschi, E. Frachtenberg, P Laplante, D Milojicic, R Saracco, “Virtual worlds (Metaverse): From skepticism, to fear, to immersive opportunities,”, Computer 55 (10), 100-106, 2022.
- P. Laplante, D. Milojicic, “Predicting Technologies That Advance Humanity,” Computer 55 (7), 15-17 2022.
- Milojicic, D., “The Art of Prediction,” presented at IEEE SERVICES, and Carl Chang Symposium, Chicago, IL., 2023.
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Written by Others

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SECTION 07

Future Work, Planned for 2025 Megatrends

- **Increase synergy and differentiation with Technology Predictions**
  - Better align calendars
  - Cross-evaluate predictions from previous and current years for similarity and leverage
- **Innovate predictions process**
  - Adopt user-centered design principles
  - Introduce classes of horizons / risk (near-term Vs long-term and disruptive vs evolutionary)
  - Seek input across: IEEE major organizational units, social media, and surveys
- **Communicate and coordinate with**
  - Non-profit organizations: UNESCO, World Economic Forum
  - Market analysts: IDC, Forrester, Gartner

SECTION 08

Summary

- Any prediction is hard; technology predictions are harder (biz & time components)
- Technology megatrends provide broader context for technology predictions and for interplay with economic, social, ecological megatrends
- IEEE is well positioned to provide its predictions to the world
- We were quite successful in our technology predictions
  - Multiple annual press releases with >250M target audience
  - Many panels, keynotes, webinars, engagements, papers, and meetings
  - Interactions with market analysts and VCs
- This is work done by multiple large teams, over 100 people

View all IEEE CS Technology Predictions: https://www.computer.org/press-room/news-archive?tag=cs-tech-trends-and-predictions

Visit Future Directions: https://www.ieee.org/about/technologies.html

IEEE FUTURE DIRECTIONS

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The IEEE Future Directions Committee (FDC), in association with IEEE Societies, Councils, and Operating Units, anticipates and determines the direction of existing, new, and emerging technologies and spearheads their investigation and development by IEEE. Taking a holistic view, the FDC emphasizes new, emerging technical areas and drives them to maturity within the IEEE infrastructure. Additionally, the FDC serves as a liaison to and fosters cooperative efforts among Societies, Councils, and industry to develop new products and services in emerging topics.

The primary working objectives of the IEEE Future Directions Committee:

- Incubates emerging technologies and new applications of current technologies
- Identifies opportunities to engage the engineering community and the general public
- Works with IEEE members and staff to focus on emerging technologies through technical, professional, and educational activities
- Serves as a catalyst for new conferences, publications, standards, educational products, forums, white papers, grants, and projects to support new technologies

IEEE Future Directions
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