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UNIVERSITÀ
DEGLI STUDI
DI PADOVA

Padova, 28 giugno 2024

WORLD ECONOMIC FORUM
UNIPD NEL PANEL DEGLI SCIENZIATI DEL FUTURO
Genomica e Trapianti - Emanuele Cozzi unico docente in Italia direttamente inserito nel *Top 10 Emerging Technologies of 2024*

Dal 1971 il World Economic Forum (WEF) riunisce i maggiori esponenti internazionali della politica e dell'economia per discutere con giornalisti e intellettuali le questioni più urgenti che il mondo si trova ad affrontare nel prossimo futuro, anche in materia di salute e ambiente, sforzandosi di avere uno sguardo imparziale e privo di vincoli politici e ideologici.

Il WEF 2024 ha appena stilato la lista dei 10 topics più importanti (*Top 10 Emerging Technologies of 2024*) che nei prossimi 3/5 anni sono destinati ad avere un peso sostanziale per l'umanità e lo sviluppo delle tecnologie.

Tra questi argomenti c'è quello denominato *Genomics for transplants*: i trapianti di organi salvano vite umane, ma la richiesta supera il pool di donatori disponibili. Solo negli Stati Uniti, più di 100.000 pazienti sono in attesa di un organo, eppure saranno solo circa 30.000 gli organi disponibili quest'anno.

Per rispondere a questa esigenza, da più di tre decenni, sono stati compiuti progressi costanti nel campo della scienza con il trapianto di organi da animali in esseri umani (in particolare xenotrapianto). Grazie alla tecnologia come CRISPR-Cas9 infatti, ora è possibile creare molteplici manipolazioni genetiche in un singolo suino per superare il problema immunologico. Proprio a marzo di quest'anno a Boston è stato effettuato il primo trapianto riuscito di un rene non umano (maiale) in un essere umano vivente.

Nel WEF 2024, proprio alla voce *Genomics for transplants*, il referente (unitamente al prof. David K Cooper della Harvard Medical School) – unico ricercatore presente di un ateneo italiano tra le eccellenze del WEF– è il prof Emanuele Cozzi, del Dipartimento di Scienze cardio-toraco-vascolari e Sanità pubblica dell'Università di Padova, delegato del Centro Nazionale Trapianti presso il Consiglio d'Europa a Strasburgo.

Emanuele Cozzi

«Fermo restando che la ricerca è pilastro condizionante di tuta la scienza a livello internazionale, è d'altra parte doveroso fare il punto sullo stato dell'arte in merito ai trapianti da animale a uomo – **spiega il prof Emanuele Cozzi** -. Nonostante i grandi passi avanti fatti negli ultimi anni, lo xenotrapianto non può sostituire a oggi la donazione di organi da esseri umani. I risultati preclinici sono incoraggianti e mostrano indubbiamente come lo xenotrapianto possa incrementare l'indice di sopravvivenza del trapiantato e al contempo migliorarne la qualità della vita. Fino ad ora gli unici trapianti da animale a uomo sono stati fatti negli USA e in Cina, mi auguro che in un tempo abbastanza breve si possano fare anche in Europa e, perché no, in Italia. Il mio personale contributo, possibile anche grazie al sostegno delle strutture in cui opero, assieme a quello di altri ricercatori, è volto soprattutto a rendere lo xenotrapianto una realtà anche a casa nostra.»

«L'idea del Dipartimento di "chiamare" il prof Cozzi a far parte dei nostri docenti è nata proprio dalla sua grande *expertise* nel campo dell'immunologia dei trapianti, unitamente ai suoi studi sullo xenotrapianto svolti prima nel Regno Unito e poi negli States – **spiega il prof Federico Rea, direttore del dipartimento di Scienze cardio-toraco-vascolari e Sanità pubblica** -. L'Azienda Ospedale/Università di Padova comprende due grandi centri dedicati al trapianto, ormai divenuti riferimento a livello nazionale per i pazienti, ed è sempre più impellente il bisogno di implementare questa attività, a fronte di una richiesta sempre maggiore. Un futuro possibile è proprio quello del trapianto di organi da non umani che le nuove tecnologie sembrano rendere ogni giorno una realtà sempre più praticabile.»

Si legge nel report WEF: «Lo xenotrapianto solleva considerazioni etiche che necessitano di ulteriore esplorazione, idealmente da parte di vari leader in spazi politici, economici e sociali. Inoltre, è ancora necessario acquisire una grande quantità di dati e sperimentazioni iniziali sui pazienti per garantire l'efficacia dei trattamenti. Tuttavia, solidi insegnamenti precedenti derivati da tecnologia di trapianto consolidata, combinata con la crescente capacità e la riduzione dei costi di tecniche di modifica genetica, indicano buone ragioni per farlo ed essere ottimisti riguardo al futuro dei trapianti "interspecie" per prevenire la perdita inutile di centinaia di persone e di migliaia di vite umane ogni anno.»

Link al WEF 2024.
https://drive.google.com/drive/folders/1HZYomcd8TTYPYhHq5tK9qregiu9FS8rZ?usp=sharing

Centre for the
Fourth Industrial
Revolution

WORLD
ECONOMIC
FORUM

In collaboration
with Frontiers

Top 10 Emerging Technologies of 2024

FLAGSHIP REPORT

JUNE 2024

Images: Midjourney, Studio Miko. All images in this report have been generated using artificial intelligence.

Contents

Foreword

Frederick Fenter
Chief Executive Editor,
Frontiers

Jeremy Jurgens
Managing Director,
World Economic Forum

Organizations make better choices when they understand the factors shaping the future. Since 2011, the Top 10 Emerging Technologies report has served as a vital source of strategic intelligence for professionals. Drawing on insights from scientists, researchers and futurists, the report identifies 10 technologies poised to significantly influence societies and economies within three to five years.

In this 12th edition, we have broadened the scope and depth of our analysis. We have enlisted the expertise of over 300 world-leading academics from the Forum's Global Future Councils and Frontiers' global network of chief editors, ensuring a diverse and comprehensive perspective. Additionally, we have introduced an innovative trend analysis methodology encompassing academic literature, funding trends and patent filings, bolstering the rigour and accuracy of our selection process.

With these enhancements, this year's report spotlights technologies with immense potential for revolutionizing connectivity, addressing the urgent challenges of climate change and driving innovation across various fields. From advancements in materials science to transformative technologies in healthcare and beyond, the report showcases a diverse array of solutions poised to shape the future.

Producing this report would not have been possible without the Co-Chairs of our Emerging Technologies Steering Group, Mariette DiChristina and Bernard Meyerson, whose leadership and expertise have been instrumental in shaping the content and ensuring its relevance and impact. We extend our heartfelt appreciation to all the dedicated members of the steering group – many of whom have been steadfast collaborators for over a decade – for their unwavering commitment to championing industry-leading and society-serving technologies.

The future is both a realm of study and a landscape to shape. We hope this report will serve as a pivotal call to action for professionals across sectors and regions to collectively build a future where technology transforms and enriches societies and economies worldwide.

Introduction

A message from the Top 10 Emerging Technologies Steering Group Co-Chairs.

Mariette DiChristina
Dean, Boston University
College of Communication

Bernard Meyerson
Chief Innovation Officer
Emeritus, IBM

At the heart of the World Economic Forum's mission of improving the state of the world lies the belief in the power of human ingenuity, entrepreneurship, innovation and cooperation. That power is on full display in this year's edition of the Top 10 Emerging Technologies report.

Breakthroughs in artificial intelligence (AI), such as deep learning, generative AI and foundation models, enable remarkable progress in strengthening human innovation. The world is on the cusp of a science discovery revolution driven by AI. Uniquely able to ingest and organize vast amounts of information, AI-enabled discoveries will likely improve disease management, propose new materials and better our understanding of the body and mind. Meanwhile, synthetic data can protect personal privacy while providing new global data sharing and collaboration opportunities.

Collaboration, of course, relies on connection, and several of the top 10 herald a shift to more adaptive, efficient and inclusive connectivity. Reconfigurable intelligent surfaces (RIS) change shape dynamically to optimize wireless communication links; they combine meta-materials, smart algorithms and advanced signal processing to control and manipulate electromagnetic waves. High-altitude platform stations, through aircraft, blimps or even simple balloons, can bring mobile network access to remote regions lacking the infrastructure required to deploy ground-based systems. Such technology can bridge the digital divide, bringing internet access to over 2.6 billion people in 100 countries that still lack internet service as of 2023. With the emergence of 6G systems, networks can now act as sensors, using radio signals to scan the physical world, improving communication performance and enabling integrated sensing and communication.

Improving the state of the world also means protecting our planet and people. This year, human health saw the first genetically engineered organ from a pig implanted successfully into a human, giving hope to the millions waiting for transplants. Immersive technologies, combining computing power and virtual approaches, promise rapid improvement in the systems and physical infrastructure we rely on daily.

On the environmental front, many of the top 10 demonstrate how technology can play a multifaceted role in addressing climate change, encompassing mitigation strategies, sustainable infrastructure development and promoting energy-efficient solutions. Elastocalorics, releasing heat under mechanical stress and absorbing it upon relaxation, promise much higher efficiency and lower energy use than current technology. Similarly, another positive environmental development is the emergence of alternative livestock feeds, reducing agroindustry waste or residues, native crop depletion and related resource consumption. Additionally, addressing global warming head-on, engineered organisms that convert emissions into products such as biofuels offer hope for mitigating increasing carbon dioxide levels.

The following pages delve into the specifications of the top 10 emerging technologies of 2024 and how they can help improve the state of the world. We invite you to engage and welcome your feedback.

Methodology

Potential technologies for the 2024 list were identified through a survey distributed across the World Economic Forum's Global Future Councils Network and University and Research Network, the Frontiers network comprising over 2,000 chief editors worldwide from top institutions, and the Top 10 Emerging Technologies Steering Group members.

Respondents were asked to provide detailed information about the technology they put forward, including technology name and description, potential impact, as well as a compelling rationale for why the technology should be on the 2024 list.

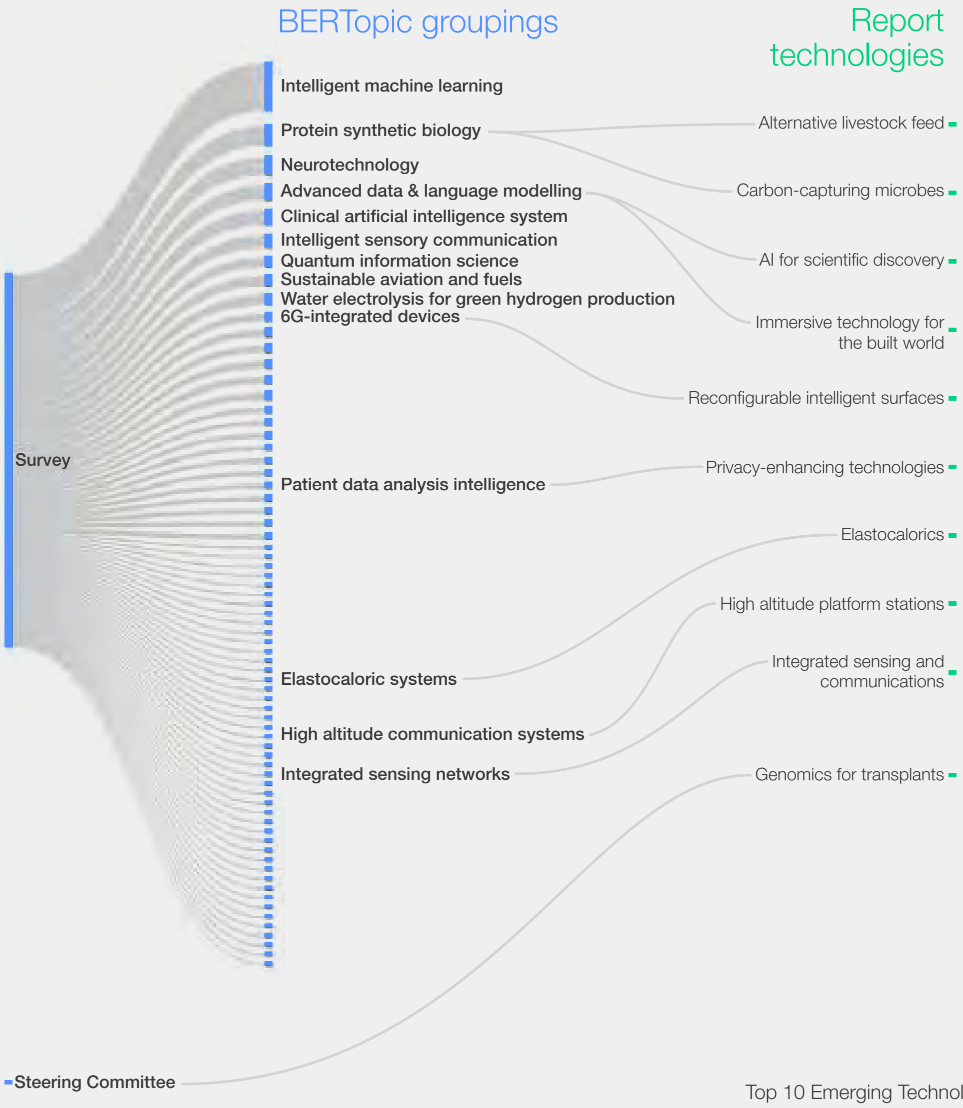
The survey received over 300 valid technology nominations from 29 countries. To handle the increased volume of responses, an AI-assisted tool – the AI Trend Analyzer, built by Frontiers – was implemented to automate the initial screening of survey answers. This tool classified and clustered responses based on trending topics identified through an analysis of academic publications in recent years.

The steering group was then presented with a curated list of 70 technologies from which the final 10 were selected. The group reviewed and selected the technologies based on the following criteria:

- **Novelty**: The technology is emerging and at an early stage of development but is not yet widely used.
- **Applicability**: The technology is potentially of significant use and benefit to societies and economies.
- **Depth**: The technology is being developed by more than one company, with the focus of increasing investment interest and excitement.
- **Power**: The technology is potentially game-changing to established ways and industries.

FIGURE 1

Top 10 selection process

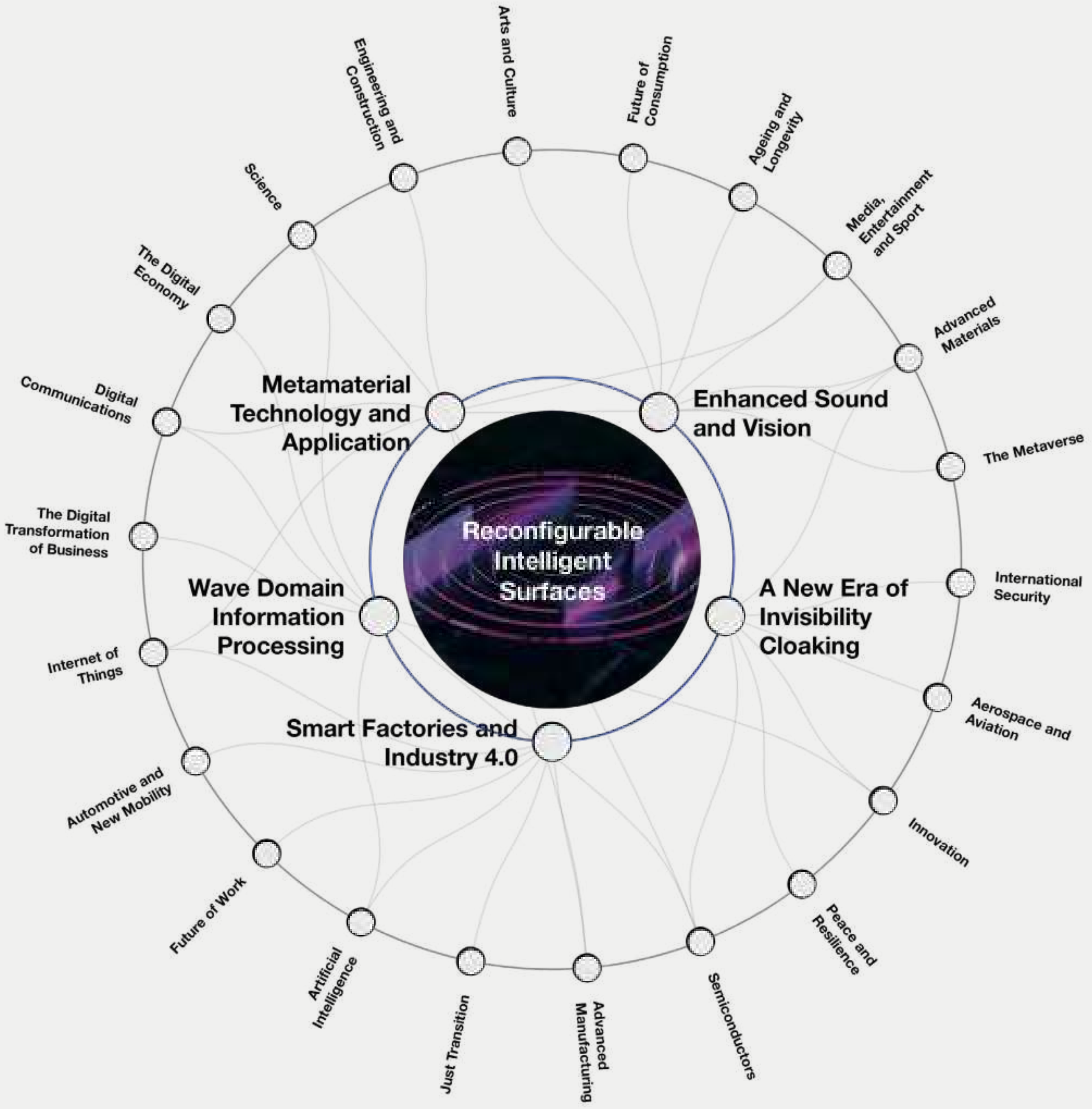


These final 10 technologies underwent further evaluation, leveraging available data on patents, funding and geographic distribution, with data pulled from CB Insights. The report also used data on academic grant funding pulled from Dimensions.

This edition delves into the technologies' ramifications across sectors, including industry, economy, society, environment, recent advancements and critical requirements essential for successful scaling. To meet the dynamism of these emerging technologies, Frontiers has co-curated transformation maps for each technology housed on the Forum's Strategic Intelligence Platform. Readers can learn more about the key issues of each technology and how it connects to other topics on the global agenda as well as find the latest articles on the topic from trusted sources.

The descriptions were predominantly based on the articles in this report. Key issues were identified based on guidance from the steering group authors and input from Frontiers' editors. These descriptions were researched and written by the editors at Frontiers. You are invited to continue to explore and monitor the technologies driving transformational change across economies, industries, and global issues. Explore more here.

FIGURE 2 **Example Strategic Intelligence transformation map**



Source: © 2024 World Economic Forum

BOX 1

Building Strategic Intelligence: a reader's guide

Emerging technologies have the potential to reshape industries, economies and societal structures, presenting both opportunities and challenges for organizations of all sizes and types.

The following questions are designed to facilitate a deeper understanding of how the top 10 emerging technologies may impact your organization and identify strategic pathways for innovation and growth.

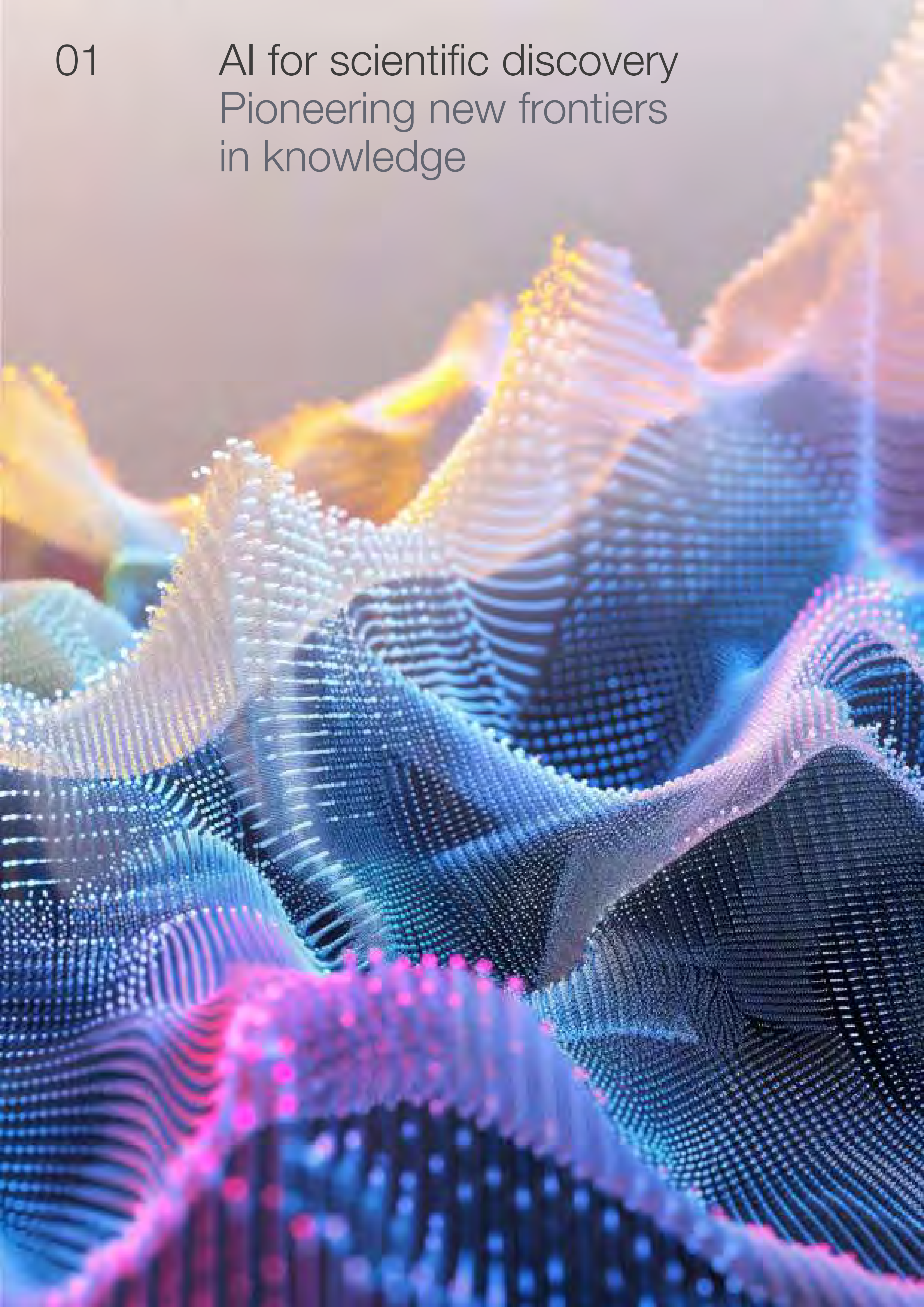
You are encouraged to approach these questions with an open mind, considering your organization's unique context and objectives. Whether you are a business leader, technologist, academic or policy-maker, this framework is intended to serve as a starting point for strategic discussions and decision-making processes within your organization.

- If this technology achieves scale, how will it impact my organization's operations and objectives?
- What are the potential applications of this technology in my organization's current or future focus areas?
- What steps can my organization take to position itself as a key player in using and applying this technology effectively?
- What partnerships or collaborations are essential for success in this rapidly evolving technological landscape?
- Does the adoption of this technology imply significant shifts in our organization's core business, talent structure or operational processes?
- How can my organization adapt its current strategy to harness the potential of this new technology as a driver of innovation, growth and/or impact?

01

AI for scientific discovery

Pioneering new frontiers in knowledge



Olga Fink
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Thomas Hartung
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Sang Yup Lee
Senior Vice-President, Research; Distinguished Professor, Korea Advanced Institute of Science and Technology

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Breakthroughs in artificial intelligence (AI) – such as deep learning, generative AI and other foundation models – enable scientists to make discoveries that would have been near-impossible otherwise and accelerate the rate of scientific discovery more broadly.

Over the past few years, there has been a transformation in how AI is used in scientific discoveries. From Deep Mind's AlphaFold – an AI system that accurately predicts the 3D models of protein structures – to discovering a new family of antibiotics and materials for more efficient batteries, the world is on the cusp of an AI-driven revolution in how new knowledge is discovered and used.[1,2,3] According to a recent report from the United States President's Council of Advisors on Science and Technology, "AI has the potential to transform every scientific discipline and many aspects of the way we conduct science".[4]

While AI has been used in research for many years, recent advances in deep learning, generative AI and foundation models are transformative. Scientists are building and using large language models to mine scientific literature, working with AI chatbots to brainstorm new hypotheses, creating AI models capable of analysing vast amounts of scientific data, and using deep learning to make discoveries. They are also exploring how AI and robotics can be integrated with lab-based methods to accelerate research in innovative ways.

As a result, AI is emerging as a transformative general-purpose technology in scientific research that can unearth discoveries that would have otherwise remained hidden. With the current rate of innovation, these are likely to lead to advances in the areas of:

- Diagnosis, treatment and prevention of diseases.
- Novel materials that enable next-generation green technologies.
- Breakthroughs in the life sciences that extend current understanding of biology.
- Transformative leaps in how the human mind is understood, and many more.

Scientists predict that general-purpose AI will transform every part of the scientific discovery process over the next few years. Researchers can draw on past findings to envision new possibilities – AI allows connections to be made and inferences to be drawn that lie beyond the capacity of human minds alone.

Ethical considerations and challenges remain – the extent of the risk to individual privacy, autonomy and identity and the possibility of societal disruptions caused by these powerful technologies are not yet fully known.[5] Additionally, environmental impacts resulting from the energy consumption and resource extraction needed to sustain AI growth must also be considered.

Equally, more research is needed to manage the impact of the technology effectively.[6] For example, tackling inherent biases in data sets and enhancing the reliability of model-generated content is crucial to scientific integrity. Ensuring ethical data use and safeguarding research subject privacy require stringent security measures. Navigating intellectual property rights, particularly ownership and copyright of model-generated content is essential to a collaborative environment and must be addressed.

> “
>
> Scientists are building and using large language models to mine scientific literature, working with AI chatbots to brainstorm new hypotheses, creating AI models capable of analysing vast amounts of scientific data, and using deep learning to make discoveries.

↑ Image:
AI breakthroughs in deep learning and generative models are transforming scientific discovery.

Credit: Midjourney and Studio Miko.

Prompt (abbreviated):
"Complex data points coming together and being simplified"

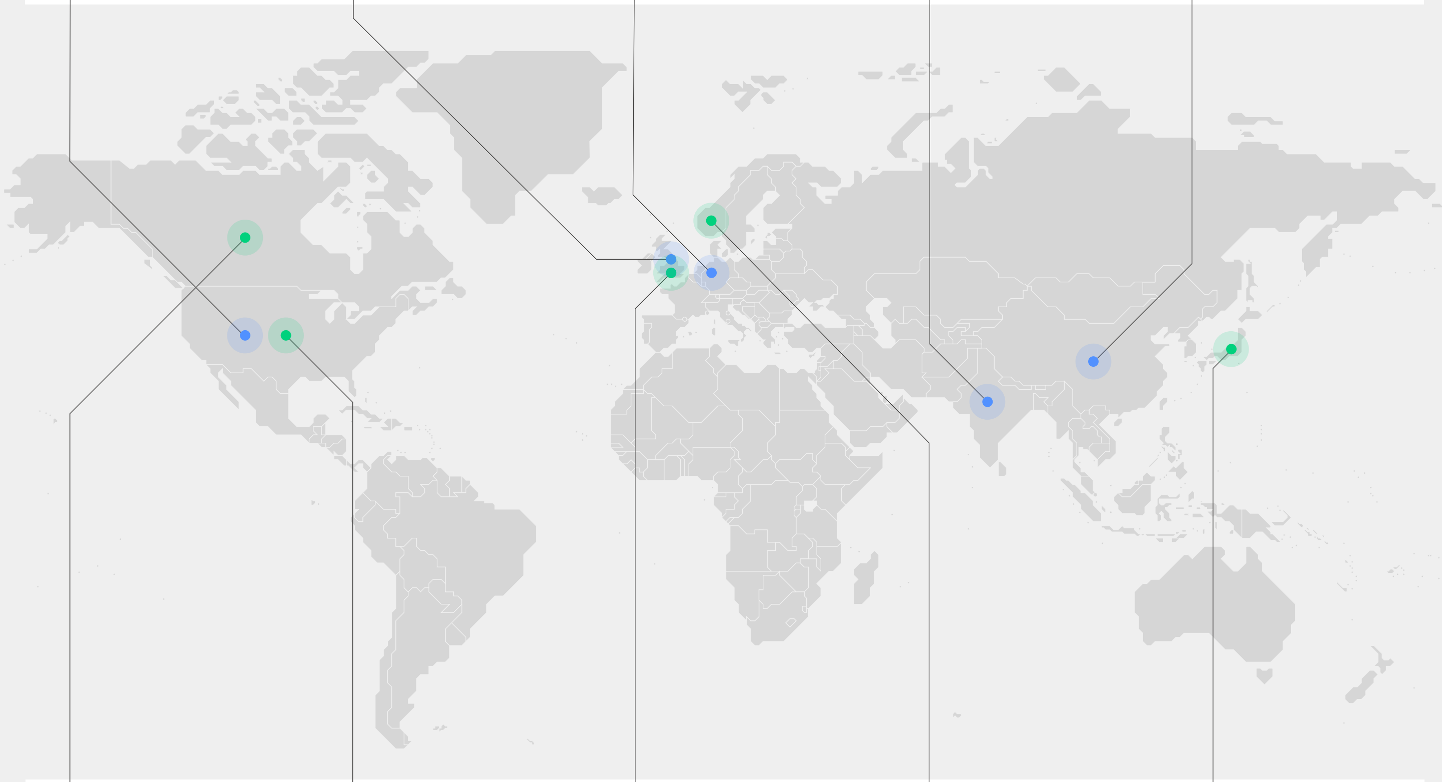
Read more:
For more expert analysis, visit the [AI for scientific discovery](#) transformation map.

Regions of innovation

Countries with the most business and academic grant funding in AI for scientific discovery from 2021-2023

Top five countries by business funding

1	**United States**	$74.1 billion
4	**United Kingdom**	$5.2 billion
5	**Germany**	$2.5 billion
3	**India**	$5.8 billion
2	**China**	$19 billion



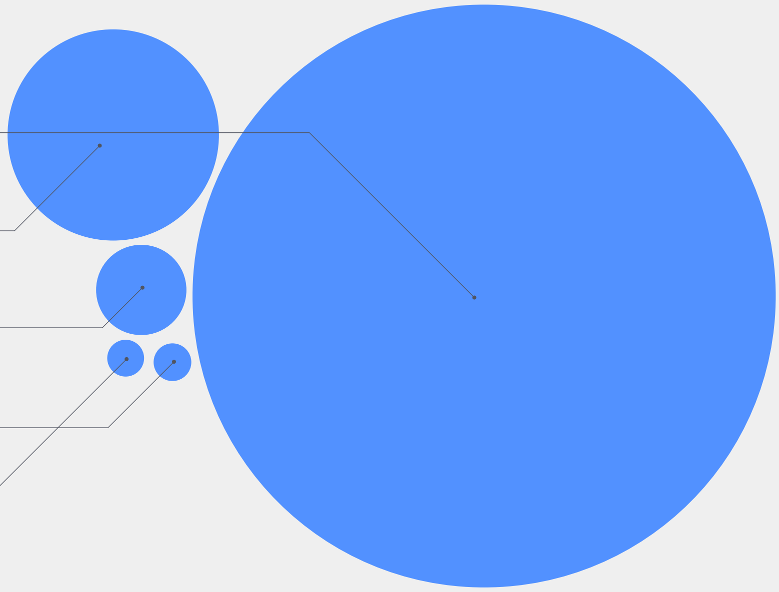
2	**Canada**	$58 million
1	**United States**	$3.6 billion
4	**United Kingdom**	$547 million
5	**Norway**	$143 million
3	**Japan**	$33 million

Top five countries by academic grant funding

Leading-edge industries

Industries with the most funding in AI for scientific discovery from 2021-2023

- **Internet** $66.5 billion
- **Software** $24.1 billion
- **Healthcare** $10.3 billion
- **Computer hardware** $4.3 billion
- **Industrials** $4.2 billion



02

Privacy-enhancing technologies

Empowering global collaboration at scale

Olga Fink
Assistant Professor, Intelligent Maintenance and Operations Systems, Swiss Federal Institute of Technology in Lausanne

Lisette van Gemert-Pijnen
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Bastiaan van Schijndel
Innovation Manager, ZORGTTP

Access to increasingly large datasets – especially when using AI – transforms research, discovery and innovation. However, concerns around privacy, security and data sovereignty limit the degree to which high-value data can be shared and used nationally and globally. An emerging and powerful suite of technologies makes it possible to share and use sensitive data in ways that address these concerns.

In recent years, there has been growing interest in "synthetic data".[7] These data replicate the patterns and trends in sensitive datasets but do not contain specific information that could be linked to individuals or compromise organizations or governments. Powered by advances in AI, synthetic data removes many of the restrictions to working with sensitive data and opens new possibilities in global data sharing and collaborative research on biological phenomena, health-related studies, training AI models and more. However, even with the advent of synthetic data at a national level, health trends in a source nation will be exposed, and such concerns will need to be overcome.

There has also been renewed interest in homomorphic encryption, a technology from the 1970s.[8,9] Rather than recreate datasets with the same characteristics as the raw data, homomorphic encryption allows encoded data to be analysed without the raw data being directly accessible. While promising, such encryption requires significantly more energy and time to achieve a secure result.

As advances in AI transform the value of data, techniques like synthetic data generation and homomorphic encryption are predicted to enable sharing and access to data while ensuring privacy, security and data sovereignty. Within health-related research, in particular, access to data in ways that don't compromise the rights and safety of individuals and communities is already showing promise for accelerating advances in disease detection, treatment and prevention.[10]

Effective data sharing and utilization technologies that protect privacy, security and data sovereignty are essential if the emerging potential of AI is to be realized. Yet, despite their potential, synthetic data and homomorphic encryption have several limitations. These include poor representation of potentially significant edge cases or outliers in the case of synthetic data and the potential ability to infer or reconstruct sensitive data despite the de-identification inherent in both techniques. Further work on the technologies and the use policies surrounding them will be necessary to ensure their success.[11]

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> Powered by advances in AI, synthetic data removes many of the restrictions to working with sensitive data and opens new possibilities in global data sharing and collaborative research on biological phenomena, health-related studies, training AI models and more.

↑ Image:
Privacy-enhancing technologies enable secure sharing and use of sensitive data.

Credit: Midjourney and Studio Miko.

Prompt (abbreviated): "Data points obscured by frosted glass with etchings"

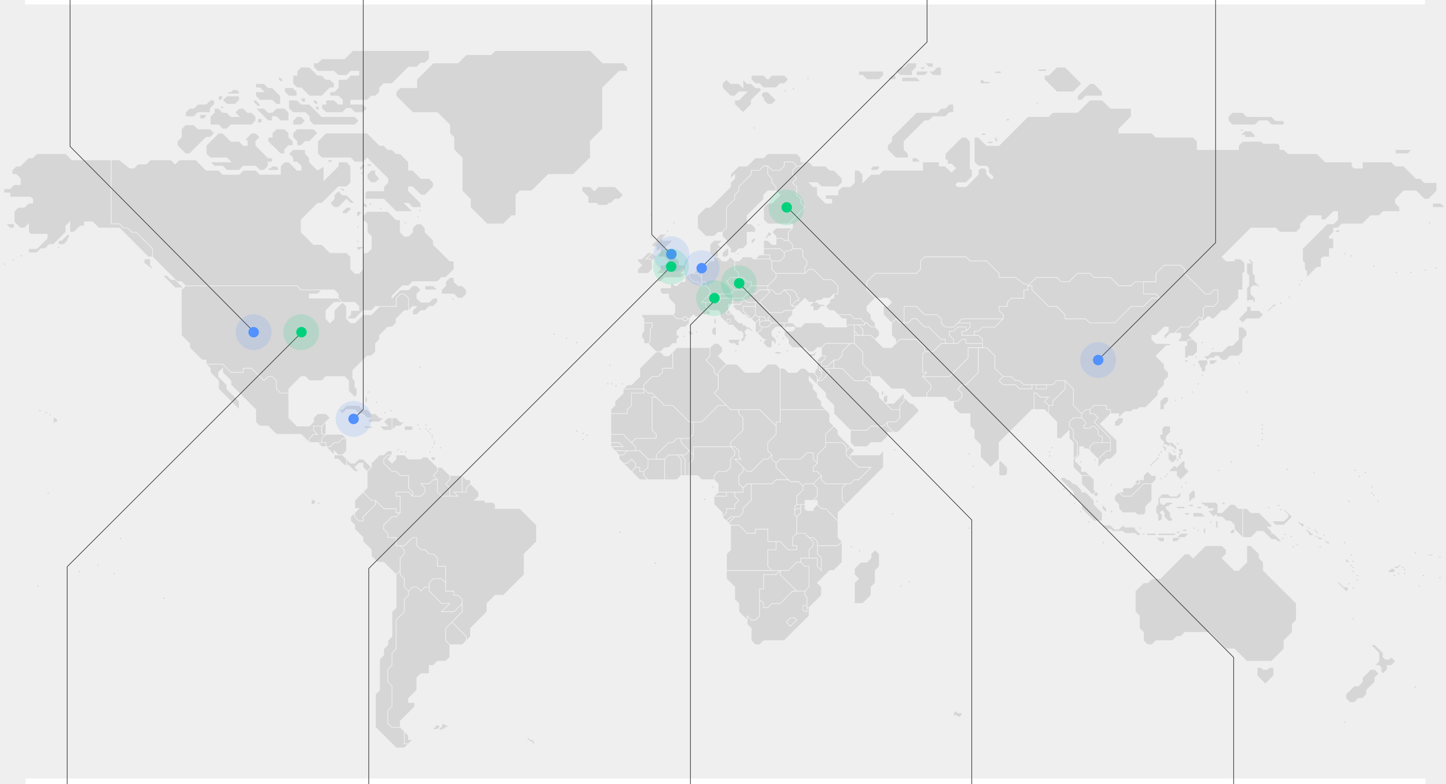
Read more:
For more expert analysis, visit the privacy-enhancing technologies transformation map.

Regions of innovation

Countries with the most business and academic grant funding in privacy-enhancing technologies from 2021-2023

Top five countries by business funding

Rank	Country	Funding
1	United States	$4.6 billion
5	Cayman Islands	$467 million
4	United Kingdom	$895 million
3	Netherlands	$1.2 billion
2	China	$1.6 billion



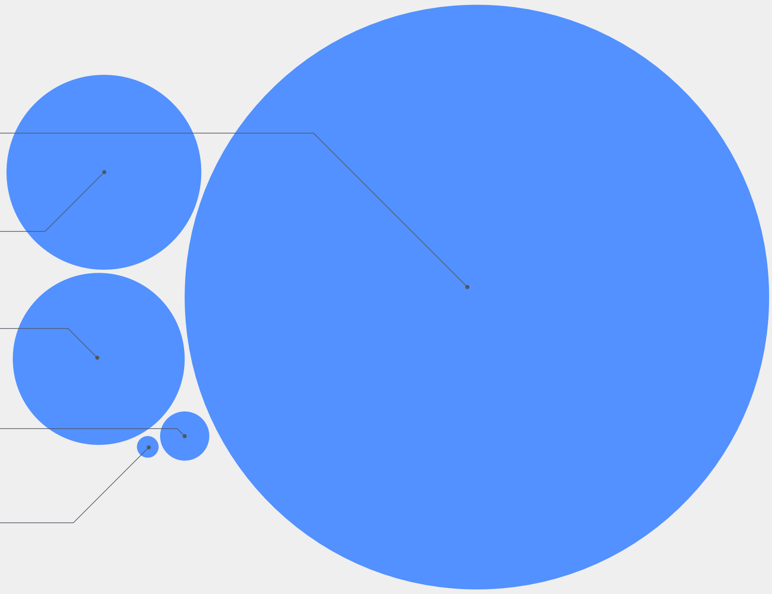
Rank	Country	Funding
1	United States	$372 million
2	United Kingdom	$39 million
3	Switzerland	$14 million
4	Czechia	$6 million
5	Finland	$4 million

Top five countries by academic grant funding

Leading-edge industries

Industries with the most funding in privacy-enhancing technologies from 2021-2023

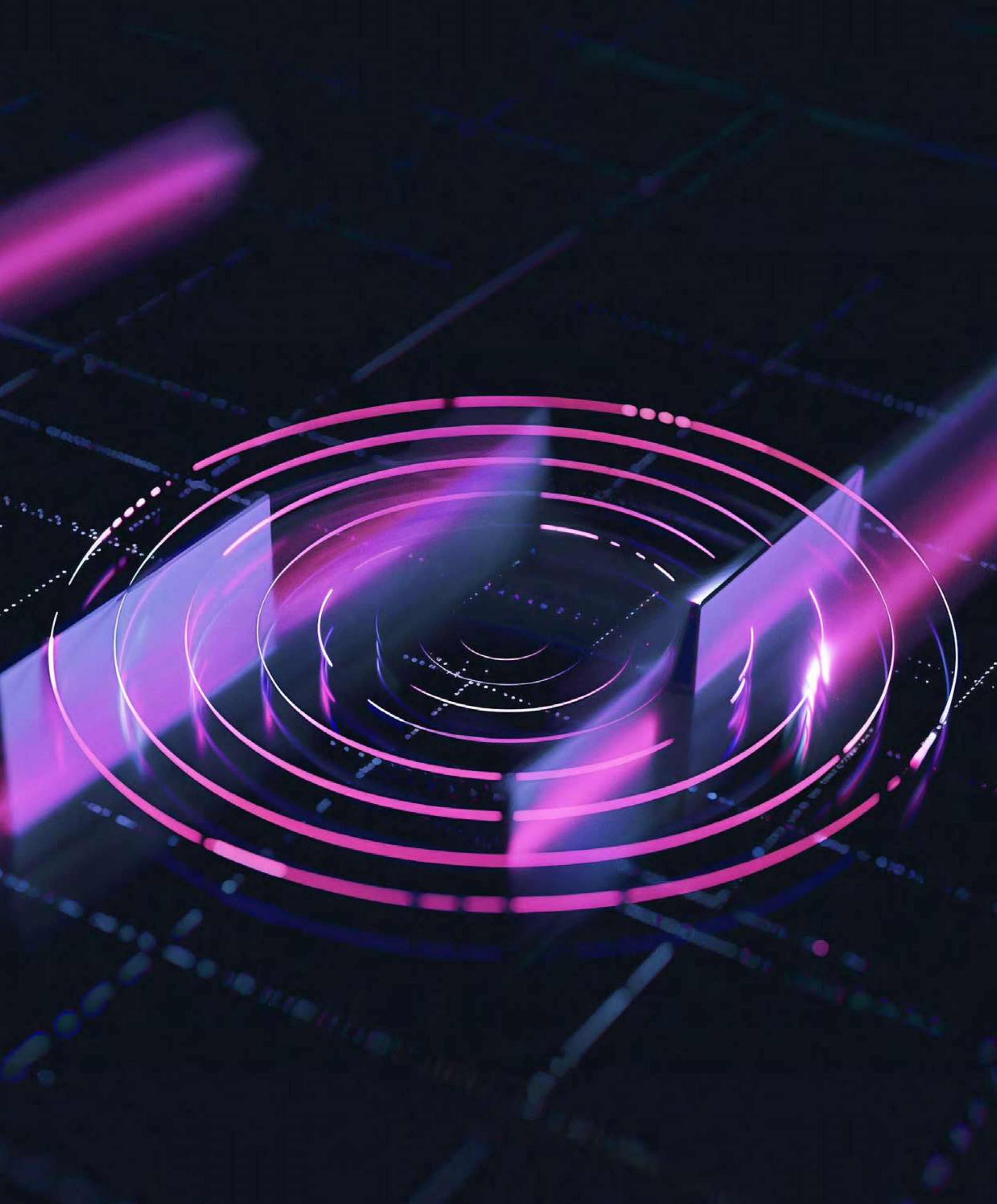
Industry	Funding
Internet	$5.1 billion
Software	$1.7 billion
Electronics	$1.5 billion
Healthcare	$429 million
Industrials	$189 million



03

Reconfigurable intelligent surfaces

Transforming wireless connectivity with smart mirrors



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Global demand for higher data rates, lower latency and energy-efficient connectivity is skyrocketing.[12] The highly anticipated launch of 6G by 2030 is expected to intensify this pressure even further. To meet these challenges, future networks will need to be engineered for enhanced capacity and connectivity and with a strong focus on environmental sustainability. Enter reconfigurable intelligent surfaces (RIS), platforms that use metamaterials, smart algorithms and advanced signal processing to turn ordinary walls and surfaces into intelligent components for wireless communication.

Akin to the idea of "smart mirrors", RIS enable the precision focusing control of electromagnetic waves, reducing interference and the need for high transmission power. Equally, RIS are highly adaptive and can dynamically adjust configurations according to real-time demands. This adaptability enables efficient use of resources and enhances energy efficiency in wireless networks.[13,14,15]

The development of hardware platforms and a surge in experimental initiatives in the field of RIS have drawn considerable interest from telecommunication stakeholders keen on exploring its potential for next-generation wireless networks. A significant milestone was the effective integration of RIS into existing wireless networks. Several RIS platforms have showcased the technology's impressive capabilities from a hardware perspective.[16]

The growth of RIS is likely to impact several industrial sectors broadly.[17] For example, tailored radio wave propagation in smart factories can ensure reliable communication in a highly complex environment. RIS allow sensors to transmit data with minimal power for the internet of things (IoT), which demands considerable energy. For vehicular networks, RIS enhance safety by enabling robust communications between vehicles and infrastructure. To improve coverage in agricultural settings, RIS are a promising solution with low energy consumption and high-cost efficiency.[18]

Market intelligence reports suggest RIS are on the cusp of exponential adoption and growth. Several companies, including Rhode & Schwarz, Huawei, ZTE, Intel and Samsung, are all investing in RIS, sending a strong signal that RIS will be central to the telecommunications landscape in the coming years.[19]

Before this happens, however, several outstanding challenges will have to be addressed, including high hardware costs and the need for clear standards and regulations on the secure and ethical use of the technology.[20]

> “
> RIS are highly adaptive and can dynamically adjust configurations according to real-time demands. This adaptability enables efficient use of resources and enhances energy efficiency in wireless networks.

↑ **Image:**
RIS enhance data rates and energy efficiency while reducing interference and are critical to next-generation wireless networks.

Credit: Midjourney and Studio Miko.

Prompt (abbreviated): "Close up 3D render of modular wireless transmitter"

Read more:
For more expert analysis, visit the RIS transformation map.

Regions of innovation

Countries with the most business and academic grant funding in reconfigurable intelligent surfaces from 2021-2023

Top five countries by business funding

Rank	Country	Funding
1	United States	$43 billion
3	United Kingdom	$5.1 billion
4	Sweden	$3.7 billion
2	China	$18 billion
5	Australia	$2.1 billion

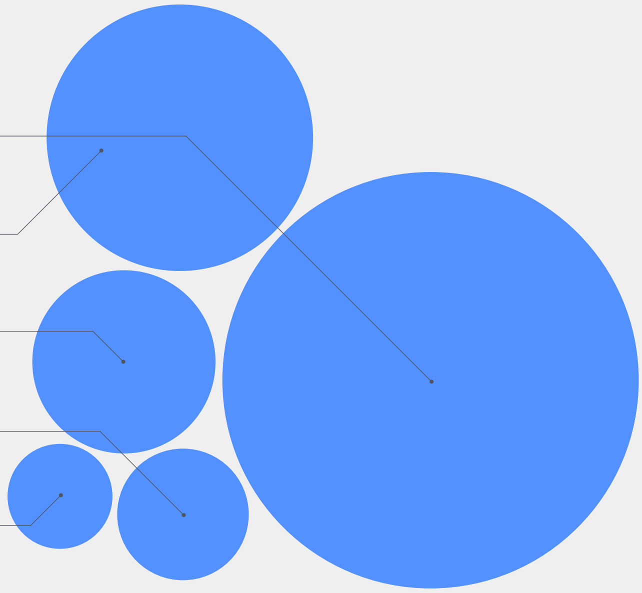
Rank	Country	Funding
5	Canada	$23 million
1	United States	$519 million
2	United Kingdom	$94 million
4	Norway	$30 million
3	China	$49 million

Top five countries by academic grant funding

Leading-edge industries

Industries with the most funding in reconfigurable intelligent surfaces from 2021-2023

Industry	Funding
Mobile and telecommunications	$25 billion
Software	$16 billion
Internet	$11 billion
Energy and utilities	$7.9 billion
Electronics	$6.3 billion



04

High altitude platform stations

Bridging the internet divide from the stratosphere

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Mariette DiChristina
Dean and Professor, Practice in Journalism, Boston University College of Communication

High altitude platform stations (HAPS) operate at stratospheric altitudes, approximately 20 kilometres above Earth. Typically taking the form of balloons, airships, or fixed-wing aircraft, they offer a stable platform for observation and communication and can operate for months. Advances in solar panel efficiency, battery energy density, lightweight composite materials, autonomous avionics and antennas, coupled with the expansion of frequency bands and new aviation standards, make HAPS viable in the near term. HAPS can deliver connectivity, coverage and performance enhancements that neither satellites nor terrestrial towers can match, particularly in areas with difficult terrains such as mountains, jungles or deserts.[21]

Access to the connected world serves as a bridge to the future, creating pathways to prosperity and new educational possibilities as well as strengthening the fabric of social connectivity. Yet, according to the International Telecommunication Union (ITU), about one-third of people worldwide remain offline. Women and older adults are disproportionally affected.[22] A key component in addressing this challenge is better infrastructure.

HAPS could improve connectivity for communities underserved by traditional communications infrastructure, particularly in remote areas. The COVID-19 pandemic highlighted the critical nature of internet access, revealing how disparities in connectivity perpetuate socioeconomic inequalities. By bridging this digital divide, HAPS technology could enable access to educational, healthcare and economic opportunities.

In addition to providing internet access, these adaptable platforms can play an important role in various critical applications, from supporting disaster management to enhancing broadband coverage and environmental monitoring. The ability of HAPS to quickly deploy and adapt to changing conditions could make them an invaluable tool in managing emergencies, where timely information and communication can save lives.[23]

Investment in HAPS from aerospace engineering leaders has created advancements in materials, propulsion systems and solar cell technology.[24] HAPS are now economically viable for commercial and real-world deployment. Organizations with extensive knowledge in and resources for developing reliable, long-endurance HAPS have aided its evolution and role in the future of communications infrastructure.

Industry examples include the Airbus Zephyr, Thales' Stratobus and Boeing Aurora projects. Lower latency, reduced costs, higher capacity, easy hardware upgrades and faster deployment are attractive commercial propositions. The market size was valued at $783.3 million in 2023 and is expected to grow at a compound annual growth rate of 10.4% from 2023 to 2033.[25]

However, HAPS, operating at stratospheric altitudes for extremely long durations, are different from traditional crewed aircraft in several ways, and current regulatory frameworks are not fit for purpose. Organizations such as the International Civil Aviation Organization (ICAO) are actively discussing new policies and guidance to enable the responsible deployment of HAPS.[26]

> HAPS can deliver connectivity, coverage and performance enhancements that neither satellites nor terrestrial towers can match, particularly in areas with difficult terrains such as mountains, jungles or deserts.

↑ **Image:**
HAPS provide enhanced, long-term connectivity and communication in remote and underserved areas.

Credit: Midjourney and Studio Miko.

Prompt (abbreviated): "High altitude scientific aerospace balloon. Digital signal connectivity"

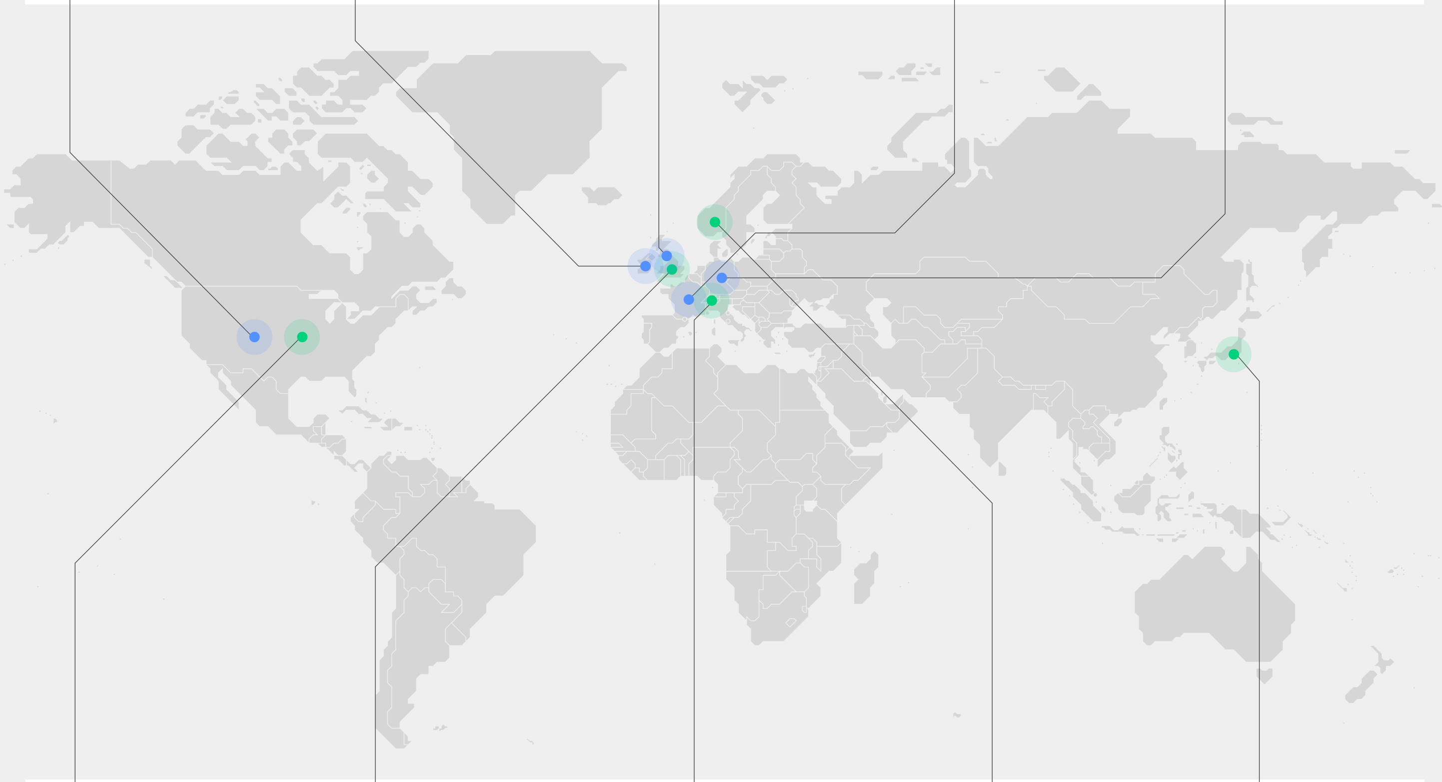
Read more:
For more expert analysis, visit the HAPS transformation map.

Regions of innovation

Countries with the most business and academic grant funding in high altitude platform stations from 2021-2023

Top five countries by business funding

Rank	Country	Funding
2	United States	$447 million
5	Ireland	$190 million
3	United Kingdom	$251 million
4	France	$222 million
1	Germany	$636 million



Rank	Country	Funding
1	United States	$78 million
2	United Kingdom	$14 million
3	Switzerland	$5 million
4	Norway	$4 million
5	Japan	$3 million

Top five countries by academic grant funding

Leading-edge industries

Industries with the most funding in high altitude platform stations from 2021-2023

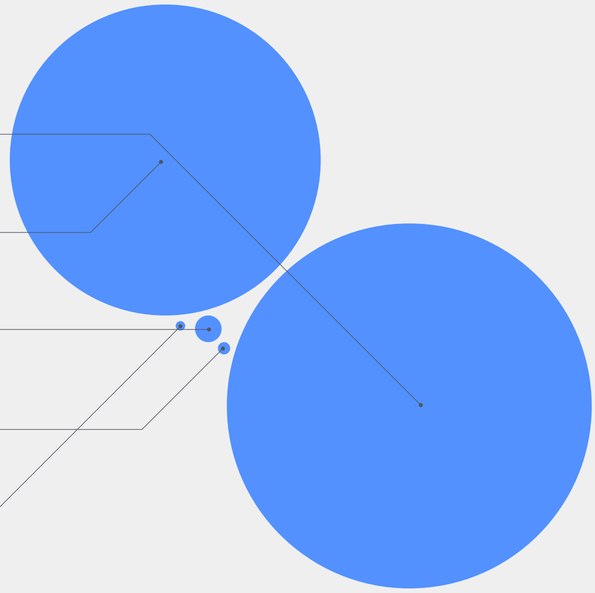
Automotive and transport $1 billion

Industrials $887 million

Software $76 million

Business products and services $35 million

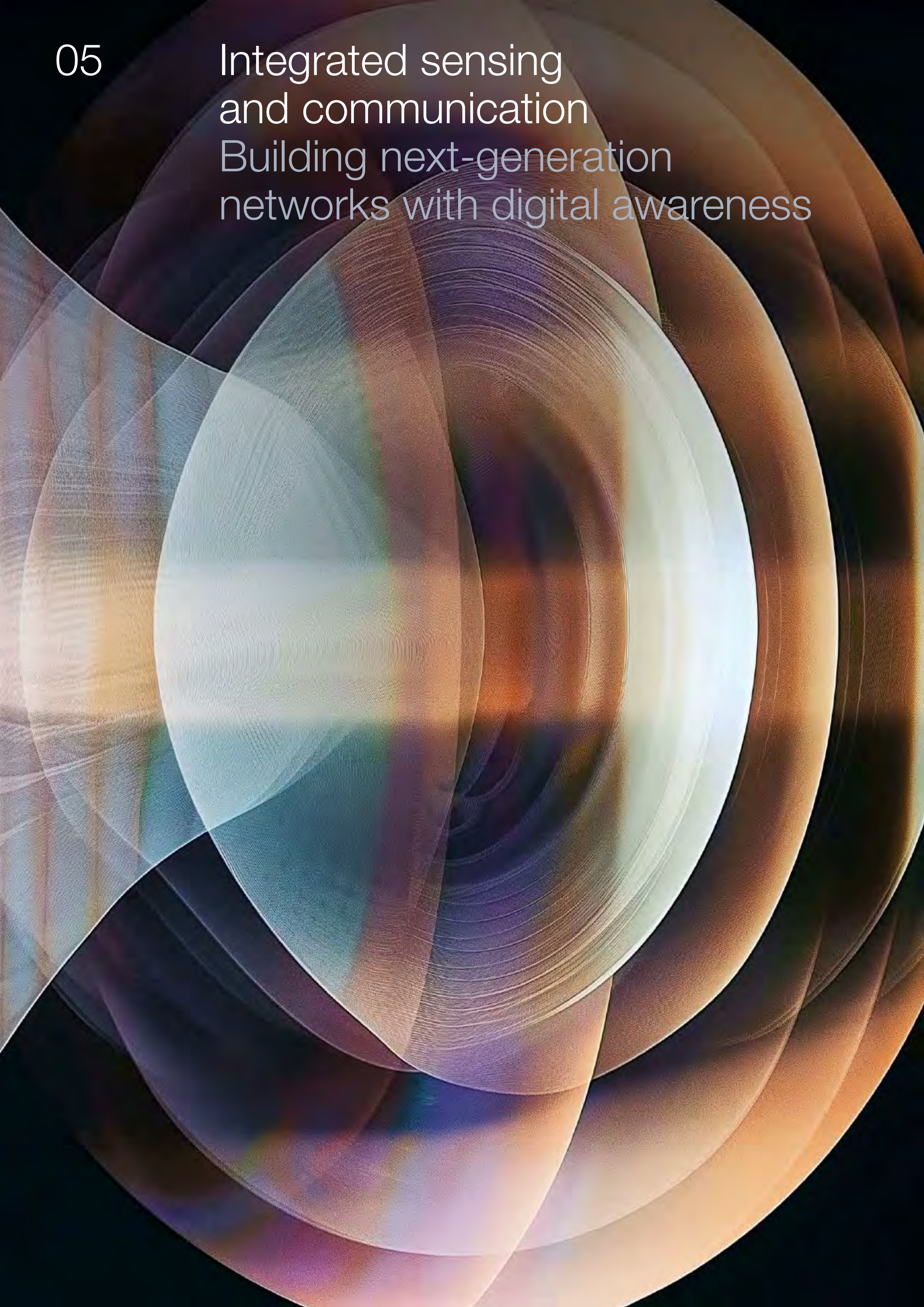
Mobile and telecommunications $27 million



05

Integrated sensing and communication

Building next-generation networks with digital awareness



Mohamed-Slim Alouini
Al-Khwarizmi Distinguished Professor, Electrical and Computer Engineering, King Abdullah University of Science and Technology

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Decades of separate development in sensing and communications technologies have resulted in a surplus of devices with overlapping functions, leading to device congestion, spectrum inefficiency and financial loss.[27] Integrated sensing and communications (ISAC) addresses this by bringing sensing and communication capabilities into a single system, facilitating simultaneous data collection and transmission. This integration optimizes hardware, energy and cost efficiency while also enabling novel applications beyond conventional communication paradigms.[28]

ISAC makes wireless networks environment-aware, enabling capabilities like localization, environment mapping and infrastructure monitoring. Examples of this include environmental monitoring systems that use sensors and data analytics to monitor air and water quality, soil moisture and weather conditions. These systems help in smart agriculture, environmental conservation and urban planning. Additionally, smart grids integrate sensors and communication technologies into power grids, enhancing efficiency and reliability while enabling the monitoring of electricity consumption and generation.[29,30]

The adoption of ISAC also promises to render device utilization more sustainable. Potential benefits include reduced energy and silicon consumption alongside improved options for device reuse, recycling or repurposing.[31]

Optical-wireless ISAC technology represents a particularly exciting advancement. By integrating sensing and communication capabilities, lighting and display systems can seamlessly become part of the wireless ecosystem. Illuminated surfaces can serve as network nodes, facilitating communication and sensing without electromagnetic interference. This is especially advantageous in sensitive environments such as smart healthcare and industrial manufacturing.[32]

However, the realization of ISAC's potential hinges on surmounting technical hurdles, establishing communication standards and ensuring network-level coordination. Its success will be gauged by its adoption across various industries, from connected cars to e-health.[33] This underscores the imperative for ongoing innovation and collaboration in this field.

> ISAC makes wireless networks environment-aware, enabling capabilities like localization, environment mapping and infrastructure monitoring.

↑ Image:
ISAC combine data collection and transmission into a single system, optimizing efficiency and enabling innovative applications.

Credit: Midjourney and Studio Miko.

Prompt (abbreviated): "Overlapping, pulsing sound waves"

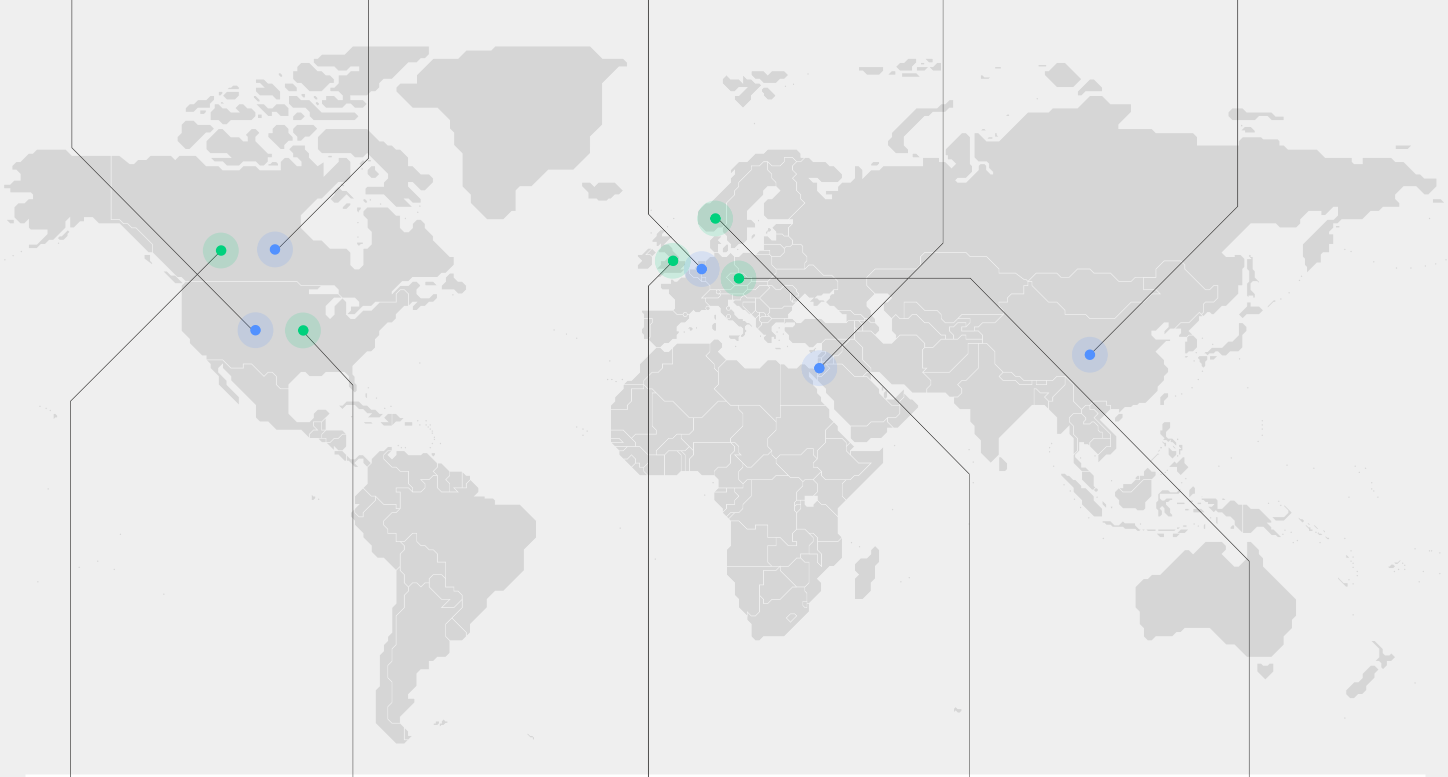
Read more:
For more expert analysis, visit the ISAC transformation map.

Regions of innovation

Countries with the most business and academic grant funding in integrated sensing and communication from 2021-2023

Top five countries by business funding

Rank	Country	Funding
1	United States	$5.2 billion
5	Canada	$221 million
2	Netherlands	$1.2 billion
4	Isreal	$507 million
3	China	$665 million



Rank	Country	Funding
4	Canada	$11 million
1	United States	$325 million
3	United Kingdom	$12 million
2	Norway	$19 million
5	Czechia	$5 million

Top five countries by academic grant funding

Leading-edge industries

Industries with the most funding in integrated sensing and communication from 2021-2023

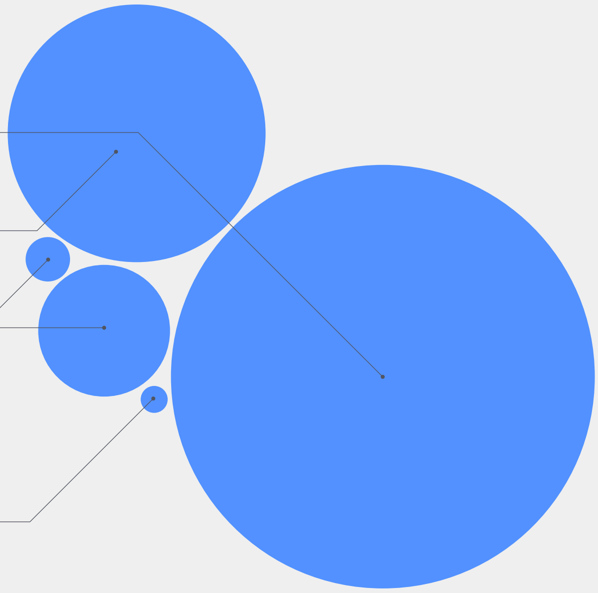
Internet $3.9 billion

Electronics $2.4 billion

Mobile and telecommunications $1.2 billion

Computer hardware $412 million

Software $250 million



06

Immersive technology for the built world

Laying new foundations for construction and maintenance

Carlo Ratti
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Massachusetts Institute of Technology

Landry Signe
Professor, Thunderbird School of Global
Management, Arizona State University

Izuru Takewaki
President and Professor, Kyoto Arts and Crafts
University Professor Emeritus of Architectural
Engineering, Kyoto University

As major tech platforms search for utility in the metaverse, one industry stands poised for transformation: construction. Immersive and AI-driven immersive reality tools for the built world allow designers and construction professionals to check the congruence between the physical and digital, ensuring accuracy and safety and advancing sustainability.

Construction is one of the world's largest and most impactful industries, contributing 40% of global carbon dioxide (CO_2) emissions.[34] Despite its immense footprint, the industry has been slow to embrace the digital revolution. However, immersive technology holds the promise of transforming this landscape.

Immersive design experiences help anticipate the challenges that could evolve during construction by testing hypotheses, identifying potential errors and providing solutions before construction starts. Virtual prototyping and experimentation increase accuracy. Digital twins, already in widespread industrial use, could be used to simulate outcomes of far more complex proposals for urban development projects, better develop infrastructure and serve constituents, and allow greater efficiency and effectiveness. Crucially, this would streamline the construction process from design to implementation, allowing waste to be identified and eliminated, improving both efficiency and sustainability.[35]

Equally, for an industry that is booming, a skill and labour shortage is emerging to the point where supply is now critically low. In the US alone, the national trade association Associated Builders and Contractors estimates that in 2025, the industry will need to bring in nearly 454,000 new workers on top of normal hiring to meet industry demand.[36] The metaverse has the potential to mitigate skill and labour shortages through the creation of immersive learning and training environments, regardless of location, for professionals in the architecture, engineering and construction industries.[37]

The metaverse also stands to improve efficiencies in upkeep and inspection. A Japanese construction company, for example, estimates that nationwide, one million hours are spent simply travelling to inspections.[38] If the metaverse provides robust and reliable remote inspection capabilities, these million hours could be reallocated towards other critical work.

Arguably, the next leap forward in this field will be the incorporation of generative AI, with text-to-building information modelling possibly converting textual prompts directly into detailed, three-dimensional building models, encompassing construction specifications, safety information and other metadata.[39]

Although risks may include privacy and access to energy, especially in the developing world, a proactive and collaborative approach will encourage innovation while making it inclusive and safe. The promise to reduce the gap between conceptualization and implementation might end up rendering obsolete some of the most technical professional figures in the design field, calling for novel training paths and upskilling programmes.

“

Crucially, this would streamline the construction process from design to implementation, allowing waste to be identified and eliminated, improving both efficiency and sustainability.

↑ Image:
Immersive technology transforms construction by integrating digital and physical worlds, enhancing accuracy, safety and sustainability.

Credit: Midjourney and Studio Miko.

Prompt (abbreviated):
“Brightly blue coloured cross section of a skyscraper”

Read more:
For more expert analysis, visit the immersive technology transformation map.

Regions of innovation

Countries with the most business and academic grant funding in immersive technology for the built world from 2021-2023

Top five countries by business funding

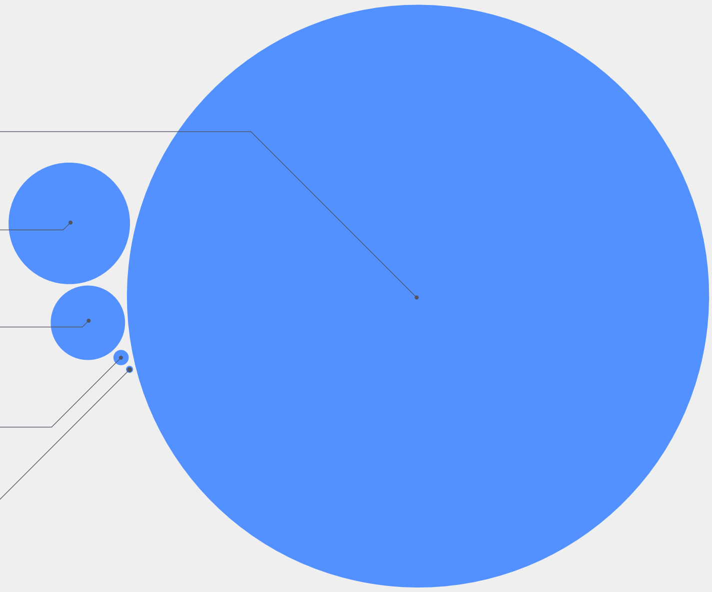
1	**United States**	$21.2 billion
3	**Canada**	$838 million
4	**United Kingdom**	$604 million
5	**Kenya**	$506 million
2	**China**	$2 billion

1	**United States**	$611 million
2	**United Kingdom**	$323 million
4	**Switzerland**	$49 million
3	**Norway**	$61 million
5	**Czechia**	$15 million

Top five countries by academic grant funding

Leading-edge industries

Industries with the most funding in immersive technology for the built world from 2021-2023



Internet	$18 billion
Industrials	$3.8 billion
Software	$2.3 billion
Mobile and telecommunications	$472 million
Computer hardware	$220 million

07

Elastocalorics

Powering heat systems to work like muscles

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Wilfried Weber

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As global temperatures rise, the need for cooling solutions is set to soar. The International Energy Agency (IEA) estimates that the global energy demand for space cooling will more than triple over the next 30 years, accounting for about 37% of global electricity demand growth by 2050.[40] Elastocaloric heat pumps are an innovative technology that can drastically reduce the energy required for heating and cooling several times over.[41]

The potential impact of elastocaloric heat pumps, particularly in the context of heightening demand for cool air, is substantial. A US Department of Energy study ranks them as the most promising alternative to current systems.[42] The heart of this technology is elastocaloric materials, which emit heat when subjected to mechanical stress and cool down when the stress is relaxed. This allows them to operate on a continuous stress and relaxation cycle. The added benefit of elastocaloric heat pumps is that they do not rely on refrigerant gases, which are potentially damaging to the environment. Instead, they make use of widely available metals like nickel and titanium.

Taken together, the environmental impact of catering to emerging energy requirements for temperate control can be significantly reduced by elastocaloric technology. Socially, this technology can enhance access to cooling in regions with limited or no grid-based electricity, thereby improving quality of life and addressing a key aspect of climate change impact.[43]

Research and development in the field is advancing quickly, with the rate of scientific publications doubling every 22 months. The surge in patent applications, with automotive and cooling industries taking the lead, underscores the growing commercial interest in this technology. On the technological side, there has been steady improvement in materials and device designs; new prototypes are able to demonstrate what elastocaloric heat pumps can achieve. Similarly, universities and businesses have introduced several functional elastocaloric heat pump models, exploring the use of complementary materials and innovative production techniques.[44]

Scaling elastocaloric heat pumps involves overcoming some big hurdles. These pumps need materials that can last through millions of cycles of being stretched and relaxed without breaking down – a process that's being tackled by experimenting with different metal alloys and manufacturing techniques. Engineers are working on systems that can efficiently move energy using hydraulics to help squeeze or stretch materials, which can trigger heating or cooling.[45]

Additionally, for these heat pumps to become widely available, the production of these materials needs to scale up significantly to align with the constantly increasing demand for cooling that has been forecast in the face of global warming. However, with growing commercial interest and technological innovation, the future looks promising for the widespread adoption of elastocaloric heat pumps, ushering in a new era of efficient and environmentally friendly cooling solutions.

> “
>
> The environmental impact of catering to emerging energy requirements for temperature control can be significantly reduced by elastocaloric technology.

↑ Image:
Elastocalorics offer a groundbreaking cooling solution, drastically reducing energy use without harmful refrigerants.

Credit: Midjourney and Studio Miko.

Prompt (abbreviated): “Close up 3D render of metal bending. Releasing heat”

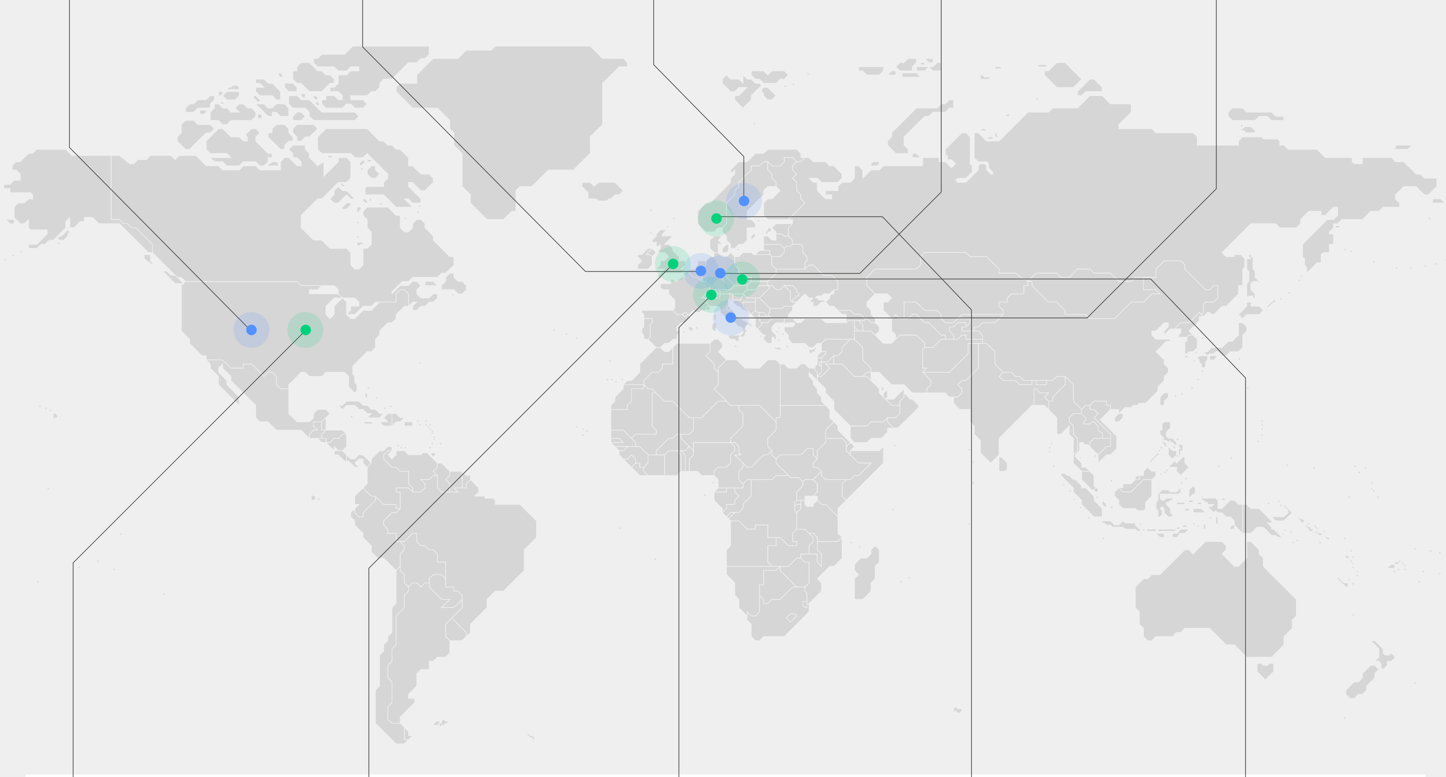
Read more:
For more expert analysis, visit the elastocalorics transformation map.

Regions of innovation

Countries with the most business and academic grant funding in elastocalorics from 2021-2023

Top five countries by business funding

2	**United States**	$1.1 billion
4	**Netherlands**	$475 million
1	**Sweden**	$3.7 billion
5	**Germany**	$443 million
3	**Italy**	$555 million



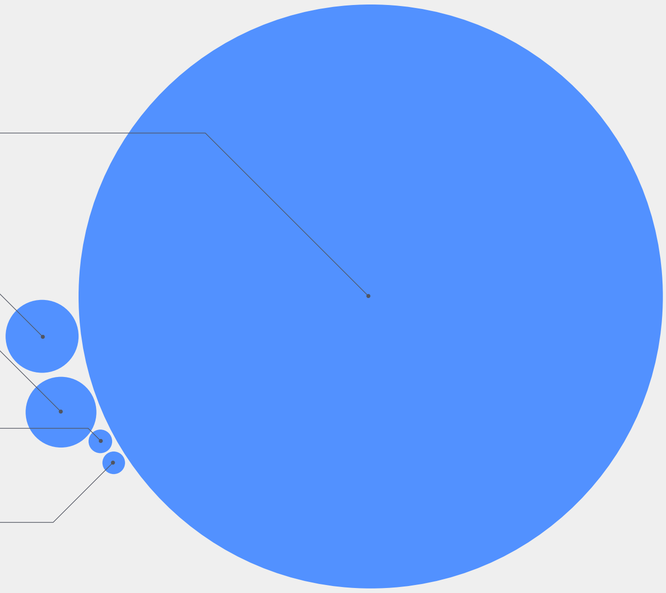
1	**United States**	$295 million
2	**United Kingdom**	$171 million
4	**Switzerland**	$11 million
3	**Norway**	$12 million
5	**Czechia**	$8 million

Top five countries by academic grant funding

Leading-edge industries

Industries with the most funding in elastocalorics from 2021-2023

Energy and utlities	$5.3 billion
Automotive and transport	$662 million
Industrials	$642 million
Business product and services	$214 million
Internet	$205 million



08

Carbon-capturing microbes

Engineering organisms to convert emissions into valuable products

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Zequn Yang
Associate Professor, School of Energy Science
and Technology, Central South University

Amid the urgency of climate change, a silent revolution brews: microorganisms are being used to capture greenhouse gases from air or exhaust gases and convert them into high-value products. To drive this process, the organisms use sunlight or chemical energy such as hydrogen. Engineering the organisms promises a wide palette of sustainable products while simultaneously reducing global warming.

Microbial carbon capture is emerging as a promising strategy to control atmospheric CO_2 and mitigate global warming.[46] Simultaneously, it can produce various products with significant market potential, such as fuels, fertilizers and animal feed. To achieve this, researchers are developing microorganisms – including bacteria and microalgae – that use sunlight or sustainable chemical energy to absorb and transform gases.

There are two main designs for microbial carbon capture. The first, photobioreactors, use photosynthetic organisms like cyanobacteria and microalgae to capture CO_2, employing sunlight to process CO_2-laden gas bubbled through a bath containing such organisms. The second is when microorganisms capture CO_2 by using energy from sources like hydrogen, organic waste streams or other chemicals derived from CO_2 using renewable energy.[47] Regardless of whether they use sunlight or chemicals for energy, both systems modify organisms to convert CO_2 into new products, such as biodiesel or protein-rich animal feed.[48] The product value of each system varies significantly; the choice between which system to use depends on the specific needs and capabilities of the implementing company, such as available resources. This also means that companies could, once implemented, generate new products for the market instead of paying between $50 and $100 per tonne of CO_2 to offset their emissions.

The technology is driven by organizations specializing in cell modification to boost specific substance production.[49] Following a series of successful demonstrations and proofs-of-concept, microbial carbon capture is now ready to transition from pilot to full-scale production. By 2022, global investment in the technology had already reached $6.4 billion, highlighting its readiness to be brought to market.[50] Companies such as Seambiotic in Israel, Alga Energy in Spain and Bio Process Algae in the US have deployed pilot-scale facilities to explore the commercial viability of microbial carbon capture systems.

Despite significant progress, microbial carbon capture systems still face challenges that hinder their widespread adoption and commercialization. Firstly, microorganisms are mostly adapted to low-temperature conditions and are less effective in capturing CO_2 from hot industrial exhaust gases. Additional energy consuming cooling facilities are needed. Optimization requires investigating how to improve microbial resistance to industrial exhaust levels of heat, as well as resistance against acidic impurities.[51] Secondly, existing microbial carbon capture systems are still very expensive.[52] However, the high value of the products could offset at least part of this cost. Lastly, production sites need an abundance of sunlight and access to renewable or clean energy, which is not guaranteed across all global regions.[53] Only when these challenges are overcome will the full potential of the technology be realized as part of the global effort to achieve a net-zero emission world.

> “
> Companies could, once implemented, generate new products for the market instead of paying between $50 and $100 per tonne of CO_2 to offset their emissions.

↑ **Image:** Microorganisms engineered to capture carbon can convert greenhouse gases into valuable products like fuels and fertilizers.

Credit: Midjourney and Studio Miko.

Prompt (abbreviated): “Bright individual green DNA encased in a square grid.

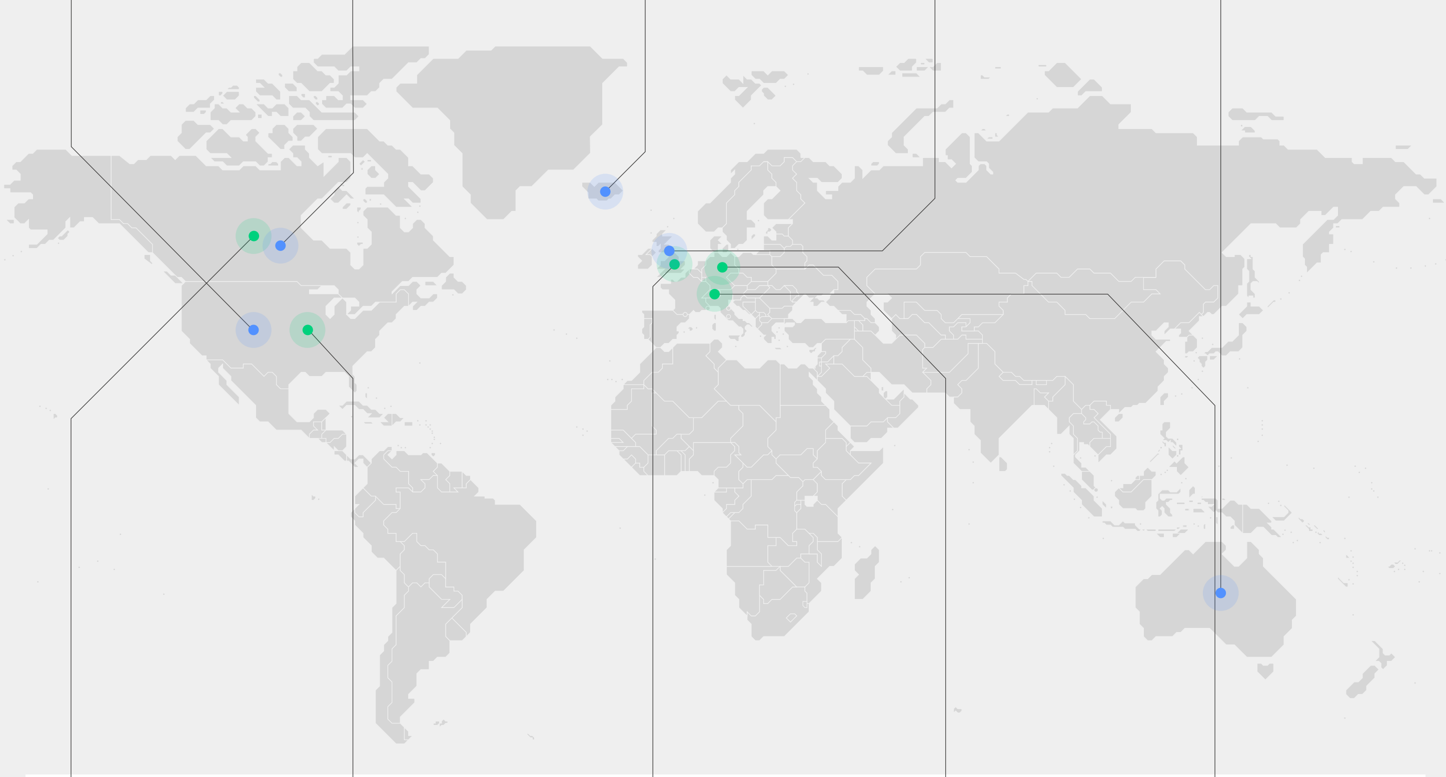
Read more: For more expert analysis, visit the microbial carbon capture transformation map.

Regions of innovation

Countries with the most business and academic grant funding in carbon-capturing microbes from 2021-2023

Top five countries by business funding

1	United States	$3.3 billion
2	Canada	$445 million
4	Iceland	$150 million
3	United Kingdom	$247 million
5	Australia	$125 million



5	Canada	$5 million
1	United States	$317 million
2	United Kingdom	$23 million
4	Germany	$5 million
3	Switzerland	$7 million

Top five countries by academic grant funding

Leading-edge industries

Industries with the most funding in carbon-capturing microbes from 2021-2023

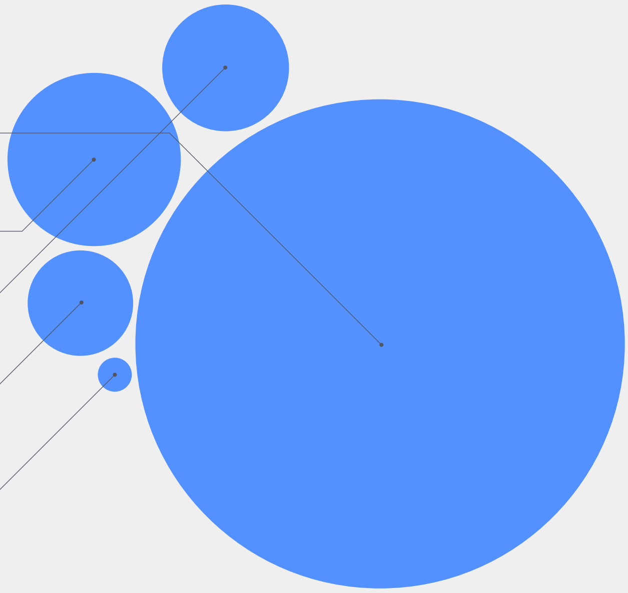
Environmental services $2.4 billion

Agriculture $846 million

Energy and utilities $619 million

Healthcare $515 million

Internet $166 million



09

Alternative livestock feeds

Revolutionizing animal nutrition for sustainability

Mariette DiChristina
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Javier Garcia-Martinez
Professor, Chemistry and Director, Molecular Nanotechnology Lab, University of Alicante

Alternative livestock feeds offer sustainable solutions to address the growing demand for protein in animal agriculture. These feeds, sourced from insects, single-cell proteins, algae and food waste, provide viable alternatives to traditional ingredients like soy, maize and wheat.[54]

Feed alternatives offer substantial sustainability improvements. Currently, nearly 80% of soy production is used as animal feed, leading to significant negative environmental consequences.[55] This demand drives deforestation, biodiversity loss, over-fertilization and greenhouse gas emissions from land-use changes. Transitioning to alternative livestock feeds could mitigate these challenges and promote more environmentally sustainable practices in animal agriculture.

A further advantage of alternative animal feed is the diversity and nutritional value it adds, which can play a critical role in protecting animal welfare. It can offer a broader range of nutrients than conventional feeds, improving animal health and well-being and, potentially, the quality of the produce itself.[56] For instance, insects can be produced on an industrial scale to yield high-quality protein, while single-cell proteins or algae can supply essential proteins and fats for several species of animals. Additionally, capturing human food waste or using ingredients like algae, azolla, chickpeas and orange pulp are emerging as promising alternatives.[57]

The cost-benefit of these alternative sources is also a key factor. They are often cheaper to produce and obtain. The use of black soldier fly larvae (BSFL) is an example; studies show that adding BSFL into animal diets can reduce the costs associated with feed. This is primarily because BSFL can be cultivated from organic waste, reducing the need for traditional, more expensive feed ingredients like fish meal or soybean meal.[58]

The market for alternative ingredients to feed livestock is vibrant, and multiple companies worldwide have now successfully introduced quality alternative options.[59] In 2023, the global animal feed alternative protein market was valued at $3.96 billion. It is projected to significantly grow in value over the next decade, increasing to $8.2 billion by 2033.[60]

Alternative animal feed is, however, more than a one-size-fits-all solution. Its feasibility varies based on local availability, manufacturing costs and environmental and social conditions. Other challenges, including environmental regulations, ethical concerns and competition, remain. Sustainable feed resources are increasingly competing with sustainable fuel production, for example. This competition could limit the availability of livestock feeds, potentially driving up prices and hindering widespread adoption. The future success of the alternative animal feed industry depends on its ability to navigate these challenges and adapt to the demand for more sustainable and efficient feed options.

> “
>
> Transitioning to alternative livestock feeds could promote more environmentally sustainable practices in animal agriculture.

↑ **Image:**
Alternative livestock feeds provide sustainable and nutritious alternatives to traditional animal feed, and reduce environmental impact.

Credit: Midjourney and Studio Miko.

Prompt (abbreviated): “Single-cell, algae”

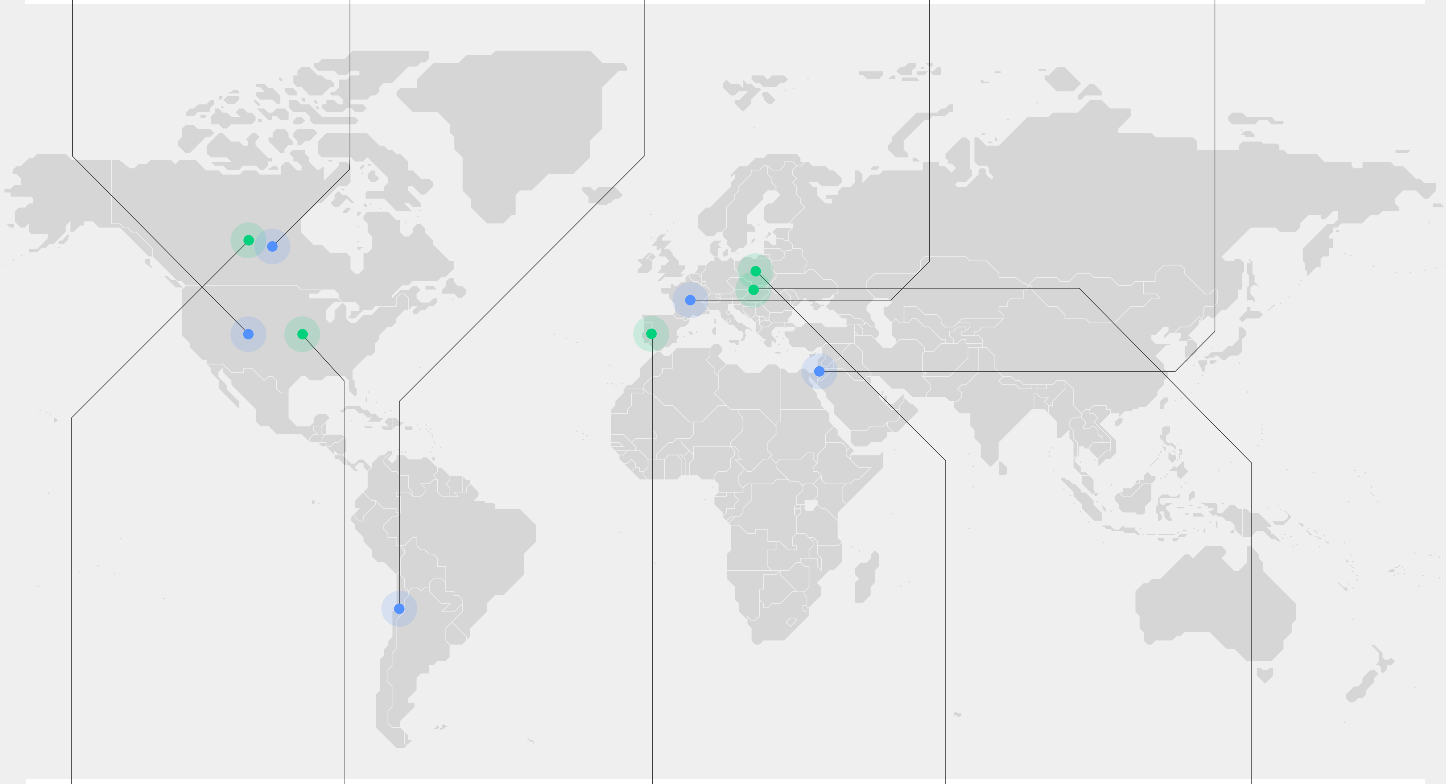
Read more:
For more expert analysis, visit the alternative livestock feeds transformation map.

Regions of innovation

Countries with the most business and academic grant funding in alternative livestock feeds from 2021-2023

Top five countries by business funding

Rank	Country	Funding
1	**United States**	$8,168 million
5	**Canada**	$676 million
4	**Chile**	$733 million
2	**France**	$2,251 million
3	**Israel**	$1,000 million



Rank	Country	Funding
4	**Canada**	$0.9 million
1	**United States**	$12 million
2	**Portugal**	$2 million
3	**Poland**	$1 million
5	**Slovakia**	$0.6 million

Top five countries by academic grant funding

Leading-edge industries

Industries with the most funding in alternative livestock feeds from 2021-2023

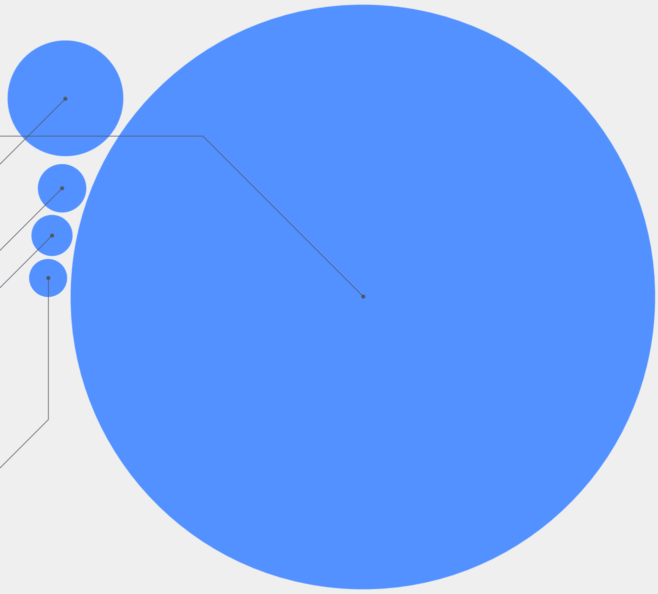
Food and beverage $11 billion

Agriculture $2.2 billion

Internet $920 million

Healthcare $781 million

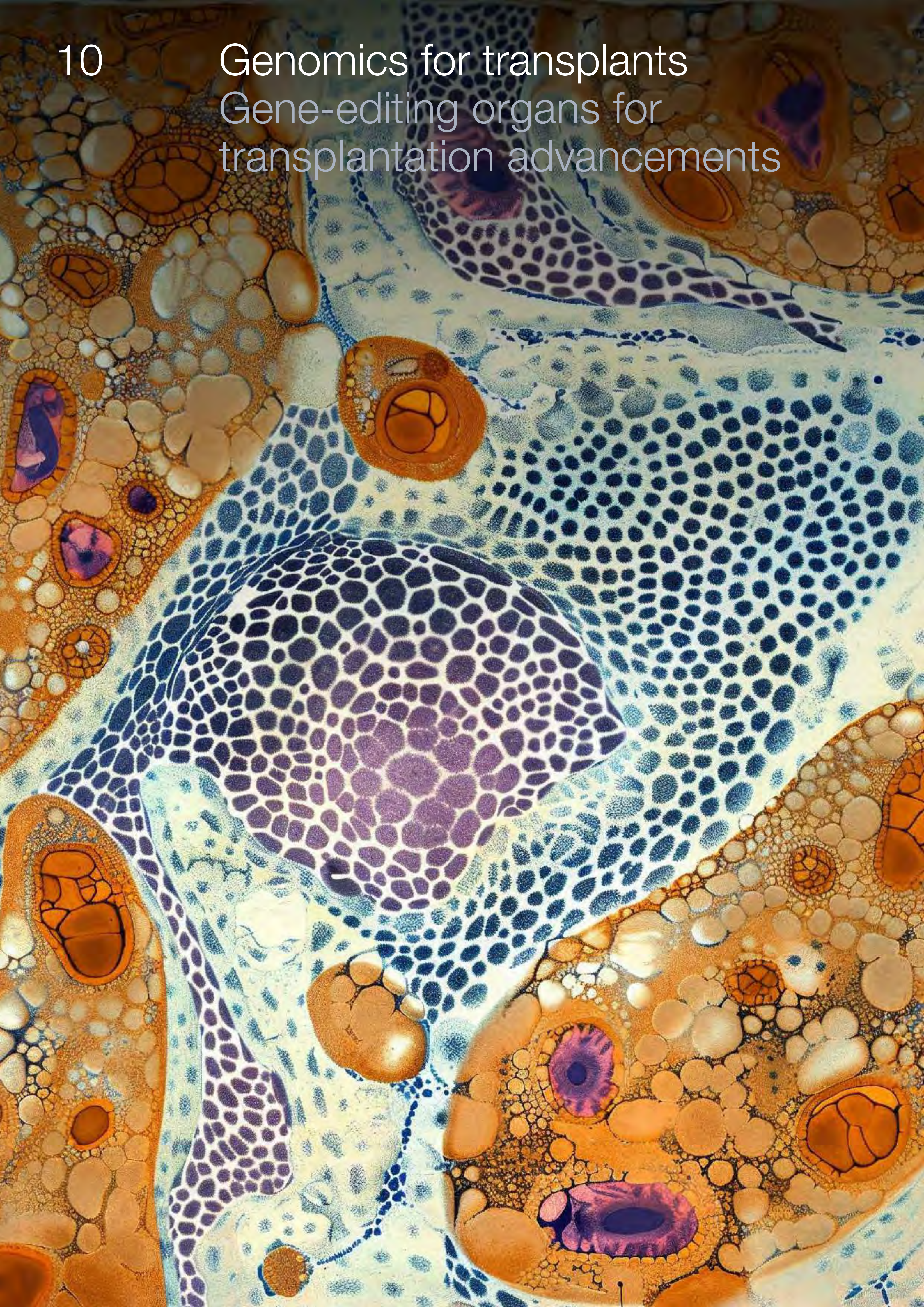
Consumer products and services $722 million



10

Genomics for transplants

Gene-editing organs for transplantation advancements



David K Cooper

Senior Investigator, Center for Transplantation Sciences, Massachusetts General Hospital, Harvard Medical School

Emanuele Cozzi

Professor, Transplantation Immunology, Padua University Hospital

Geoffrey Ling

Professor, Neurology, Johns Hopkins Hospital

Bernard Meyerson

Chief Innovation Officer Emeritus, IBM

Organ transplantation, a significant advancement in medicine during the latter half of the 20th century, has continued to progress. This ongoing evolution was underscored by a remarkable milestone in March 2024: the first successful transplantation of a non-human (pig) kidney into a living human recipient.[61] This progress is driven by fundamental enablers such as our ability to understand and precisely edit the genome.

Organ transplants save lives – but the need far outstrips the available donor pool. In the US alone, more than 100,000 patients are awaiting an organ transplant, and yet only approximately 30,000 organs will become available this year.[62]

To meet this need, for more than three decades, steady progress has been made in the science dealing with the transplantation of organs from animals into humans. Thanks to technology like CRISPR-Cas9, it is now possible to create multiple genetic manipulations in a single pig to overcome the immunological (rejection) barrier. These include inserting genes that may impact the function of the transplanted pig organ and deleting genes for viruses that might infect the patient who receives a pig graft. While some pigs have undergone as many as 69 gene edits, the majority have approximately 10 gene edits.[63]

This ability to understand and precisely edit the genome, coupled with novel immunosuppressive drug regimens, has enabled the survival of non-human primates with life-supporting pig kidneys or hearts for periods now extending months or even years in the case of kidney transplantation.

Furthermore, understanding genomes offers much more than organs for transplantation. Over one million patients in the US have type 1 diabetes (juvenile diabetes), and an estimated 30 million have type 2 diabetes, which could be cured by the transplantation of pig pancreatic islet cells (which produce insulin).[64] There are over one million patients in the US with debilitating Parkinson's disease; implanting specialized pig cells could improve their condition.[65]

If "xenotransplantation", or the transplantation of organs from animals into humans, becomes a common form of therapy, it would impact not only the quality of life of millions of patients but could also bring about changes in the healthcare economy. For example, there could be significant reductions in the number of staff involved in dialysis programmes and an increase in those involved in all aspects of organ and cell transplantation, including pig breeding. Although xenotransplantation will initially be expensive, it might soon prove less costly than maintaining a patient on long-term dialysis or a patient with heart failure who requires frequent emergency admissions to the hospital.

Progress in the laboratory has been sufficiently encouraging, enabling the US Food and Drug Administration (FDA) to approve pig heart transplants in two living patients (in 2022 and 2023) and a pig kidney transplant in one patient (in 2024).[66,67,68] Although the recipients of all three transplants sadly passed away after the procedures, the trajectory of human organ donations indicates that survival rates will significantly improve as research progresses and techniques advance.

Xenotransplantation raises ethical considerations that need further exploration, ideally by various leaders in policy, business and societal spaces. In addition, a vast amount of data still needs to be acquired from initial patient trials to ensure the efficacy of treatments is maximized. However, solid prior learnings from established transplant technology, combined with the increasing capability and dropping costs of gene-editing techniques, indicate good reasons to be optimistic regarding the future of interspecies transplants to prevent the needless loss of hundreds of thousands of human lives each year. How quickly these changes in healthcare and industry occur will also depend on how regulatory authorities and society respond to this new therapy field.

> This ability to understand and precisely edit the genome, coupled with novel immunosuppressive drug regimens, has enabled the survival of nonhuman primates with life-supporting pig kidneys or hearts for periods now extending months or even years.

↑ Image:
Genomics for transplants can potentially revolutionize transplantation and address organ shortages.

Credit: Midjourney and Studio Miko.

Prompt (abbreviated): "Cells"

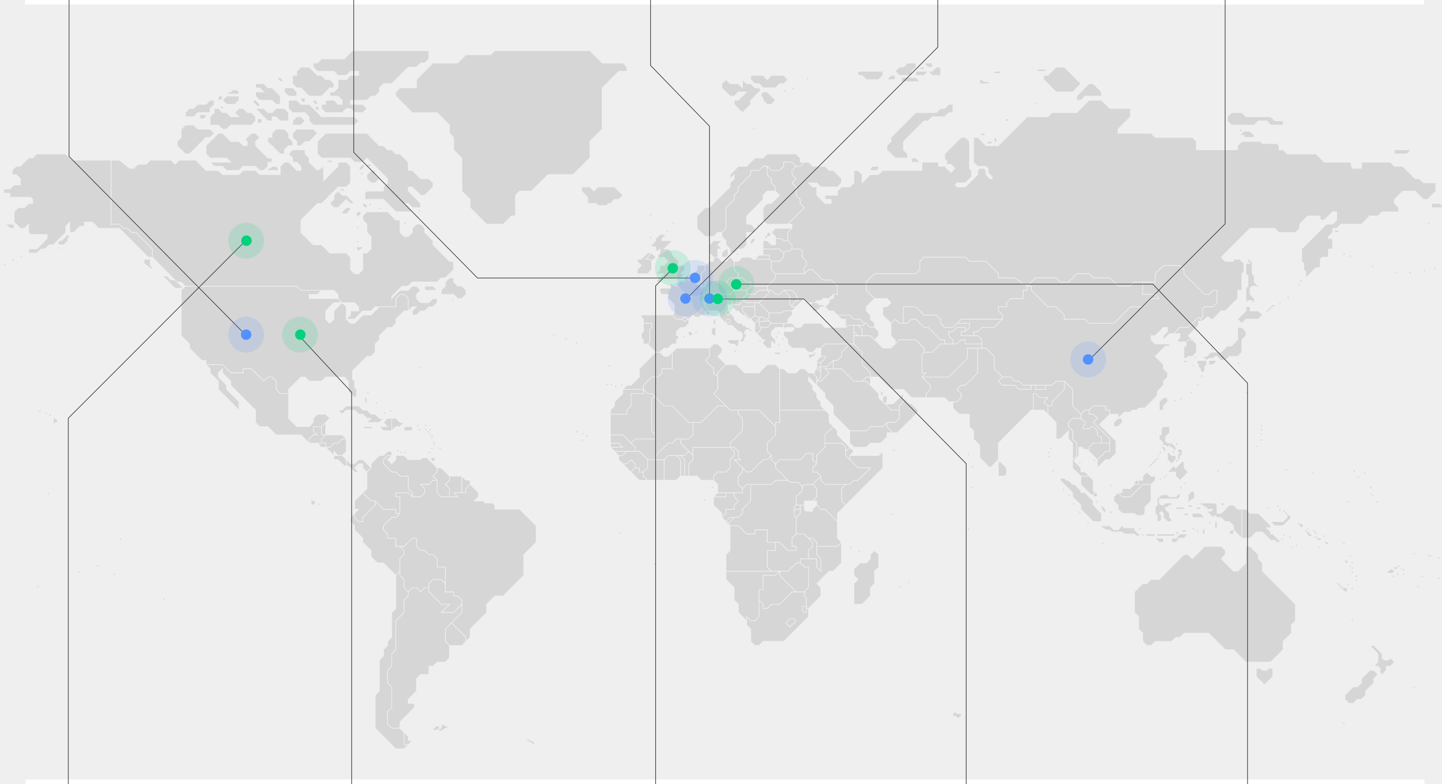
Read more:
For more expert analysis, visit the genomics for transplants transformation map.

Regions of innovation

Countries with the most business and academic grant funding in genomics for transplants from 2021-2023

Top five countries by business funding

Rank	Country	Funding
1	United States	$2.4 billion
2	Belgium	$299 million
5	Switzerland	$107 million
4	France	$141 million
3	China	$178 million



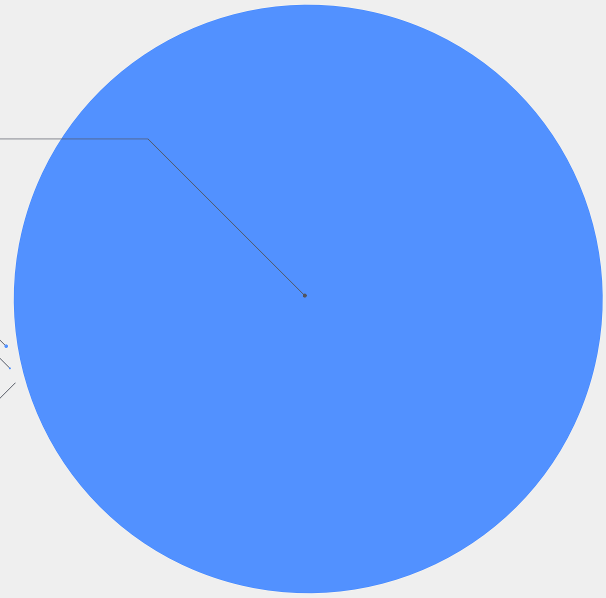
Rank	Country	Funding
5	Canada	$14 million
1	United States	$610 million
2	United Kingdom	$70 million
3	Switzerland	$25 million
4	Czechia	$19 million

Top five countries by academic grant funding

Leading-edge industries

Industries with the most funding in genomics for transplants from 2021-2023

- **Healthcare** $3.3 billion
- **Industrials** $21 million
- **Agriculture** $11 million
- **Consumer products and services** $1 million



Appendix: Data methodology

A1 Introduction

This appendix provides a detailed overview of the data sources, collection methods, processing steps, analytical techniques, assumptions and limitations used in this report. This information is crucial for understanding the context and reliability of the data presented in the graphics.

A2 Data sources

- **Academic grant funding:** Data was sourced from Dimensions for all grants starting between 2021 and 2023.
- **Business funding:** Data was sourced from CB Insights for total funding from 2021 to 2023.

A3 Data collection methods

Data was collected based on the following criteria:

- **Geographical scope:** For academic grant funding, the location of the primary affiliated institutions of the grantees was used. For funding data, the location of the companies that received funding was considered.
- **Time period:** Data was collected for the period from January 2021 to December 2023.
- **Industry scope:** Specific technology sectors were analysed using key phrase matches against titles and abstracts of grants and funding records.

A4 Data processing

The following steps were taken to process the data:

- **Cleaning and preparation:** Grants with no funding amounts were excluded from the counts and sums. Similarly, data entries without relevant funding amounts were excluded from the analysis.
- **Transformation:** Key phrase matching was performed against titles and abstracts to identify relevant records.
- **Software and tools:** Data processing was conducted using software tools such as Python for data cleaning and transformation.

A5 Analytical techniques

The following analytical techniques and methodologies were employed:

- **Statistical methods:** Analysis of the number of grants and total funding amounts by region and industry.
- **Visualization tools:** Visualizations were created using CB Insights to illustrate funding trends by geography and industry.

A6 Assumptions and limitations

- **Assumptions:** It was assumed that the data provided by Dimensions and CB Insights is accurate and up-to-date as of the run date.
- **Limitations:** Potential biases exist due to the exclusion of grants and funding records with no funding amounts. The availability and granularity of data may vary across different regions and industries.

A7 References

Dimensions Database, 2024. Data retrieved on 24/04/24.
CB Insights Database, 2024. Data retrieved on 24/04/24.

TABLE 1 **Key phrase matches for tech sectors**

Technology	Key phrases
AI for scientific discovery	(Artificial intelligence OR large language models) AND (scientific discovery OR research OR science)
Privacy-enhancing technologies	Synthetic data OR data simulation OR data generation OR data anonymization OR privacy-enhancing data
Reconfigurable intelligent surfaces	Reconfigurable intelligent surfaces OR 6G OR wireless communication OR smart cities
Integrated sensing and communications	Integrated sensing OR communications integration OR sensor fusion OR telemetry OR wireless sensor network OR multi-sensor systems
High altitude platform stations	High altitude platform system OR aeronautical engineering OR high-altitude platforms OR stratospheric OR high-altitude OR airship technology
Immersive technology for the built world	Assistive reality OR built environment OR building information modelling OR design complexity OR construction technology OR digital twin OR spatial computing
Elastocalorics	Elastocaloric OR heat pumps OR cooling system OR thermal management
Carbon-capturing microbes	Microbial systems OR microbial carbon capture OR bioremediation OR microbial consortia OR microbial metabolism
Alternative livestock feeds	Alternative animal feed OR animal nutrition OR plant-based feed OR insect-based feed
Genomics for transplants	Genetically engineered organs OR genetic engineering OR organ engineering OR transgenic organs OR organ transplantation OR tissue engineering

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1. *Google*. (n.d.). *DeepMind AlphaFold*. https://deepmind.google/technologies/alphafold/.
2. Wong, F., E. J. Zheng, J. A. Valeri, N. M. Donghia, et al. (2024). Discovery of a structural class of antibiotics with explainable deep learning. *Nature*, vol. 626, no. 7997, pp. 177-185. https://doi.org/10.1038/s41586-023-06887-8.
3. Conover, E. (2024). *Artificial intelligence helped scientists create a new type of battery*. Science News. https://www.sciencenews.org/article/artificial-intelligence-new-battery.
4. President's Council of Advisors on Science and Technology. (2024). *Supercharging Research: Harnessing Artificial Intelligence to Meet Global Challenges.*
5. Ibid.
6. Maynard, A.D. & S. M. Dudley. (2023). Navigating Advanced Technology Transitions Using Lessons from Nanotechnology. *Nature Nanotechnology*, vol. 18, pp. 1118-1120.
7. Jordon, J., L. Szpruch, F. Houssiau, M. Bottarelli, et al. (2022). Synthetic Data -- what, why and how? *arXiv*. https://arxiv.org/abs/2205.03257.
8. Williams, E.A. (2024). *From Promising to Practical: The Transformative Impact of Homomorphic Encryption*. Techspective. https://techspective.net/2024/04/04/from-promising-to-practical-the-transformative-impact-of-homomorphic-encryption/#google_vignette.
9. R. L. Rivest, L. Adleman, M. L. Dertouzos, et al. (1978). On data banks and privacy homomorphisms. *Foundations of Secure Computation*, vol. 4, no. 11, pp. 169-180.
10. Gonzales, A., G. Guruswamy & S.R. Smith. (2023). Synthetic data in health care: A narrative review. *PLOS digital health*, vol. 2, issue 1, e0000082. https://doi.org/10.1371/journal.pdig.0000082.
11. Bartell, J. A., S.B. Valentin, A. Krogh, H. Langberg & M. Bøgsted. (2024). A primer on synthetic health data. *arXiv*. https://arxiv.org/abs/2401.17653.
12. *International Energy Agency*. (n.d.). *Data Centres and Data Transmission Networks*. https://www.iea.org/energy-system/buildings/data-centres-and-data-transmission-networks.
13. Basar, E., M. Di Renzo, J. De Rosny, M. Debbah, et al. (2019). Wireless communications through reconfigurable intelligent surfaces. *IEEE Access*, vol. 7, pp. 116753-116773.
14. Di Renzo, M., A. Zappone, M. Debbah, M-S. Alouini, et al. (2020). Smart radio environments empowered by reconfigurable intelligent surfaces: How it works, state of research, and road ahead. *IEEE Journal of Selected Areas in Communications*, vol. 38, no. 11, pp. 2450-2525.
15. Abdelhady, A., A. Salem, O. Amin, B. Shihada, & M-S. Alouini, VLC via intelligent reflecting surfaces: Metasurfaces vs mirror arrays. *IEEE Open Journal of Communication Society*, vol. 2, pp. 1-20, January 2021.
16. Feng, Y., Q. Hu, K. Qu, W. Yang, et al. (2023). Reconfigurable Intelligent Surfaces: Design, Implementation, and Practical Demonstration. *Electromagnetic Science*, vol. 1, no. 2, pp. 1-21, https://www.emscience.org/en/article/doi/10.23919/emsci.2022.0011.
17. Syed, M.S.B., H.M. Attaullah, S. Ali, & M.I. Aslam. (2023). Wireless Communications beyond Antennas: The Role of Reconfigurable Intelligent Surfaces. *Engineering Proceedings*, vol. 32, no. 10. https://doi.org/10.3390/engproc2023032010.
18. Nie, S. & M. Can Vuran. (2023). AgRIS: wind-adaptive wideband reconfigurable intelligent surfaces for resilient wireless agricultural networks at millimeter-wave spectrum. *Frontiers in Communications and Networks*, vol. 4. https://www.frontiersin.org/articles/10.3389/frcmn.2023.1169266/full.
19. Wood, L. (2022). Global 6G Communications Reconfigurable Intelligent Surface Materials and Hardware Markets 2022-2023 and 2043. *Businesswire*. https://www.businesswire.com/news/home/20220726005634/en/Global-6G-Communications-Reconfigurable-Intelligent-Surface-Materials-and-Hardware-Markets-2022-2023-2043---ResearchAndMarkets.com.
20. *European Telecommunications Standards Institute (ETSI)*. (n.d.). *Reconfigurable Intelligent Surfaces*. https://www.etsi.org/technologies/reconfigurable-intelligent-surfaces#:~:text=RIS%20can%20be%20potentially%20deployed,RIS%20a%20sustainable%20technology%20solution.
21. Belmekki, B. E. Y. et al. (2024). Cellular Network From the Sky: Toward People-Centered Smart Communities. *IEEE Open Journal of the Communications Society*, vol. 5, pp. 1916-1936.
22. Lopez, E. (2024). Digital inequalities faced by older people have been exacerbated by COVID-19. *Universitat Oberta de Catalunya*. https://www.uoc.edu/en/news/2024/digital-inequalities-faced-by-older-people.
23. GSMA. (2021). *High Altitude Platform Systems Towers in the Skies*. https://www.gsma.com/solutions-and-impact/technologies/networks/wp-content/uploads/2021/06/GSMA-HAPS-Towers-in-the-skies-Whitepaper-2021.pdf.
24. GSMA. (2021). *High Altitude Platform Systems*. https://hapsalliance.org/wp-content/uploads/formidable/12/Driving_the_potential_of_the_stratosphere_HAPSAlliance_082021.pdf.

25. Grand View Research. (2022). *High Altitude Platforms Market Size & Trends*. https://www.grandviewresearch.com/industry-analysis/high-altitude-platforms-market-report.

26. International Civil Aviation Organization (ICAO). (2022). *Aviation Safety and Air Navigation Standardization*. https://www.icao.int/Meetings/a41/Documents/WP/wp_085_en.pdf.

27. Sweeney, M. (2021). *Global shortage in computer chips 'reaches crisis point'*. The Guardian. https://www.theguardian.com/business/2021/mar/21/global-shortage-in-computer-chips-reaches-crisis-point

28. Haider, M.A., & Y.D. Zhang. (2023). RIS-aided integrated sensing and communication: a mini-review. *Frontiers in Signal Processing*, vol. 3. https://www.frontiersin.org/articles/10.3389/frsip.2023.1197240/full.

29. Liberato Ullo, S. & G.R. (2020). Advances in Smart Environment Monitoring Systems Using IoT and Sensors. *Sensors*, vol. 20, issue 11. https://www.mdpi.com/1424-8220/20/11/3113.

30. *US Department of Energy*. (n.d.). *Smart Grid: What is a Smart Grid?* https://www.energy.gov/oe/services/technology-development/smart-grid.

31. Liu, Y., & K. Yang. (2022). Communication, sensing, computing and energy harvesting in smart cities. *IET Smart Cities*, vol. 4 issue 4, pp. 265-274. https://doi.org/10.1049/smc2.12041.

32. Metin, T., M. Emmelmann, M. Corici, V. Jungnickel, et al. (2020) Integration of Optical Wireless Communication with 5G Systems. *IEEE Xplore*. https://ieeexplore.ieee.org/document/9367502.

33. *ETSI*. (n.d.). *Industry Specification Group (ISG) Integrated Sensing and Communications (ISAC).* https://www.etsi.org/committee/2295-isac.

34. United Nations Environmental Programme. (2023). *Building Materials And The Climate: Constructing A New Future*. https://www.unep.org/resources/report/building-materials-and-climate-constructing-new-future,

35. *Digital Twin Consortium*. (n.d.). *Why Sustainability for Buildings?* https://www.digitaltwinconsortium.org/the-why-and-the-what-of-digital-twin-building-performance-and-sustainability-an-owners-perspective-form.

36. Associated Builders and Contractors. (2024). *ABC: 2024 Construction Workforce Shortage Tops Half a Million* [Press release]. https://www.abc.org/News-Media/News-Releases/abc-2024-construction-workforce-shortage-tops-half-a-million.

37. *McKinsey & Company*. (2022). *What is the metaverse?* https://www.mckinsey.com/featured-insights/mckinsey-explainers/what-is-the-metaverse.

38. *Shimizu*. (2024). *Remote Inspections of Under-Construction Buildings in the Metaverse*. https://www.shimz.co.jp/en/company/about/news-release/2024/2023063.html.

39. Babalola, A., S. Musa, M.T. Akinlolu, & T.C. Haupt. (2023). A bibliometric review of advances in building information modelling (BIM) research*. Journal of Engineering, Design and Technology*, vol. 21, no. 3, pp. 690-710.

40. International Energy Agency. (2018). *The Future of Cooling*. https://www.iea.org/reports/the-future-of-cooling.

41. US Department of Energy. (2014). *Energy Savings Potential and RD&D Opportunities for Non-Vapor Compression HVAC Technologies*. p.7. https://www.energy.gov/sites/prod/files/2014/03/f12/Non-Vapor%20Compression%20HVAC%20Report.pdf.

42. Ibid.

43. Wang, Y., Y. Liu, S. Xu, G. Zhou, et al. (2023). Towards practical elastocaloric cooling. *Communications Engineering*, vol. 2, no. 79. https://doi.org/10.1038/s44172-023-00129-5.

44. Ibid; Qian, S., D. Catalini, J. Muehlbauer, B. Liu, et al. (2023). High-performance multimode elastocaloric cooling system. *Science*, vol. 380, no. 6646, pp. 722-727. https://doi.org/10.1126/science.adg7043; Tusek, J., K. Engelbrecht, D. Eriksen, S. Dall'Olio, et al. (2016). A regenerative elastocaloric heat pump. *Nature Energy*, vol. 1, no. 16134. https://doi.org/10.1038/nenergy.2016.134; Kirsch, S-M., F. Welsch, N. Michaelis, M. Schmidt, et al. (2018). NiTi-Based Elastocaloric Cooling on the Macroscale: From Basic Concepts to Realization. *Energy Tech*, vol. 6, no. 8, pp. 1567-1587. https://doi.org/10.1002/ente.201800152; Zhou, G., Y. Zhu, S. Yao, & Q. Sun. (2023). Giant temperature span and cooling power in elastocaloric regenerator. *Joule*, vol. 7, no. 9, pp. 2003-2015. https://doi.org/10.1016/j.joule.2023.07.004; Exergyn. (n.d.). *SMA Technology*. https://www.exergyn.com/technology/.

45. Wang, Y., Y. Liu, S. Xu, G. Zhou, et al. (2023). Towards practical elastocaloric cooling. *Communications Engineering*, vol. 2, no. 79. https://doi.org/10.1038/s44172-023-00129-5.

46. Yaashikaa, P.R, A. Saravanan, P. Senthil Kumar, P. Thamarai, & G. Rangasamy. (2024). Role of microbial carbon captue cells in carbon sequestration and energy generation during wastewater treatment: A sustainable solution for cleaner environment. *Internation Journal of Hydrogen Energy*, vol. 52, part D, pp. 799-820. https://www.sciencedirect.com/science/article/abs/pii/S0360319923027234.

47. Lim, J., S.Y. Choi, J.W. Lee, S.Y. Lee, & H. Lee, H. (2023). Biohybrid CO_2 electrolysis for the direct synthesis of polyesters from CO_2. *Proceedings of the National Academy of Sciences of the United States of America*, vol 120, issue 14, e2221438120. https://doi.org/10.1073/pnas.2221438120.

48. Examples of companies active in the field: Using photosynthetic organisms: Algae Systems (https://www.algaesystems.com), CyanoCapture (https://www.cyanocapture.com), Photanol (https://photanol.com), Phytonix (https://phytonix.com); Using other microbes: Cemvita (https://www.cemvita.com), Deep Branch Biotechnology (https://deepbranch.com), Novonutrients (https://www.novonutrients.com).

49. Ibid.

50. *Bloomberg Finance* (2024). *Carbon Capture Investment Hits Record High of $6.4 Billion*. https://about.bnef.com/blog/carbon-capture-investment-hits-record-high-of-6-4-billion/.

51. Bhatia S.K. et al. (2019). Carbon dioxide capture and bioenergy production using biological system - A review. *Renewable and Sustainable Energy Reviews*, vol. 110, pp. 143-158.

52. Hong, W.Y. (2022). A techno-economic review on carbon capture, utilisation and storage systems for achieving a net-zero CO_2 emissions future. *CCST*, vol. 3*,* 100044. https://doi.org/10.1016/j.ccst.2022.100044.

53. Nappa, M., M. Lienemann, C. Tossi, P. Blomberg, et al. (2020). Solar-Powered Carbon Fixation for Food and Feed Production Using Microorganisms – A Comparative Techno-Economic Analysis. *ACS Omega*, vol. 5 no. 51, pp. 33242-33252. https://dx.doi.org/10.1021/acsomega.0c04926.

54. *Food and Agriculture Organization of the United Nations (FAO)*. (n.d.). *FAOSTAT - Food and Agriculture Data*. https://www.fao.org/faostat/en/#data.

55. *World Wide Fund for Nature (WWF)*. (n.d.). *Deforestation and Food: Your Questions Answered*. https://www.wwf.org.uk/food/deforestation-and-food-your-questions-answered.

56. Guo, R., et al. (2021). Microalgal-based feed: promising alternative feedstocks for livestock and poultry production. *Journal of Animal Science and Biotechnology*, vol. 12, no. 5. https://jasbsci.biomedcentral.com/articles/10.1186/s40104-021-00593-z.

57. Altman, A.W., et al. (2024). Review: Utilizing industrial hemp (Cannabis sativa L.) by-products in livestock rations. *Animal Feed Science and Technology*, vol. 307, no. 115850.

58. Li, H., & A. Chaudhuri. (2022). Animal Design Through Functional Dietary Diversity for Future Productive Landscapes. *Frontiers in Sustainable Food Systems*, vol. 6, no. 933571. https://www.frontiersin.org/articles/10.3389/finsc.2022.933571/full.

59. *Verified Market Reports*. (n.d.). *Top Companies in the Edible Insects Market*. https://www.verifiedmarketreports.com/blog/top-companies-in-the-edible-insects/.

60. *Future Market Insights*. (n.d.). *Animal Feed Alternative Protein Market Report*. https://www.futuremarketinsights.com/reports/animal-feed-alternative-protein-market.

61. Chase, B. (2024). *World's First Genetically-Edited Pig Kidney Transplant into Living Recipient Performed at Massachusetts General Hospital*. Massachusetts General Hospital. https://www.massgeneral.org/news/press-release/worlds-first-genetically-edited-pig-kidney-transplant-into-living-recipient.

62. *US Department of Health & Human Services*. (n.d.). *Organ Donation Statistics*. https://www.organdonor.gov/learn/organ-donation-statistics.

63. Anand, R.P., J.V. Layer, D. Heja, et al. (2023) Design and testing of a humanized porcine donor for xenotransplantation. *Nature*, vol. 622, no. 7982, pp. 393-401. https://pubmed.ncbi.nlm.nih.gov/37821590/.

64. *American Diabetes Association*. (n.d.). *Diabetes Statistics*. https://diabetes.org/about-diabetes/statistics/about-diabetes.

65. *Parkinson's Foundation*. (n.d.). *Parkinson's Disease Statistics*. https://www.parkinson.org/understanding-parkinsons/statistics.

66. Griffith, B.P., C.E. Goerlich, A.K. Singh, et al. (2022). Genetically-modified porcine-to-human cardiac xenotransplantation. *New England Journal of Medicine*, vol. 387, pp. 35-44.

67. Cooper, D.K.C., & E. Cozzi. (2024). Clinical pig heart xenotransplantation - where do we go from here? *Transplant International*, vol. 37, no. 12592.

68. Mallapaty, S., & M. Kozlov. (2024). First pig kidney transplant in a person: what it means for the future. *Nature*, vol. 628, no. 8006, pp. 13-14.

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