Imperial College London

Enterprise

2041 SCENARIOS

Computation, energy and the planet

Contents

Foreword

Running an organisation means looking at the present and having an eye on what's coming next. At Imperial, we're helping businesses explore the possible future through Imperial Tech Foresight, a dedicated unit within our membership network Imperial Business Partners.

The Tech Foresight team uses structured thinking, informed by Imperial's academic expertise, to look ten or even twenty years into the future. The team considers the implications of emerging science and technology to organisations and people's lives. This report examines two of the most important technological drivers of societal change, energy, and computation, and explores their unfolding consequences for the planet, in particular the urgent sustainability challenges we now face.

The negative effects of human activity on the biosphere are a planetary challenge. Imperial has resolved to address the sustainability challenge as a central component of its Academic Strategy, and experts across the College are contributing to the transformation of industrial and economic systems the world urgently requires.

Data centre demands for energy, for example, are expected to significantly increase by 2030 influenced by crypto currencies and social platforms. This report presents four future scenarios in which emerging technologies may combine to support increased use of powered computation but with a reduced carbon footprint.

The report looks beyond today's technologies, both legacy fossil fuels and present-day renewables. It considers the far future where the next generation of low-carbon energy like nuclear fusion and computation technologies like quantum computing have matured. What does it mean to organisations and lives when the limitations of the present and short-term future have been reduced?

Many of our business partners think in terms of having a portfolio of innovation investments. Some innovation projects are for short term opportunities, and some are for longer-term possibilities. If you like to think that way too, this report, and online video material including expert interviews, will be of interest.

If you'd like to know more about connecting your organisation to Imperial experts, our business support specialists will be happy to help.

Dr Simon Hepworth
Director of Enterprise
Imperial College London

Executive summary

Computation, Energy, and the Planet consists of four competing visions of the year 2041. Each of the four scenarios describes a possible future in which technology, in one way or another, addresses an urgent question we are presented with today: How will emerging technologies combine to support the increasing demand for computation, and provide enough energy for it, in twenty years' time?

Central to any answer to this question is how we produce energy with low or zero carbon emissions.

Each scenario presents a combination of computation and energy technologies that are under research and development today and have potential to transform the world of tomorrow. Included in each scenario is a timeline, a narrative, a map of implications, and a set of actions that organisations could usefully take today to be ready to take advantage of the technologies it describes.

Quantum
New computation and traditional energy

There is increasing demand for large-scale computation and energy. The demand for computation is partly met by quantum computers. These can mitigate increases in energy demand by taking on intensive tasks that classical computers required more energy for. Quantum computers are also used for large-scale optimisation problems in global energy smart grids, leading to better energy distribution and management.

Convergence
Classical computation and traditional energy

Increasing demands for computation and energy-efficiency drive forward novel computing architectures such as memristors and neuromorphic AI. These form the basis for a new generation of IoT (Internet of Things) devices that connect, compute and sense with minimal energy. The transmission of energy over-the-air helps drive forward the roll-out of small-scale devices. These work without batteries and cables, minimising waste, and pollution.

Unknowable
New computation and new energy

Fusion energy, unlimited energy generation, and better sharing of energy makes it possible to meet society's increasing energy demand. Greenhouse gases are no longer a threat, as fusion energy eliminates the needs for fossil energy. Quantum artificial intelligence is used for planetary-scale energy optimisation. In the process, tensions between nations are eased as core disparities are removed.

Automated
Classical computation and new energy

Increases in energy demand are managed by environmental optimisation. This is delivered with technologies such as ambient energy harvesters that are widely distributed in cities. AI plays an expanding role in automating and optimising scientific research, reducing its energy footprint. In chemistry, for example, chemical reaction studies requiring many experimental iterations are automated and sometimes digitally simulated.

Scenario matrix

New computation

Classical computation

Traditional energy

New energy

SCENARIO THREE

Quantum

Traditional energy — New computation

SCENARIO FOUR

Unknowable

New energy — New computation

SCENARIO ONE

Convergence

Traditional energy — Classical computation

SCENARIO TWO

Automated

New energy — Classical computation

Scenario building
Computation, energy, and the planet

Signal amongst the noise

In the early 2020s, there are well-known, large issues of illnesses, conflict, wealth inequity, unequal access to resources and changes in the climate. At the same time there are quieter signals of revolutionary scientific and technological advances.

Nascent developments in computation and energy that have the potential to rewrite the social future over the next 20 years.

The following scenarios, featuring four possible technological futures, explore the potential of those developments.

Possibility is controversial

The following scenarios will appear possible to some and implausible to others. They are based on emerging science – where the definitive truth is still contested. No doubt over their lifetime, assumptions and claims within them will be proven both true and untrue. Their goal is conversation.

These are prompts for alternative views, criticism and, more importantly, for people to ask, 'what would that mean to us if it were to come true?'

Framing question

Scenarios start with a framing question.

The computational research tools of today are found in the businesses of tomorrow. In the industrial to informational ages, the computer moved from being a specialist tool for defence to a general-purpose tool that rewrote society. Computation is now moving on from devices and becoming an ethereal facility available anywhere and everywhere. As we become more reliant on computation, so will our reliance on energy to deliver it.

In our age of data collection, storage, and interconnection, how will the nature of computation change in the next 20 years? Under pressure from a changing climate, how will our energy systems be reconstructed? And in turn, how will these changes flow into organisations and the way they serve the general population?

How will emerging technologies combine to support the increasing demand for computation, and provide enough energy for it, in twenty years' time?

Trends and signals

A research scan of the problem space, the planet, and discussion sessions were used to refine a set of signals and trends.

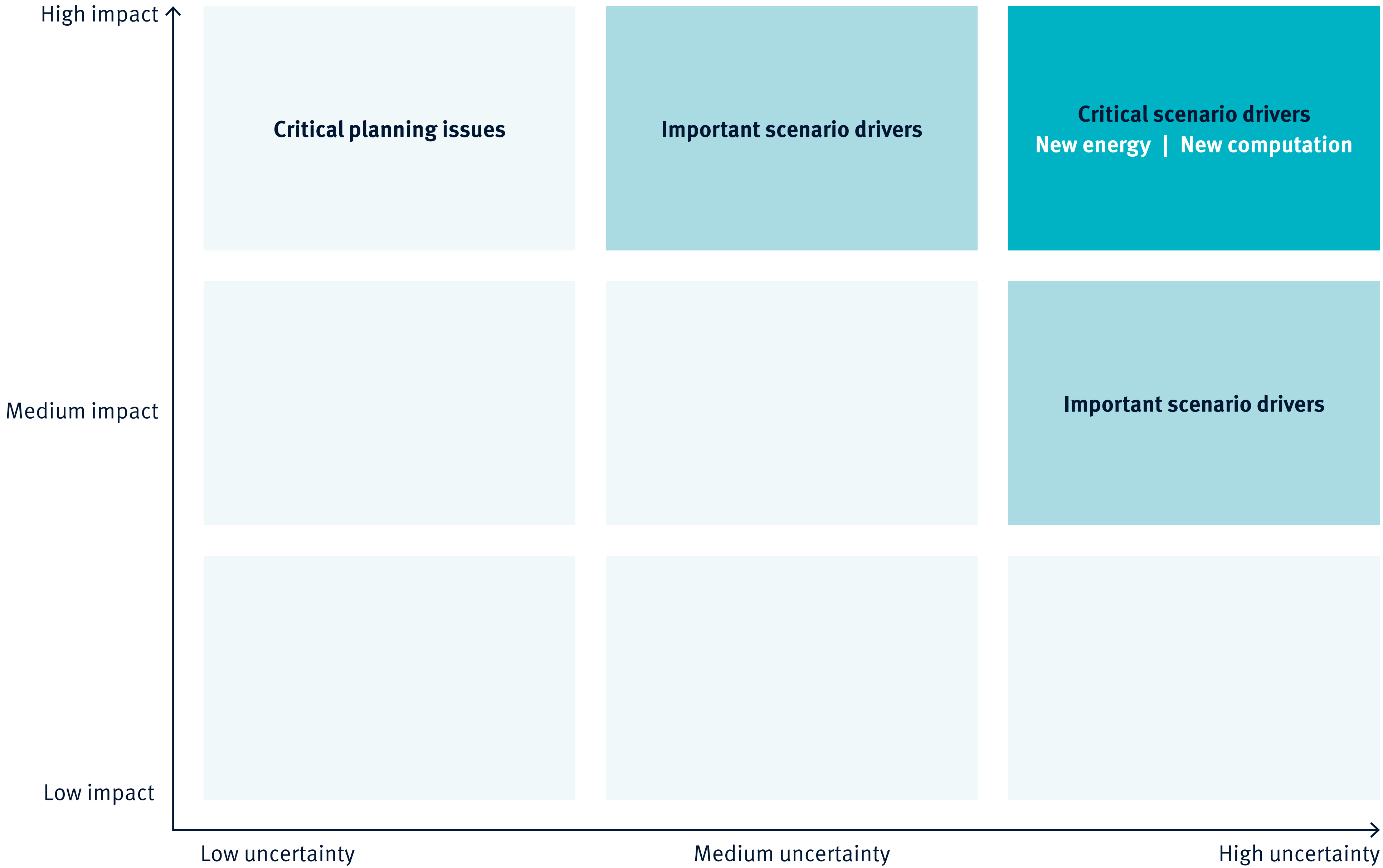
Signals and trends ordered across the STEEPV (Social Technological Economic Environmental Political and Values) scanning categories. Tech Foresight emphasises science and technology in its scanning.

These were clustered down into technology and science focused key drivers.

Ranking for drivers

The drivers were ranked in a matrix of impact (low, high) and uncertainty (low, high). The high uncertainty and high impact drivers were selected as scenario drivers as per scenario planning methods.

Driver ranking



Axes and assumptions

Drivers and axes

The two drivers were new computing and new energy sources. Their opposites were classical computation and traditional energy. These give us two axes to create our scenarios with.

Computation axis

Classical computation — Extension of existing computational paradigms i.e., binary based. This includes new developments such as edge computing.

New computation — Artificial Intelligence that supersedes human understanding. Powerful and usable quantum computing and communications.

Energy axis

Traditional energy — Ongoing progression from fossil to renewables, smart grids, local power grids.

New energy — Fusion reactors and energy harvesting environments

Assumptions

Some special assumptions were also made:

- Electronic waste will be resolved by design for reuse in the circular economy (rather than design for optimisation) and new materials including post-semi-conductor technologies. The trend for miniaturisation of electronics, with consequent reduced energy needs, will continue.
- Rare earth mineral sourcing will be resolved by new materials, new sources (e.g., deep-sea environmentally sensitive harvesting, Greenland, asteroid / space sources), design for recycling which allows their return to service.
- Aberrations in the climate will continue to challenge humanity as it has dispersed itself across the planet. Whatever the sources of these aberrations, e.g., human activity, planetary cycles or solar cycles, human intervention is needed.
- AI will continue to impact society's life and grow its presence across all fields of industry, requiring more and more energy to support its computational needs.
- Energy needs of society will increase across all scenarios, with different solutions to ease energy consumption considered in each of them.

For a full set of reference material used to develop the Computation and Energy axes and the assumptions please visit the references webpage

Four possible futures

What happens when a transformation in energy systems comes together with a quantum computing revolution? What if one field leaps forward while the other stalls? These four scenarios represent different ways that computation and energy, two key drivers of societal change, could combine.

Quantum

New computation and traditional energy

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Convergence

Classical computation and traditional energy

Increasing demands for computation and energy-efficiency drive forward novel computing architectures such as memristors and neuromorphic AI. These form the basis for a new generation of IoT (Internet of Things) devices that connect, compute and sense with minimal energy. The transmission of energy over the air helps drive forward the roll out of small-scale devices. These work without batteries and cables, minimising waste, and pollution.

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Automated

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Increasing energy demand is managed by environmental optimisation. This is delivered with technologies such as ambient energy harvesters that are widely distributed in cities. AI is increasingly applied to automate and optimise scientific research, reducing its energy footprint. In chemistry, for example, chemical reaction studies requiring many experiment iterations, can be automated and sometimes digitally simulated.

Four scenarios of 2041 for balancing the increasing demand for computation, and the energy required for it, through....

New computation

SCENARIO THREE

Quantum

Traditional energy — New computation

Energy management through grid optimisation

SCENARIO FOUR

Unknowable

New energy — New computation

Energy management by bottomless generation

Traditional energy

New energy

SCENARIO ONE

Convergence

Traditional energy — Classical computation

Energy management by small-scale optimisation

SCENARIO TWO

Automated

New energy — Classical computation

Energy management by environment optimisation

Classical computation

SCENARIO ONE

Convergence

Classical computation — Traditional energy

Key technologies and concepts
Everything computes, energy transmission, ubiquitous computation, Internet of Everything (IoE), brain-computer interfaces (BCI), bio-electronic medication, ambient energy-harvesting, miniaturisation, AI Privacy Guardians, smart energy grids

Convergence
Overview

Everything computes, and everything is computed

By 2041, some previously separate fields of science and technology have become closely integrated and unified in their purpose. Their main practical purpose is to support the increasing use of data by society for computation, communication, and energy-efficiency. In both wealthy and impoverished societies, everything computes, and everything is computed. Data communication and energy transmission have also become integrated.

The tight relationship between data and energy transmission

In 2041, information is life. People, commerce, and economies rely on it. As a result, more energy is used for information generation and retrieval than ever before. Ubiquitous computation and pervasive sensing demands have driven changes in energy transmission and distribution.

Energy delivery for many devices has moved from the solid i.e., cords and batteries, to far-field wireless energy transmission. For smaller devices, both power and information transfer take place over post-6G wireless telecommunications networks. Low-maintenance, internet-connected devices and objects are widely distributed and can be fixed or mobile.

Electronic devices have advanced in other ways. Novel architectures for electronics, pushed by the needs of miniaturisation, resource scarcity, energy-efficiency and distributed intelligence, are now available.

There has also been a blending of electronics and neuroscience. These advances have unlocked the Internet of Everything (IoE) with novel connections between the digital and the biological worlds. Brain-computer interfaces (BCI) and bio-electronic medication are readily available.

These progressions have changed the environmental footprint of technology.

Power transmission has reduced the need for onboard battery storage in devices. Battery-less devices are possible using ambient energy-harvesting materials. Progress in electronics miniaturisation and design-for-recycling has reduced the amount of electronic waste. Sensor devices have become simpler in form and function, increasing their lifespan. Sensor-soaked environments that share data, watched over by AI privacy guardians, have reduced the need for individual ownership of devices.

Wireless power transmission has opened opportunities for smart energy grids. Local energy grids distribute household and community generated energy without requiring national infrastructure.

Convergence
Organisation overview

Cable-less and almost battery-free

Commercial organisations have hugely benefitted from breakthroughs in energy. One large pharmaceutical company joined the Internet of Everything (IoE) and the post-6G revolution ahead of others in its sector. Through new technology architectures it transformed its factories from being organised as industrial lines of production into several 'living' and symbiotic ecosystems. Many operating machines have become cable-less and have reduced their needs for batteries. This has significantly reduced their complexity, resource costs, safety costs and carbon footprints.

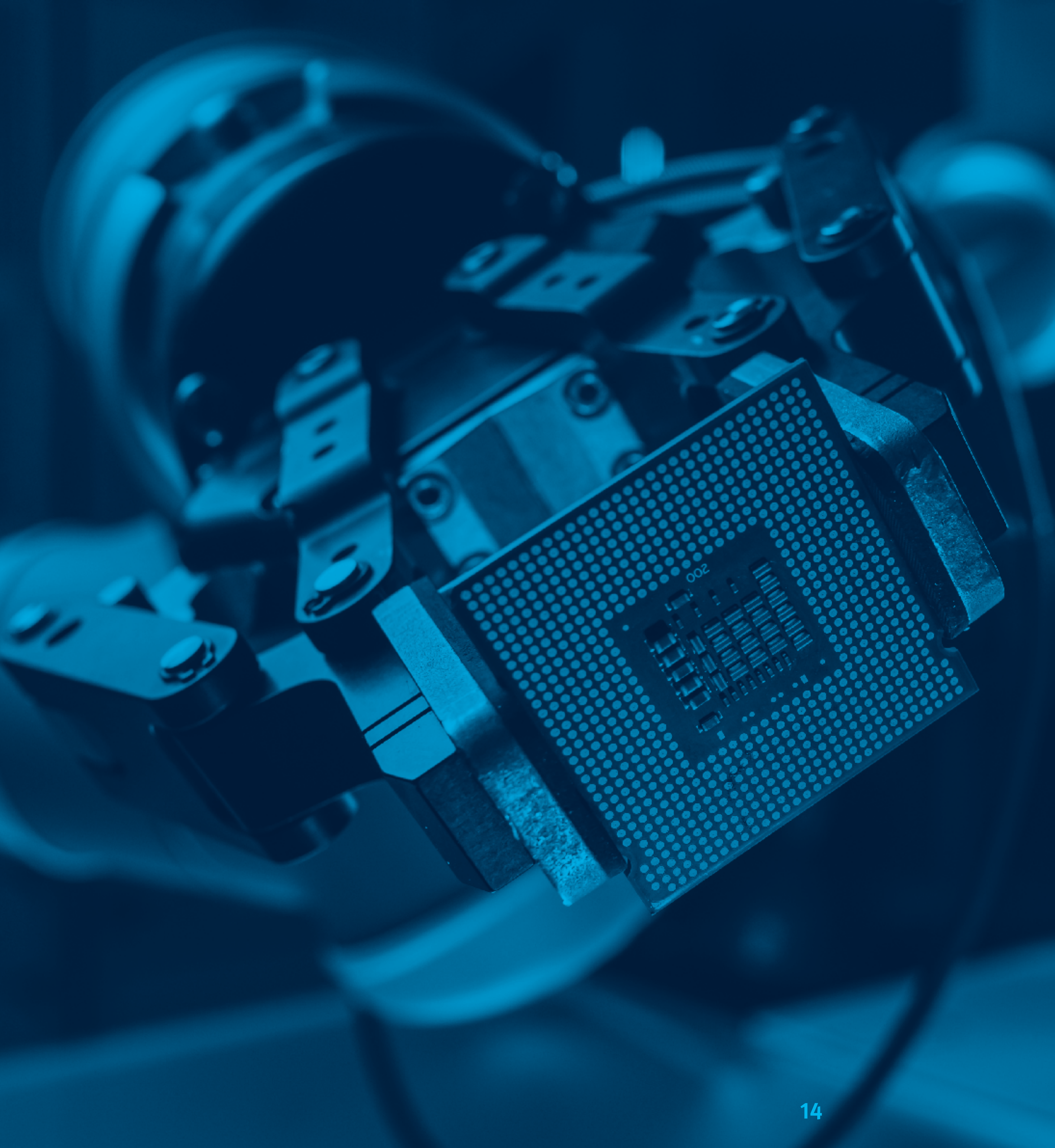
Small drones are used on the factory floor for monitoring and edge computing tasks. The use of wireless energy transmission has reduced the need for downtime while they dock and recharge. The same applies to the factory's wireless power scanners, wearables, and tablets. Wireless energy is supplied by hyper-walls in the factory that in turn receive their energy from a neighbouring renewable energy plant.

Always-on battery-free sensors now pervade the indoor production areas. These low-power IoT based on neuromorphic computing devices sense and compute the environment around them without needing maintenance. This has led to a massive improvement in real-time operational efficiency. The physical factory is mirrored by its digital twin: a virtual representation of the whole factory hosted in the cloud. The digital twin is interpretable by humans as well as machine intelligence.

Everything is connected to the company's cloud. A resident AI is embedded within the cloud, communication network and edge computing devices and is constantly simulating and refining processes to improve the factory's operations. This web of computation generates and computes huge amounts of small data in real-time. It uses this to optimise the production lines inside and the supply-chains it is part of outside.

New products are geotagged using biodegradable energy-harvesting sensors. Their locations are recorded on a central ledger and their delivery precisely monitored until they reach the customer. A modern direct-to-consumer model has allowed the pharmaceutical company to dramatically cut costs and reinforce its position in personalised medicine solutions, such as electroceuticals.

Electroceuticals are a category of therapeutic agents which act by targeting the neural circuits of organs operated by means of a brain-computer interface and assisted by drugs. The new field is now an integral part of the company's personalised medicine services.



2024 Over the air energy transmission is embedded in large factories to power battery less sensors networks

2026 Miniaturisation and low cost production of electronic components allows cognitive devices, embedded intelligence, to be widely deployed from built and natural environments, devices down to clothing

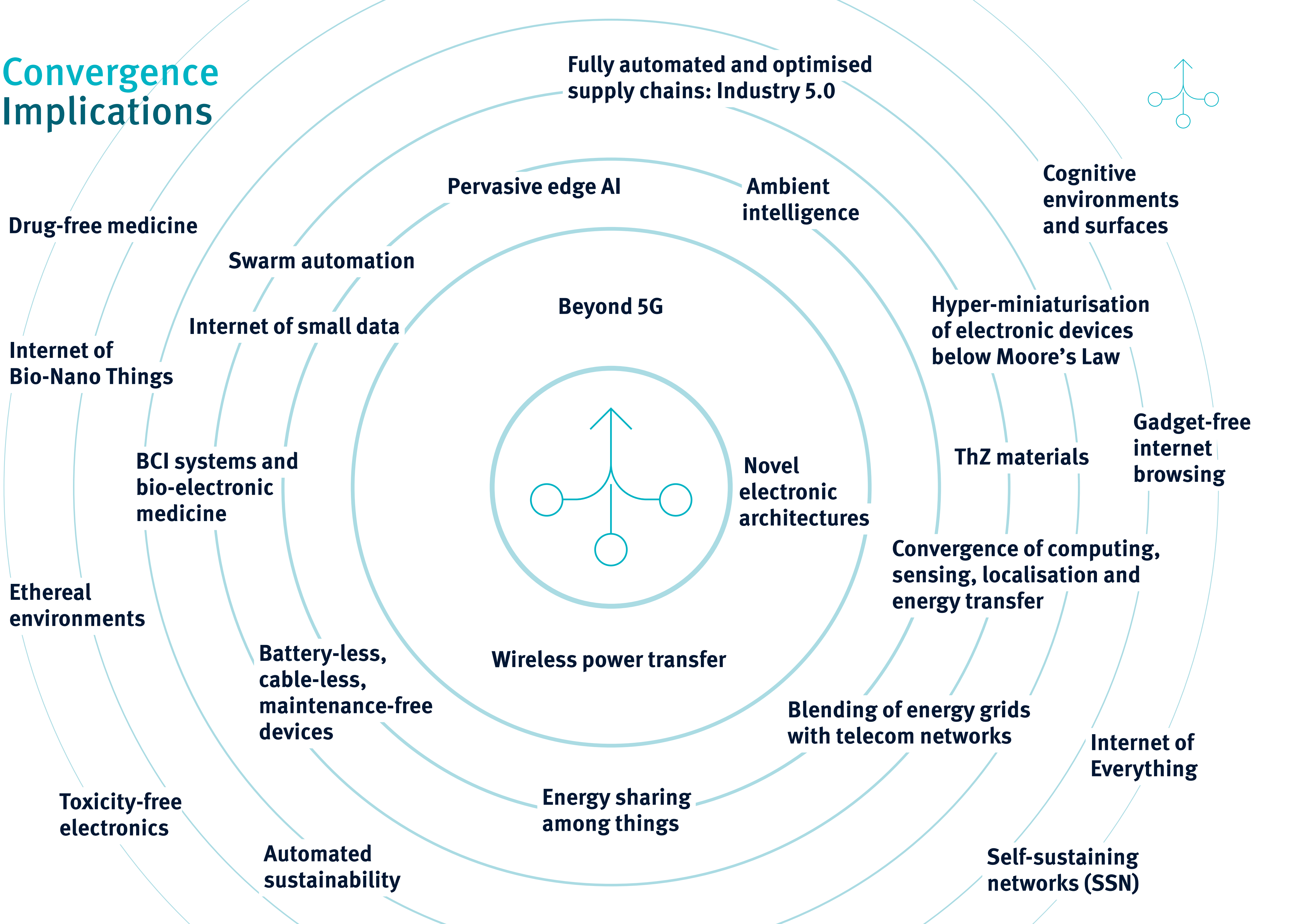
2030 6G rollout

2032 WIPT (Wireless Information and Power Transfer) becomes mainstream on localised telecommunication networks

2036 Large-scale deployment of WIPT technologies starts to transform city and industrial infrastructures into cable less and battery less environments

2040 7G rollout

Convergence Implications



Convergence
What does this mean today?

Technologies that were formerly separate are becoming intertwined – particularly energy technologies and computation.

So what? Environment

An increasingly data-reliant environment has implicit costs. These include the economic, environmental, and material costs of new hardware and the energy required to power it. The requirement to offset those costs, engineer products in sustainable ways, and deliver them with minimal infrastructure presents an opportunity. By introducing new solutions, we can retire old technologies such as wired telecommunications and natural gas networks, rather than keep them on expensive life support.

So what? Organisations

Data-saturated environments require extensive data-processing to make sense of. Information technology becomes more complex rather than simpler to implement and use. Industry will need more computer-literate technology workers with user experience (UX) skills and the ability to create digital models over which 'what if' scenarios can be played out.

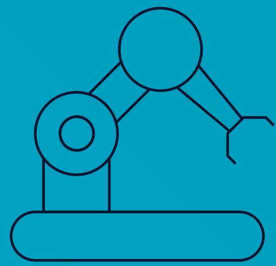
When all physical systems are potentially measurable, there could be a temptation to regard the unpredictability of human behaviour as a headache. However, data about human performance can also be used to rethink processes. Rather than seeing human labour as another physical tool, we can put people in positions where they can apply the human strengths of dealing with uncertainty, unpredictable events, and creative needs.

So what? People

More richly enabled built environments, like the home, can be made even more user-friendly and assistive for individuals. In healthcare, richer monitoring and caring will soon be possible through technology. So will assistive technology like household AI.

When creating new products and services today, we can consider certain predictions about the more technically enhanced environments they will eventually be used in. Rather than a service and one product, for example a voice assistant, a suite of products may be provided. Less emphasis may be placed on the technology itself, like smart meters, and more on services being provided to users.

For a full set of reference material used to develop the convergence scenario please visit the references webpage



SCENARIO TWO

Automated

Classical computation — New energy

Key technologies and concepts
Computation, AI directed science, experimentation simulation, transdisciplinary research, Automated science, energy-hungry society

Automated Overview

Inseparable science and computation

Computation is an integral to all fields of science. Scientific experiments are often performed on virtual models of the world, rather than on the world itself. These experiments draw on new techniques in AI and big data. Computational science is used for discovering new molecules, materials, and chemistry.

AI-directed science has outpaced traditional science. It has opened-up the world of discovery, and transdisciplinary research, across different branches of knowledge, is the norm rather than the exception. The legacy boundaries of the scientific revolution and the Enlightenment are being rewritten.

Accelerated science

In 2041, automated science is the automation not only of experiments themselves but also their design. AI systems design experiments to find new molecules or optimise chemical reactions and materials with the performance characteristics sought by humans. Automated systems find matching patterns in large data sets of possible compounds. Digital technologies have reduced the energy requirements of experimentation by minimising repetition and errors. Open sharing of data has also helped towards this, making data from automated experiments available to labs around the world.

Large automated companies are now champions at reusing waste energy, their whole supply chain is designed to recycle it for different chemical processes and they are greener than ever.

Scientists' jobs have changed. Their work no longer requires as many routine technical or managerial tasks, and the focus is on designing research and directing AIs. They direct many automated experiments to discover new pathways via large-scale, trial-and-error simulated experiments. Old and new discovered knowledge is combined. As a result, there is greater control of the creative side of science.

2023 The first automatically synthesized molecules are on the market

2026 A UK chemical company collaborating with universities realises the first on-demand material

2031 A personalised medicine solutions company allows the first pharmaceutical to be 3D-printed at home from scratch

2036 Experiments beyond human capability are being performed globally, allowing new materials and new physics and chemistry to emerge

2040 AI takes over many areas of research

Automated
Organisation overview

Novel possibilities from AI

The ability to use AI to develop new materials has created novel possibilities and changed industries such as construction. Materials are created to enable building features such as unique geometries and properties that make them suited to their local climates.

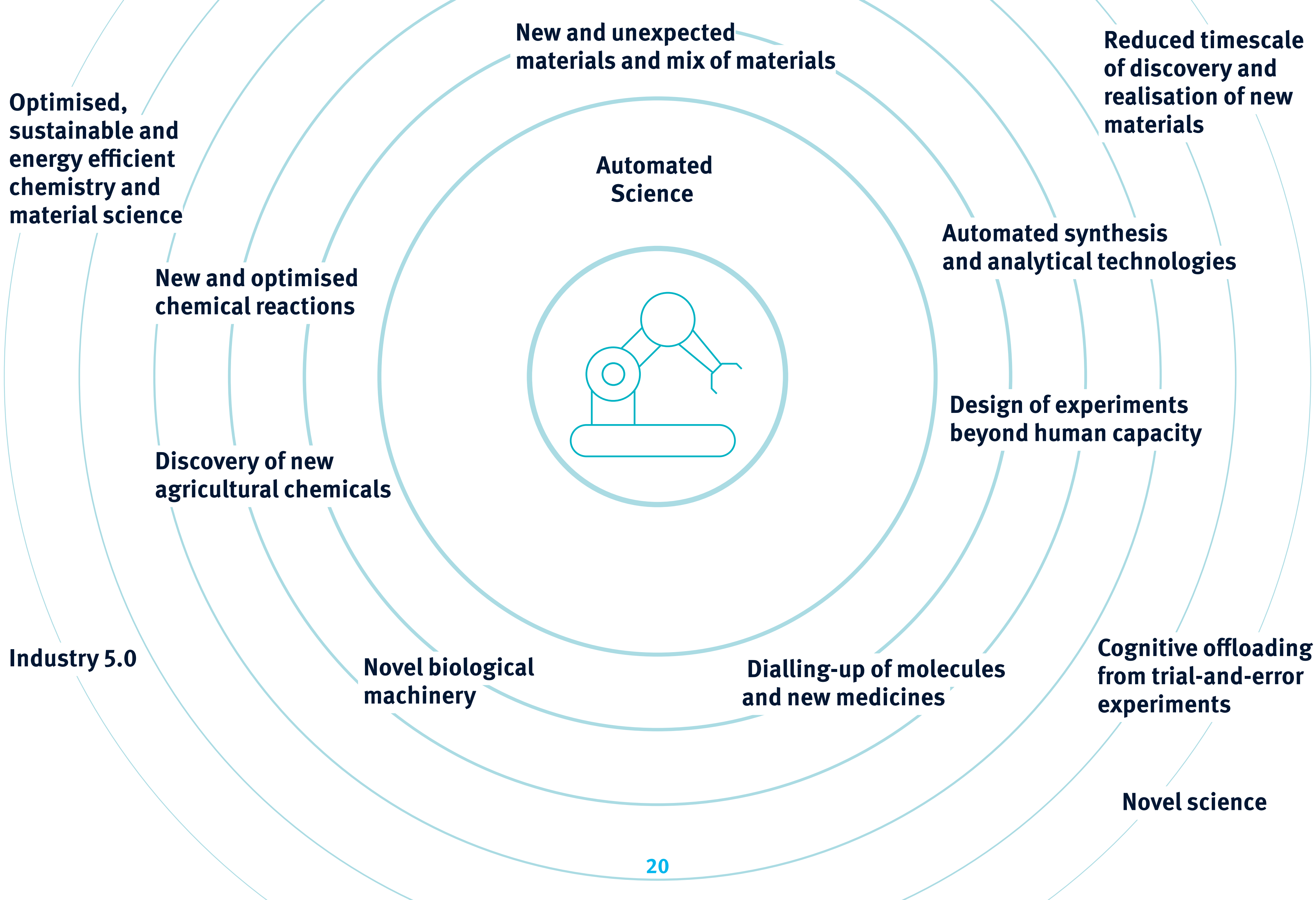
ImpossibleDesigns is a global Danish architecture studio famous for structures on the verge of physical impossibility. In a new project for a museum in Dubai, they have designed a structure resembling a shell that needs to be 3D printed from the bottom up. The building will be able to harvest energy from light and wind and sequester atmospheric CO_2.

The blueprint has been created by an AI to optimise the building's performance on criteria such as resistance wind, erosion, and other stressors. These criteria account for ongoing climate change. The building should withstand these stressors during its operation with its unique geometric structure. The performance properties are blended with the desired energy and CO_2 harvesting characteristics to be delivered through the building walls.

The blueprint is then sent to the contractors, which use their advanced AI material designers to find the most suitable new mix of materials for the project. After their initial investigation, they propose additional colour-shifting features and light-reflection characteristics for aesthetic purposes.

The result is a 3D-printed building with unique aesthetic and structural properties. It is built with a mix of highly resistant and multifunctional flexible materials that are not found elsewhere but can be produced again as needed.

Automated Implications



Automated
What does this mean today?

Technology is used to automate not only physical tasks but also knowledge work. The increased energy capacity required to power this technology this is provided partly by ambient energy harvesting.

So what? Environment

Automation allows us to make more efficient use of capital. However, the ability to provide products and services more cheaply comes with negative externalities, particularly an increased environmental cost as demand increases. How will consumption be moderated?

The expectation here is for increasing governance to 'bake' environmental costs into the supply chain and thus prevent out of control end-consumption.

So what? Organisations

The automation of industrial and business processes using AI creates opportunities for optimisation, the use of algorithms to improve performance. This reduces energy consumption, makes more efficient use of materials, and reduces the need for human intervention.

An organisation that has greater independence of materials, energy, computation, and supply-delivery logistics will be in more control of compliance to new governance requirements.

Supply-side governance may be complemented by greater controls being imposed on consumption, e.g., reduced energy options. It will be important to be able to take advantage of consumption side governance.

Transition to a more automated organisation warrants anticipatory strategies for workforce transition.

So what? People

The most obvious impact is a reduction in workforce. The need for manual labour may be reduced by new industrial processes.

Knowledge workforces may change in two ways. Some jobs will be replaced altogether by machines. In other cases, the nature of jobs will change. For example, from a project manager to an orchestrator of intelligent systems that do most of the work.

In our everyday lives, increasing automation will also mean we are submerged in technology. Rather than explicit technology, like room lighting controls, anticipatory intelligent technology will pre-empt interaction.

For a full set of reference material used to develop the automated scenario please visit the references webpage

SCENARIO THREE

Quantum

New computation — Traditional energy

Key technologies and concepts
Quantum information theory, quantum technologies, quantum computers, quantum-secure cryptography, quantum communications, quantum cloud, quantum blockchain

Quantum Overview

New forms of science

The advances of quantum information theory and quantum technologies have revolutionised our capacity to model nature and harness its power. Computation is used for new forms of communication, the creation of new, energy-efficient technologies, enhanced drug development, simulation of complex chemistry and biology. They are used for making sense of the environment and asking deep questions about the world.

Quantum computers work together across long distances to solve challenges of incredible complexity. The quantum internet has brought forth immense capacities for collaborative computation. This allows the exploration of new areas of research and automated economic development. Quantum communications allow the transfer of large volumes of data across immense distances faster than the speed of light.

These communications use quantum-secure cryptography against interception, interpretation, and manipulation. The level of security offered means cyber-threats in most financial and governmental areas are now a thing of the past. Some argue however that the capabilities of quantum computing can be applied to attack encryption applied under classical computing.

A solution to an energy-hungry society

In 2041, quantum computers now run alongside those based on classical architectures. Energy-intensive computations once performed by classical supercomputers and energy-hungry machine learning models are now made by quantum computers. This dramatically reduces the energy needs of our data-reliant society.

Large-scale optimisation, such as in telecommunications, finance and energy supply are solved using AIs using cloud-based quantum computing services. 'Quantum clouds' allow companies to use quantum computing through partnerships with the cloud technology owners.

Quantum blockchains, which enable supply chains and transactions between different parties, have become mature and offer revolutionary security, performance, and a more sustainable level of energy consumption.

2025 The first commercially available photonic quantum computer offers quantum supremacy on cloud

2027 The first successful quantum internet established among federation of companies

2029 Distributed quantum computing is now starting to be used in large energy grid modeling

2032 Mobile quantum communication becomes commercially available on 6G network

2034 Quantum computing starts to curb energy use globally

2037 Quantum computing is used to create first generation of post-electronic materials

Quantum
Organisation overview

Quantum computer-managed grids

Over the last 20 years, the world's electrical energy usage has increased due to, as examples, the electrification of transport, building heating, use of computers, growth in consumer technology, increasing technology integration into the built environment, and activities that previously directly used fossil fuels. Energy networks have also expanded to accommodate a variety of distributed energy sources e.g., atomic energy power stations and home solar feeds. And the complexity of the computational systems required to support these networks has grown in parallel.

Vastly increased volumes of data are needed to maintain and optimise power grids and there is increased strain on the security and communication infrastructures used to support them.

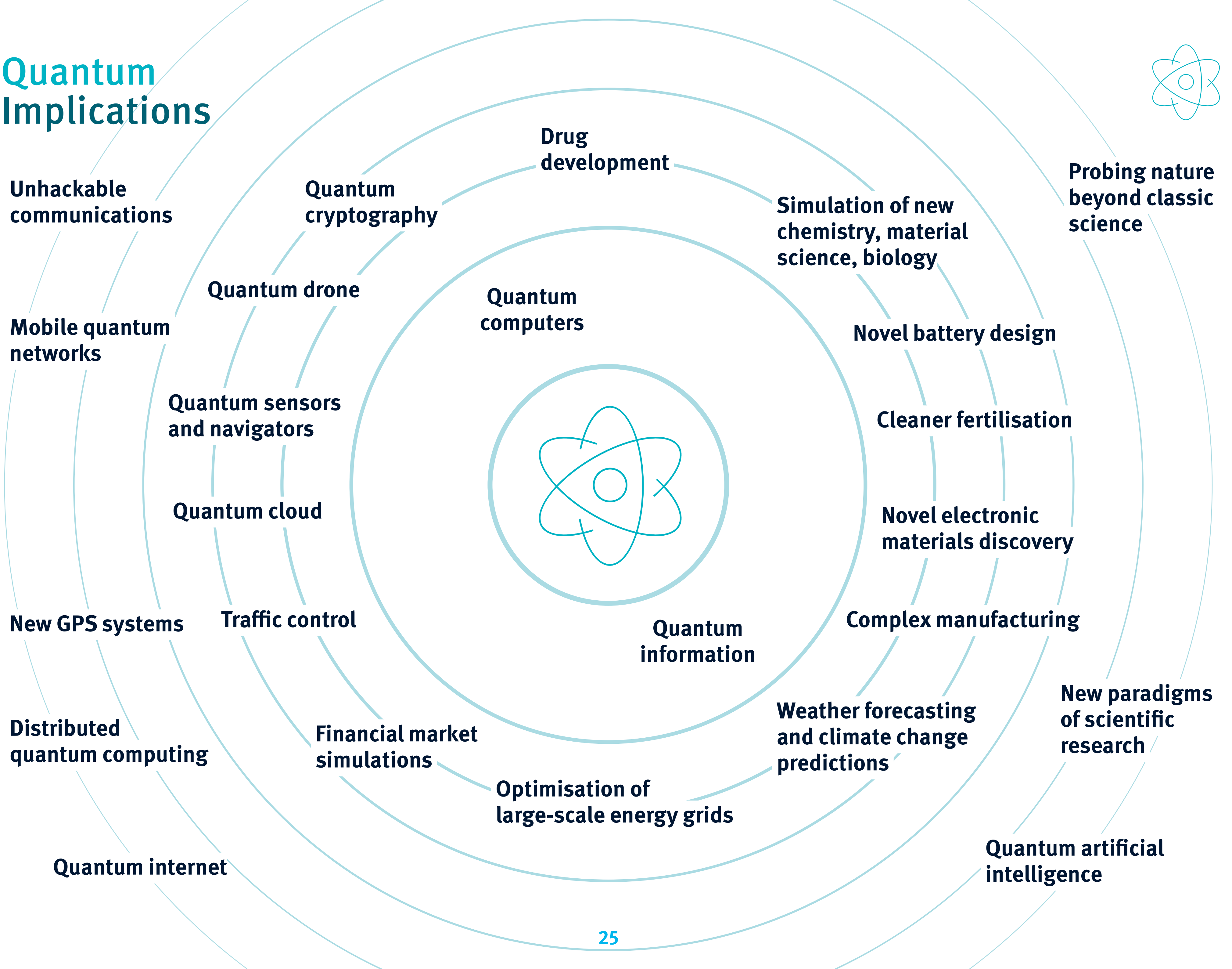
One large energy company anticipated this and established an early partnership with a quantum computing company, which is providing technology to optimise smart electricity grids.

Accelerated processing of energy system data allows the energy company's grids to deal with many types of energy source including dispatchable, non-dispatchable, community and household. This enables enhanced, flexible, and dynamic network operation of a grid which includes millions of networked distributed energy resources. Problems such as grid topology control, synthetic grid inertia modelling, and large-scale cross-network transactive energy are now more manageable.

Due to the quantum computing, large volumes of customer data introduced by smart meters, buildings, and online user data are used to make better predictions about customer demand.

The energy company has established a secure communication network using quantum key distribution. It securely transmits important asset control data to guarantee the privacy of the organisation and its customers' data. Furthermore, their investment in quantum sensors has allowed them to dramatically improve the accuracy and precision of data from their grid. This allows it to reduce outages and increase system and supply reliability.

Quantum Implications



Quantum
What does this mean today?

In the future, quantum computing will offer several advantages over classical computing. Among other things, it will enable AI systems to apply smart energy management to energy grids.

So what? Environment

Quantum computation will offer both direct and indirect benefits to tackling environmental challenges. One direct benefit is that it can be used to solve problems that require intensive data-processing, such as managing a complex ecosystem.

An indirect benefit is the energy saving that can potentially be achieved by changing the computation type applied to massive problems. Computational types can be applied to computational problems for efficiency.

So what? Organisations

Unless your organisation is involved in creating new technology, it is currently too early to make concrete plans for adopting quantum computing. Whilst companies like IBM are already selling quantum computing platforms, these are used as learning platforms. There are some expectations that, due to the physical construction of quantum computers (they require supercooling), their computational power will be accessed through cloud services.

In setting long-term strategy, it is worth exploring the problems quantum computing can be applied to, and where in an organisation they occur. Future innovations, efficiencies and new competitors can be anticipated and situated on a timeline.

So what? People

How will people benefit from quantum computing in the short term? Having yet to mature to a point of widespread commercialisation, there will be little benefit. In the medium term, the benefits will be both direct and indirect.

Quantum computing can be applied data-intensive operations for complex system optimisation such as power and traffic networks. It can also be applied to simulation and modelling tasks such as weather forecasting.

It may also improve the speed at which artificial intelligence can be trained.

Other indirect benefits of quantum computing may come from computational chemistry. Solving chemical problems that may benefit the challenge of a changing climate. In the same realm, it can be applied to materials science. It could help create materials for challenges such as space exploration and a less carbon-intensive replacement for concrete.

For a full set of reference material used to develop the quantum scenario please visit the references webpage

SCENARIO FOUR

Unknowable

New computation — New energy

Key technologies and concepts
Quantum computing, fusion reactors, Artificial Intelligence (AI), globally interconnected networks, over-the-air energy transmission, borderless energy, corderless computing, borderless knowledge, quantum artificial intelligence, terraforming-as-a-service resource orchestration, chaordic, digital twins, Internet of Everything (IoE), living planetary data skin.

Unknowable
Overview

Computing and energy on tap

In 2041, technology has given the world large amounts of disposable computation and energy. Computation has progressed through mature quantum computing and energy from stable fusion reactors. In fact, pressures from the changing climate in time has pushed private companies to invest into fusion energy, creating the conditions for it to develop commercially across the world. The technology is now cheap and distributed enough to compete with renewable technologies such as wind and solar. Limitless and safe energy is now available to the world, while pollution from energy generation is a thing of the past. Alongside computation, the powers of artificial intelligence have also developed.

Energy is distributed through globally interconnected smart networks. Long power cables have been built to connect even distant countries in a common energy grid. Energy networks have been redesigned from one way distribution to ones that cope with energy flowing both in and out of many endpoints. These network changes ease demand peaks and distribution outages. Distribution through wire is complemented by over-the-air transmission to small form factor devices.

The availability of zero carbon energy to wealthy and poorer nations benefits people and planet. Computing can be used to co-ordinate and orchestrate an economy for efficiency. As an economic enabler also eases pressures on resources.

Prior to 2041, inequities between countries had developed partly due to unequal sharing of access to traditional computation and energy. These inequities, on top of changes in the climate, led to life-taking conflicts between nation states and even within nations. Overcoming the direct and indirect problems caused by climate change was seen as a global goal.

One planet, many nations

Having evolved from the United Nations One Planet Network established in the 2020s, the One Planet, Many Nations (OPMN) initiative brings borderless energy, borderless computing and borderless knowledge to a more unified world. Signatories to the initiative get access to pollution-free fusion power, quantum cloud computing resources and AI that can be trained to suit the wants, needs and values of a particular society. In return, signatories commit to the interconnection of their economy, including power networks and transportation networks, to the OPMN network management, enabling the creations of a resilient global resource. Through this mechanism, economic inequalities are reduced, and economic surpluses distributed to people who need them.

Terraforming-as-a-service

Through the window of OPMN, quantum artificial intelligence is used as a force for civilisational continuity through improved resource usage and planetary engineering. In effect, this is terraforming-as-a-service.

Quantum computers are involved in the construction and the organisation of cities and their energy networks. They are used to optimise agriculture, plan food supply, and manage transport networks. AI has rewired human society and reduced its impact on the environment.

The centralisation and provision of the major resources of computation and energy leaves space for societies to maintain their social and cultural individuality. This gives us a chaordic (involving a mixture of chaos and order) world economy with optimised resource usage.

Digital mirrors

Digital twins of the earth are used by large-scale interconnected quantum computers to optimise the planet's resources. Originally devised for weather management, they have gone to be used for managing food supply, mass healthcare issues, and finance. There are now many more IoE devices per person than before. These devices, which are smart but simple, sense and communicate. Together they form an almost living planetary data skin and contribute to a new covenant of care between AIs and the biosphere.

Unknowable science

Humans are no longer in control of the progress of science. Quantum automated science now allows new physics and chemistry discoveries. Discoveries supersede human understanding and need to be made explainable to human scientists. The realm of knowable, within the limits of human understanding, discovery is moving to the discovery of what was previously considered unknowable. Unknowable science is beginning to pervade the OPMN initiative. This heralds the beginning of a new era of humanity.

2027 The first fusion reactor is under construction in the US

2029 Energy sharing becomes borderless

2031 OPMN is established as a global initiative, the first countries sign the agreement

2034 Access to AI is now considered a human right

2036 The bottomless currency backed on energy assets becomes a standard among OPMN nations

2039 Quantum science provides the first example of new physics beyond human comprehension

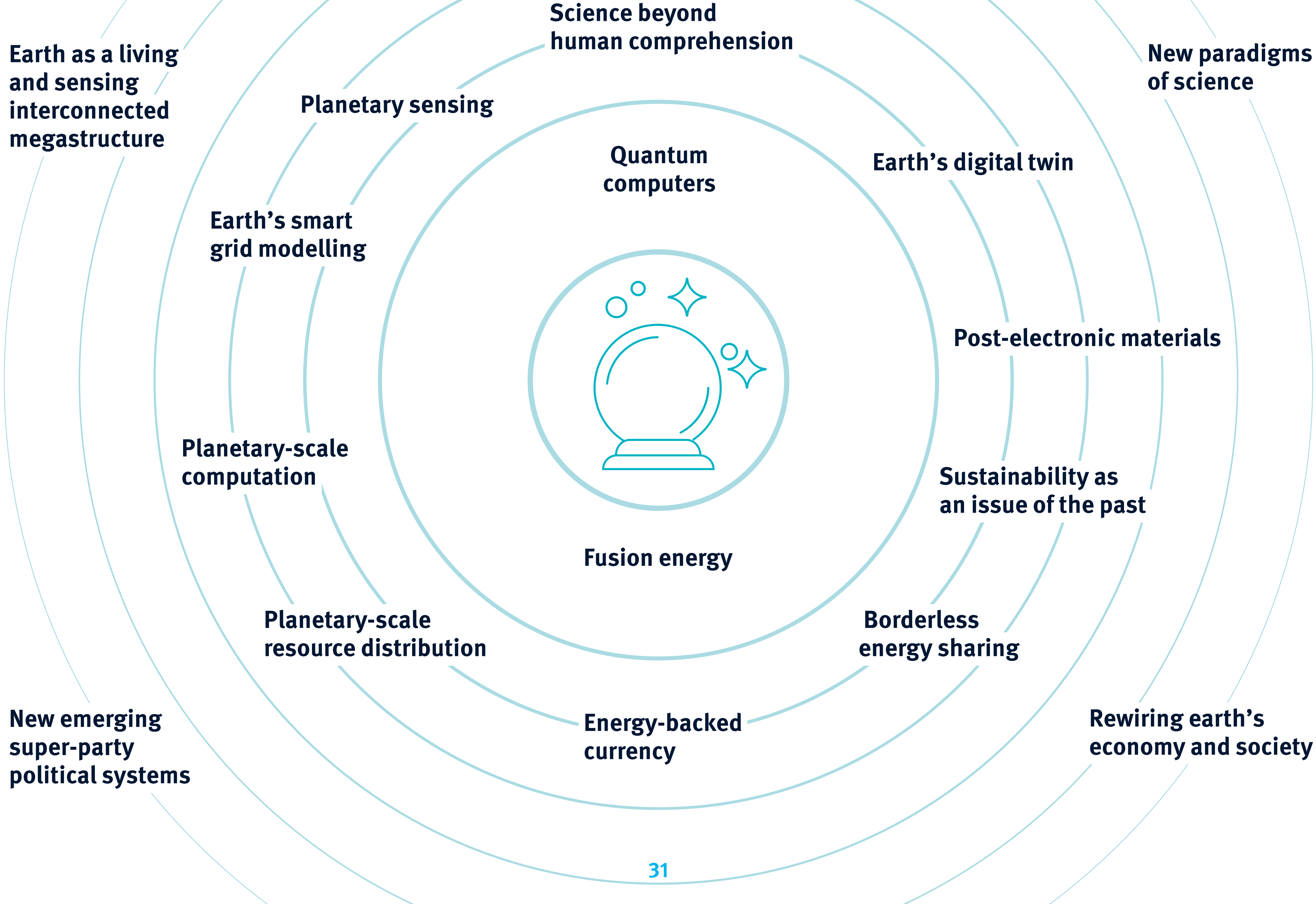
Unknowable
Organisation overview

Banking on new energy and computation

The Isbjør Bank is now the largest financial institution in the world. Established in 2030 as Greenland became a key source of the rare earth and other minerals needed by the modern world. As an innovator and early adopter, the Bank became the agent of choice to run the bottomless currency that runs alongside the bottomless energy and computing networks from the OPMN. A sibling currency was needed to allow inter-economy trading of credits associated with the OPMN networks.

The bottomless currency is backed by energy-delivery assets rather than government debt. It is slowly replacing the multiregional US Dollar, Renminbi and Riyal trading currencies. The Isbjør Bank offers macroeconomic advisory services as countries join the OPMN. Blending an economy across a local and global currency is not an easy task, but lessons learned in one economy can be applied elsewhere.

Unknowable Implications



Unknowable
What does this mean today?

The combination of quantum computing and widely deployed fusion energy will change the planet. At the time of writing, the timeline of the maturity of these two revolutionary technologies is contested. This scenario assumes that they will be commonly deployed within the scenario timeframe. Making relatively limitless energy and powerful computation available to many will have profound effects.

So what? Environment

In the long term, fusion energy has the potential to be a low-carbon game changer for energy generation. It could reshape power politics around legacy fossil fuel resources. It could also resolve energy inequities between nations.

In the shorter term, other low-carbon energy sources may come online. For example, SMR (small modular reactors), thorium-fuelled nuclear reactors, and increasingly powerful and efficient renewables.

To transform an energy system requires not only technological advances, but also political will. This is gaining momentum.

So what? Organisations

In the coming decades, energy consumption is likely to become more expensive. This will affect companies and other organisations, and often their customers.

In the short term, these higher costs can be mitigated by looking for ways to optimise operations. This could involve shifting high energy demand operations to regions where it is cheaper to source e.g. near hydroelectric sources.

So what? People

In the short term, initiatives to decrease carbon pollution from human activity are likely to increase costs in supply chains. These costs will be passed on to end users.

The timescale of the costs coming into the supply chain are governed by legislation. Currently there are targets being set in a ten-to-fifteen year window on home energy consumption, vehicle propulsion, and industrial pollution.

A knock-on effect is that there will be less discretionary household spending as more is needed for baseline expenses.

For a full set of reference material used to develop the unknowable scenario please visit the references webpage

Dictionary of technologies

Ambient energy harvesters – Technologies for capturing and converting energy from the surroundings into electricity. The energy could be heat, vibration, light.

Artificial intelligence – Computer systems that emulate human intelligence to perform tasks such as pattern recognition, decision-making, problem-solving and natural language processing.

Automated science – Scientific research conducted without the need for significant human intervention. From the use of robots to run experiments, to the investigation and discovery of new materials, chemistry, physics, and biology performed through artificial intelligence software relying on big data analytics and pattern recognition.

Brain-computer interface – A devices that allow users to interact with computers by mean of brain-activity only, enabling mind-to-machine communication with various applications, for example in healthcare and consumer electronics.

Broadcasting of energy – The possibility given by technologies like WIPT (wireless information and power transfer) to convey energy over-the-air through electromagnetic waves for powering small and medium devices. It will reduce the use of cables and batteries.

Classic computation – Computation performed through logical operations on binary information (bits) that can be either 0 or 1. The basis of modern computation.

Digital twins – Virtual copies of physical objects or processes obtained using real-time data coming from IoT sensors.

Edge computing – Computing carried out at or near the source of data, as opposed to cloud computing that relies on far away data centres to perform the work. IoT (Internet of Things) is an instantiation of edge computing.

Fossil fuels – Traditional energy sources based on coal, petroleum, natural gas, that were formed because of geological processes acting on the remains of organic matter over millions of years. Destined to be depleted, their consumption emits greenhouse gases and other pollutants as by-products.

Fusion energy – A form of power generation that generates electricity by using heat from nuclear fusion reactions. The fusion process happens when two lighter atomic nuclei combine to produce a heavier nucleus, while releasing energy. The process doesn't produce dangerous waste. It is distinct from the classic nuclear power that works on fission reactions, where a heavy and unstable atom is broken into two lighter nuclei to produce energy.

Low-energy devices – Devices such as IoT that use novel computing architectures to perform computation and sensing with minimum energy requirements.

Neuromorphic AI – A computational architecture that uses artificial neuronal synapses on a chip to perform computation mimicking the human-brain. It can perform heavy computation while using dramatically less energy than classic software based artificial intelligence. It can be used for edge computing purposes on IoT devices.

Quantum cloud – A quantum computer that can be accessed through the cloud. This allows companies to harness the power of quantum computing for their businesses without having to own a quantum computer.

Quantum computing – A new paradigm in computing that harnesses quantum mechanics to perform certain kinds of computation in an exponentially faster way than classical computing. It does so by substituting the use of bits (0 or 1) with qubits, which can be in a superposition of 0 and 1. This allows for multistate computing that is able to perform massive parallel computation.

Quantum cryptography – also called QKD (quantum key distribution), a technology that uses quantum physics to secure the distribution of encryption keys. The encrypted messages are sent in a way (through photons over a fibre cable) that allows only the intended recipient to read the message. Any attempt to read the message by an eavesdropper will result in the perturbation of the message that will lead to transmission errors.

Quantum internet – A network that will allow quantum devices to exchange information through quantum signals rather than electromagnetic waves. It could lead to un-hackable and faster-than-light communication. It could also allow distant quantum computers to perform computation collaboratively in a parallel manner.

Renewable energy – Any energy that comes from a source that is not depleted when used and doesn't emit pollution as a by-product. Examples include solar, wind, geothermal, hydroelectric, and tidal energy.

Smart grids – An electricity network that enables a two-way flow of both electricity and data, with digital technology that enables it to detect, react to and pre-empt changes in usage. Allowing electricity customers to become active participants in the system, smart grids are an important new paradigm that could enable the effective distribution of local renewable energy resources. Note that while traditional energy grids allow some bidirectional flow of energy there are limitations at a higher scale.

Wireless information and power transfer – A technology that allows both information and energy to be conveyed over the same medium, electromagnetic waves. The technology could revolutionise current telecommunication networks.

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References

For a full set of reference material please visit imperialtechforesight.com/2041-scenarios-gated/2041-scenarios-references

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