

DEEP DIVE

The Geopolitics of Technology

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Making Sense of the World



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The Evolution of Technology

The application of knowledge and research for practical use is something humans have endured since the dawn of man. Being able to reproduce these results and expand this productive process is the very definition of technology. Since the dawn of man, humans were required to live, eat, travel, fight, play and survive. All of this required using what was in their environment, making sense of this environment and then making practical use of them.

The first technology is considered by many to have been simple stone tools developed through observation and trial and error. The simple hand axe forms part of history's first wave of technology. Animals could be killed more efficiently, carcasses butchered, rivals fought. Eventually, early humans learned to manipulate these tools finely, giving rise to sewing, painting, carving, and cooking. The discovery of fire is considered by many as the greatest discovery ever. Fire, fuelled with wood and charcoal, allowed early humans to cook their food to increase its digestibility, improving its nutritional value and broadening the number of foods that could be eaten. The invention of the polished stone axe allowed large-scale forest clearance and farming which increased agriculture, which now meant people could have more children and bigger families.

The invention of clothing, adapted from the fur and hides of hunted animals is considered to have helped humanity expand into colder regions; humans began to migrate out of Africa.

Understanding fire and continuing improvements led to the furnace and bellows and provided, for the first time, the ability to smelt and forge gold, copper, silver, and lead – native metals found in relatively pure form. The advantages of copper tools over stone, bone and wooden tools were quickly apparent to early humans. The working of metals led to the discovery of alloys such as bronze and brass.

After harnessing fire, humans discovered other forms of energy. The earliest known use of wind power was the sailing ship; the earliest record of a ship under sail is that of a Nile boat dating to around 7,000 BCE. This now meant the oceans could be traversed cutting down journey times.

Archaeologists estimate that the wheel was invented in Mesopotamia somewhere in between 5,500 to 3,000 BCE. The invention of the wheel revolutionised trade and war. It did not take long to discover that wheeled wagons could be used to carry heavy loads. The use of the wheel as a transformer of energy, through water wheels, windmills, and even treadmills revolutionised the application of nonhuman power sources.

The invention of silk, horse collar and horseshoes revolutionised transport and survival. The lever, the screw, and the pulley may be considered simple tools today, but they were the machines of the Middle Ages. They were combined into more complicated tools that led to the wheelbarrow, windmills and clocks.

The reformation and enlightenment in Europe led to the formulation of knowledge, leading to the emergence of universities in Europe and the spread of ideas and practices including the movable type printing press.

The development, refinement and operationalisation of the compass, cross-staff, carvel technique and gunport led to the emergence of Europe's first modern powers - Portugal and Spain. The Iberian Peninsula went from being a quiet corner of Europe to the centre of the world in the 16th century.

The Industrial revolution in the 18th century developed the technology that created the modern world we live in today. It began with steam power emerging as an energy source that replaced muscle, wind, and water as the primary means of power. The first successful modern steam engine was introduced to pump water out of coal mines, thus allowing for deeper excavations. This made accessibility to coal abundant, leading to developments in power, smelting and transport. In a parallel development industry breakthroughs led to steel becoming available in high enough volumes and strength to be used to build railroads and steel ships, which revolutionised transport. The first wave of the Industrial Revolution combined steam power, mechanised looms, the factory system, and canals.

“The Industrial revolution in the 18th century developed the technology that created the modern world we live in today.”

Steam engines then became small and powerful enough to power steel vessels and railway locomotives. Steamships made navigation— deepwater and riverine—faster, more versatile, and more cost-efficient by breaking the link between seasonal winds and shipping.

The age of railways, telegraphs, and steamships, and then steel and machine tools formed the First Industrial Revolution. Then in the Second Industrial Revolution came the internal combustion engine, chemical engineering, powered flight, and electricity.

Breakthroughs in chemicals led to the mass production of sulfuric acid and sodium carbonate, which led to the precursor materials for everything from glass,

dyes, toothpaste, and washing detergent to steel, paper, medications, and fertilizer.

The need to communicate saw the world move from flying pigeons and horseback messengers to the telegraph, undersea cables, satellites and eventually the internet.

The two World Wars were the first industrial wars in history and led to the atomic age. The need to break Nazi communication led to the first computers that could crunch large amounts of data. Analog computers were invented to make the complex calculations faster, which were needed for nuclear detonation, missile launches and eventually space travel.

These early computers were eight-foot-tall behemoths of thousands of vacuum tubes capable of three hundred operations a second. When the first transistor was invented, it was a crude device, comprising a paper clip, a scrap of gold foil, and a crystal of germanium that could switch electronic signals. This laid the basis for the digital age. Eventually imprinting multiple transistors on silicon wafers produced what came to be called silicon chip. This led Gordon Moore to propose his eponymous “law”: every twenty-four months, the number of transistors on a chip would double, implying the world of digital and computational technology would be subject to the upward curve of an exponential process. This computational power led to a flowering of devices, applications and users.

This extremely condensed time-line of technology development shows the forward march of tech development. There has been more technological development in the last 100 years than all of human history put together. Technology is now moving so quickly, and in so many directions, that new markets are being created at a rapid rate. Technological development and progress continue to drive economic growth and in some cases, unleash disruptive change. Economically disruptive technologies—like the semiconductor microchip, the Internet, or steam power in the Industrial Revolution—transformed the way we live and work. They revolutionised and disrupted existing business structures, markets and society when they were invented.

Many forces can bring about large-scale changes in economies and societies from demographic shifts, labour force expansion, urbanisation or new patterns in capital formation. But since the Industrial

Revolution of the late 18th century, technology has had a unique role in powering growth, transforming economies and creating global powers. Technology represents new ways of doing things, and once mastered, creates lasting change, which cultures do not 'unlearn'. Adopted technology becomes embodied in capital, whether physical or human, and it allows economies to create more value with less input. At the same time, technology often disrupts, supplanting older ways of doing things and rendering old skills and organisational approaches irrelevant.

The East India Company factored heavily into geopolitics from the 17th century through the 19th century. Then tobacco companies defined their nation's geopolitical ambitions. Eventually, railroad companies in large countries such as the US rose to become dominant regional forces. Since Standard Oil's emergence more than 100 years ago, oil companies have arguably been the most geopolitically important firms. As oil's dominance in the global economy is beginning to ebb, technology companies are replacing the oil giants of the past.

Technology has a clear, inevitable trajectory: mass diffusion in great roiling waves. This is true from the earliest flint and bone tools to the latest AI models. As science produces new discoveries, people apply these insights to make cheaper food, better goods, and more efficient transport. Over time demand for the best new products and services grows, driving competition to produce cheaper versions bursting with yet more features. This in turn drives yet more demand for the technologies that create them, and they also become easier and cheaper to use. Costs continue to fall. Capabilities rise. Experiment, repeat, use, grow, improve, adapt. This is the inescapable evolutionary nature of technology.

Technology's Unstoppable Evolution: From Stone Tools to Silicon Chips

THE DAWN OF TOOLS (PREHISTORY)



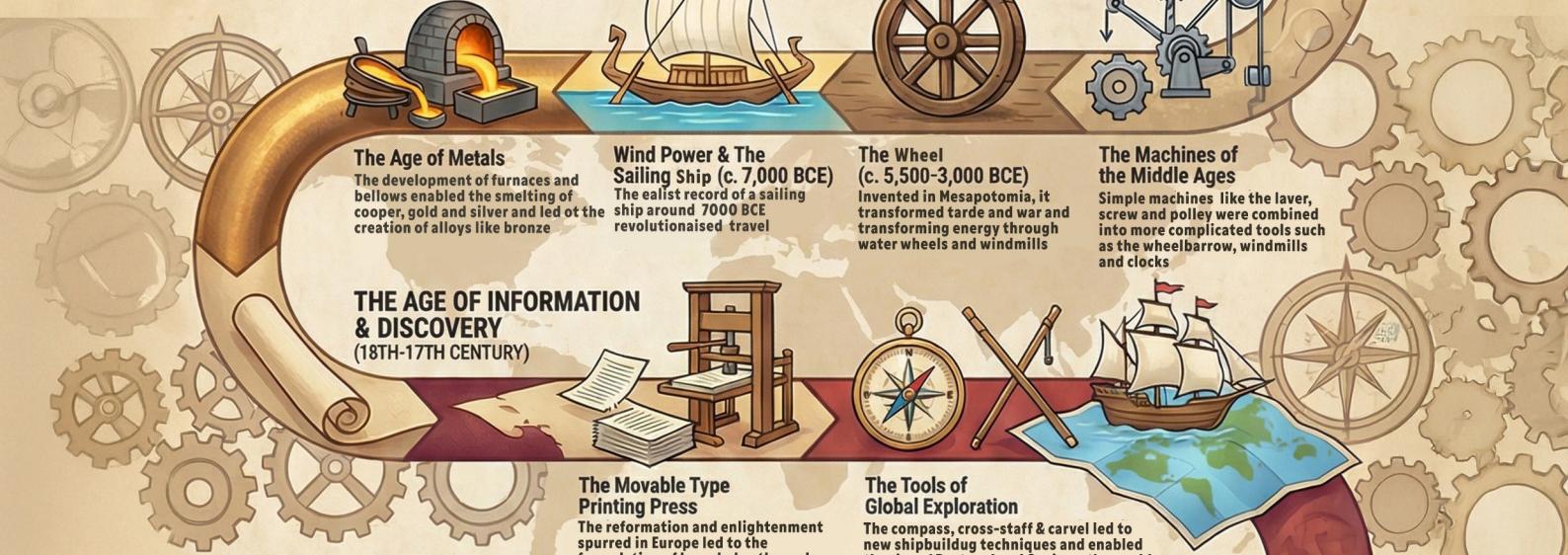
Stone Hand Axe: Humanity's First Technology
Enabled more efficient farming, animals could be killed and later to painting, carving and cooking

The Discovery of Fire
Considered by many to be the greatest discovery. It allowed for improved digestion and expanded the range of edible foods.

The Polished Stone Axe
Allowed for large-scale forest clearance, enabling farming and supporting large populations

The Invention
Made from animal hides, clothing helped humans migrate to colder regions of the world.

HARNESSING MATERIALS & ENERGY (ANTIQUITY TO MIDDLE AGES)



THE AGE OF INFORMATION & DISCOVERY (18TH-17TH CENTURY)

The Movable Type Printing Press
The reformation and enlightenment spurred in Europe led to the formulation of knowledge through universities

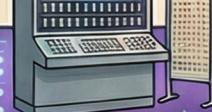
The Tools of Global Exploration
The compass, cross-staff & caravel led to new shipbuilding techniques and enabled the rise of Portugal and Spain as the world's first modern global powers.

THE INDUSTRIAL REVOLUTIONS (18TH-19TH CENTURY)

First Industrial Revolution: Steam & Steel
Steam power replaced muscle, wind, and water, first by pumping water from coal mines. Combined with mass produced steel it led to railroads and ships

Second Industrial Revolution: Engines & Electricity
The combustion engine led to light and electricity

THE DIGITAL AGE (20TH CENTURY - PRESENT)

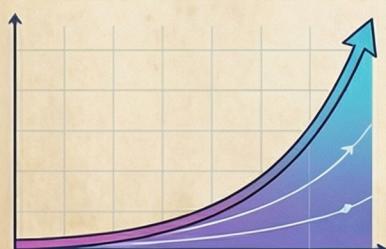


The Birth of the Computer
WW2 led to the birth of the computer to break enemy codes and perform complex calculations for nuclear weapons and missile launches

The Transistor Replaces the Vacuum Tube
When the first transistor was invented, it was a crude device, comprising a paper clip, a scrap of gold foil, and a crystal of germanium that could switch electronic signals. This laid the basis for the digital age

Moore's Law & The Silicon Chip
The observation that the number of transistors on a chip doubles every 24 months, describing the exponential growth of computational power.

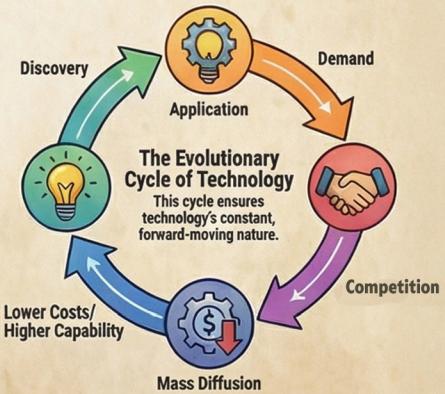
THE INESCAPABLE TRAJECTORY



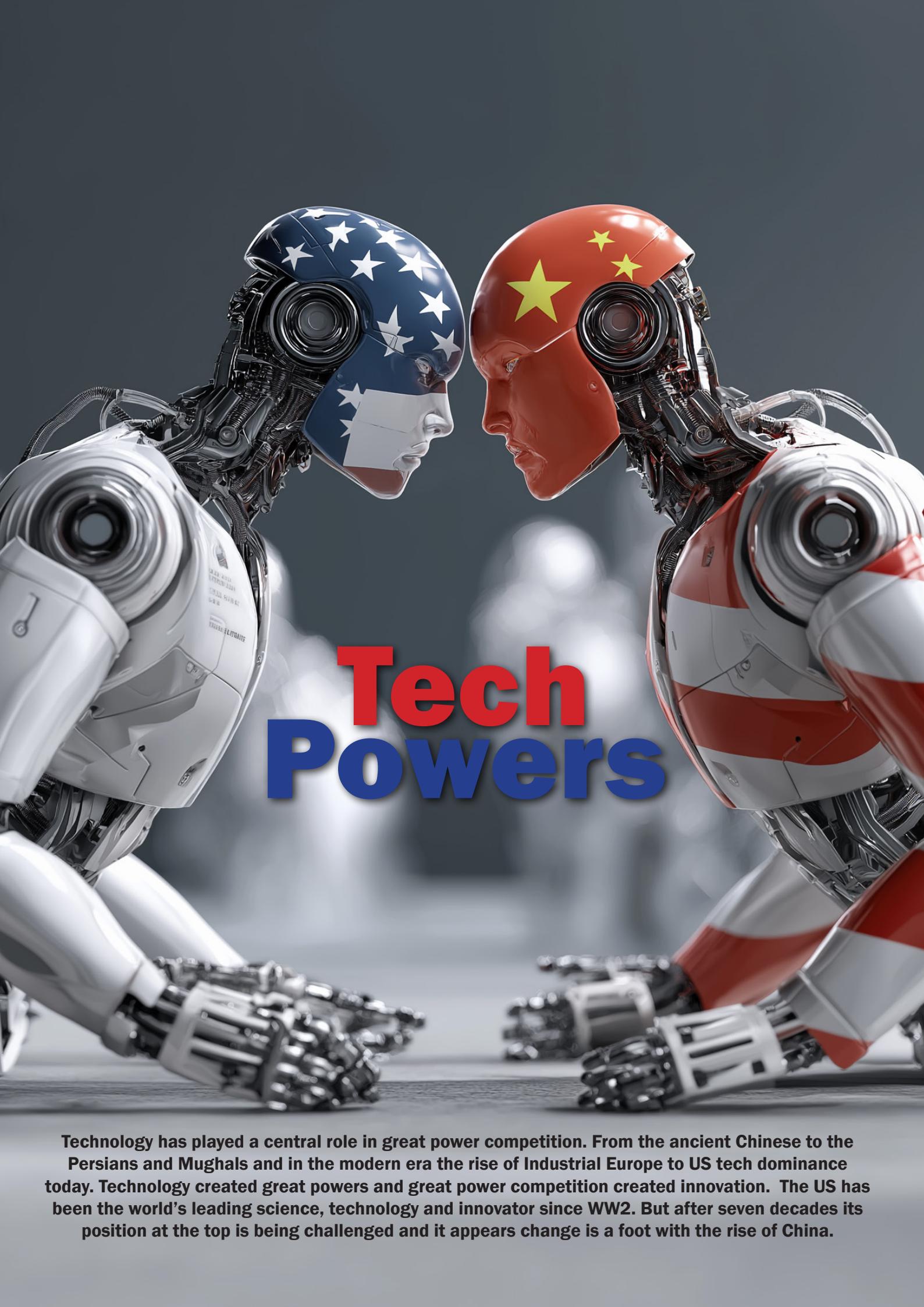
An Accelerating Pace
There has been more technological development in the last 100 years than in all of previous human history combined.



The Shifting Seat of Power
Geopolitical power has shifted over the centuries from Trading firms to resource giants to today's tech companies



Lower Costs/ Higher Capability
Mass Diffusion



Tech Powers

Technology has played a central role in great power competition. From the ancient Chinese to the Persians and Mughals and in the modern era the rise of Industrial Europe to US tech dominance today. Technology created great powers and great power competition created innovation. The US has been the world's leading science, technology and innovator since WW2. But after seven decades its position at the top is being challenged and it appears change is afoot with the rise of China.



Ancient China: From Technological Primacy to Stagnation

For most of human history, China was the world's most technologically advanced civilisation. European powers, alongside many others, traded extensively with China, yet none came close to matching its innovative capacity. Chinese advances in metallurgy, agriculture, engineering, and administration placed it centuries ahead of its peers.

Despite reaching extraordinary technological heights, China eventually fell behind. By the nineteenth century, it was overtaken by the very "barbaric Europeans" it had long viewed as inferior. These powers forced their way into the Middle Kingdom, humiliating the Qing emperor and compelling China to sign a series of unequal treaties. What followed was China's "century of humiliation." Only now—nearly two centuries later—is China once again approaching the technological frontier it once dominated.

Dynastic Rule and the Foundations of Innovation

China's four millennia of recorded history are defined by the rise and fall of dynasties. These ruling houses expanded and consolidated power around the Yellow and Yangtze rivers, gradually incorporating vast territories populated by non-Han peoples across mountains, deserts, and steppes. Governing such a diverse and expansive realm required administrative sophistication, and many of China's most important technological innovations emerged in response to this challenge—strengthening the state's autocratic

rule in the process.

The Qin dynasty (772–230 BC), in particular, shaped the foundations of China's bureaucratic state. The preceding Zhou dynasty (1047–772 BC) had endured relentless conflict: over 1,200 wars were fought and around 110 political units eliminated. This Darwinian struggle for survival forced rulers to compete fiercely for talent, fostering an environment where innovation and experimentation flourished. Although many civil service roles were initially hereditary, military competition increasingly rewarded aptitude over privilege. By the time the Qin dynasty rose to power, sixteen rival states had been reduced to seven, which were eventually unified under Qin rule. This consolidation marked the beginning of a centralised administrative system unlike anything seen elsewhere in the ancient world.

State-Led Innovation and Bureaucratic Power

After unification, the Qin dynasty constructed a highly centralised bureaucracy focused on order, control, and state capacity. Many of China's most celebrated pre-industrial achievements were state-sponsored projects. Su Song's water-powered astronomical clocks and vast irrigation works such as the Zhengguo Canal were designed for officials, not private entrepreneurs. Technology, from the outset, served governance.

Qin bureaucrats standardised the written script, unified coinage, imposed consistent weights and

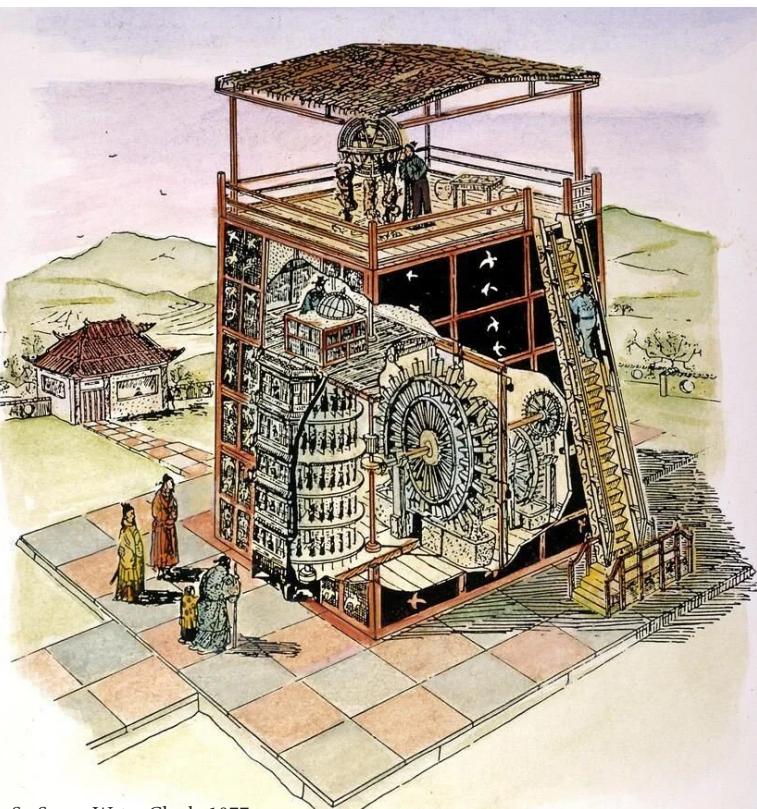
measures, and built an extensive road network radiating from the capital, Xianyang. Large-scale irrigation projects—most notably the Zhengguo Canal in Henan, which irrigated over 180,000 hectares—stabilised agricultural output and made taxation easier to administer. Population registers recorded residences and landholdings, providing the emperor with precise data on taxable resources.

Advanced farming techniques were deployed across the Loess Plateau, the cradle of Chinese civilisation. Unlike Europe's fragmented and dispersed farmland, China's fertile land was highly concentrated. Bureaucratic routinisation of agriculture made production predictable and taxable. Soil-mapping technologies enabled differentiated tax rates based on land quality, allowing rulers to extract revenue directly without relying on local councils or assemblies, as emerged in post-Roman Europe.

This created a self-reinforcing cycle: a powerful bureaucracy raised revenue, funded innovation, and used new technologies to further entrench its authority.

Infrastructure, Scale, and the Song Golden Age

The Chinese state invested heavily in infrastructure to bind its vast territory together. The Grand Canal—stretching 1,776 kilometres from Beijing to Hangzhou—was the linchpin of this system. It enabled the rapid diffusion of goods, people, and ideas. During a drought in 1012, the state used this network to distribute drought-resistant Champa rice and instruct



farmers in its cultivation, dramatically improving living standards.

By the eleventh century, Chinese technological sophistication was most visible in Kaifeng, then one of the world's largest cities. Su Song's thirteen-metre astronomical clock tower did far more than measure time: it tracked celestial movements using a water-powered escapement mechanism unknown in Europe for centuries.

This period marked the zenith of the Song dynasty (960–1279 AD). Shipbuilding, iron production, paper-making, and printing flourished. True porcelain revitalised ceramics, while the magnetic compass entered widespread use—nearly a century before its European adoption. Movable-type printing appeared centuries before Gutenberg.

Even earlier, China had been casting iron by 200 BC, a technology Europe would not master until around 1400. As Francis Bacon later observed, printing, gunpowder, and the compass “changed the face and state of things throughout the world.” Joseph Needham's monumental *Science and Civilization in China* leaves little doubt: for most of recorded history, China led the world technologically.

Innovation Through Centralisation

China's technological leadership emerged from the interaction of several reinforcing factors. A useful metaphor is to view the ancient Chinese state as a colossal, pre-modern venture capital firm, with the emperor as CEO. Because the state controlled the “data” (soil maps) and the “distribution network” (canals and roads), it could identify promising innovations and deploy them across its entire domain at unmatched speed and scale.

Technological advances both emerged from and reinforced autocratic rule. China's centralised political economy shaped the direction of innovation: discoveries were often state-driven or state-controlled. Water clocks, irrigation systems, and transport infrastructure were built for officials and administrators. While this did not lead to an Industrial Revolution, it supported population growth, rising productivity, and unprecedented prosperity. By around 1090, Song China was likely the richest society on Earth.

China also created the world's first modern state—one unconstrained by the rule of law or democratic

accountability. No councils or assemblies existed to limit imperial authority. Conquering powers such as the Mongols, Manchus, and Tanguts initially sought to preserve their own institutions but ultimately adopted China's top-down bureaucratic model, recognising its effectiveness in governing such a vast territory.

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From Momentum to Inertia

China's trajectory shifted dramatically by the late eighteenth century. In 1792, Lord George Macartney led a British mission to Beijing seeking reciprocal embassies and expanded trade access. The Qing emperor dismissed Britain's overtures, insisting China needed nothing the English could offer. For Britain, the rebuff was humiliating. Macartney later concluded that if China remained closed, its doors would have to be forced open.

That moment arrived with the First Opium War in 1839. British cannon—once dismissed by Chinese officials—proved devastating. The Treaty of Nanking (1842) inaugurated a series of unequal treaties and the beginning of China's century of humiliation.

To understand why China's centuries-long momentum stopped, it would be like a successful company that once dominated its market through bold new products. Over time, the Board of Directors becomes obsessed with rules, internal hierarchy, and tradition. They begin to promote only those who perfectly memorised the founding CEO's speeches, while firing anyone who suggested a new way of doing business. Eventually, the company becomes so focused on maintaining its internal order that it stops noticing—or even forbids—the new inventions being made by smaller, more chaotic rivals.

Where Was China's Galileo?

China's civil service system, formalised centuries earlier, recruited the most talented individuals through rigorous examinations. Public office offered prestige, wealth, tax privileges, and legal protections unavailable to commoners. It was also a powerful engine of social mobility, encouraging families across society to invest in education.

Yet this success came at a cost. Talent flowed overwhelmingly into bureaucracy rather than independent inquiry. Stability was prioritised over reform. If Galileo had lived in imperial China, he would likely have become an official, not a scientist. The system rewarded incremental improvements that served the state but discouraged disruptive ideas. As a result, China never experienced a scientific revolution comparable to Europe's.

The Dictator's Dilemma

China's early technological dominance was built on centralised power—but that same power became a constraint. Because innovation depended on state patronage, it could be halted at will. Ming and Qing rulers neglected canals, starved armies of new equipment, and allowed sophisticated technologies to decay. A single hegemonic authority could suppress heterodox ideas across the entire realm.

This tension was starkly illustrated by China's retreat from maritime power. Despite pioneering naval technology and possessing the magnetic compass, imperial edicts in the fifteenth century banned overseas trade and the construction of large seagoing vessels. Zheng He's vast fleets—once the most powerful in the world—were left to rot.

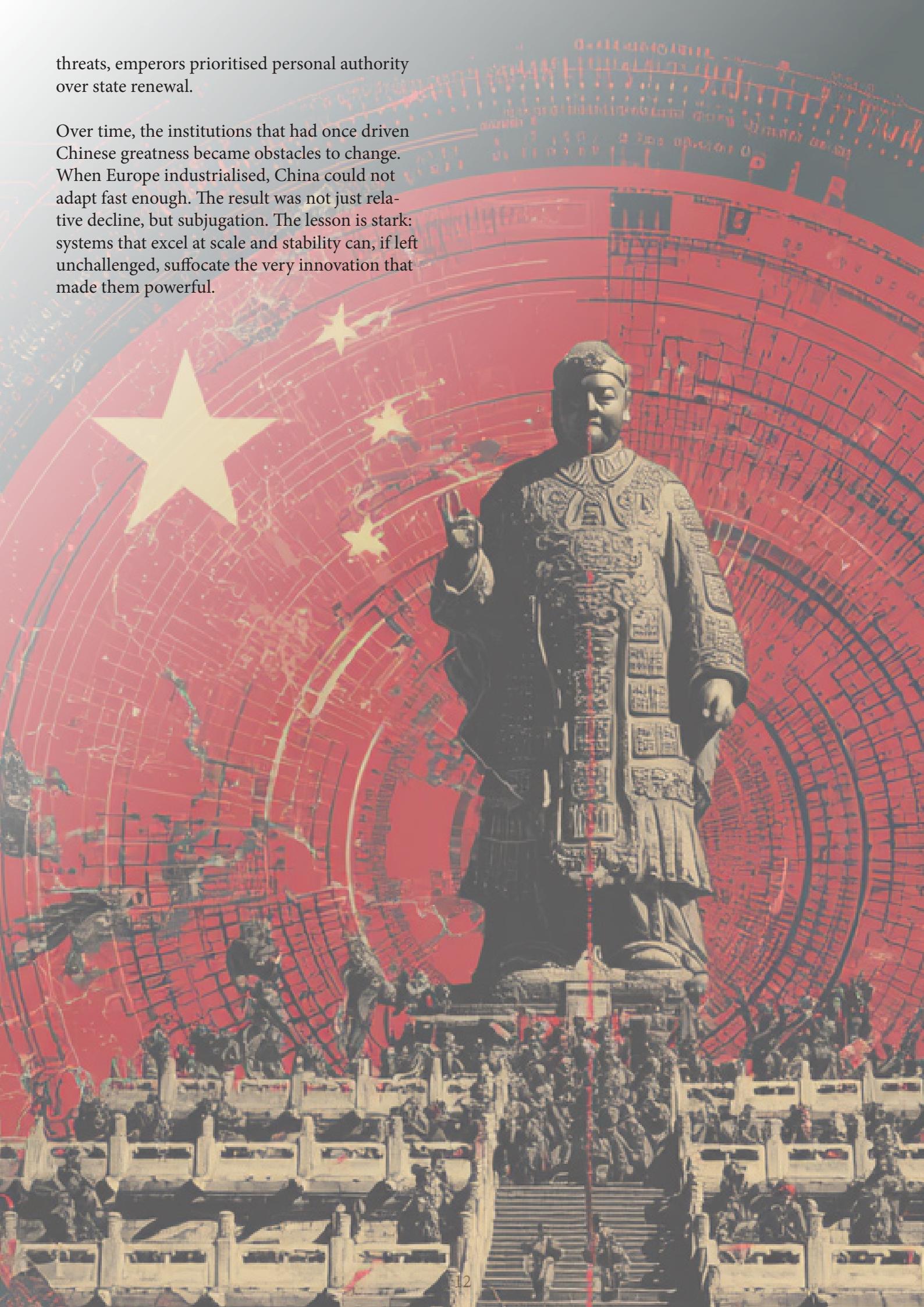
In 1420, the Ming navy fielded over 1,350 combat vessels, with established trade routes stretching from East Asia to Africa. Yet bureaucratic suspicion of merchants and fears over uncontrollable trade revenues led the state to turn inward. Stability was preserved, but progress was sacrificed.

The Cost of Standing Still

Nothing prevented China from learning from Europe, as Russia and Japan later did. It could have hired foreign engineers or sent envoys abroad. But bureaucratic orthodoxy viewed trade and innovation as destabilising forces. With no immediate external

threats, emperors prioritised personal authority over state renewal.

Over time, the institutions that had once driven Chinese greatness became obstacles to change. When Europe industrialised, China could not adapt fast enough. The result was not just relative decline, but subjugation. The lesson is stark: systems that excel at scale and stability can, if left unchallenged, suffocate the very innovation that made them powerful.



The 21st Century: The Chinese Dragon Returns



In the 21st century China has made a number of impressive achievements on the technology front. It is considered to have leap-frogged the US in areas such as artificial intelligence (AI), life sciences, 5G and quantum computing. Whilst China is long known for creating cheap knock-offs and imitations it is now a major threat in the 4th industrial revolution of technologies.

China's commanding lead in high-impact research in almost every critical technology may be surprising for many. However, the Chinese Communist Party (CCP) has been signalling, for decades now, the importance it places on technological advancement, talent, research and 'emerging strategic industries,' and those priorities are regularly and publicly outlined in its visions and plans.

China's view towards science and technology and its importance is rooted in its history. For millennia, China was a great and powerful civilisation that had technology, wealth and prosperity. But then the industrial revolution took place and China stagnated and fell behind the West. The Europeans with their superior technology and violence descended upon China, beginning with the opium war in 1839 and forced their way into China. This was the beginning of China's humiliation which would last for 100

years. The century of humiliation ended with the defeat of the Japanese at the end of World War 2. The rejuvenation of the Chinese nation – the slogan adopted by successive leaders is by revitalising the economy which will be achieved by being at the forefront of new technologies.

During the Mao era technology was transferred from the Soviet Union to China, from nuclear reactors to military jets and engines. But little progress was made by the CCP to develop indigenous technologies as Mao focused on consolidating China and its borders and firmly establishing the CCP as the sole political entity in the country. The disaster of the great leap forward from 1958-1962 set the country back and then the Sino-Soviet split and the Cultural Revolution (1964-1974) all obstructed the conditions needed to excel in technological development. Chinese science and technology were in a perilous state due to years of isolation from the global mainstream, the systematic disparagement of intellectuals under Mao and the collapse of the formal education system during the Cultural Revolution left their marks on China.

The Open and Reform era

The passing of Mao led to the emergence of Deng Xiaoping and the beginning of China's economic rise. Under his leadership an analysis of the nation was undertaken by technocrats from the CCP. The analysis presented at the 3rd Plenary Session of the 11th Central Committee of the Communist Party of China in 1978, concluded that the prior efforts to develop China had been failures. Mao's theory of continued revolution under socialism was abandoned and mass class struggle came to an end. It proposed a new comprehensive policy for China called the "Four Modernizations" of industry, agriculture, national defence and science-technology.

Realising China's industrial base was in a poor state, Deng established Special Economic Zones (SEZs) and focused on developing infrastructure such as ports, roads, railways and telecommunications in order to attract foreign companies. What China was offering the world's manufacturers was an endless supply of labour, cheaper than anywhere in the world. This offer was based on foreign firms transferring skills and technology to China's large labour force. Since 1979 many of the world's premier brands shifted manufacturing facilities to China to take advantage of the cheap endless supply of labour. The CCP carefully managed this process ensuring tech, skills and foreign companies came to China, rather than their foreign ideas and values.

Scientists suffered under the Cultural Revolution as they were accused of not being ideologically pure. In 1978 the National Science Conference in Beijing was a milestone in science policy. The conference, called by the CCP Central Committee, was attended by many of China's top leaders, as well as 6,000 scientists and administrators. It publicly announced the government and party policy of encouragement and support of science and technology. Science and technology were assigned a key role in China's "New Long March" toward the creation of a modern society by the year 2000. A major speech by then-Vice Premier Deng Xiaoping declared: "The crux of the Four Modernizations is the mastery of modern science and technology. Without the high-speed development of science and technology, it is impossible to develop the national economy at a high speed."

China's R&D had for long followed the Soviet model where experts worked in specialised research institutes rather than in academic or industrial enterpris-

es. The research institutes, of which there were about 10,000 in 1985, were funded by various central and regional government bodies. Who also determined their research tasks as well as the employment of scientists. Scientists usually spent their entire working careers within the same institute with the usual features of lifetime employment and limited contact with other units not in the same chain of command. The limited channels for exchanges of information led to little innovation and often duplication and repetition of research.

"This lure of China's colossal market has seen companies, researchers, scholars and universities from around the world transfer, or otherwise hand over their knowledge and experience, which has helped China build its technological capabilities."

As a result the CCP made sweeping reforms of science management. The main reforms made a major break with past practices. It changed the method of funding research institutes, encouraging the commercialisation of technology and the development of a technology market, and rewarding individual scientists. The reforms were meant to encourage the application of science to the needs of industry. It was envisaged that most research institutes would support themselves through consulting and contract work and would cooperate with factories through partnerships, mergers, joint ventures, or other appropriate and mutually agreeable means. The ultimate goal was to encourage exchange and cooperation and to break down the compartmentalisation characterising China's research and development structure.

The principal means for accomplishing the reforms was changing the funding system to force research institutes to establish contact with productive enterprises and to do work directly supporting those enterprises. Direct allocation of funds to research institutes was to be phased out and replaced by a system under which institutes sold their services in the marketplace. The reforms were not intended as a

budget-cutting measure, and total state funding for science and technology actually increased.

What China did was build a system in which Chinese companies and innovation satisfy the vast internal market, while exporting around the world. Deng Xiaoping's open and reform was designed to attract technology, skills and talent. This lure of China's colossal market has seen companies, researchers, scholars and universities from around the world transfer, or otherwise hand over their knowledge and experience, which has helped China build its technological capabilities. In this way China's State-Owned Enterprises (SOEs) flourished throughout the 1980s and helped form the foundation of China's economic miracle.

Up to the early 2000s China focused on acquiring, learning and mimicking foreign technology. As the 2000s went by, talk of indigenous innovation and self-sufficiency began to emerge at CCP summits and policy papers. When the CCP was pushing its industrial titans to invest abroad it was also to acquire the technology needed to move China up the tech ladder. Three broad tactics evolved ever since China's national champions went global:

Acquisitions – Mergers and acquisitions have been a major hallmark of China's global companies. Chinese companies have been buying up tangible assets such as mineral deposits and oil reserves. By 2009 more than 70% of Chinese deals involved either energy or natural resources. Among these were Yanzhou Coal's \$2.8 billion takeover of Australia's Felix Resources, and Sinopec's \$7.2 billion acquisition of the Swiss-registered oil and gas company Addax.

China National Chemical Corporation (ChemChina), took over French Adisseo in 2006. By buying the French company for \$480 million, ChemChina obtained methionine production technologies that were then non-existent in China. The Chinese also targeted companies that can deliver emerging and new technologies and possess offshore R&D facilities. Their value lies in their intellectual property, knowledge, and research and design processes. Patents and blueprints can be beamed to China, where an engineer can easily interpret them.

Cybertheft – China has state-sponsored hacking that focuses on stealing intellectual property and in 2021 it reached a record high. Cybertheft has ranged from theft of designs for advanced US fighter planes

and gas distribution networks to personal information from healthcare providers. The process has lasted years, with almost daily raids on Silicon Valley firms, military contractors and other commercial targets. In 2020 Chinese hackers reportedly stole data from the credit rating firm Equifax. Data of over 145 million Americans was compromised. The huge cyber effort by China has seen a massive theft of intellectual property from companies around the world and is now referred to as "the greatest transfer of wealth in history."

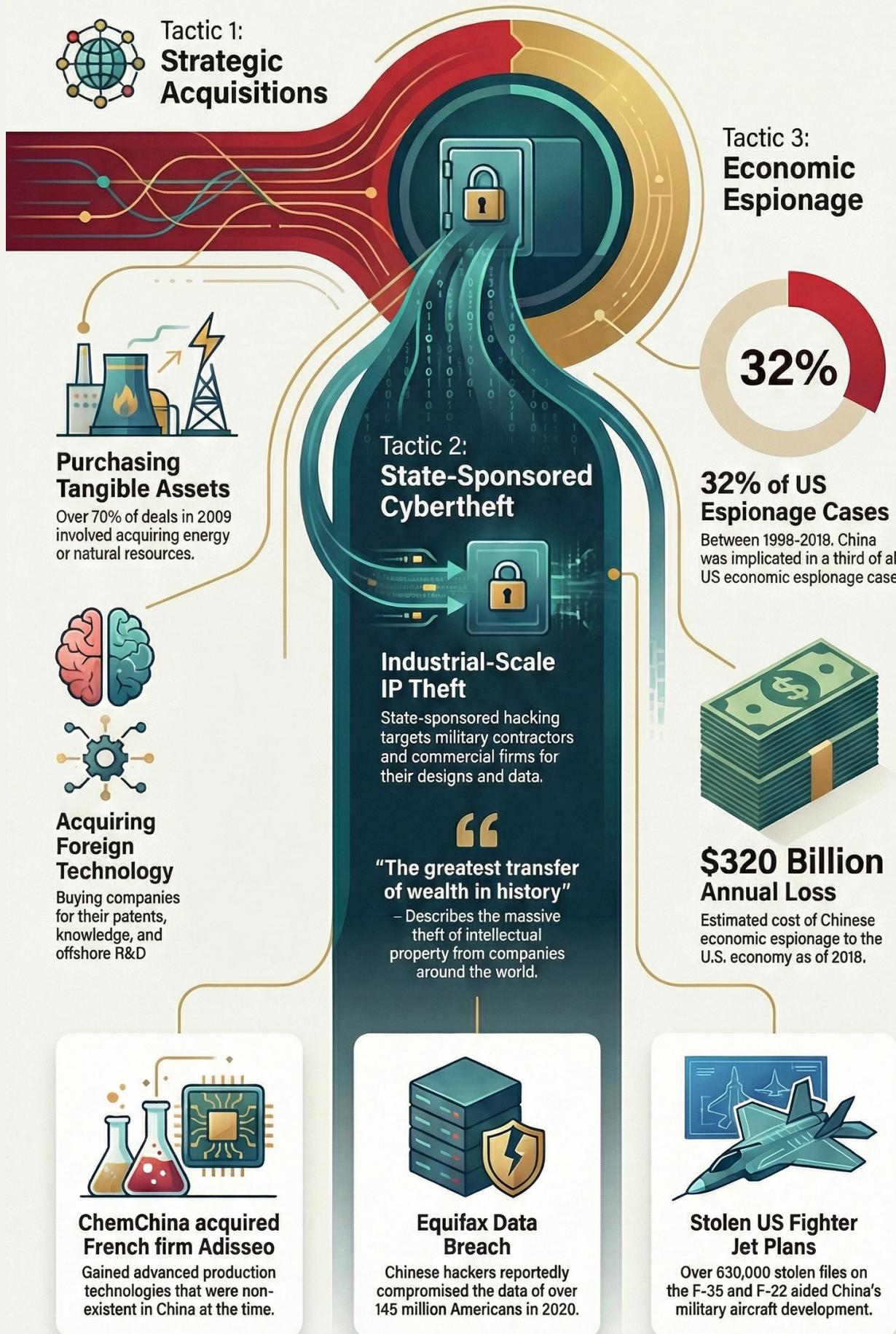
Espionage - China and its Ministry of State Security has been implicated in scores of espionage activities in the US and around the world. Between 1996 and 2019, China faced 66 (32%) of the 206 US federal cases involving charges related to economic espionage. From 2016-2019 China accounted for half of all charges related to economic espionage (18 of 36 cases). Researcher Nicholas Eftimiades estimated that Chinese economic espionage activities accounted for \$320 billion in losses per year as of 2018, or 80% of the total cost of intellectual property theft to the US estimated at \$400 billion per year by the director of national intelligence. China's major scalp was Su Bin who established an aerospace firm in Canada which successfully targeted US defence companies and managed to get hold of over 630,000 files containing information on the C-17, F35 and F22. China's J-20 and F-31 were produced by China's air force with this information.

"China's innovation and technology strategy is built on forced technology transfer, cybertheft, massive state-led capital investment, and global strategic acquisitions done by state-run corporations."

China's innovation and technology strategy is built on forced technology transfer, cybertheft, massive state-led capital investment, and global strategic acquisitions done by state-run corporations. When the world's largest companies come up against Chinese companies they are in effect competing with a 17 trillion-dollar state who is pouring billions into robotics, biotechnology, and quantum computing, or snapping up strategic acquisitions such as deep-sea mining corporations and leading-edge aerospace composites

China's Playbook for Global Industrial Expansion

A multi-pronged global strategy to fuel industrial and technological advancement, combining legitimate business with covert operations to acquire assets, technology, and intellectual property.



companies. The CCP has also brought China's corporations and military together through a policy of "Civil Military Fusion." Here, China's private sector and military technology development combine, spanning a wide range of emerging technologies from artificial intelligence to robotics.

China's DARPA

The Chinese Academy of Sciences (CAS), is the world's best-performing institution when it comes to technology research. It has been found to be the world leader in research in over half the technologies of the future. CAS is more than a research institute; it plays a vital role in China's whole-of-nation approach to Science and Technology (S&T) policy and has been at the centre of the country's major technological breakthroughs since the founding of the People's Republic in 1949. CAS is a ministerial-level institution sitting directly under the State Council and has spearheaded the development of China's indigenous science, technological and innovation capabilities, including in computing technologies, nuclear weapons and intercontinental ballistic missiles. It's believed to be the world's largest scientific institution, with a reported departmental budget of \$23.8 billion, has more than 69,000 employees, as well as investment arms and a large number of branches, institutes and national labs. CAS has a robust internal communist party apparatus, and CAS members are required to 'model love of the Party', 'serve national security' and follow the policies of the Chinese Communist Party's Central Committee.

CAS specialises in commercialising its findings and creating new companies. That approach can be traced back to 1985, when CAS undertook a reform named 'one academy, two systems' which encouraged its research institutes with application capabilities to enter the market. According to CAS, by 2022 more than 2,000 companies had been founded from the commercialisation of its scientific research. Companies that CAS has established or helped to create include Lenovo, iFlyTek, Sugon, Cambricon Technologies and Loongson. A number of them have been added to the US Entity List over the past five years for reasons ranging from links to China's military modernisation to human-rights violations.

Whilst CAS is not exactly the same as America's DARPA, it has played a central role in developing China's innovation capabilities.

Made in China 2025

The state driven Made in China 2025 (MIC2025) plan unveiled in 2015 aimed to lift the country's industries up the value chain, replacing imports with local products and building global champions able to take on the Western technology giants in cutting-edge technologies. The strategic plan of China issued by Chinese Premier Li Keqiang and his cabinet in May 2015 aimed to move China away from being the world's factory floor for cheap goods and low quality and to move to higher value products and services. Made in China 2025 is the natural evolution of China's strategy of being a technology giant and self-sufficiency in the next generation of technologies.

The goals of 'made in China 2025' included increasing the Chinese-domestic content of core materials to 40% by 2020 and 70% by 2025. The plan focused on high-tech fields including the pharmaceutical industry, automotive industry, aerospace industry and semiconductors, IT and robotics etc, which are presently the purview of foreign companies. It was an initiative to comprehensively upgrade the Chinese industry.

"MIC2025 has been a resounding success and has seen China achieve in a decade what previously would take a lifetime."

A 2024 analysis by the South China Morning Post found that of the more than 260 goals proposed under the MIC2025 plan, more than 86% of the targets had been achieved. The report found targets in sectors such as electric vehicles and renewable energy were well surpassed, all the goals in robotics, agriculture machinery, biopharmaceuticals and marine engineering were fulfilled, though some targets such as advanced photolithography technology, intercontinental passenger aircraft and broadband internet satellite networks were unfulfilled. The sector with the lowest completion rate was new materials, at 75%.

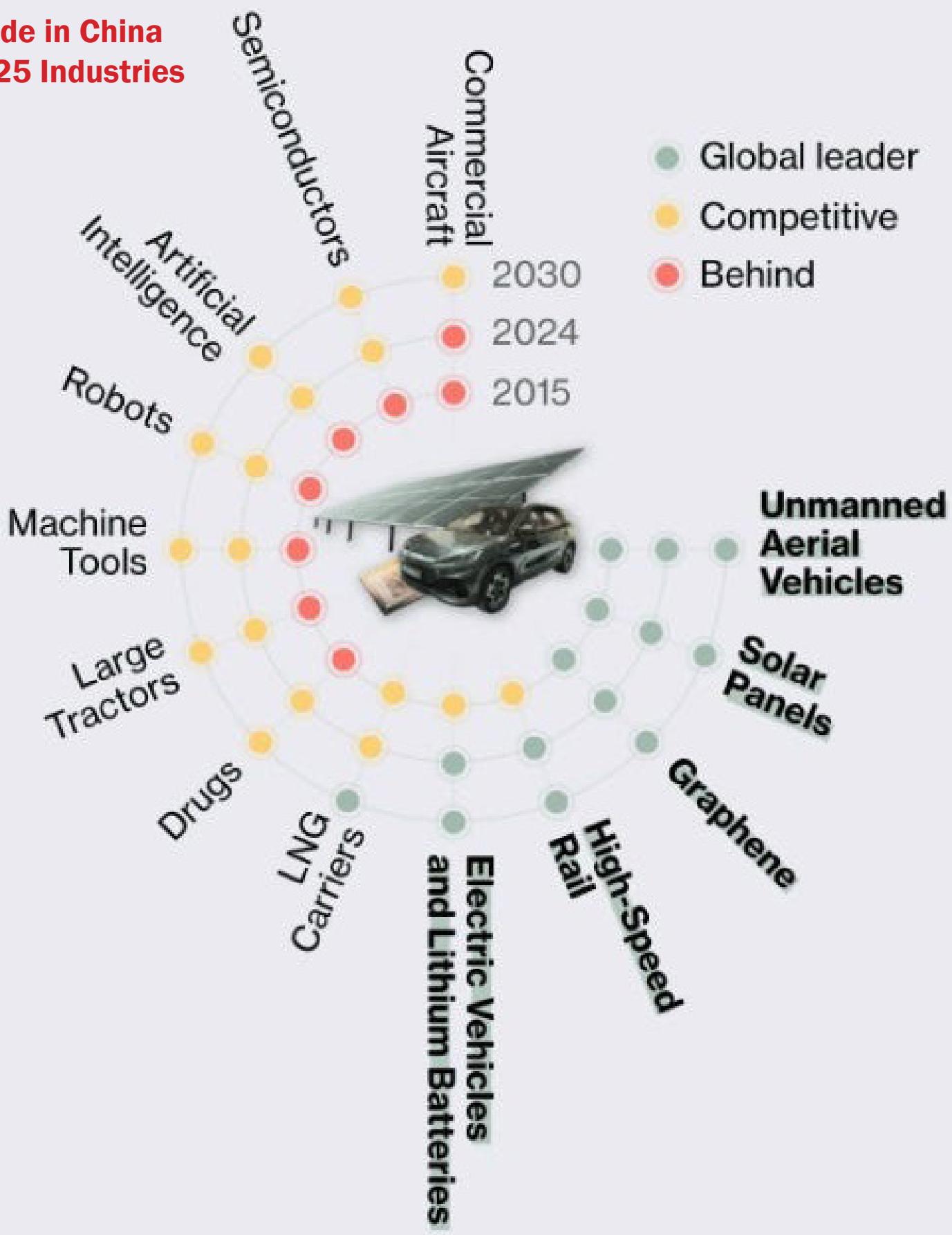
MIC2025 has been a resounding success and has seen China achieve in a decade what previously would take a lifetime. By focusing on strategic sectors, throwing money at it and acquiring the skills and knowledge from abroad it now leads in areas that just a decade ago was led by tech and science organisations from the West. China has reached, or is near

to reaching, the technological cutting edge in most of the sectors it has targeted. Of the 10 sectors targeted by MIC2025, China can credibly claim to be the world leader in four (Electric Vehicles, Energy and Power Generation, Shipbuilding, and High-Speed Rail); China is therefore shaping up to be a super-power of green energy and advanced logistics, often in areas of technology with obvious military application. In five sectors, China has made substantial

progress toward the technology frontier but is not yet a leader: Aerospace and Aviation, Biotechnology, New Materials, Robotics and Machine Tools, and Semiconductors.

China in just two decades has moved into pole position to be a technological leader and this is threatening the US who has held the position since the 1950s.

Made in China 2025 Industries





Europe and the Power of Decentralisation

The Industrial Revolution was born in Europe. It transformed a cluster of fragmented states into global powers capable of harnessing technologies unprecedented in human history. Both the industrial-technological revolutions emerged on the European continent—and nowhere else. This outcome was far from inevitable.

For centuries after the collapse of the Roman Empire in the fifth century, Europe was a geopolitical backwater. Wars of religion, rigid class hierarchies, endemic poverty, and political instability dominated the continent. Few observers would have expected England—or any European nation—to become the epicentre of global innovation, let alone the driver of world conquest and industrial capitalism.

China's Bureaucratic Advantage—and Europe's Absence of It

China constructed a vast bureaucratic state because its rulers needed reliable mechanisms to raise revenue, maintain security, and govern a unified empire. Centralisation was the logical outcome of these pressures.

Even at its height, the Roman Empire never devel-

oped a bureaucratic apparatus comparable to China's. Crucially, Rome lacked the technological tools to systematically track production and tax its population—a deficiency that European monarchs would still suffer from a millennium after Rome's fall. Without these capabilities, Roman rule relied on scale without administrative penetration. Rather than dismantling local power structures, Rome governed indirectly, allowing conquered elites to retain their armies and institutions while integrating them into a broader imperial order.

Fragmentation as a Feature, Not a Bug

Europe's technological backwardness entrenched decentralisation. This tendency intensified after the Roman Empire collapsed, producing a continent defined by political fragmentation. Europe became a patchwork of competing kingdoms, duchies, city-states, religious authorities, and semi-autonomous territories.

This stood in stark contrast to China's unified legal system, single written language, and highly centralised administration. Europe lacked strong central bureaucracies and instead developed a distinctive social and political structure marked by weak states,

powerful local institutions, and intense interstate competition.

The Latin Church and the Breakdown of Kinship

A critical but often overlooked driver of Europe's decentralised trajectory was the Latin Church. Through its marriage and family policies—most notably the prohibition of close-kin marriage—the Church systematically weakened clan-based and tribal structures across Europe.

This forced individuals to look beyond extended families for partners, collaborators, and patrons. Over time, Europeans developed broader and more fluid social networks. Learning shifted from vertical transmission within families to horizontal exchange between unrelated individuals. This transformation laid the foundations for a collective intellectual ecosystem in which ideas could circulate freely across social and geographic boundaries.

Following the collapse of Rome, the Church emerged as the only pan-European institution. While it collaborated with monarchs and nobles, its family policies unintentionally reinforced decentralisation by undermining kin-based power structures. This further expanded social networks, increased mobility, and accelerated the diffusion of ideas.

Governing Without Bureaucracy: Consent Over Command

Unlike China, European rulers lacked the technologies—such as detailed land surveys and soil mapping—needed to monitor production and extract taxes directly. This administrative weakness forced monarchs to govern through negotiation rather than command. Power remained dispersed among local assemblies, towns, estates, and guilds.

“Following the collapse of Rome, the Church emerged as the only pan-European institution.”

Throughout the medieval period, cities and towns enjoyed substantial political autonomy. Monarchs could not easily impose their will, so urban centres competed fiercely to attract talent and investment. This environment also gave rise to the modern business corporation, which replaced kinship-based cooperation with impersonal legal entities. Firms could now scale beyond local communities, enabling

economic coordination impossible in clan-based societies.

Competition, Mobility, and the Republic of Letters

In China, the emperor ultimately decided which ideas flourished and which were suppressed. In Europe, fragmentation prevented any single authority from enforcing intellectual conformity. Thinkers persecuted in one territory could relocate to another.

This mobility produced the “Republic of Letters”—a transnational intellectual community linked by correspondence, printing, and, later, postal services. Scientific societies, academies, and professional associations emerged, connecting scholars across borders. Ideas travelled faster than rulers could suppress them.

By contrast, in China, social networks rarely extended beyond family or clan. This limited portability, hindered knowledge diffusion, and prevented the emergence of autonomous knowledge communities.

The Enlightenment and the Irreversibility of Pluralism

By the Enlightenment era, Europe consisted of numerous competing rulers and jurisdictions. Revolutionary ideas could not be extinguished continent-wide. The Protestant Reformation illustrates this dynamic: it began in fragmented Germany, spread rapidly across Europe, and survived because some rulers embraced it while others opposed it. Such ideological diffusion was structurally impossible in a unified empire like China, where a single emperor could suppress dissent.

Europe certainly produced repressive regimes, but rivalry between them constrained their ability to impose lasting orthodoxy. Intellectuals such as Comenius, often regarded as the father of modern education, moved across borders—from Bohemia to Sweden, Poland, and England—carrying ideas with them.

Europe’s Narrow Escape

Europe might have followed China's trajectory had the Roman Empire endured. Roman elites showed little interest in labour-saving innovation and often resisted it. Pliny the Elder recounts how Emperor Tiberius executed an inventor whose discovery

threatened employment. Emperor Vespasian banned a machine for transporting columns cheaply, asking instead how he would “feed the populace.” Political stability mattered more than productivity.

As a result, Roman engineering brilliance was directed toward monuments, aqueducts, and baths rather than manufacturing efficiency. Rome’s vast infrastructure served elite power, not industrial transformation. This is why most progress in mechanics—including the development of cranes, pumps, and water-lifting devices—were made to support the vast construction and hydraulic engineering efforts of the empire rather than to save labour. With its 1,780 great houses, 423 neighbourhoods, 28 libraries, 19 aqueducts, 2 circuses, 886 baths, 144 public latrines, 37 gates, and 1,352 cisterns, Rome was an extraordinary place, but technology served Rome’s ruling class rather than the expansion of manufacturing. The empire was magnificent—but technologically static.

Why Britain Industrialised First

The transition to the modern world was not a smooth one, as powerful incumbent forces had an interest in protecting the status quo. In the end it was Britain, rather than its rivals on the continent, that made the leap and reaped the bounty of the 18th and 19th centuries industrial breakthroughs.

To understand why Britain industrialised first, imagine a marathon where every other country’s track was filled with hurdles and gates guarded by people who didn’t want the runners to go too fast. In those countries, the referees (the government) helped the gatekeepers keep the hurdles in place to avoid a fight. Britain was the only place where the referees decided to tear down the hurdles and protect the fastest runners, even when the gatekeepers tried to riot and stop the race.

All over Europe, those wanting to be a butcher, a baker, or a brewer could not just open a shop—they had to become a member of a guild. These organisations had controlled urban life since the twelfth century, regulating industries and ensuring that their members maintained high standards. Consumers trusted guilds as brands—a bottle of Burgundy wine or a wheel of Parmigiano cheese carried a seal of quality. But guilds were not just quality control systems. They were also gatekeepers, keeping membership exclusive and making it difficult for outsiders to compete. Extensive training was required to

become a master, and even then, the number of new members was kept low. Local rulers, in turn, had no interest in breaking this system, since guilds helped them collect taxes.

Guilds played a complex role in the history of innovation in Europe. On one hand, they helped pass down knowledge and skills, ensuring high standards within trades. But they also functioned as cartels, tightly controlling their industries and fiercely resisting any technology that threatened jobs or incomes, including those that made the Industrial Revolution.

In Britain, guild power had largely eroded by 1700, even though they were not formally abolished until the Municipal Corporations Act of 1835. This erosion created space for new industrial centres such as Manchester and Birmingham, which developed outside the reach of ancient regulation. Manchester grew from a town of 2,000 people in the seventeenth century to a city of 300,000 by 1841. Both emerged in formerly rural areas and became Britain’s industrial powerhouses.

With the Guilds out of the way a host of British businessmen in the late 1700s combined a series of nascent technologies that changed the world. Britain’s Industrial Revolution began in textiles but quickly spread to tools, furniture and railroads. Among the wave of technologies that entered British factories, the steam engine stands as the crowning achievement. As a general-purpose technology, it revolutionised a range of industries, not only driving



machinery but also transforming transportation. In contrast to many inventions of the era, which were born purely from engineering pursuits, the creation of steam power was rooted in discoveries from the scientific revolution. It relied on the insight that the atmosphere has weight and therefore can be used to do work. The full transformative impact of the steam engine would only be felt after nearly a century of further tinkering and development.

The technologies from the Industrial revolution - the

factory floor, steam power and then electricity and chemicals spread to France, Holland and then Germany. They would eventually make their way across the continent to the US and turn her into a global power. They would lead to the first industrial war in the Great War of World War One. The Industrial Revolution took place in Europe and not another place as fragmented and decentralised societies allowed ideas, tinkering and innovation to spread across borders, societies and ancient lines.



Forging the First Industrial Revolution: Why Britain Led the Way

Continental Europe: Held Back by Tradition



Britain: Clearing the Path for Progress



Guilds Controlled the Economy

Headline: Revolt Begins in Textiles
With institutional barriers gone, British innovators combined nascent technologies, starting with the textile industry.



A Mark of Quality, But at a Cost

Guilds ensured high standards and acted as trusted "brands" for consumers, but they also functioned as cartels.



Gatekeepers Against Innovation

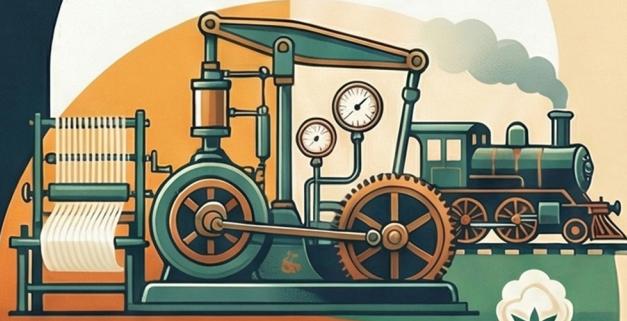
They fiercely resisted any new technology that threatened jobs or markets making it difficult for outsiders to compete or innovate.



Rulers Upheld the Status Quo

Local rulers had no interest in breaking the system, as guilds were effective partners in collecting taxes.

The Technological Breakthrough



The Steam Engine: A Crowning Achievement

The steam engine stands out as a general purpose technology that revolutionized machinery and transportation.



Rooted in the Scientific Revolution

Its creation relied on the scientific discovery that the atmosphere has weight and can be harnessed to do work.



The Power of Guilds Eroded

By 1700, the influence of guilds in Britain had largely disappeared, long before they were formally abolished in 1835.



New Industrial Cities Emerged

This power vacuum allowed new industrial centers to develop outside the reach of ancient regulations.



The Explosive Growth of Manchester

Formerly a small town of 2,000, Manchester grew into an industrial powerhouse of 300,000 people by 1841.



An Analogy: The Unfettered Race

Britain was the only place where the referee decided to tear down the hurdles and protect the fastest runners.

The Revolution Spreads



Innovation Crosses Borders

The new technologies spread from Britain to France, Germany, and eventually to the US, transforming it into a global power.



A New Era of Conflict

This new industrial might ultimately led to the first industrial conflict, the Great War (World War One).



Why Europe?

The continent's fragmented and decentralized nations allowed innovative ideas to spread across borders and societies, fostering a unique environment for change.



Europe's Industrial Titan

Germany's technological story is one of transformation. In the early nineteenth century, it was a divided region with little heavy industry compared to Britain or France. Yet within a few decades it became a global leader in chemicals, steel, and electrical engineering. By the early twentieth century, it was producing cars, planes, and scientific breakthroughs that set global standards. The Nazi period revealed the destructive power of technology mobilised for war, while the post-1945 decades showed how careful state policies, research institutions, and a skilled workforce could rebuild an advanced industrial economy. Today, Germany remains a technological leader in high-precision engineering, renewable energy, and applied research, even as it struggles to keep pace in digitalisation and artificial intelligence. To understand the German journey, we need to look at how domestic politics, global pressures, and scientific culture worked together.

Industrial Catch-Up in the 19th Century

Until the late nineteenth century, Germany remained politically fragmented. The creation of the German Empire in 1871 under Prussian leadership provided the political framework for rapid industrialisation. The new state coordinated economic policies, supported railways, and invested in technical universities. The Zollverein customs union had already created a common market among German states, reducing trade barriers and giving firms the scale

they needed to expand.

By the 1880s, Germany was challenging Britain. It became particularly strong in industries dependent on scientific knowledge. Chemical giants such as BASF, Bayer, and Hoechst dominated synthetic dyes and pharmaceuticals, turning laboratory discoveries into globally competitive products. Siemens became prominent in telegraphy, electrical power, and, later, household appliances. Krupp emerged as a major name in steel and armaments.

Historians emphasise that Germany's advantage lay in integrating science and industry. Thomas Misa wrote, "German industry was born in the laboratory," meaning that industrial innovation depended on systematic research rather than trial-and-error tinkering. This approach was supported by universities that trained chemists and engineers, and by firms that created in-house research laboratories.

Domestic politics reinforced this growth. The German state adopted tariffs to protect emerging industries, funded rail and canal projects, and cultivated ties between military needs and industrial capacity. Global politics also played a role. The Kaiser's Welt-politik, or "world policy," aimed to make Germany a great power with colonies and a navy to rival Britain. Technological strength became a central component of these geopolitical ambitions.

Technology Between the Wars and Under the Nazis

By 1914, Germany had become an industrial giant. It led the world in automobiles, aircraft engines, chemicals, and heavy engineering. The First World War showcased this capacity—German submarines, artillery, and chemical weapons demonstrated technological sophistication. Yet defeat in 1918 revealed the limits of even advanced technology. The Treaty of Versailles restricted German rearmament and banned certain kinds of military research.

However, German innovation did not stop. Engineers continued work in fields such as aviation, often through clandestine collaborations abroad. Political instability during the Weimar Republic made state funding unpredictable, but firms like BMW and Daimler-Benz maintained research capabilities.

The Nazi regime's rise in 1933 transformed the situation dramatically. Adolf Hitler placed technology at the heart of rearmament and national renewal. The Volkswagen project was meant to symbolise affordable mobility, while massive state investments went into jet aircraft, synthetic fuels, radar, and the V-2 rocket. Historian Adam Tooze argued that the Nazi economy showed how "...technology was pressed into the service of total war."

This era underscores the double-edged nature of technological power. Innovations that pushed engineering frontiers were used destructively, but they also had lasting influence: German rocketry became the foundation of both American and Soviet space



programs, while advances in chemicals and materials were absorbed by Allied industries. Thus, even in defeat, German technological capacity shaped global development.

Rebuilding After World War II

The devastation of 1945 was total. Cities lay in ruins, infrastructure was destroyed, and much of the industrial base had been dismantled. Politically, Germany was split into East and West, each aligned with opposing global powers.

In West Germany, recovery was built on stability and export strength. The Marshall Plan provided capital, but domestic policy choices were equally key. Rather than trying to compete with the United States in consumer electronics, West Germany refocused on sectors where it had long traditions—automobiles, machinery, and industrial equipment. Companies like Volkswagen, Mercedes-Benz, and Bosch became global exporters.

"The backbone of this recovery was the Mittelstand, a network of small and medium-sized specialised firms. These businesses often operated in niche markets producing world-class tools, machine parts, or chemical components."

The backbone of this recovery was the Mittelstand, a network of small and medium-sized specialised firms. These businesses often operated in niche markets producing world-class tools, machine parts, or chemical components. They were supported by the dual vocational education system, combining classroom learning with firm-based apprenticeships. Historian Joachim Radkau pointed out "Germany's workshop of skilled labour was as important as its factories of steel..." highlighting the importance of workforce quality to competitiveness.

East Germany, under Soviet direction, followed a different path. The German Democratic Republic prioritised heavy industry, chemicals, and energy. It preserved strengths in optics and precision mechanics, but central planning and restricted access to international markets limited innovation. Global politics shaped both halves distinctly. West Germany's integration into NATO and the Europe-

an Economic Community provided access to vast markets and collaboration in key areas. East Germany was tied to the Soviet Bloc, where technological strategy was defined by central decisions and Cold War military priorities. This contrast illustrates how political systems shape innovation.

Research Institutions and State Policy

A significant post-war achievement in West Germany was constructing a robust research system. The Max Planck Society continued basic science traditions in physics, chemistry, and biology. The Fraunhofer Society, established in 1949, specialised in applied research and technology transfer to industry. The Helmholtz and Leibniz associations added further capacity, covering large-scale and interdisciplinary science.

This plural system was a deliberate political choice. After the Nazi era's misuse of science, policymakers wanted a research structure that balanced academic independence with societal usefulness. Stable state funding allowed long-term projects, while industrial contracts encouraged application. Historian Wolfgang König observed that "*Germany built not one but several pillars of research, which together formed a balanced system between pure science and industrial application.*"

"Germany remains a technological leader in high-precision engineering, renewable energy, and applied research."

Global alignment added momentum. NATO membership spurred investments in aerospace, nuclear research, and computing. Later, European integration fostered shared ventures like Airbus and CERN, keeping Germany at the forefront in aeronautics and particle physics.

Reunification and Globalisation

The fall of the Berlin Wall in 1989 and reunification in 1990 brought a new chapter filled with both opportunity and difficulty. West Germany had to absorb East German industries, many of which were outdated and economically fragile. This resulted in closures and unemployment, particularly in the East.

Yet reunification also transferred skilled workers, traditions in optics and chemicals, and new domestic markets into the unified Germany.

Domestically, reunification required massive investments in infrastructure, science parks, and bridging research networks. Globally, it gave Germany more weight in European policymaking, making it central to shaping both EU technological initiatives and overall innovation agendas.

The 1990s also ushered in globalisation. Competition from Japan, later China, reshaped markets. German firms, especially in precision engineering, found pressure from lower-cost producers, prompting a deeper focus on quality and specialisation. Germany lagged in information technology compared to the U.S. but remained strong in automation, machine tools, and industrial software. This reflected a consistent pattern; Germany's strength lay in high-precision sectors where incremental innovation and reliability mattered more than disruptive upheavals.

Germany in the 21st Century

Germany remains a technological leader in high-precision engineering, renewable energy, and applied research. Its "hidden champions", small and medium-sized firms dominating global niche markets, excel in advanced machine tools, specialised medical devices, and high-precision automotive parts. This industrial depth reflects the enduring strength of its innovation model. Yet Germany faces major challenges in digitalisation and artificial intelligence.

Digitisation and AI Uptake - Germany lags behind in adopting digital technologies within businesses. A 2020 report by the digital association Bitkom found that only about one in four companies had implemented AI tools in operations, compared to higher rates in North America and parts of Asia. Even in manufacturing, where Germany is traditionally strong, integration of AI-driven analytics and automation has been slower than global leaders (Bitkom, 2020).

Public and Private R&D Spending in AI - Though Germany invests heavily in research institutions, its share of global R&D in AI remains modest. A report by the German Council of Economic Experts (2021) noted that Germany's AI funding lags behind that of the U.S. and China, both in size and in strategic coordination. Many initiatives remain fragmented across

ministries and regions, preventing critical mass.

Startup Ecosystem and Venture Capital - Germany's startup financing environment, especially for deep tech and AI ventures, is less developed than in the U.S. Venture capital remains risk-averse and focused on later-stage funding. As of 2022, Germany attracted only around one-tenth of EU venture capital investment in AI startups, despite being Europe's largest economy (European Commission, 2023).

Talent Shortages - AI and advanced technology depend on skilled professionals such as data scientists, machine learning engineers, and hardware specialists. Germany faces shortages in these fields due to rigid university structures and slower academic adaptation. The German Economic Institute (IW) reports a mismatch between industry needs and graduate output as a key bottleneck.

Integration of AI in SMEs - The Mittelstand remains the backbone of the German economy. Yet many SMEs lack the resources or expertise to deploy AI solutions. A 2022 survey by the German Ministry for Economic Affairs showed that around 60% of SMEs still rely largely on traditional processes, even though they are crucial to national competitiveness.

The history of German technological innovation demonstrates how science, industry, and politics are deeply interconnected. Unification in 1871 established a nation-state framework for industrial growth. The Nazi regime showed how technology can serve militarism. Post-war West Germany built resilience through strong research institutions, vocational training, and export-oriented industries. Reunification and globalisation brought new opportunities and pressures.

Today, Germany continues to lead in high-precision engineering, renewable energy, and applied industrial research. Yet its ability to harness AI and digitalisation lags behind global competitors. Challenges include fragmented funding, venture capital shortages, AI talent gaps, and slow uptake among SMEs. Germany's enduring strength lies in its well-structured innovation ecosystem, incremental engineering culture, and highly skilled workforce. The key challenge now is to adapt these assets effectively for the digital era so that the country remains resilient and competitive for the next 150 years.





Japan: From Imitator to Innovator

Japan's rise from a largely agrarian society in the early nineteenth century to a global technology leader is one of the most remarkable stories of modern history. The country's path has been marked by abrupt political transformation, war and defeat, deliberate state planning, and close cooperation between government and industry. Across two centuries, Japan developed an innovation system that combined long-term investment, disciplined workforce practices, and a culture of continuous improvement. Today, Japan is still known for world-class engineering, robotics, and advanced manufacturing, even as it grapples with new challenges in the digital era.

Tokugawa Japan and the Encounter with the West

For much of the Tokugawa period (1603–1868), Japan was closed off from the outside world. Contact with Western science and technology came through Dutch merchants at Nagasaki, a practice called *Rangaku*, or Dutch learning. Japanese scholars translated Western works on medicine, astronomy, and engineering, which provided an intellectual foundation that later reformers could build on. Although industrialisation was still distant, these early encounters meant that Japan was not entirely isolated from global knowledge flows.

The Meiji Restoration and Rapid Industrialisation

The Meiji Restoration of 1868 transformed Japan into a modernising nation determined to catch up with Western powers. The new government invested heavily in infrastructure such as railways, shipyards, and telegraph lines. It imported foreign experts, sent students abroad, and reformed education to emphasise science and engineering. State-owned model factories demonstrated new methods, while private business groups called *zaibatsu*, such as Mitsui and Mitsubishi, were encouraged to expand into banking, shipping, and heavy industry.

The Meiji state understood technology as central to national power. Industrialisation was not only about economic growth but also about securing independence in a world dominated by imperial powers. This fusion of national security and technological ambition became a lasting theme in Japanese development.

Pre-War Technology and Militarisation

By the early twentieth century, Japan had become a regional power. The victory in the Russo–Japanese War (1904–05) was made possible by naval modernisation and industrial strength. Heavy industry expanded, with advances in steel, shipbuilding, and

chemical production. Universities and research laboratories multiplied, laying the basis for indigenous innovation.

The 1930s and 1940s saw Japanese technology directed toward militarisation. Aircraft production surged, and companies such as Nakajima and Mitsubishi developed advanced fighter planes. Electronics and radio technologies were mobilised for war. However, resources were overstretched, and Japan's industrial base was devastated by defeat in 1945.

Post-War Reconstruction and the Economic Miracle

Japan's post-war recovery was extraordinary. Under Allied occupation, many zaibatsu were broken up, but their successor keiretsu groups soon re-emerged, fostering networks of banks, manufacturers, and trading companies. The Ministry of International Trade and Industry (MITI) coordinated industrial policy, protecting strategic sectors while encouraging exports.

By the 1950s and 1960s, Japanese firms were known for adopting Western technologies and improving them through disciplined production methods. Statistical quality control, promoted by experts such as W. Edwards Deming, was embraced with enthusiasm. The philosophy of kaizen, or continuous improvement, spread through factories, turning Japan into a symbol of efficiency and reliability.

The "economic miracle" of the 1950s to 1970s was built on sectors like steel, shipbuilding, automobiles, and electronics. Companies such as Toyota pioneered lean production, while Sony and Panasonic became global household names. Japan moved from imitation to innovation, developing colour televisions, the Walkman, and cutting-edge semiconductors.

Research Institutions and Innovation System

Alongside corporate dynamism, Japan built a strong public research base. RIKEN, founded in 1917, became a major centre for physics and chemistry. After the war, the Science and Technology Agency, the Agency of Industrial Science and Technology (AIST), and later the New Energy and Industrial Technology Development Organisation (NEDO) guided R&D priorities. Tsukuba Science City, developed in the 1960s, concentrated universities and laboratories to promote collaboration.

These institutions reflected Japan's belief that innovation required coordination between state, academia, and industry. Unlike the laissez-faire approach of the United States, Japan relied on long-term planning and close ties between ministries and corporations.

Global Context and Competitive Pressures

Japan's rise occurred in the shadow of the Cold War. The United States provided security guarantees and opened its market to Japanese goods. In return, Japan aligned with Western bloc politics while focusing on economic development. This partnership allowed Japan to avoid heavy military spending and direct resources toward industrial upgrading.

By the 1980s, Japan was seen as a technological superpower. It dominated the global semiconductor market, produced the most fuel-efficient cars, and led in consumer electronics. Yet success bred tension. Trade frictions with the United States escalated, leading to the Plaza Accord of 1985, which revalued the yen and slowed export competitiveness.

"By the 1980s, Japan was seen as a technological superpower. It dominated the global semiconductor market, produced the most fuel-efficient cars, and led in consumer electronics."

The 1990s "lost decade" followed the collapse of the asset bubble, and Japanese firms struggled against rising competitors in Korea, Taiwan, and later China. The digital revolution, led by Silicon Valley, exposed weaknesses in Japan's software industry and its conservative corporate culture.

Twenty-First Century Strengths and Challenges

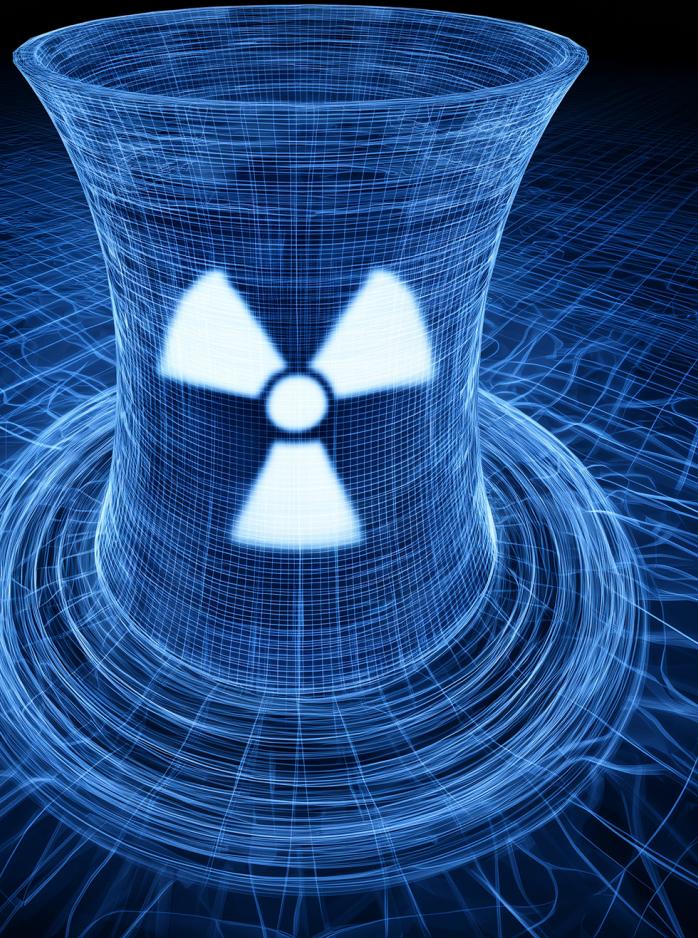
Despite setbacks, Japan remains a technological leader in several areas. It is the world's largest producer of industrial robots and a pioneer in humanoid robotics. Its automotive sector continues to excel, with hybrid and electric vehicle technologies developed by firms such as Toyota. Precision equipment, optics, and advanced materials remain Japanese strengths. Government policy has sought to revitalise innovation through initiatives like Society 5.0, which envisions integrating AI, big data, and the Internet of Things into all aspects of society. Japan has also invested heavily in renewable energy and hydrogen

technology, partly in response to the Fukushima nuclear disaster of 2011.

Yet challenges are significant. Japan faces demographic decline, with a shrinking workforce and ageing population. Venture capital and entrepreneurial risk-taking remain weaker than in the United States. In AI and digital platforms, Japan lags behind both Silicon Valley and China's tech giants. Talent shortages in software and data science are barriers to rapid adoption.



US: From Nuclear Power to AI



US innovation in science and technology is a broad-based system that includes public-private partnerships, government-funded research, public venture capital initiatives and a huge private sector that all act as supply lines that turned the US into a technological superpower.

Prior to WW2 the US was characterised by state development and a number of huge infrastructure projects that saw the creation of the Transcontinental Railroad. The needs of WW2 and the global environment thereafter propelled US innovation. What emerged during and after WW2 was the national security state (NSS) which led to the expansion and transformation of US resources in order to deal with the needs of permanent war.

It was the government that drove, funded and organised the technology, research and creation of the first nuclear bomb in the Manhattan project. This created the foundation for the research universities of today. The project brought together the best minds in physics and engineering, with the state coordinating the scientists, engineers and the industrial partners.

The Sputnik Moment

The Soviet Union launched the first satellite, Sputnik in 1957, causing panic among US policymakers

who were fearful that they were losing the technological battle. Whilst the US led the development of the nuclear bomb, it came as a shock that the USSR created the world's first satellite. The US response was the creation of the Defense Advanced Research Projects Agency (DARPA) in 1958. Prior to DARPA, the military was the sole controller of all military Research and Development (R&D) dollars. Through the formation of DARPA a portion of military spending on R&D was now designated to 'blue-sky thinking' – ideas that went beyond the horizon in that they may not produce results for one or two decades. DARPA's job was to focus on advancing innovative technological development. The results ever since have included technologies like the semiconductor chip, GPS, human computer interface, voice recognition and the internet. It also led to development of the computer industry in the US during the 1960s and 1970s and the emergence of Silicon Valley as well as the personal computer.

DARPA played the role of an intermediary that facilitated and acted as a middle-man for researchers to gather and share ideas while also learning of the paths identified as 'dead ends' by others. DARPA linked university researchers to entrepreneurs interested in starting a new firm, connecting start-up firms with venture capitalists as well as finding larger companies to commercialise technology.

The US then built on the successes of DARPA's decentralised industrial policy with the Small Business Innovation Development Act in 1982. This set up a consortium between the Small Business Administration and different government agencies like the Department of Defense, Department of Energy and Environmental Protection Agency. The Small Business Innovation Research (SBIR) programme required government agencies with large research budgets to designate a fraction of their research funding to support small, independent, for-profit firms. As a result, the programme has provided support to a significant number of highly innovative start-up firms ever since.

"US innovation in science and technology is a broad-based system that includes public-private partnerships, government-funded research, public venture capital initiatives and a huge private sector that all act as supply lines that turned the US into a technological superpower."

Biotech: From War to Peace

The biotech industry in the US was created in 1969 by President Nixon, although he did not know this at the time. Nixon ordered for the conversion of the country's biological warfare program into a biological research program. All the scientists, labs, and equipment that were focused on developing weapons were suddenly redirected to explore the potential of biology for peaceful purposes. This laid the groundwork for the whole commercial biotechnology industry. Many of the early pioneers in biotechnology were scientists who used to work on the American biological warfare program. All the knowledge, infrastructure and expertise of the US biological warfare programme was given a new mission and a huge head start in civilian biotechnology.

Silicon Valley

Silicon Valley emerged and eventually became a global hub for technology and innovation. It achieved this due to the coming together of multiple factors. Stanford University played a pivotal role

originally through its collaboration with industry. Frederick Terman, a professor and later dean, is often called the "Father of Silicon Valley" for encouraging students to start tech companies. An example of this is the establishment of Hewlett-Packard (HP), who with ties to Stanford focused on electronics and radio technology.

Two technologies drove the original rise of the Silicon Valley area, that of aerospace and the semiconductor. The Cold War drove federal investment in defence and aerospace technology, much of it centered in California. This drove companies like Lockheed to establish research centers in the area, attracting talent and infrastructure for electronics and innovation.

In the 1950s, William Shockley, a co-inventor of the transistor, founded Shockley Semiconductor Laboratory in Silicon Valley. His firm attracted talented engineers and several of them left to form Fairchild Semiconductor in 1957, which became the bedrock for the semiconductor industry. Fairchild's alumni went on to create iconic companies like Intel and AMD, which developed the profile of Silicon Valley being a hub for expertise on emerging tech.

The emergence of the personal computer in the 1970s saw venture capital arrive providing startups with funding and mentoring. This created a cycle of innovation and entrepreneurship, drawing more talent to the area. When companies like Apple and Microsoft were created, they capitalised on the expertise in Silicon Valley making it the epicentre of American tech.

The Internet

During the Cold War, US authorities were concerned about the possibility of nuclear attacks and the state of communication networks following the aftermath of a possible attack. Paul Baran, a researcher at RAND – an organization with its origins in the US Air Force's project for 'Research and Development', or RAND for short – recommended a solution that envisioned a distributed network of communication stations as opposed to centralised switching facilities. With a decentralised communication system in place, the command and network system would survive during and after a nuclear attack. The technological challenges of devising such a network were overcome thanks to the various teams assembled by DARPA to work on networking stations and the transmission of information. Although DARPA approached AT&T and IBM to build such a net-

work, both companies declined the request believing that such a network was a threat to their business. DARPA eventually successfully networked various stations from the west to east coast of the US. From the 1970s through to the 1990s, DARPA funded the necessary communication protocol (TCP/IP), operating system (UNIX) and email programs needed for the communication system, while the National Science Foundation (NSF) initiated the development of the first high-speed digital networks in the US.

In the late 1980s, British scientist Tim Berners-Lee was developing the Hypertext Markup Language (HTML), uniform resource locators (URL) and uniform Hypertext Transfer Protocol (HTTP).

Berners-Lee, with the help of another computer scientist named Robert Cailliau, implemented the first successful HTTP server for the computers installed at CERN. Berners-Lee and Cailliau's 1989 manifesto describing the construction of the World Wide Web eventually became the international standard for computers all over the world to connect. Public funding played a significant role for the Internet from its conception to its worldwide application. The Internet is now in many ways a foundational technology that has affected the course of world history by allowing users all over the globe to engage in knowledge sharing, commerce and socialising.

Nanotech

The National Nanotechnology Initiative (NNI) was set up in 1998 in order to find the 'next new thing' to replace the Internet. After receiving 'blank stares' from the private sector, the US government invested in the creation of a new research agenda. With the private sector focused on at most a 5-year horizon they were unable to provide a list of new era technologies that the US government should fund. In the end US civil servants succeeded in convincing President Bill Clinton, and then George W. Bush, that investment in nanotechnology would have the potential to "...spawn the growth of future industrial productivity...", and that "...the country that leads in discovery and implementation of nanotechnology will have great advantage in the economic and military scene for many decades to come." The US is today the leading researcher and developer in nanotechnology.

Apple and the iPhone

Apple is the world's largest company valued in excess

of \$3 trillion. Apple has been at the forefront of introducing the world's most popular electronic products as it continues to navigate the seemingly infinite frontiers of the digital revolution and the consumer electronics industry. The popularity and success of Apple products like the iPod, iPhone and iPad have altered the competitive landscape in mobile computing and communication technologies. In less than a decade the company's consumer electronic products have helped secure its place among the most valuable companies in the world. Whilst Apple and its late founder Steve Jobs gain a lot of credit for innovation and making mistakes and learning from these, Apple is a good example of where commercial companies fit into America's innovation ecosystem. Whilst small private companies gain a lot of coverage and credit when it comes to innovation, they are really a small part of the broader innovation process and are more a part of the commercialisation process.

Apple's innovative products are in fact the results of decades of federal support for innovation. While the products owe their beautiful design and slick integration to the genius of Jobs and his large team, nearly every state-of-the-art technology found in the iPod, iPhone and iPad is the research efforts and funding support of the government and military. Apple incorporated in 1976 as a personal computer company during the rise of the computer industry in the US. Originally named Apple Computer Inc. and for 30 years focused on the production of personal computers. In 2007, the company announced it was removing the 'Computer' from its name, reflecting its shift in focus from personal computers to consumer electronics. This was the same year Apple launched the iPhone and iPod Touch featuring its new mobile operating system.



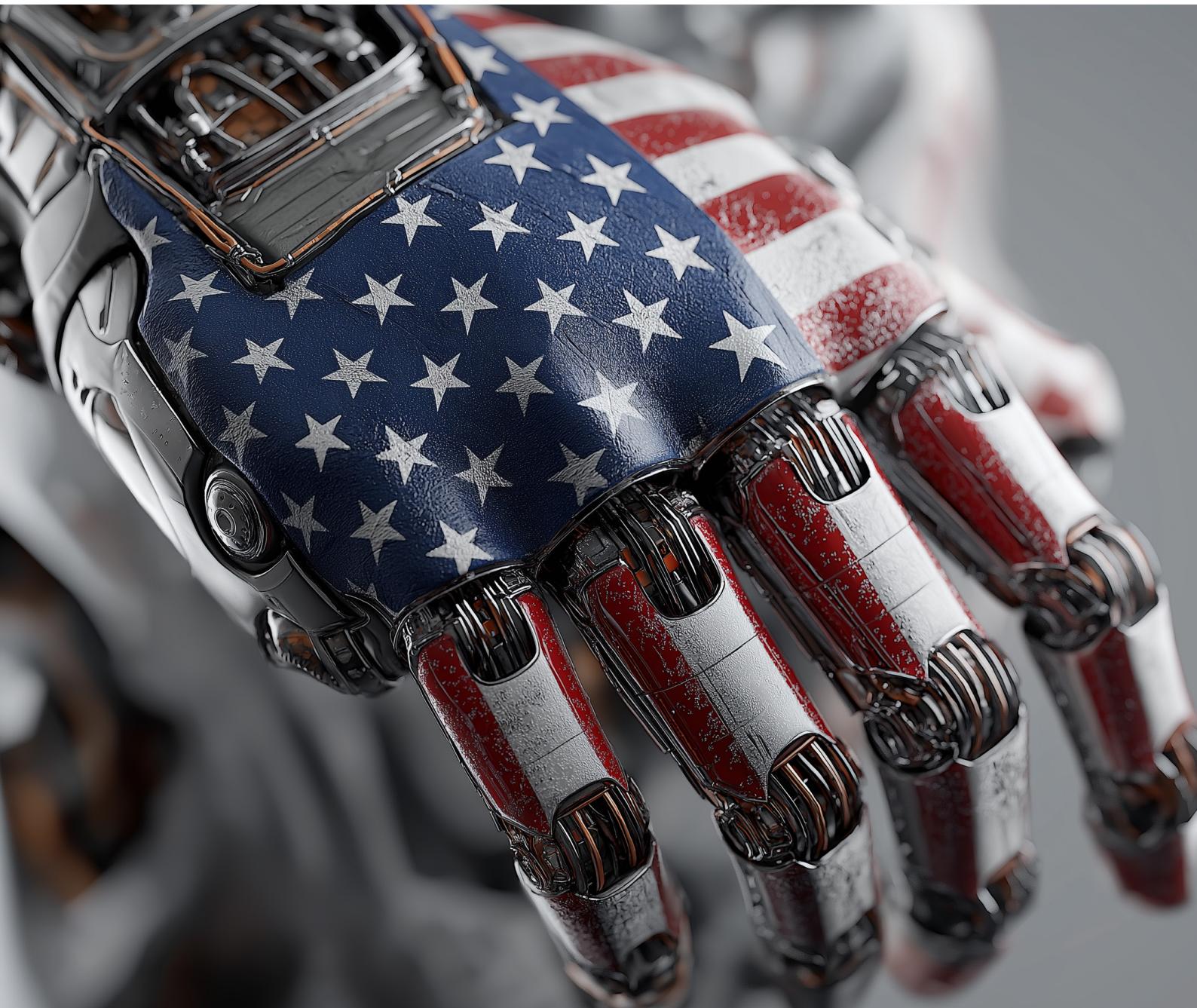
What Apple did and showcased is through concentrating its ingenuity not on developing new technologies and components, but on integrating them into an innovative architecture. Apple integrated and merged technologies that were first developed and funded by the US government and military. Apple's capabilities are recognising emerging technologies with great potential, applying complex engineering skills that successfully integrate recognised emerging technologies, and maintaining a clear corporate vision prioritising design-oriented product development for ultimate user satisfaction.

There are 12 major technologies integrated within the iPod, iPhone and iPad that stand out as features from the semiconductor devices such as the central processing units (CPU). The liquid-crystal displays (LCDs), the lithium-polymer (Li-pol) and lithium-ion (Li-ion) batteries, as well as the Internet; the Hypertext Transfer Protocol (HTTP) and Hypertext Markup Language (HTML) and cellular technology

and networks. Alongside these technologies, what made the Apple products drastically impact consumer expectations and user experiences was the integration of GPS, the click-wheel navigation and multi-touch screen and artificial intelligence with a voice-user interface program (a.k.a. Apple's Siri).

America's corporate sector may get the most media coverage, but they are the smallest part of the innovation curve, but as they are the entities that commercialise the technologies, they receive the most attention. But they form a very small aspect of America's innovation ecosystem.

The US has for long stood at the forefront of research and development in almost all areas of science and technology. The country boasts strong institutions that work on developing long term innovative ideas and alongside its education system can attract foreign researchers, But America's decades long dominance is now facing major competition.



Innovation



The world has witnessed more innovation in the last century than the whole of human history put together. New products, services and processes have been possible due to a broad variety of things coming together. Experts find it difficult to agree on what innovation is, but broadly speaking innovation is the practical implementation of ideas that result in the introduction of new goods, services and processes or improvement with existing ideas. In the standard ISO 56000:2020, it defines innovation as "*a new or changed entity, realizing or redistributing value*". Others have different definitions; a common element in the definitions is a focus on newness, improvement, and spread of ideas or technologies. Innovation often takes place through the development of more-effective products, processes, services, technologies, art works or business models that innovators make available to markets, governments and society.

In 1968, a research project funded by the US Department of Defense launched a revolution. The focus was not a Cold War adversary or even a third world nation, but rather to "augment human intellect" and the man driving it was not a general, but a mild mannered engineer named Douglas Engelbart.

His presentation that day would be so consequential that it is now called The Mother of All Demos. Two of those in attendance, Bob Taylor and Alan Kay

who would launch Xerox and would go on to develop Engelbart's ideas into the Alto, the world's first truly personal computer. Later, Steve Jobs would take many elements of the Alto to create the Macintosh.

So who deserves credit? Engelbart for coming up with the idea? Taylor and Kay for engineering solutions around it? Jobs for turning it all into a marketable product that created an impact on the world? Strong arguments can be made for each, but this example illustrates there are numerous parts and pieces that lead to innovation.

The Myth of the Genius

Alexander Fleming discovered penicillin in 1928, but it wasn't until 15 years later, in 1943, that the miracle drug came into widespread use. Alan Turing came up with the idea of a universal computer in 1936, but it wasn't until 1946 that one was actually built and not until the 1990s that computers began to impact productivity numbers.

Every new invention takes many individuals and follows a convoluted path to productivity. Discoveries of mysterious phenomena must be engineered into innovative solutions, a process that can take decades. Then those solutions must be adopted by industry, which can take decades more. What is therefore

needed is to better connect the realms of discovery, innovation and transformation.

Many tend to think of innovation as arising from a single brilliant flash of insight. The isolated genius is usually thought of as an inventor or scientist working alone, often in secret, and achieving a brilliant idea through a sudden flash of insight, which then transforms the world. However this is largely the exception rather than the rule for innovation. Innovation is really a drawn out process involving the discovery of an insight, engineering a solution and then the transformation of an industry or field. This is almost never achieved by one person or even within one organisation.

Whilst Thomas Edison gets the credit for inventing electricity, the reality was it was a long drawn out process. The basic principles of electricity were discovered by Michael Faraday and James Maxwell in the mid 1800's and engineered into practical solutions by Edison and Nikola Tesla in the later part of that century. By the beginning of the 20th century, the technology came into wide use in factories, but provided little tangible benefit at first.

The problem, as it turned out, wasn't with electricity, but the factories themselves. In a steam driven plant, machines had to be organised around the power source and the first factories powered by electricity were designed the same way. Work processes changed little and productivity barely budged. It took about thirty years for a new generation of managers, who had little memory of steam plants, to realise that factories could become much more efficient if they were designed around workflow. Once that happened, productivity soared and industry, along with quality of life, was transformed.

The romantic view of the isolated genius is really the exception and the most significant innovations are the result of collaboration, interconnectedness and the cross-pollination of ideas within open environments.

Collaboration

Alexander Fleming is credited for discovering penicillin in 1928, but it took until 1943 for the miracle drug to come into widespread use. The reason that Fleming was unable to bring penicillin to market was that, as a biologist, he lacked many of the requisite skills. It wasn't until a decade later that two chemists,

Howard Florey and Ernst Boris Chain, picked up the problem and were able to synthesize penicillin. Even then, it took people with additional expertise in fermentation and manufacturing to turn it into the miracle cure we know today.

"The world has witnessed more innovation in the last century than the whole of human history put together."

This isn't the exception, but the norm. American biologist James Watson and English physicist Francis Crick's discovery of DNA was not achieved by simply plowing away at the lab, but by incorporating discoveries in biology, chemistry and x-ray diffraction to inform their model building.

Great innovation almost never occurs within one field of expertise, but is almost invariably the product of synthesis across domains. In the early 1950's, the most coveted scientific prize was the discovery of the structure of DNA. The greatest scientists of the day, including the already legendary Linus Pauling, raced to decipher one of nature's best kept secrets. However, the glory went to two young, unknown scientists: James Watson and Francis Crick. Neither of them were famous, or even particularly accomplished, even for men of their relative youth. What they did have was something no one else did; the information needed to get the job done. The two were possibly the only people on earth with the biological expertise, x-ray diffraction data and chemical model building approach needed to discover DNA's structure.

All of the other people working on the problem, many perhaps more talented than Watson and Crick, were working feverishly on one aspect of the problem. Watson and Crick, spent most of their time talking about others' research rather than doing their own.

As with many big problems, the answer to the fundamental genetic question was a matter of putting all the information together rather than uncovering new facts. The irony of many great discoveries is that they really weren't discoveries at all, at least not in the sense that Columbus discovered America. In actuality, they came from people who took well established concepts and applied them to new domains.

The Right Size for innovation

When most people think about innovation, they think about startups. And certainly, new firms like Uber, Airbnb and Space X can transform markets. But innovation comes from all sorts of places both big and small.

Large companies such as IBM, Procter and Gamble and 3M have managed to stay on top for decades, even as competitors rise up to challenge them and then, when technology and markets shift, disappear just as quickly into oblivion.

There are both pros and cons on the size of the organisation looking to innovate. Small firms are agile and can move fast. Larger enterprises have the luxury of going slow. They have loyal customers and an abundance of resources. They can see past the next hot trend and invest for the long term. There's a big difference between hitting on the next big thing and developing it consistently, generation after generation.

Small and Medium Enterprises have for long been associated with innovation and whilst this is true, the innovative landscape is much more complex and fluid. Being a large organisation doesn't mean you cannot innovate, whilst being a SME does not mean you will succeed in innovation.

Openness and innovation

When Microsoft launched Kinect for the Xbox in 2010, it quickly became the hottest consumer device ever, selling 8 million units in just the first two months. Almost immediately, hackers began altering its capabilities to do things that Microsoft never intended. Yet instead of asking them to stop, it embraced the hackers, quickly releasing a software development kit to help them along.

Like Microsoft, many firms embraced open innovation to expand capabilities. Cisco outfoxed Lucent not by developing technology internally, but by smartly acquiring startups. Procter & Gamble has found great success with its Connect and Develop program and platforms like Innocentive allow firms to expose thorny problems to a more diverse skill set.

As was the case with Alexander Fleming found with the penicillin, and numerous innovators have experienced since, most find that solving their most impor-

tant problems require skills and expertise they don't have. That means that, at some point, you will need to utilise partners and platforms to go beyond your own internal capabilities. Without such openness, innovation will be constrained.

Ecosystems

When Douglas Engelbart presented 'The Mother of All Demonstrations' in 1968, about a personal computer It's no accident that the people who would make Engelbart's vision a reality actually attended the event and knew Engelbart personally. In those days, it was difficult, if not impossible, to actively collaborate across time and space. Today, however, we can use platforms to access ecosystems of technology, talent and information.

Take Apple's App Store. It is, of course, a highly effective way for Apple's network of customers to access functionality on their phones, but it also allows the firm to access the talents of literally millions of developers. It's hard to imagine any single enterprise, no matter how efficient or well organized, pulling off that kind of scale.

Whilst historically the surest path to success was by acquiring and controlling assets, in the modern networked world it's about widening and deepening connections.

Innovation is a broad based, wide encompassing process. It's not linear and in fact is rather convoluted and is not just about investment and finance. Innovation goes far beyond just research labs, Silicon Valley meetings and large corporate initiatives. Innovation can begin and end in places not expected and therefore cannot be forecasted. This is why a nation's political system, ideology, business environment and the role of the state, can have a huge impact on innovation. It also means innovation can prosper in places, not traditionally considered possible.



The Architecture of Innovation: Beyond the Lone Genius

Innovation is rarely a single flash of insight from a lone genius; it is a drawn-out process of discovery, engineering, and transformation. Success depends on synthesis across fields and the ability to leverage open ecosystems rather than working in isolation.

THE THREE STAGES OF INNOVATION

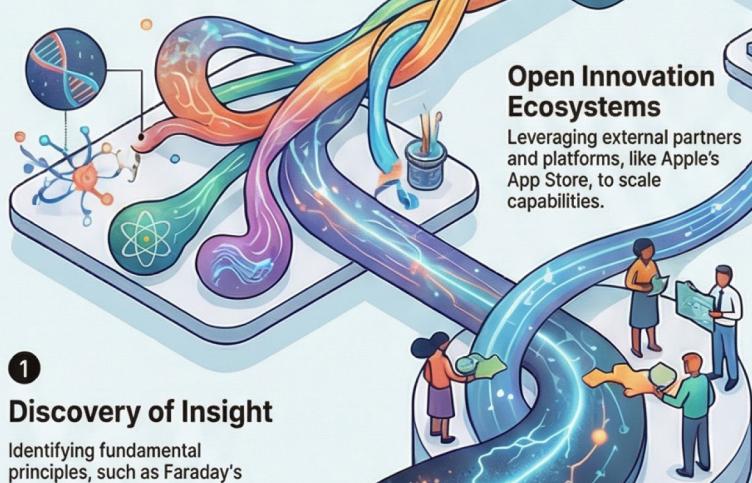
A process, not an event.



THE POWER OF SYNTHESIS & OPENNESS

Cross-Domain Synthesis

Great breakthroughs often come from combining established concepts from entirely different fields.



1

Discovery of Insight

Identifying fundamental principles, such as Faraday's discovery of severers basic electrical principles.



Open Innovation Ecosystems

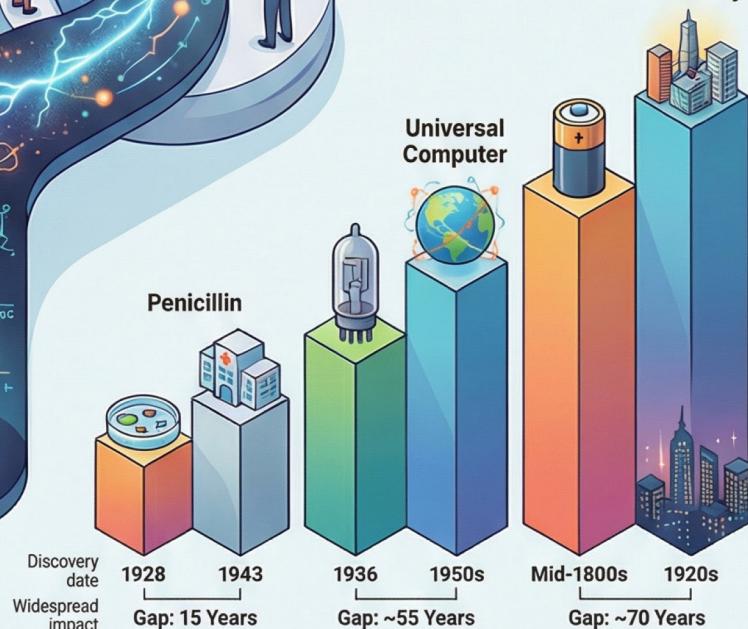
Leveraging external partners and platforms, like Apple's App Store, to scale capabilities.



Innovation Gap: Discovery to Impact

Illustrating the significant 'time lag' between initial discovery and widespread transformation.

Electricity



Tech Myths

A hand and a robotic hand are positioned in the lower half of the image, reaching towards each other as if to shake hands. The background is a dark, textured surface with numerous glowing, star-like nodes connected by a network of lines, suggesting a digital or futuristic environment.

Patents = innovation

Patents are seen as a measure of innovative success. Patents are viewed as central to the innovation economy because they sit at the intersection of incentives, investment and knowledge-sharing. When we look at the number of patents in the pharmaceutical industry, it's considered one of the most innovative sectors in the world.

The number of patents applied for by the world's premier economies has become a key measure for innovation. China leads the world in total patent filings, especially in telecommunications, AI, EVs, and green tech. The US is still dominant in high-quality patents, whilst Europe remains strong in pharmaceuticals, biotech, and engineering. Japan & South Korea are innovation powerhouses in electronics, robotics, semiconductors. While India & Southeast Asia are considered rising players, focusing on pharmaceuticals, IT, and renewable energy.

The assumption is without patents why would anyone take the risk of bringing a new innovation to the market. With patents, innovation is protected and this leads to new ideas to make it to market. But upon closer scrutiny, this is a misconception. The exponential rise in patent numbers, particularly since the 1980 Bayh-Dole Act, does not primarily reflect a rise in actual innovation. Instead, it indicates changes in patent laws and their strategic use.

In the Information and Communications Technology (ICT) sector, the use of patents has shifted from protecting in-house research and development (R&D) to cross-licensing in open systems to acquire technology developed elsewhere. This means some large companies, like IBM, saw their R&D budgets fall while their patent numbers rose, indicating a shift in purpose. Venture capital firms often use patents as a signal for which companies to invest in, which further increases their strategic value for attracting finance, independent of their inherent innovative content.

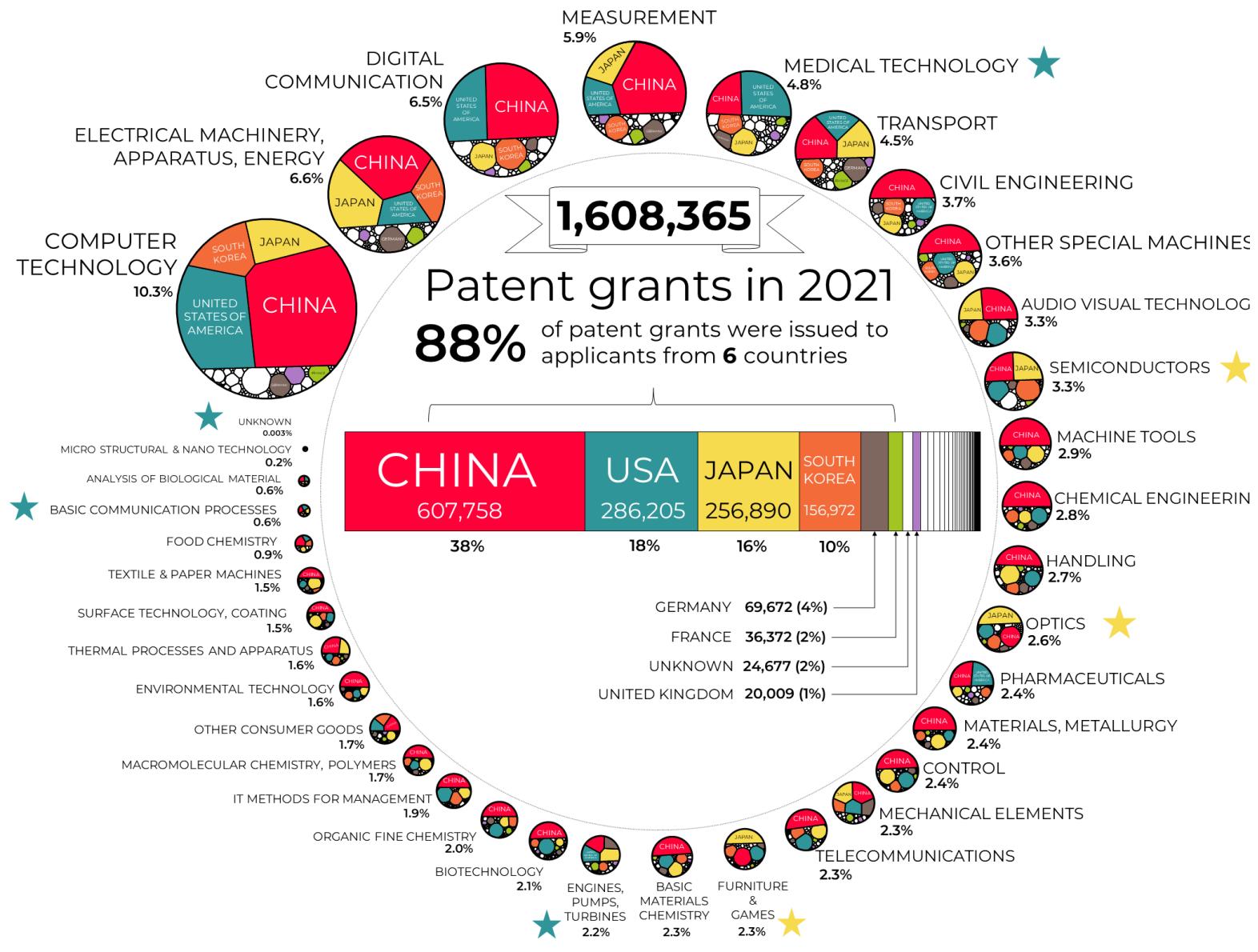
The pharmaceutical industry that gains the most coverage regarding patents, when they register a new development are often found to be of little actual worth, receiving few citations and not leading to a significant number of new drugs.

Many of the large global corporations use patents for tax avoidance purposes and to ensure their competitors cannot make use of a new finding. According to the World Economic Forum, over 1.7 million patents were granted in 2023. But 90% of these patents remain dormant. They are filed either for defensive reasons, prestige, or speculative value.

This points to the reality that patents do not equal innovation, in fact the relationship between both is tenuous.



PATENT GRANTS BY ORIGIN COUNTRY & FIELD OF TECHNOLOGY



Japan tops 3 fields
Semiconductors, Optics, Furniture & Games

China
tops 29 fields

USA tops 4 fields
Medical technology; Engines, pumps, turbines; Basic communication processes; Unknown

* DATA SOURCE: WWW.WIPO.INT/IPSTATS
(UPDATED FEB 2023)

Innovation is about Research and Development (R&D)

R&D has come to be closely associated with innovation. There is a direct link between R&D, innovation, and economic growth and this is why R&D expenditures have become a key measure for innovation.

Globally R&D spending is over \$2.5 trillion, with the US and China representing 45% of this market. The key areas are in the tech race from AI, green tech, biotech and chips.

Whilst R&D is a component of innovation on its own it would not lead to innovation. There are very few studies that definitively prove innovation, whether by large or small firms, directly increases their growth performance. While some studies show a positive impact, others find no significant effect, and some even report a negative impact.

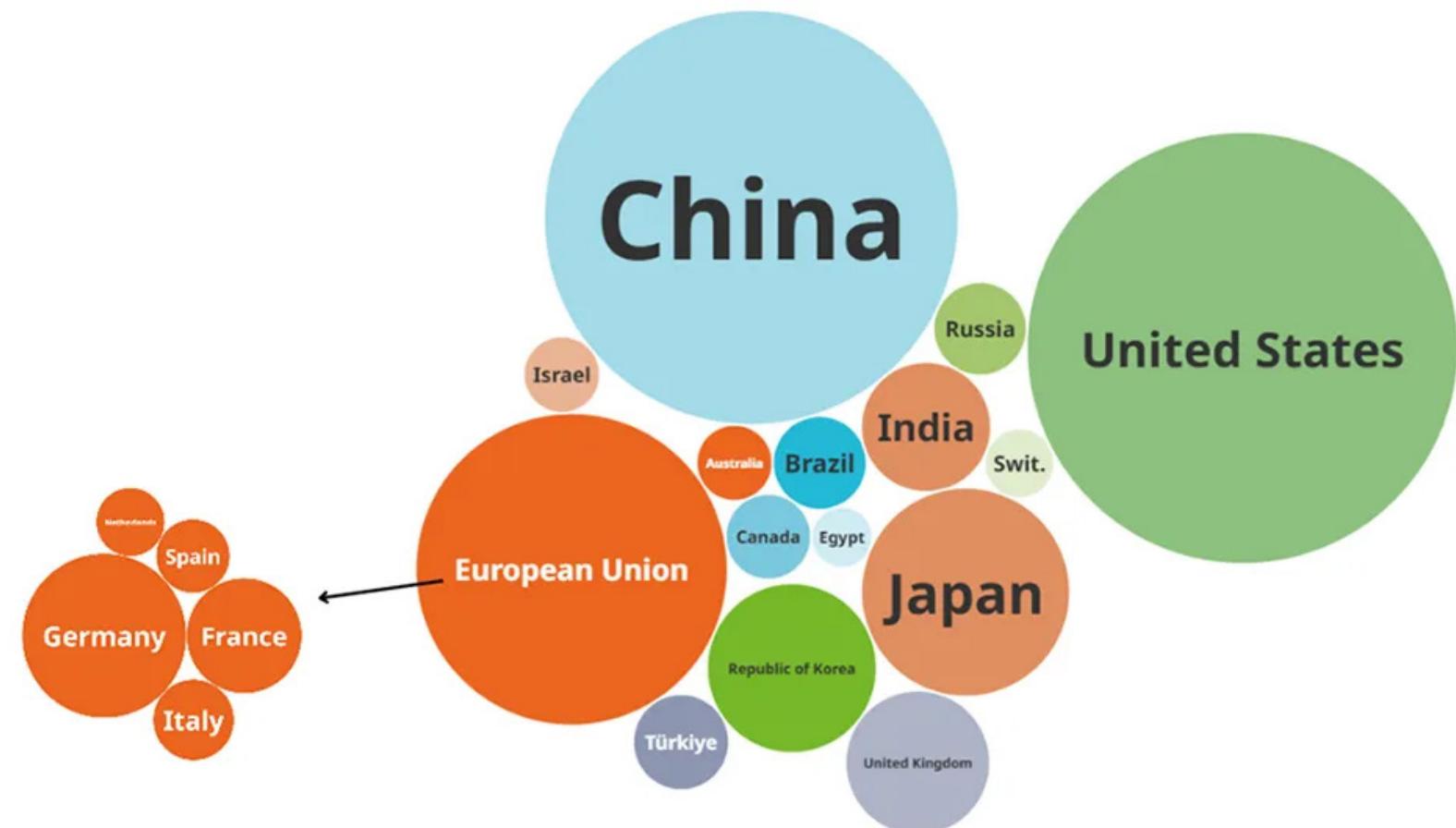
For R&D spending to positively affect growth, company-specific conditions are fundamental. For instance, in the pharmaceutical industry, only firms that patent consistently over several years and engage in alliances actually achieve growth from their

R&D spending. The relationship between R&D and fast-growing firms is also limited to specific periods in an industry's life cycle when competition is intense.

For R&D to deliver a number of other things have to come together such as government regulation, the building of interactions and commercialisation support. Without a wider ecosystem, innovation will not thrive. Innovation requires a highly networked economy where knowledge is shared, and institutional changes promote technological and structural advancement, rather than just focusing on R&D expenditure.

While R&D is a component of innovation, innovation is a collective, cumulative, and uncertain process that requires a broader ecosystem, particularly the proactive, risk-taking role of others to move ideas from basic research through development, commercialisation and then to market.

Top global R&D spenders, 2023



The crucial role of the state

The state has for long received a bad name when it comes to innovation. The regulatory and overbearing presence of the state is seen as the biggest obstacle to innovation. Innovation is something the private sector does and the state should just deal with market failures and property rights and keep its bureaucratic self away from the market.

But what we find is the most revolutionary innovations that fuelled the modern world from railroads to the Internet, to modern-day nanotechnology and pharmaceuticals, were government funded. In fact all of the technologies that make Apple's iPhone so 'smart' were government funded from the Internet, GPS, touch-screen display and the Siri voice activated personal assistant.

In all of these innovations, in the early period there were doubts about the innovation's future and it remained unclear of its role in the broader economy. When the private sector was not prepared to do the R&D and were not prepared to invest in the long-term horizon, but wanted returns within 2 years it was the state that made the initial crucial investment.

It was the state that was the lead risk-taker and market creator. The State was willing to make the most uncertain, capital-intensive, and long-term investments that the private sector often shies away from. This is particularly true for radical, revolutionary innovations like the Internet, biotech, nanotech, and modern pharmaceuticals.

It was the state that actively created new markets and technological spaces, rather than just correcting existing market imperfections. For example, the Internet and nanotechnology did not emerge because the private sector was looking for resources but due to the government's vision in areas not yet fathomed by the private sector. It is central government that invests in areas where the potential of the new idea and its technological and demand conditions are completely uncertain

The state's role also includes setting broad visions and missions. It was not the private sector that put a man on the moon and developed the frontiers of knowledge. Agencies like DARPA (Defense Advanced Research Projects Agency) were created to achieve technological superiority through targeted resource

allocation and opening new opportunities. This proactive approach involves "picking winners" – selecting particular sectors or technologies to back forcefully – which is often necessary for major revolutions to take off, such as the Internet or green technologies.

The state has also played a crucial role providing long-term capital that private finance, especially venture capital, is often unwilling or unable to provide due to high uncertainty and the long term wait for profit. Even today, public spending accounts for a much higher proportion of basic research compared to overall R&D, demonstrating its critical role in foundational knowledge creation.

Despite the state's critical role, there is a skewed reality of risk and reward, where the risks are socialised (borne by the public) but the rewards are privatised (reaped by private firms and individuals). Companies like Apple, for instance, have significantly benefited from State-funded technologies and risk finance, yet they employ practices that result in very low tax payments.

"The state needs to get out of the way for innovation to take place" is a myth spread by private companies who want to reap the profits from new innovations. At the same time they refuse to invest for long-term risky investments as the horizon is too long. The state is not a bureaucratic machine but an entrepreneurial entity that is necessary for innovation. The role of the private sector comes well down the line when an innovation first emerges.



The Entrepreneurial State: Who Really Drives Innovation?

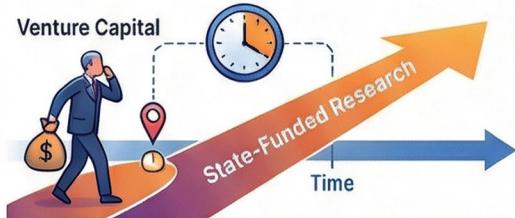
Debunking Private Sector Myths

90% of Patents Remain Dormant



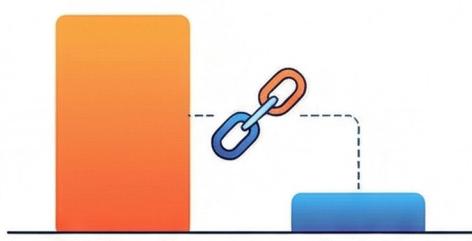
Most patents are filed for defensive or speculative reasons rather than actual innovation.

The 15-20 Year VC Lag



Venture capital typically enters years after the State has funded the initial high-risk research.

R&D Expenditure Does Not Equal Growth



R&D Spending Growth
High R&D spending only drives growth when supported by a wider public ecosystem.

The State as the Lead Risk-Taker

The iPhone is a State-Funded Product



GPS, touchscreens, Siri, and the internet were all originally government-funded technologies.

The State as a Market Creator



Agencies like DARPA actively create new technological spaces rather than just fixing market failures.

Socialized Risk, Privatized Reward



The public bears the foundational risks while private firms reap the commercial profits.

Data Table

Investment Profiles: Public State vs. Private Venture Capital

	Public State Funding	Private Venture Capital
Risk Tolerance	High: Invests in completely uncertain, radical science	Low: Prefers "safer bets" with low technological complexity
Time Horizon	Patient: 15-20 year foundational research cycles	Short-term: 3-5 year exit strategies via IPO or sale
Primary Goal	Market Creation: Forging new technological frontiers	Capital Gains: High returns from existing innovation waves

Small and Medium Enterprises (SMEs) are critical for innovation

When it comes to innovation, small is beautiful. SMEs are considered to be inherently critical for innovation and economic growth and are often called the backbone of innovation ecosystems.

SME's are considered to be agile and risk taking, they can pivot quickly, experiment with bold ideas, and embrace disruptive technologies faster than large corporations with rigid structures. They often explore niche markets or cutting-edge solutions that big firms ignore.

Over the years it is believed SMEs have made a disproportionate contribution to radical innovation. Many breakthrough technologies from personal computing to biotech startups originated in SMEs before being scaled by large firms. Studies also show SMEs produce a higher ratio of patents per dollar spent on R&D compared to large firms.

SMEs also employ the majority of the workforce in most economies and they provide a platform for young researchers, engineers, and entrepreneurs to test ideas in real markets.

Upon closer examination however many of these assertions do not hold. The common assumption that small firms are crucial for growth often confuses their size with their growth potential. The most

robust evidence points to the importance of young, high-growth firms, rather than merely small ones. While many high-growth firms are small, a significant number of small firms are not high-growth. Rapid bursts of growth that promote innovation and create employment are often staged by firms that have existed for several years and grown incrementally until they reach a "take-off stage".

The notion that small firms are primary job creators is also largely a myth. While small firms do create jobs, they also destroy a large number when they go out of business. Research indicates there is no systematic relationship between firm size and growth; instead, it is age that significantly contributes to job creation, with young firms (and start-ups) being the key drivers.

While specific types of small and young firms can contribute significantly to innovation and economic dynamism, we cannot generalise that all SMEs are critical. Their success often depends on prior, patient, and extensive state investments that create the foundational technologies and market opportunities, highlighting the necessity of a proactive, entrepreneurial state that takes on the uncertain, long-term risks that the private sector, including most SMEs, are unwilling to bear.



Venture capital is key for risk taking

Venture Capital (VC) is often described as the fuel that powers innovation, especially in high-tech and high-risk sectors. Unlike traditional bank loans or government grants, VC provides not just money but also networks, expertise, and credibility.

It is believed VC finances are high risk with the most radical innovations such as AI, biotech, space tech, fintech, green energy too risky for banks or traditional investors. VC firms are willing to bet on uncertain but potentially transformative technologies, absorbing high failure rates in return for occasional “unicorn” successes.

VC firms claim they can help turn research ideas into market-ready products by funding prototyping, scaling, and go-to-market strategies. Without VC, many university spin-offs and startups would remain “lab-bound.”

VC firms argue they can bring more than cash—they offer mentorship, industry contacts, recruitment pipelines, and market access. They connect startups to supply chains, potential clients, and even future acquirers.

Venture capital being crucial for innovation is a highly contested assertion. VC often chases trends such as the dot-com boom, crypto hype, AI frenzy rather than patient, long-term innovation. VC has been found to pressure startups to scale fast or exit, which can harm sustainable innovation.

We also see VC is concentrated in a few hubs, leaving much of the world underfunded. With funding favoring certain demographics,

regions, and industries.

VC being risk takers is a myth as they are not the primary risk-takers in radical innovations. VCs typically enter the innovation process after the most uncertain, capital-intensive, and long-term investments have already been made by the public sector. VCs have been found to surf the wave of innovation created by state investments, rather than creating the wave itself. For instance, in biotechnology, nanotechnology, and the Internet, venture capital arrived 15–20 years after crucial foundational investments were made by public funds. Their funding tends to concentrate in areas of high potential growth but with low technological complexity and low capital intensity. When risk is highest in very early stages, VC funding focuses on safer bets rather than the truly radical innovation required to transform society.

VC funds typically have a short-term bias, preferring to exit investments much earlier than their typical ten-year fund life, often within a 3-to-5-year period. This is driven by the desire to establish a winning track record and raise subsequent funds. Their objective is to earn a high return following a successful Initial Public Offering (IPO), merger, or acquisition of the company. This focus on early exits and capital gains from stock sales, rather than cash flow from operations, means they are not interested in sustaining the long-term risks and costs of technological development.

VC also depends on state funding and infrastructure. Despite their

public image, venture capitalists are reliant on the government for the more expensive and uncertain research phases of innovation.

Public programmes like the Small Business Innovation Research (SBIR) programme in the US have provided significantly more early-stage funding to technology firms than private venture capital.

The establishment of speculative markets like NASDAQ was crucial for the emergence of VC as a well-defined industry, facilitating quick exits for start-ups.

Venture capital's role is limited and primarily focused on later-stage, less uncertain investments with clear short-term exit strategies. Its success is heavily predicated on the courageous, risk-taking, and patient capital provided by the state, which undertakes the foundational, high-risk research and market-shaping necessary for radical innovations to emerge and mature.



Capitalism and the Free market lead to risk taking which is crucial for innovation

The industrial revolution, railways, the combustion engine, the atomic bomb and the internet are considered some of the most innovative technologies. These were created by the west who embraced free markets and capitalism and therefore are seen as crucial precursors for innovation

Capitalism, it is believed, rewards entrepreneurs and firms who create new products or processes. The possibility of high returns motivates people to take risks, invest in R&D, and disrupt industries. Competition acts as a catalyst in free markets as competition forces companies to innovate or die. Firms constantly try to outdo each other with better, cheaper, or more efficient products.

Free markets allow capital to flow (via VC, stock markets, private equity) to promising ideas. This flexibility accelerates the commercialisation of new technologies. Silicon Valley, biotech clusters, and consumer tech revolutions thrived in capitalist, market-driven ecosystems. Historically, industrial revolutions (Britain, U.S, post-war Japan, South Korea) were fueled by market competition and capital incentives.

As has been illustrated already, many groundbreaking innovations from the internet, GPS, semiconductors, vaccines, nuclear power and space tech were born from government-funded R&D, in the defence industries rather than due to the market. Free markets, in many cases commercialised and scaled them, but the initial breakthroughs were not purely capitalist outcomes.

The free market has not been the creator of innovation due to competition. The market regularly underinvests in long-term, high-risk science as can be seen with climate tech and basic research because payoffs are uncertain. Public funding, not private profit, drives much of this early innovation.

We also find Capitalism can concentrate innovation in wealthy nations and companies, leaving global challenges like diseases in poor regions under-researched. Free markets have been proven to neglect “unprofitable” but socially vital innovations.

Paradoxically, capitalism can stifle innovation when large firms use patents, lobbying, or acquisitions to block competitors. In many cases big tech today often buys startups to neutralize potential disruption.

Some of the most successful innovation countries, such as the US, South Korea, Germany, China etc are really hybrids with a mix of capitalism and anti capitalist policies. Capitalism and free markets are powerful engines for applied, commercial innovation—they reward speed, efficiency, and disruptive products. But they all need the state, public institutions for foundational science and long-horizon innovation.

Capitalism and free markets have a proven track record when it comes to scaling and accelerating innovation, but they are not sufficient on their own. Most real-world innovation arises from a partnership between markets and government. As can be seen with China.

In essence, a nation innovates by fostering a complex tangled bank of ideas, in an ecosystem, where connection and recombination are valued over strict protection, and where opportunities for accidental discovery and productive error are abundant. This often means deliberately designing systems and policies that encourage information spillover and cross-pollination across various sectors and disciplines over profit.



Technologies of the Future

The technologies of the future are many and can be grouped into a number of categories. From advanced materials to quantum technologies. In this section we will look at the key categories of technologies that are currently leading research and development and have the potential to disrupt societies, economies and national security.

Most are dual or multi-use and have applications in a wide range of sectors. By focusing early on the science and technology life cycle, rather than examining technologies already in existence and fielded, this provides insights into which technologies are likely to dominate the future.

Research and Development (R&D) is only one piece of the puzzle. Actualising and commercialising research performance into major technological gains, no matter how impressive a breakthrough is, can be a difficult, expensive and a complicated process. A range of other inputs are also needed, such as a manufacturing base and ambitious policy implementation. But the research into key technologies is an indicator of national priority and allows us to assess which technologies are being prioritised and then we can look at who leads research into them and compare and contrast who will be the technological leader of the future.



Defence, space and robotics

Advance aircraft engines, drones, swarming and collaborative robots, small satellites, autonomous systems operation technology, advanced robotics and space launch systems

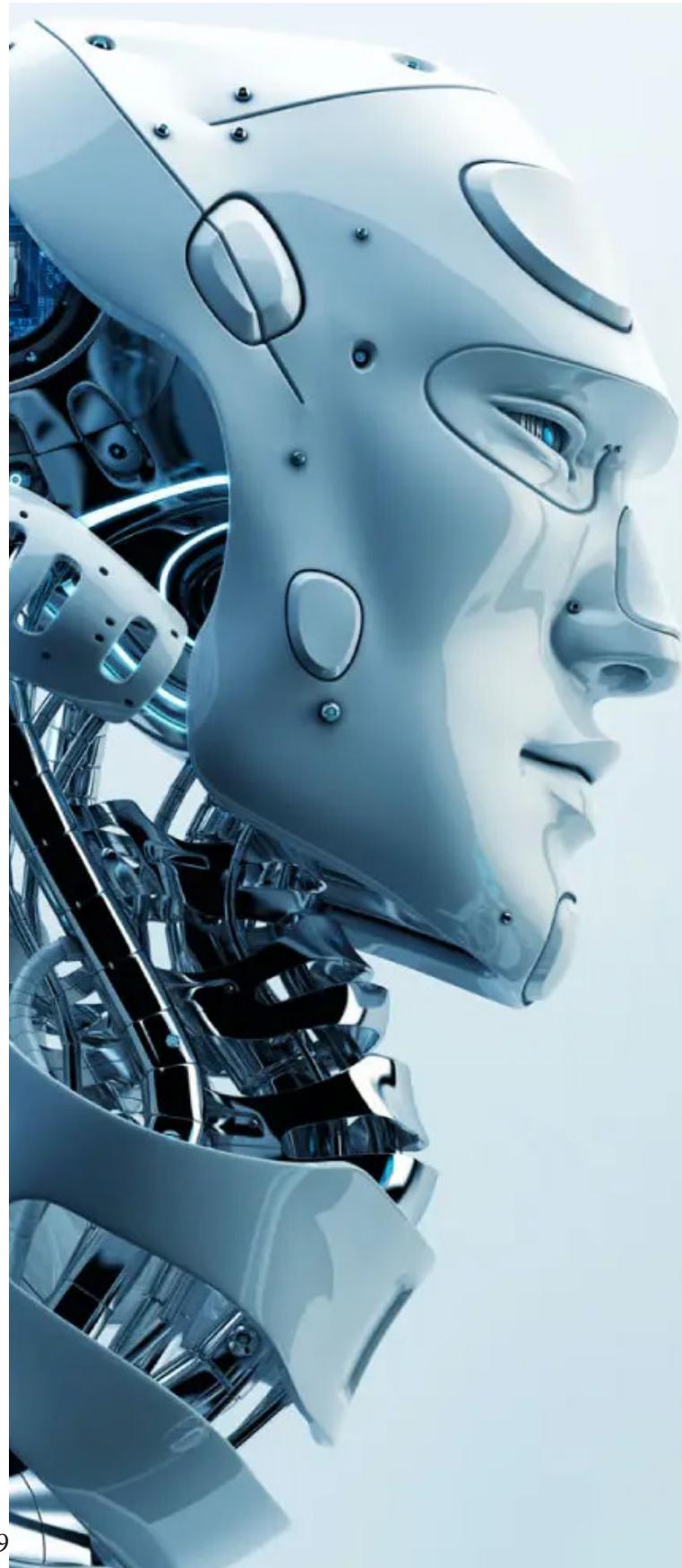
The world was shocked in 2021 when it was revealed that China had tested a nuclear-capable hypersonic glide vehicle. What many did not know was China dominates the research into the next generation of aircraft engines, including hypersonics. The Australian Strategic Policy Institute (ASPI), technology tracker found China had a 48% share of the world's most high-impact research in this area, well ahead of the US who only has a share of 11% of high-impact research in the area.

The challenge with hypersonics is the difficulties for projectile to reach hypersonic speeds - over mach 5, while enduring the stress and extreme temperatures of hypersonic flight. Then there are the challenges of maintaining such speeds for an extended period of time. Then there are the high velocities that can result in instability in the missile's airframe during flight. China is the global leader in most of the technological fields relevant to advancing hypersonic missiles, including novel metamaterials, coatings and high-specification machining processes. This is what has allowed China to build a world-dominating lead in these distinct but interrelated research fields.

Drones have become a key tool on the battlefield as well as civilian use. A number of nations are working on creating a multiplier effect by creating the tech that will allow drones to calibrate independently. Swarming drones represent a cutting-edge approach to unmanned aerial systems (UAS), where multiple drones coordinate their actions autonomously to achieve a shared objective. This technology is inspired by natural swarms (e.g., birds or bees) and relies on advanced algorithms, sensors, and communication systems. Currently China is leading the research into this area.

The other area that is showing great promise is in advanced robotics, which encompasses cutting-edge systems designed to perform complex tasks autonomously or collaboratively with humans. These systems combine artificial intelligence (AI), machine learning (ML), sensor technologies, and advanced materials to push the boundaries of what robots can achieve. Current research includes Collaborative Robots (Cobots), where robots will work alongside humans safely in shared spaces. As well as soft robots

that will use flexible, deformable materials to mimic biological structure. Both China and the US are neck and neck when it comes to high impact research in this area.



Artificial Information and Communication

Advanced radiofrequency communications (5G and 6G), advanced optical communications, artificial intelligence (AI) algorithms and hardware accelerators, distributed ledgers, advanced data analytics, machine learning (neural networks and deep learning), protective cybersecurity technologies, high performance computing,

AI, more than any other technology, continues to dominate the tech of the future. Within two months from its release by OpenAI, the online chatbot ChatGPT acquired over 100 million regular users. It took TikTok over nine months and Instagram over 2 years to achieve the same user take-up. Most significantly, ChatGPT aspires to satisfy the Turing test, in which a human is unable to distinguish a chatbot-generated response from a human response. ChatGPT is built on a language model trained on big data, combining supervised learning and reinforced learning from human feedback. Thus, chatbots such as ChatGPT, Google's Apprentice Bard and the like benefit from developments in a number of other AI subcategories.

The progress in AI has been due to developments in Natural Language Processing (NLP), a field that uses computational linguistics and statistical modelling to enable computers to process and generate naturally

developed languages at a level that's indistinguishable from human interaction. Breakthroughs in deep learning over the past two decades have made such interactions possible, using large language models (LLMs) trained on growing volumes of data.

The future of this technology is being dominated by the need to integrate it more deeply into human activities, address its limitations, and leverage new technologies. This includes expanding AI to control autonomous robots, vehicles, and drones. Creating hardware designed to mimic the human brain's architecture for AI and creating a direct interaction between AI systems and the human brain.

Whilst US corporations dominate the commercial products that have been released, its Chinese institutions that are dominating all the high-level research in all areas of information and communication.



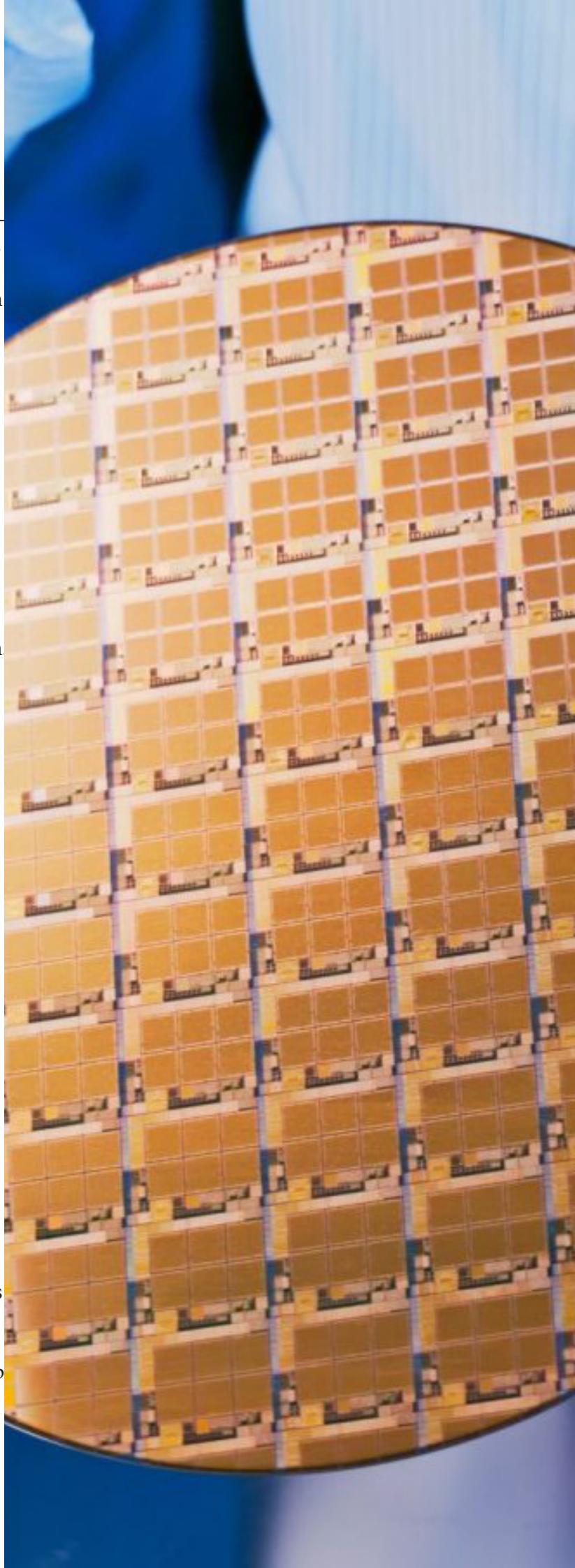
Advanced integrated circuit design and fabrication

The demand for faster AI capabilities has placed semiconductor chips at the centre of the race for a tech-driven economy and boosted research. Currently the most advanced semiconductor chips are IBM's 2-nanometer (nm) chips, unveiled in 2021. These chips boast transistors as small as 2 nm, smaller than the width of a strand of DNA. With such tiny transistors, a chip the size of a fingernail can hold about 50 billion transistors, significantly improving performance and energy efficiency compared to older technologies like 7nm or even 5nm chips.

The semiconductor industry is evolving rapidly to meet the demands of advanced technologies like AI, IoT, 5G, and renewable energy. Innovations in materials, design, and manufacturing processes are driving the future of semiconductors. Today design and fabrication processes are optimised towards scaling the smallest feature on the chip down to 2nm. Because the scaling happens in all three dimensions, completely different processes (and tools) are required for every generation of chips.

As we get to smaller semiconductors at 1 nm, quantum phenomena like quantum tunnelling and leakage currents become significant issues as transistor gates shrink below 2 nm, requiring the development of new materials and architectures. Traditional silicon may not remain effective at this scale due to its physical limitations. Extreme ultraviolet (EUV) lithography, which enables the production of 2 nm chips, will likely not suffice for 1 nm features; more advanced methods, such as high-energy electron-beam lithography or novel quantum-based techniques, are being explored.

The US excels in the design and development of the most advanced semiconductor chips and has a research lead in the technology areas of high performance computing and advanced integrated circuit design and fabrication. It's worth mentioning that, while Taiwan is a semiconductor manufacturing powerhouse and is supplying over 90% of the world's advanced semiconductors, most of the chip research and design is conducted in the US. Taiwan interestingly ranks ninth for the number of papers in the top 10% of highly cited papers for advanced integrated circuit design and fabrication.



Quantum technologies

Quantum computing, quantum communications, post-quantum cryptography and quantum sensing

Quantum technologies are systems and devices that leverage the principles of quantum mechanics, which is the fundamental framework that describes the behaviour of particles at the smallest scales. These technologies harness quantum phenomena such as superposition, entanglement, and quantum tunneling to perform tasks that are infeasible for classical systems.

Quantum computers use quantum bits, or qubits, which can represent both 0 and 1 simultaneously due to superposition. Superposition in quantum systems can exist in multiple states simultaneously and this allows quantum computers to process massive amounts of data. Using quantum states allows the performance of certain computations in a fraction of the time required to perform the same tasks on classical computers.

In secure communication systems based on quantum mechanics these systems use properties like entanglement to ensure eavesdropping can be detected. This is because quantum entanglement is a phenomenon in quantum mechanics where two or more particles become interconnected in such a way that the state of one particle instantly influences the state of the other(s), regardless of the distance between them.

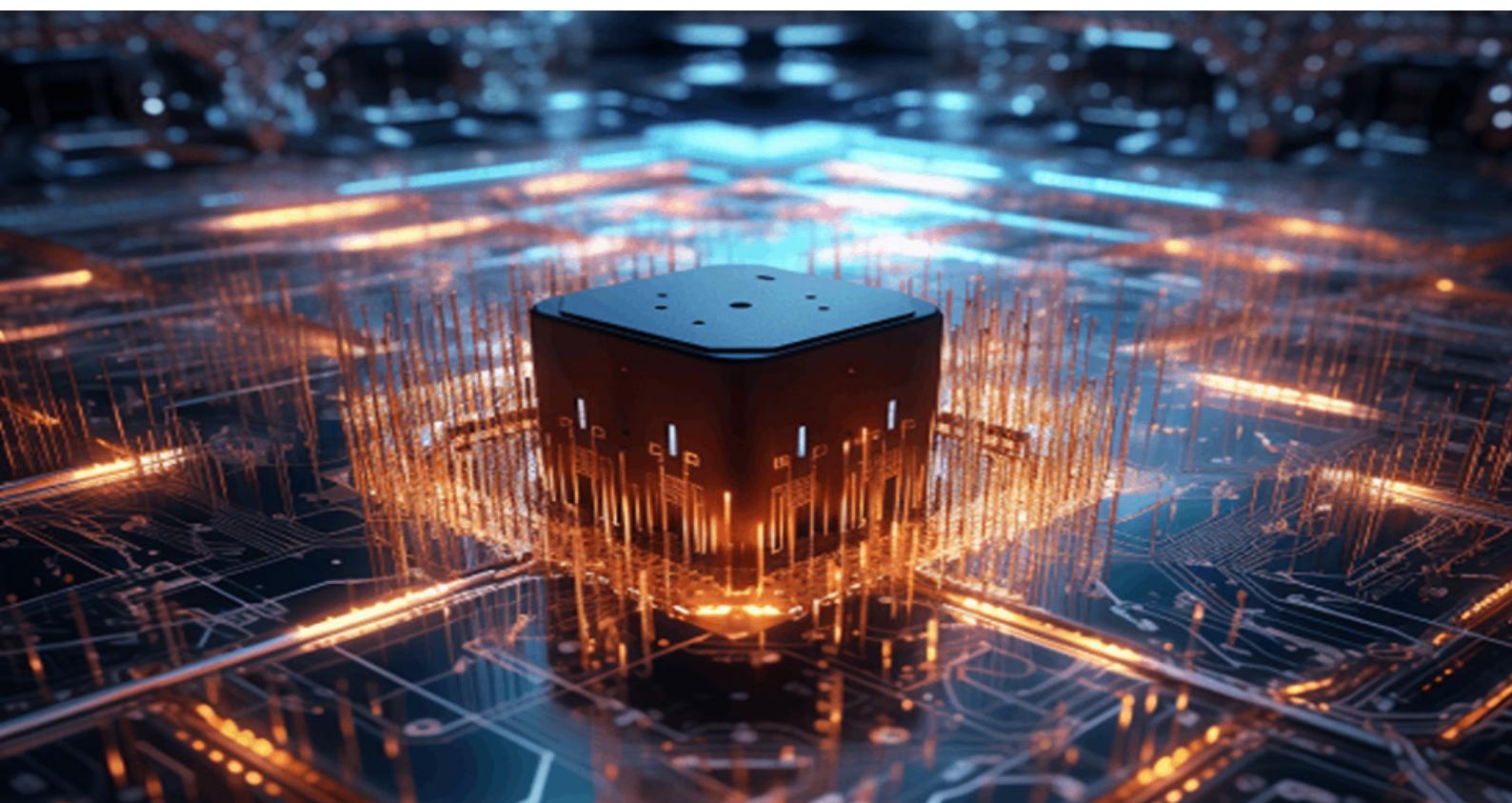
Quantum technologies promise revolutionary ad-

vancements in computing power, communication security, and measurement precision. They can solve problems far beyond the reach of classical systems, with the impact ranging from accelerating AI development to ensuring secure communications.

The current challenges include building large, error-tolerant quantum systems as well as getting over Quantum systems being easily disrupted by noise, requiring specialised environments.

Quantum technology is currently supported by over \$30 billion of public R&D funding internationally. China is estimated to have the highest level of public funding allocated to quantum technologies (over \$14 billion), followed by the EU (\$7.2 billion) and countries such as Germany, France, the Netherlands and Sweden are among the top funded European nations.

The US dominates high impact research into quantum computing, whilst China leads in quantum communication, sensors and cryptography. The world's largest quantum device is IBM's "Condor" quantum processor, with 1,121 qubits. It's the largest general-purpose quantum computer, capable of performing a wide range of tasks and represents a milestone in scalable quantum computing. IBM is also working on modular systems to connect multiple processors, aiming to achieve over 4,000 qubits.



Advanced materials and manufacturing

Nanoscale materials and manufacturing, coatings, smart materials, advanced composite materials, novel metamaterials, high-specification machining processes, advanced explosives and energetic materials, critical minerals extraction and processing, advanced magnets and superconductors, advanced protection, continuous flow chemical synthesis and additive manufacturing

Advanced materials encompass all the materials that have been engineered to display superior and novel properties compared to their un-engineered properties. Progress in the field of advanced materials has the potential to shape the future of technological-advance-generating outputs that include new materials with high performance characteristics that could, for example, be more cost-effective, energy efficient, durable, lightweight, fire resistant or smaller. There are clear gains to be made from advances in this area whether from manufacturing, trade or defense.

The area of most research in advanced materials is on nanoscale materials, also known as nanomaterials. Nanoscale materials have various major applications that exploit their engineered mechanical, electrical and photonic properties. Eleven of the 12 subcategories in the advanced materials category are directly related to their applications. Critical minerals extraction and processing has broader indirect applications in electric batteries, superconductors and magnets.

China dominates high impact research on advanced materials. In all the 12 subcategories Chinese institutes do the most high impact research and are referenced the most by others. The US comes second with its institutes and its research is quoted the most after China with advanced materials.

India also enters the fray with its researchers quoted the most after China when it comes to high-specification machining processes, smart materials and high-specification machining processes.

When it comes to smart materials three Iranian institutions are ranked among the top 20 institutions: the Islamic Azad University, Babol Noshirvani Institute of Technology and the University of Tehran.

The research into advanced materials is focused on engineering them to possess superior properties such as strength, flexibility, conductivity, and sustainability. Materials for polymers, coatings and antimicrobial and Hygienic Materials all need research and innovation.

Biotechnology, gene technologies and vaccines

Synthetic biology, Biological manufacturing, Novel antibiotics and antivirals, Genetic engineering, Genomic sequencing and analysis, Nuclear medicine and radiotherapy and Vaccines and medical countermeasures.

Biotechnology is a multidisciplinary field that utilises biological systems, organisms, or derivatives to develop technologies and products that improve human life, health, and the environment. It encompasses technologies that integrate biology and engineering into new products and processes.

The financial incentives to gain advantage in the sector are enormous given most countries spend more than 6% of their annual gross domestic product on healthcare, which accounts for more than 50% of the biotech industry.

The huge investment driven by the Covid-19 pandemic has helped boost the market to an estimated value of \$2.44 trillion. Future tech and current research are dominated by the intense competition between the US and China which, along with artificial intelligence, is anticipated to deliver some of the most life-changing technologies over the coming decades. Not surprisingly it is China and the US that dominate high impact research in this area.

Synthetic biology is the most nascent of the biotechnologies and is an emerging technology on par with quantum. The field involves redesigning living organisms into ones with new functions with applications in medicine, manufacturing and agriculture. The main distinction between synthetic biology and genome editing is that compared to genome editing, synthetic biology can involve the insertion of longer sections of DNA with the possibility of creating an entirely different organism like a recorded E. Coli. Lab grown meat is another example of synthetic biology, as is engineering of stem cells into mini robots.

China produced the most high impact research in biological manufacturing, genome sequencing and synthetic biology. Whilst the US leads the high impact research in genetic engineering and nuclear medicine.

Sensing, timing and navigation

Inertial navigation systems, multispectral and hyperspectral imaging sensors, photonic sensors, sonar and acoustic sensors, magnetic field sensors, atomic clocks and gravitational-force sensors

Acoustic sensors have long dominated military and civilian needs for detection, measurement and analysis. The technology that detects, measures and converts sound waves or vibrations into electrical signals for analysis and interpretation have played a critical role in both the military and commercial world.

The next generation of sensors being researched include devices with extremely sensitive detection capabilities for magnetic and gravitational fields, light and radio waves, as well as measuring time with atomic precision. These include atomic clocks, inertial navigation systems, gravitational force sensors, magnetic field sensors, multispectral and hyperspectral imaging sensors.

These all have the potential to make use of light, energy, atoms and sound waves to make more accurate measurements which will help from missile accuracy to GPS navigation. The US leads in high impact research in quantum, gravitational force sensors and atomic clocks. Whilst China leads in 7 out of 10 of the other next generation sensors. In 4 out these 7, China is so far ahead there is the risk it will monopolise the commercial applications and achieve technological dominance.



Energy and Environment

Electric batteries, hydrogen and ammonia for power, directed energy technologies, nuclear waste management and recycling, photovoltaics, biofuels and nuclear energy.

The battle to find alternatives to fossil fuels has been on-going for over a decade and this has seen the emergence of renewable energy sources and other technologies. There are numerous energy sources being researched as potential replacements for fossil fuels as well as technologies that can store and direct energy for specific uses.

The area of research and already seeing some commercial applications is electric batteries and the electrification of transport. Policies banning the internal combustion engine vehicles in favour of Electric Vehicles (EVs) has accelerated battery innovation. This has already led to the rising adoption of EVs that require batteries with higher energy density, longer lifespan, and faster charging capabilities. Next generation technologies include changing the chemical composition of batteries with lithium-sulfur (Li-S) batteries, sodium-ion batteries, zinc based batteries and magnesium and aluminium batteries. The research into these batteries creates the opportunity for large-scale batteries for grid energy storage and battery-powered aircrafts and ships.

China dominates high impact research into electric batteries, hydrogen and ammonia power and supercapacitors. Its lead is large enough that it is likely China will have a monopoly in these technologies when developed commercially, which we are already seeing with EVs. China is already pushing the boundaries in battery technology, and manufacturing excellence, which is putting EV manufacturing costs below that of the combustion engine.

China is also leading the high impact research into supercapacitors. This is an energy storage device that bridges the gap between traditional capacitors and rechargeable batteries. It stores energy electrostatically, enabling rapid charging and discharging compared to batteries, but with lower energy density. China's dominance of research in this area means it will likely have a monopoly over the technology when it is developed for commercial and military purposes.

The two fuels that are receiving the most study as future replacements for fossil fuels are hydrogen and ammonia. Ammonia is seen as a promising fuel in

the global transition to net-zero emissions. Hydrogen is also considered a clean and versatile energy source, especially when produced using renewable methods, as it generates little to no emissions at the point of use. China also leads the high impact research into these fuels and potentially will monopolise the technology when it's commercially available.

The other technology China is leading high impact research into is directed energy technologies (DET). These are systems and devices that generate and project energy in a focused and controlled manner to achieve specific effects. These technologies are often associated with military, industrial, and research applications and typically involve energy forms like lasers, microwaves, or particle beams. They hold significant potential for reshaping defence systems, industrial processes, and medical applications. Advances in power generation, miniaturisation and material science are expected to overcome current limitations. China in this area and all the current research on the future energy tech research, dominates and leads the research and is well ahead of the US and others.



Conclusions

AI, drones and many of the technophiles analysed are general purpose technologies that all have the ability to transform economies, societies and the lives of people. But the west, who has for long dominated research and development and innovation, is also changing. China's lead continues to grow in innovation and is currently leading in 57 of 64 critical technologies of the future. Over the past two decades, China's rise from a mid-tier position in global research in the late 2000s to mid-2010s into a research and science powerhouse today has been gradual but consistent. It's been able to convert its research lead into manufacturing in some fields such as electric batteries, though there are other areas in which China has been slower to convert its strong research performance into actual technology capability

The US is losing the strong historical advantage that it had. Over the last two decades the US has been unable to hold its research advantage. In the early to mid-2000s, the US was by far the dominant research power. Its performance between 2003 and 2007 saw it leading in research for 60 out of 64 technologies of the future. But now, that research lead has slipped to only seven technologies. The notable hold-outs include quantum computing and vaccine and medical countermeasures, in which the US still maintains a dominant position. The knowledge, expertise and institutional strengths built over decades of investment and pioneering research are likely to continue to benefit the US in the short term, but China is catching up rapidly through huge investments in its own science and technology areas and supporting top-performing institutions, especially in key defense and energy technology areas.

Our Mission

The world is a complex place with daily political events taking place which affect us all in different ways. The sheer number of events happening makes making sense of the world even more complex.

Geopolity.com aims to help in making sense of this complex world.

At geopolity.com we look at the world through the lens of power and ideology. We see forces such as geography, politics, economics and military capability constrain world leaders and nations. Through understanding these forces, we believe we can make sense of what nations are attempting to achieve. We also believe by determining the ideology nations embrace we can appreciate why the US is interested in the Middle East and why much of the world worries about Pakistan's nuclear capability.

This allows us to filter out all the noise and focus on the important political actions, moves and developments.

Who are we? Geopolity has no office as we believe it is people and ideas that are key, not offices and buildings. We are individuals who believe the world should be a better place for all and this can be understood by understanding the world around us. We are a non-profit-making organisation and so have no shareholders to satisfy.

We believe the more people can understand the world, the better the world would be.

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