Emerging Disruptive Technologies

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Executive Summary

Emerging disruptive technologies have the potential to significantly impact and transform various industries, shaping the way we live, work, and interact with the world around us. In this report, we explore a range of such technologies and their potential applications, as well as the ethical and moral considerations that they raise.

These technologies include cultured meats, which are an alternative to traditional animal agriculture; artificial intelligence, which has the potential to revolutionize various industries; quantum computing and quantum cryptography, which leverage the principles of quantum mechanics to perform calculations and transmit information; nuclear fusion reactors, which could provide a virtually limitless and clean source of energy; solar geoengineering, which involves manipulating the Earth's climate to mitigate the effects of global warming; asteroid mining, which could provide access to rare and valuable materials; space-based solar power, which could provide a stable and reliable source of renewable energy; green hydrogen, which is produced through the electrolysis of water using renewable energy sources; lethal autonomous weapon systems, which are a type of military technology that can select and engage targets without human intervention; directed energy weapons, which use focused energy to disable or destroy targets; anti-satellite weapons, which are designed to disrupt, disable, or destroy satellites in orbit; regenerative medicine, which involves the repair and replacement of damaged or diseased tissues and organs; and finally genetic engineering, which involves the manipulation of an organism's genome using biotechnology.

Throughout this report, we delve into the characteristics, current development status, key actors, the technology's supply chains, as well as the technologies' potential applications. We also examine the potential impacts of these technologies on their respective industries and on society as a whole.

Agriculture

Cultured Meats

Lewis Chapman

Cultured meats are genuine animal meats that are produced by cultivating animal cells in bioreactors, creating a genetically identical piece of meat without the need to raise livestock. This is not to be confused with plant-based meats, which try to imitate meat, since cultured meat *is* meat. Though still at an early stage, there are high hopes that the industry may play a significant role in tackling climate change and environmental degradation. Indeed, 35% of global emissions are due to animal based foods, whilst grazing land and cropland used for animal feed together make up almost 80% of all agricultural land, whilst producing only 20% of the world's supply of calories. Cultured meats generate up to 96% less emissions, use up to 96% less water and require 99% less land compared to their animal based counterparts.

Current Development Status

The industry is rapidly growing, investors are piling in and consumers seem willing to embrace this new form of meat. One study has even found that they are willing to pay substantially more for it. The industry is still young, though progress is rapid and cultured meat looks to become mainstream in the coming years, perhaps even worth $25 billion USD by 2030.

One major challenge of cultured meat is developing a texture similar to animal meat which develops by growing around sinew and tissue within muscles. Scientists are trying to replicate this by encouraging cells to grow around a cellular-level scaffolding to develop a similar texture. 3D printing may also be a solution here. Another major challenge involves scaling up the technology to an industrial scale, however with continued increasing investment this appears achievable.

In 2020, Singapore became the first, and still the only, country to approve the sale of a cultured meat product when it authorised the sale of cultured chicken made by the US firm Eat Just. Singapore is currently a global centre for cultured meats. Over 20 lab-grown meat start-ups have located their recently, one of which, Shiok meats, created the first ever lab-based crab meat in 2021. Part of the reason for Singapore's push in this area is due to its aim to grow 30% of its food domestically by 2030 and improve food security. For a small

island with very limited agricultural land, cultured meat is an ideal solution. For other countries too, cultured meats may offer a significant improvement in food security, whilst countries with strong agricultural export sectors may lose out if animal farming is slowly replaced by cultured meats. Overall, however, significant improvements in sustainability, efficiency, cost and perhaps even taste mean that there will be significant widespread gains as the industry grows.

Key Developers and Beneficiaries

In 2020, Singapore became the first, and still the only, country to approve the sale of a cultured meat product when it authorised the sale of cultured chicken made by the US firm Eat Just. Singapore is currently a global centre for cultured meats. Over 20 lab-grown meat start-ups have located there recently, one of which, Shiok meats, created the first ever lab-based crab meat in 2021. Part of the reason for Singapore's push in this area is due to its aim to grow 30% of its food domestically by 2030 and improve food security. For a small island with very limited agricultural land, cultured meat is an ideal solution. For other countries too, cultured meats may offer a significant improvement in food security, whilst countries with strong agricultural export sectors may lose out if animal farming is slowly replaced by cultured meats. Overall, however, significant improvements in sustainability, efficiency, cost and perhaps even taste mean that there will be significant widespread gains as the industry grows.

There are dozens of start-ups operating in the industry and investment is rapidly growing, in 2020 more than $360 million USD was invested into cultured meat companies, whilst in 2021 this had more than tripled to $1.38 billion USD. Eat Just have announced that it will build the world's largest cultivated meat facility in the US by 2024 – a strong sign of investor confidence in the market. Currently, sale of cultured meat is banned in the US but there are signs that regulatory approval is close, as the US is keen to become a leader in the industry. Several landmark US facilities opened in 2021, UPSIDE Foods opened a facility with planned capacity of 400,000 pounds after a $400 million funding round whilst Future Meat, Wildtype and Shiok meats all launched pilot plants.

The industry is growing globally too. China has included cultivated meats in its 5 year agricultural plan, the EU has launched Cellular Agriculture Europe and JBS, the world's largest protein company, announced a $60 million USD cultivated meat R&D facility in Brazil.

Supply Chain

Just like animals in fields, cell cultures in bioreactors need feeding, and they require lots of nutrients. Currently, many cultured meat companies are using Fetal Bovine Serum (FBS), a nutrient-rich liquid derived from the blood of pregnant cows during slaughter. For an industry that prides itself on avoiding animal slaughter and harm, it seems unlikely that FBS will be a long-term solution and its current use is to ensure proof of concept. Furthermore, it is very expensive – between £300 and £700 per litre – which is part of the reason the first cultured meat burgers cost £4,400. Yet moving beyond FBS has proven difficult.

A key part of the supply chain is the raw ingredients needed for the cultures, this will include large amounts of sugar as well as basic media components (such as minerals and amino acids) and more complex growth media additives including insulin and micronutrients. Scaling up these media, particularly the more complex growth media, may require new industries and supply chains to form. However, there is much uncertainty here since it is not clear exactly which compounds will be used, and as companies continue to innovate, they will likely change their mix of ingredients. Mosa Meat, a leading cultured meat company, has acknowledged legitimate concerns over the prospect of a large-scale supply chain of pharma-grade nutrients needed to bring costs down and enable economies of scale. Compared to animal-based meats, the process of cultured meat involves far fewer stages of processing and is easy to centralise in urban/industrialised areas. Cultured meat also has a far longer shelf life as well as reduced refrigeration requirements, creating significant cost advantages and improvements in supply chain efficiency.

Use Cases and Political Implications

Most efforts to create cultured meats so far have been focused on chicken and beef, but other prototypes have been created such as salmon, pork, shrimp, caviar, pet food and even attempts to use the same technology to grow animal fur. There are also accelerating efforts to use the technology to create eggs, gelatine, milk etc with three companies already focused on this domain, raising a combined $30 million in 2021 alone. The greatest opportunity, however, remains within the staple meats such as chicken and beef which is indeed where the largest companies and investors are focusing their efforts.

The most significant political implication is of shifting global food-supply chains and the resultant changes in food security. For most countries, cultured meats will result in improving food security as land and climate are no longer significant limiting factors in meat production.

Of course, there will be entirely new supply chains that form for the cultures – i.e. the food that the cultured cells feed from – but how exactly this forms, and who this directly benefits, remains to be seen. In the long-run, there will be economic and political effects of changing land use – the 77% of agricultural land that is currently used for animals or growing animal feed may all be put to new uses. Crop prices may be forced lower as demand for animal feed declines – albeit slightly offset by a demand for the ingredients used in cultures – and farmland prices may fall. There will be further effects on labour markets and local economies as the agricultural sector shrinks and food production becomes centralised within industrial clusters.

Electronics

Artificial General Intelligence

Lewis Chapman

Firstly, it is worth defining what artificial general intelligence (AGI) is, and how it differs from current AI. AGI, also known as deep AI or strong AI, is the representation of generalised human cognitive capabilities in software, such that, faced with an unfamiliar task, the AGI system could find a solution in the same way that a human would. In many ways, AGI would resemble a human – it would exhibit creativity, sensory perception, and social and emotional engagement. However, the broad intellectual capabilities of AGI would far exceed that of a human due to the ability to access and process huge volumes of data at once. AGI can be seen as the final step in AI development, since once we have AGI, it will begin to improve itself to create yet more advanced AGI's. This compounds, perhaps leading to an intelligence explosion.

This is far beyond current levels of AI – known as weak or narrow AI – which is the application of an AI system to solve specific tasks of problems. The main difference here is that AGI, unlike narrow AI, can think for itself and form opinions – potentially even be conscious or sentient, although much debate still exists here.

Current Development Status

There is significant uncertainty over when we will have a working AGI model, some suggesting it is just a few years away whilst others suggest that it may never occur. In a 2019 survey of AI experts, 45% predicted that we will have AGI by 2060, whilst 21% said it will never happen. Ray Kurzweil, an American futurist reputable for his many accurate predictions about the future, estimates that by 2029 AI will reach human levels of intelligence, and by 2045 we humans will have multiplied our collective intelligence by a billion fold.

Globally, AI investment is growing rapidly. In 2021, total investment reached $93.5 billion – more than double the figure for 2020. The number of AI patents filed in 2021 was 30 times higher than in 2015, a compound annual growth rate of 76.9%. Clearly, AI is advancing exponentially, not linearly – the consequences of this are profound, particularly when considering the long run.

Key Developers and Beneficiaries

Currently, the US is ranked as the dominant player in AI investment. This is largely due to the thriving tech hub of Silicon Valley combined with strong capital markets. Indeed, US total private investment in AI is three times higher than the next country, China, whilst also having twice as many AI start-ups.

China, despite still being behind the US in AI investment, is rapidly emerging as a leader in AI research. Indeed, if we consider AI research publications, China had 63.2% more publications than the US in 2021. The development of AI is a key focus for the Chinese Communist Party who have set the target for overtaking the US in AI development by 2030. Abroad, there is much concern over China's approach to ethics within AI as well as concern over how China may use AI to boost its military capabilities. This lack of focus on ethics may be part of the reason behind China's AI progress. Whilst other countries are held up by regulation and lengthy discussions and deliberation on ethics, China can power ahead. Nicolas Chaillan, the Pentagon's first chief software officer, has already criticised debates on AI ethics slowing down development within the military. Chaillan also directed blame towards Google's refusal to work with the military on AI. This is a stark contrast to China where, he said, Chinese companies are obliged to work with Beijing and were making "massive investment" into AI without regard for ethics.

Despite ongoing political tensions between the two global superpowers, there is significant, and increasing, cooperation on AI research, with the number of collaborations increasing five-fold since 2010. This bilateral collaboration produced 2.7 times more publications than between China and the UK – the partnership with the second highest collaborations.

The potential impacts and uses of AGI are vast. It has the power to immensely benefit the whole of humanity and change lives in truly profound ways. For example, AGI may be used to cure diseases and find treatments for cancer, drive autonomous cars and much more aside. Indeed, the eventual uses of AGI will be for things we cannot yet even imagine. However, there are also severe risks – most particularly the fear that we could create a 'runaway AI' that could potentially end human civilisation. This is a scenario explored by Professor Nick Bostrom in the paperclip maximiser argument whereby a misconfigured AGI is given the sole target of producing as many paperclips as possible, leading to it using every resource on Earth to make paper clips, ending civilisation in the process.

Supply Chain

The success of AGI relies on computation on a vast scale. Computer chips are therefore the central piece of hardware to AGI development. The enormous computational power required is delivered by computer chips that not only pack the maximum number of transistors but are also tailor made to perform specific calculations required by AGI systems – primarily, the ability to perform calculations in parallel rather than sequentially. Whilst general purpose chips, usually central processing units (CPUs), can still be used, they are thousands of times slower than purpose-built chips, which are Graphics Processing Units (GPUs). Even with these cutting-edge chips, training an AI system can cost tens of millions of US dollars and take weeks to complete. However, costs are falling precipitously. Over the past 10 years AI training costs, on average have fallen by a factor of 10 every year. If AGI is to be deployed, cost-effectively, at scale, then there will need to be continued improvements in the capabilities of these leading AI chips. Alternatively, quantum computing could be a solution here, an industry in which China and the US are both investing heavily, but neither has yet emerged as a dominant leader.

The supply chains behind these chips are complex and rely on numerous highly specialised suppliers. Currently, the US and its allies have a significant competitive advantage in several parts of the supply chain of these chips. For example, the US firm Nvidia dominates AI chip design, and other US firms dominate electronic design automation (EDA) software used to design chips. Notably, Chinese firms are far behind on AI chip design and heavily rely on US EDA software.

Another key aspect of the supply chain is the production of these chips, a hugely demanding process operating at the limit of known physics. Taiwan Semiconductor Manufacturing (TSMC) dominates this industry and produces the bulk of Nvidia's cutting-edge chips. Situated in Taiwan, this is of course a geopolitical hotspot and therefore any conflict or escalation between China and Taiwan would have global repercussions for the development of AI, as well as for the wider technology sector. Whilst there are other firms capable of producing AI chips, notably Samsung and Intel, they lack the cutting-edge capabilities of TSMC – which is dominant in all forms of chip fabrication, not just AI. Recently, however, in a bid to diversify suppliers due to geopolitical tensions in Taiwan, Nvidia are planning to work with American firm Intel to produce their chips.

Use Cases and Political Implications

The potential of AGI cannot be understated. It is an entirely new form of intellect that will change the world in unimaginable ways. By its very nature - being more advanced than our biological intelligence – we will not be able to understand much of its reasoning and decisions. For this reason, many of its potential use cases will be things we cannot yet imagine.

In theory, AGI would be able to carry out any task that a human could do, and likely many others that a human could not. AGI would be able to combine human-like flexible thinking with immense computational ability such as a vast memory that can be recalled in an instant as well as split-second number crunching. These capabilities could be used to control robots that can replicate any human task, and much more aside. They may render human labour obsolete as they replace workers in offices, leading to dramatic economic and societal change. Indeed, a Mckinsey study has found that 50% of today's work activities can be automated by AI – an advanced AGI system would see an even higher figure.

There are numerous political implications of AGI. It may open new routes to surveillance and control of populations. There are also fears of AGI being used to create fearsome weapons and use its powers to sway democratic elections. Perhaps the most significant political implication is that of entrenching power (and, likely, large profits) within a small number of organisations, mainly large US tech firms. This may result in calls for higher taxes to fund an increased welfare state or universal basic income (UBI) in response to dramatic shifts in the labour market and resultant unemployment.

Quantum Computing

Matthew Johnson

Current Development Status

Quantum computing is a unique form of technology understood through the use of quantum mechanics and falls under the category referred to as "deep tech". A quantum computer, at its core, serves to calculate what are currently incalculable problems even for the most powerful supercomputers of today. Research surrounding Quantum Computers (QCs) extends back to the 1980s, however, over the past two decades we have seen more dramatic progress in its development. The research, until recently, presented "proof-of-principle quantum devices and processors". Now we are witnessing a period where the advancing tech is capable of solving present-day issues.

While revolutionary in and of itself, QCs offer major upgrades in support of other technologies and industries, including but not limited to artificial intelligence, encryption, pharmaceutical discovery, and weather forecasting. An exact cost for a quantum computer is difficult to add-up due to the array of options organisations can take, from Universal QCs, Adiabatic QCs, or quantum annealers. In terms of cost, according to SEEQC, a general estimate to build a single "useful quantum computer" at present can reach upwards of "tens of billions of dollars". Thus a "scalable, commercial-grade quantum computer" has yet to become widely available as the issue lies with "the qubits that run in the computers." A highly controlled environment is required due to the qubit's sensitivity "to vibration or temperature change", factors that will affect a quantum computers ability to complete calculations successfully and without errors.

While these issues will continue to hinder its development, they have not prevented organisations from providing access to already available quantum computing technologies. For instance, D-Wave now offers their quantum computing technology, that of a quantum annealer, via cloud services. Based on the ease of access through cloud services, commercial-grade access to quantum computing technology (though limited in application) will continue to be offered through cloud services by organisations such as IBM, Intel, or Google. The technology has hence already begun some level of integration into the real-world. A Deloitte report in 2020 estimated that fully error-corrected quantum computers could be engineered within 8 years if the current rate of development continues, yet the report did not give a prediction for the technology's commercial viability. With technology yet to be fully developed, it will likely take decades until we see commercial-grade quantum computers made available.

Key Developers and Beneficiaries

According to P&S Intelligence, the market size "is predicted to rise from $89.6 million in 2019 to $1,866.8 million by 2030," with a compound annual growth rate of 33.1% between 2020 and 2030. In other words, the industry will have a value of over $60 billion USD by 2030. Companies involved in the development of quantum computers include IBM and Google, with IBM having 20 quantum processors currently in use while Google has stated plans to have a quantum computer by 2029. The increasing interest is therefore set to continue due to it receiving support via government funding in addition to certain industries, especially banking and insurance seeing as the tech will have the capacity to search larger data sets and factor larger numbers much more quickly.

In the case of banking, quantum computing's capacity to process massive data sets that take into account a greater number of past variables will allow, for example, a more accurate projections on returns. Furthermore, financial institutions are becoming increasingly interested in quantum technologies in general in order to improve encryption. In 2020, the use of a quantum key distribution (QKD) was discussed by JP Morgan as a potential solution to improving modern-day encryption. As of February 2022, a QKD network – intended to protect against potential attacks against blockchain technology – was successfully demonstrated in February through a joint effort between JP Morgan, Toshiba and Ciena.

Government funding is one of the key drivers behind the technologies progress. The United States' budget for quantum technology over the past few years has only increased. In 2018, the government passed the National Quantum Initiative Act to coordinate and accelerate research. In 2019 the annual budget of $449 million has now doubled in size as of 2022 to $877 million. One example of investment being Princeton University receiving $115 million USD to be paid out over the course of five years towards a new quantum science research department. Researchers at Princeton noted their ambitions of achieving "quantum advantage", a level of computing tasks in which classical computers are incapable of solving. In a recently released White House memorandum, the Biden administration demonstrated a more serious position towards the technology in its recognition the threat quantum computing will pose to national security, in addition to the benefits it will have for different fields, "from materials science and pharmaceuticals to finance and energy." Additionally, the National Quantum Initiative Advisory Board is now set to directly advise the White House on government quantum policies.

According to estimates by Quantum Computing Report, China has invested a sum of "$25 billion" into quantum technology between the mid-1980s and 2022, however, this estimate has yet to be officially confirmed. However, we are able to see part of this investment (an estimated $10 billion) in Hefei, China where the worlds' largest quantum laboratory is currently undergoing construction and will allow for a reported 10,000 experts to conduct quantum research. Quantum technology was further declared a key priority in its 14th Five Year Plan (2021-2026).The investment into the field has certainly produced results as Chinese scientists this year revealed a new and efficient way to speed up the production of "entangled photons" – photons being one of the possible candidates, through their physical manipulation, which aids in the computation process. In comparison to the United States, where the government has yet to generate greater incentives in the field, China is arguably leading in overall government investment in quantum technology.

Supply Chain

The materials required to build a QC can be difficult and at times rare to obtain. In the case of coolant in order for the QC to remain at the necessary temperature below zero, helium-3 is required to ensure stability. The gas, which is also a key ingredient to the fusion process, is one of the rarest in the world with costs estimating at one gram at $1,400 (or $140 million for 100 kg). Through the use of cloud services, it will be possible for organisations to maintain the necessary stable environments for QCs which will likely support further advancement of the cloud.

Another important component of a QC is a Josephson junction - a device that is made by sandwiching a thin layer of a non-superconducting material, usually aluminium oxide, between two layers of superconducting material, normally aluminium. China is the world's top producer of aluminium oxide, with its industry concentrated in Guizhou province due to friendly policy and abundant supply of resources, particularly bauxite which is used to produce aluminium in many industrial processes. Around five actors account for 40% of the global aluminium oxide market with the largest being the Aluminium Corporation of China Limited (CHALCO). The importance of China in the aluminium supply chain could generate risks for QC development, especially in the US and the European Union, as a result of geopolitical instability. We have witnessed disruptions to the aluminium supply chain recently, as a result of the COVID-19 pandemic. These supply chain problems have been exacerbated by Russia's invasion of Ukraine since Russia accounts for around 13% of aluminium production outside China. Indeed, in early February, during the build-up to the war, aluminium prices rose to a 13-year high of $3,236 a tonne.

The development of QCs also face difficulty when trying to create and increase the number of qubits. The types of technology to make qubits varies, with scientists focusing leading tech, including: "superconducting qubits, qubits made from trapping ions with light, qubits made from the silicon materials found in today's computers, qubits captured in "color centers" in high-purity diamonds, and topologically protected qubits represented in exotic subatomic particles." In terms of silicon, we witnessed supply chain issues that severely impacted the semiconductor industry as a result of the pandemic. As scientists continue to research and develop the technology, it has been suggested that semiconductor manufacturers will play a key role in creating "silicon quantum dots". One of the more advanced manufacturers, Taiwan Semiconductor Manufacturing Co. (TSMC), already began developing quantum processers in

2018 where they researched issues surrounding temperature limitations. Additionally, in 2019, TSMC and IBM formed a partnership to design and build the quantum chips.

Aside from the physical materials, there will also be a need for increasing experts in the field in order to have continued advancement. The skills shortage will be difficult to solve as it requires individuals to have highly-advanced knowledge on quantum mechanics, physics and computer science. Furthermore, the field is still relatively low-demand given the small number of companies involved in research and development. If quantum computing is to reach a point of commercialisation, advancement in the technology will greatly depend on the amount of experts in the field as investment can only bring it so far.

Use Cases and Political Implications

Due to the basic computational nature of a quantum computer, they are able to be involved in, as well as disrupt, almost any industry. According to US House Representative Will Hurd, chairman of the congressional subcommittee on information technology, "In the same way that atomic weaponry symbolized power throughout the Cold War, quantum capability is likely to define hegemony in today's increasingly digital, interconnected global economy."

In the area of security, one issue involves the potential QCs have in decrypting modern-day encryptions such as blockchain. As mentioned above, JP Morgan and other partners have already begun taking measures with goals to get ahead of the future issue. As it is a major security issue wherein the public key infrastructure, the "backbone" to current encryption standards, could become unsecure, governments are investing resources into quantum-safe algorithms.

The pharmaceutical industry is another area that quantum computing promises the idea of new discoveries in medication. As quantum computing offers greater advancement in simulations, drug discovery will benefit immensely as scientists will be able to better understand in a more precise manner the interactions between molecules that lead to certain diseases.

In terms of military application, one potential and interesting use of quantum computing involves its increased rate of calculation that can enhance the artificial intelligence used to create war game simulations. With specially crafted algorithms, it would be possible for militaries to gain a critical advantage and quantum computing could provide that promise. Of course, this has yet to be proven and applied in the field, however governments have already taken steps to begin understanding and testing QCs. For instance, the UK Ministry of

Defence has already acquired its first QC in June 2022 to "gauge the possibilities of what working on a quantum computer would have if you can scale this machine to really large system sizes." Developed by Orca, the QC will be able to operate at room temperature rather than the standard below freezing. How this will fare in contrast to their QC counterparts that require below-freezing environments remains unclear.

Quantum Cryptography

Issy Ronald

Current Development Status

The advent of quantum cryptography, in part as a reaction to quantum computing, heralds a new age for encryption by ensuring that data can be secured and transmitted without being hacked by harnessing the natural properties of quantum physics. It uses individual particles of light, or photons, to transmit data over fibreoptic wire. The quantum properties of these photons ensure that they can exist in more than one place or state at a time, and cannot be observed without leaving a trace. It is impossible, therefore, to copy whole particles, and their information, or eavesdrop without informing the sender.

This differs from the current standard method of digital encryption known as RSA codes - a mathematical algorithm that relies on the difficulty of factoring large numbers. While it would take a digital computer about six quadrillion years to break a 2048-bit RSA code, a quantum computer could solve the algorithm in eight hours, posing an existential cryptanalytic threat. Quantum cryptography, therefore, would negate this threat.

Although the theory behind quantum cryptography is well-developed, it has not quite been fully realised in practice. Several universities, national governments and private companies, however, have successfully implemented quantum cryptography on a limited scale.

Key Developers

The Defense Advanced Research Projects Agency (DARPA) Quantum Network, established by Boston University, Harvard University and IBM Research from 2002-2007, was the world's first quantum key distribution (QKD) network. The project tested the network against sophisticated eavesdropping attacks, concluding that it was both "extremely secure and 100% compatible with today's Internet technology."

The University of Cambridge and Toshiba Corp announced in October 2021 that it had developed the first ever chip-based QKD system, an important step towards allowing mass manufacturing.

In Canada, the company Honeywell and the Canadian Space Agency aims to launch a quantum cryptographic satellite into the Earth's orbit by the end of 2022. Current quantum encryption technology relies on fibreoptic cables limited to a 200km so this satellite could allow for the technology to be used over greater distances.

In Western countries such as the US, Canada and the UK, development has been driven by large companies who have focused on quantum computing. On the other hand, China has focused on quantum cryptography through government-led action, based on a preoccupation with internet security. China has built a prototype quantum communication network between Beijing and Shanghai, asserting its presence as an emerging leader. There are concerns, particularly in the US, that China may become the first to gain a cryptologic advantage. In its 2021 report to Congress, the Pentagon warned that China "continues its pursuit of leadership in key technologies with significant military potential." This competition, however, does not necessarily equal interstate conflict. Brookings Institution pointed out in 2020 that China's leading position in quantum cryptography could allow for US-Chinese collaboration that would benefit both countries.

Uses

Quantum cryptography allows users to communicate more securely since after the data is encrypted, there is little concern that a malicious actor could decode it without the key. This carries enormous political and security implications.

Military planners could would be able to transmit information without other actors tapping it, while the promise of quantum cryptanalysis is such that some countries are already gathering encrypted communications in the hope of decoding them in the future.

Theoretically, quantum cryptography could become an equalising force but in reality, the technology may only be attainable for wealthy countries, further reinforcing inequality at a global level. This could leave poorer countries more vulnerable to hacking and fraud as well as severely reducing the efficacy of their intelligence services. It could also reduce their ability to manoeuvre in situations where secrecy provides some political advantage such as the build-up to armed conflict or in sensitive negotiations.

The advent of completely confidential communications would also impact on intelligence gathering. Criminals, terrorists, and state actors could have the ability to completely hide their activities from intelligence services, allowing them to act unimpeded. Governments unable to collect intelligence from their communications could also be denied warning of a surprise attack.

As well as the national security implications, quantum cryptography carries uses in the communications, banking, and tech industries. IBM and Ponemon estimated that the average total cost of a data break for the financial industry is $5.86 million with an average stock price decline of 6.8%. Using quantum cryptography, data breaches in the banking and health sectors could be avoided.

Energy

Nuclear Fusion Reactors

Matthew Johnson

Current development status

A nuclear fusion reactor is the technological replication of the natural energy production of a star. The science is rooted in Einstein's theory of relativity ($E=mc^2$) on the convergence of mass. In order to achieve a fusion reaction to create electricity, "two light nuclei merge to form a single heavier nucleus", and it is through the fusing of the nuclei where the leftover mass is provided and becomes energy. However, the conditions where this is actually possible are one of the many issues scientists have faced over the many decades. A controlled environment which allows for heating of up to 50 million degrees Celsius in addition to the need for intense pressure is necessary to "allow the nuclei to fuse." At present, two approaches are most prominent in the field. The first is *magnetic confinement*, where a magnetic field is used to contain the plasma, and the second being *inertial confinement*, a process that requires the use of high-powered lasers.

The pitch for nuclear fusion – "a star in a bottle" – illustrates not only the promise of an unlimited energy source, but also the sense of it being forever unobtainable. While scientists began researching fusion in the 1920s, the development of nuclear fusion still remains in the early stages and it is unclear as to when (or even if) it will begin supplying energy. Since the 1990s, however, major progress can be noted. One recent example of success came in 2021 when researchers at the Joint European Torus (JET) facility in Oxfordshire, UK documented a "record-breaking 59 megajoules (MJ) of fusion energy", surpassing the 1997 record of 21.7 MJ. At present, the JET facility is the world's largest operating "tokamak". A tokamak can be understood as the most advanced structure that uses magnetic fields to harness fusion, operating in pulses rather than continuously in operation like a power plant.

The research conducted at JET is set to provide foundational support in scientific research for what will soon be the largest tokamak in the world. This tokamak, known as the International Thermonuclear Experimental Reactor (ITER), has been under construction since 2007 with a predicted completion by 2035. The members of the international project include China, the EU, India, Japan, South Korea, Russia, and the United States, all of whom will "benefit from 100 percent of the scientific results and all generated intellectual property." The project aims to demonstrate that nuclear fusion is possible and can be sustained for 400 seconds yet will not actually be providing any throughout its planned 20 years of operation. Recently, the project has faced severe delays due to Covid-19, and with Russia's invasion of Ukraine delays will likely continue. In saying this, it is important to note that political tensions provide an easier excuse for the reasoning behind project derailment, but this is far from reality. At the beginning, it set out as a 10-year project, expected completion by 2020 and an estimated cost for construction, operation, deactivation and decommissioning of a little over $8 billion USD. This of course changed when in 2018 the US Department of Energy forecasted a new estimate of over $65 billion in construction costs alone, not including costs of its operation, deactivation or decommissioning. Taking Covid-19 and the war in Ukraine into account, the estimate is likely to only increase and the ability to continue funding the project only more difficult for countries involved.

The significance in creating a source of limitless energy continues to drive the interest from the public and private sectors, all of which have helped in nuclear fusions progress to achieving such goals. If the ITER project is completed and is able to begin testing, it is sure to provide benefit in its published researched. In looking to the private sector, where delays due to political tension are less common, swifter advancement of nuclear fusion may deliver more critical technological feats through trial-and-error in addition to willing investors.

Key developers and beneficiaries

As global energy demand continue to rise, nuclear fusion is gaining increased levels of investment from both the private and public sectors. In a recent report by the Fusion Industry Association in which 33 private fusion companies were surveyed, an estimated $4.8 billion USD has been invested into the industry, an increase of 139% since last year. One US-based private fusion start-up, Helion, raised $500 million in capital at the end of last year. The company aims to generate net electricity by 2024 by extracting energy directly from the fusion reaction (rather than by the tokamak, which depends on fusion reaction to steam turbines).

While research in the private sector is beneficial, government funding of nuclear fusion, particularly in United States, has continued to support the technology for decades via funding, of which is typically invested into either ITER or non-ITER research. The US budget in 2022 provided $242 million in the international effort to building the ITER facility, in addition to increasing non-ITER funding to $471 million with $45 million in reimbursements being directed towards private fusion companies after reaching certain technology goals. As the current administration debates the FY 2023 Budget, officials are proposing an increase of funding for the Department of Energy, with the research and development of fusion energy having an increase of 4.2% to $743 million USD. Results of the Department of Energy's funding is demonstrable by the National Ignition Facility (NIF) experiment in their successful effort to achieve "ignition", described as "an experiment that generates more energy than it consumes." The laser technology used at NIF known as inertial confinement, of which is different from that of the magnetic confinement used in the tokomak, is similar to the work of Helion in that it shows great promise yet has received criticism and deemed a "dead end" due to researchers being unable to replicate NIF's experiment.

In competition with the US, the Chinese government as well as private investors have begun taking nuclear fusion much more seriously over the past two decades. In 2006, the Chinese government began investment into building its own nuclear fusion reactor, known as the Experimental Advanced Superconducting Tokamak (EAST), with an initial cost estimate of $37 million USD in addition to offering significant findings to support the global ITER project. As of 2022, it is reported that the EAST project has cost China almost $900 million USD, in addition to a second investment of $900 million USD. (A recent and widely reported estimate of $1 trillion USD remains unverified.) The EAST project has recently achieved two noteworthy world-records in the past year, the first being the reactors ability to sustain 120 million Celsius for 101 seconds, and the second being the reactors production of the world's strongest steady magnetic field at 45.22 tesla.

Other key players include the UK, who has since decided to remain with the ITER's Horizon 2020 research programme as well as the Broader Approach partnership between Europe and Japan in order to benefit fusion's research and development. The UK Atomic Energy Authority (UKAEA) recently declared this year its nuclear fusion initiatives, with interests in developing commercially viable nuclear fusion energy. The UKAEA is bolstering its efforts in research exchange by having recently partnered with the US-based private company, Commonwealth Fusion Systems (CFS). In addition, a major private company in the UK, Tokamak Energy, whose scientists have connections with the research conducted at the JET facility, specialises in constructing "spherical tokamaks" as well as the required magnets of high temperature superconducting materials. To date, the company has received a total of $250 million USD in funding, and while it fails in comparison to its US-competitor CFS with over $2 billion in funding to date, Tokamak Energy plans to prepare for an international fundraising later this year.

Supply Chain

As research and investment continues into nuclear fusion, there remains a minimal level of success in terms of its energy production. One area of concern is in the energy supply chain and how the produced energy is to be delivered to consumers. Based on the expected mass quantity, it's possible that any energy produced will be injected into the countries national grid rather than becoming an export for other energy consuming countries. What the energy storage technology will look like when capturing nuclear fusion energy is also unclear, and therefore only logical concepts can be discussed without further research.

The materials required to construct the technology include those which can be difficult to extract. Three key natural resources used in the making of nuclear fusion reactors are lithium, beryllium, and lead. According to the Brookings Institute, beryllium, which will be used to coat the metal panels inside the reactor, is considered to become a critical mineral by 2030. As for lithium, it was reported by the IEA in 2020 that China (9.7%), Australia (54.5%) and Chile (23.4%) are the top three producers of the mineral. Over the next few decades, as demand for the mineral continues to rise, the resulting costs from the supply chains of lithium will be heavily affected, however as supply chains become more sustainable, this could alleviate such impacts.

Finally, similar to other emerging technologies, the need for experts remains important if the field hopes to achieve any commercial scalability. Government policies which support young individuals' interest in the field will yield great results for the field of nuclear fusion in the coming decades.

Use Cases and Political Implications

As the global powers continue in their race to gain technological advantage over others in a wide range of fields, nuclear fusion is potentially a top priority. With more private investment flowing into its development, in addition to more companies experimenting with different technologies, government support in funding as well as sharing scientific findings remains a key driver for nuclear fusion reactors. Historically, countries have fought to be the first in specific major tech advancements, such as the nuclear arms race or the first to land on the moon. Currently the US and China appear in direct competition with one another, yet it is unclear who will come out ahead over the next decade. At its core, nuclear fusion offers limitless supply of energy and that alone is what the majority of individuals are after. If successful and it can provide large quantities of low-carbon energy on a national grid, the global dependency on fossil fuels will only decrease.

The misuse of the technology is seemingly non-existent in terms of the potential harm it could cause. In the past, the technology behind inertial confinement fusion (ICF) has been sought after by militaries, such as the US Department of Defence. ICF technology remains second to the superior magnetic confinement fusion when it comes to nuclear fusion reactors, but they both have little to no use in warfare. However, it has been suggested that ICF could "allow weapon designers to continue to study and to maintain their expertise in the physics of matter compressed to very high densities".

Solar Geoengineering

Lewis Chapman

Solar geoengineering is the process by which we can use technology to reflect sunlight back to space in order to partially offset the energy imbalance caused by the rise in greenhouse gasses. From cloud thinning to space sunshades, the range of proposed techniques all come with unique technical, ethical, and political challenges.

Current development status

The idea of solar geoengineering has been debated for over 50 years, yet most projects have been confined to computer simulations, very little field work research has actually been carried out. There remains much uncertainty over possible side effects, as well as big challenges over governance. However, as the climate crisis becomes more urgent, it is a solution that many think we will have to call upon.

The greatest barrier to geoengineering projects is not technical or economic, but rather political. The governance challenges are severe and fraught with difficulties. The central issue is that we are essentially creating a single thermostat for the earth, yet everyone wants their say over what value we set it at. Countries such as the Maldives and Bangladesh, which are highly vulnerable to climate change, will be inclined to increase the level of geoengineering to limit sea level rises. Whereas countries such as Russia, which aren't as vulnerable and may even stand to gain from climate change due to increasing arable farmland and greater use of the Northern Sea route, may not support geoengineering at all. There are also significant costs involved, around $10 billion according to a Harvard scientist working on a stratospheric aerosol injection project.

There is another important scenario that must be considered: a rogue geoengineering project. This may occur if an individual country decided unilaterally that solar geoengineering is necessary and pursues their own project, without any form of international agreement. As the climate crisis worsens, this scenario becomes more plausible as some countries such as the Maldives and Bangladesh become particularly vulnerable to climate change and are forced into action. This may have grave consequences for diplomacy and international relations and may even result in conflict.

Key developers and beneficiaries

The inherent issue with solar geoengineering research is that there is no testing ground or ability to practice. We only have one Earth so any efforts to manipulate its climate must be cautiously analysed and understood, hence most research has been based on predictive models. These models have indicated that solar geoengineering can be used to decrease average temperatures and dampen extreme temperatures, yet many are worried about unknown side effects. Another reason for slow progress in empirical research is that many are worried that the use of solar geoengineering may lesson efforts to cut emissions. Scientists are clear that solar geoengineering is not a substitute to emissions cuts, but rather a solution that we may have to resort to in fighting climate change, alongside emissions cuts and climate change mitigation.

Slow progress and a lack of political support has meant that solar geoengineering research totalled only $10 million globally between 2008 and 2018. Recently, however, more scientists have been researching solar geoengineering using existing funds for climate change research, but formal funding is still negligible. Calls for further research are growing, major environmental groups such as the Natural Resource Defence Council and the Environmental Defence Fund are supporting research whilst the US has published the Climate Science Special Report which called for further research into solar geoengineering.

The key beneficiaries from solar geoengineering will be those who are most vulnerable to the effects of climate change which is primarily people living in low-lying areas or vulnerable to extreme weather events such as storms or droughts. The benefit of solar geoengineering is what economists call a public good; it is non-excludable, i.e., nobody can be excluded from its benefits, and non-rivalrous, i.e., use by one person does not affect anyone else's ability to benefit from it. Therefore, we will all benefit from it – albeit unequally - but similarly, if there are adverse side effects of solar geoengineering, we will all suffer the costs. The unique aspect of solar geoengineering is that, firstly, this is a global public good, and secondly it is subject to the 'free-driver effect' – since the cost is not prohibitive, a single nation, company, or billionaire could unilaterally press the play button on geoengineering and affect the whole planet.

Supply chain

The most widely discussed method of solar geoengineering is that of spreading aerosols into the lower atmosphere. The supply constraint here is not a matter of sourcing raw materials as the aerosols being discussed are widely abundant and easily obtained, but rather a challenge of transporting the aerosols to the upper stratosphere. According to an analysis published in 2018 by Wake Smith, at Yale University, and Gernot Wagner, at New York University, this would require a large fleet of customised aircraft, designed with four jet engines and huge wings to allow them to sustain flight in the thin air of the stratosphere. They conclude that, although no existing aircraft design – even with extensive modifications – can fulfil this mission, it would be possible to develop new, purpose-built aircrafts with adequate payload capacity. This would be a major challenge however, and hence there may be a time lag between a geoengineering project being agreed/launched and the first aerosols being pumped into the stratosphere.

Use cases and political implications

As discussed, there are various methods of solar geoengineering that could be used. The most discussed method, and most heavily researched, is stratospheric aerosol injection which involves injecting sulphur particles into the stratosphere to reflect a small amount of light back into space. Other potential use cases include marine cloud brightening, a technique that aims to increase the reflectivity of marine clouds.

The greatest challenge of solar geoengineering is its governance. As previously mentioned, there is a plausible scenario of a single country deciding to unilaterally start solar geoengineering, hence altering the entire planet's climate. Ideally, there would be an international framework, likely through the UN, within which negotiations could take place, research discussed, and agreements made for the deployment of solar geoengineering projects. However, the growing strain of nationalism in the world isn't conducive to international treaties and agreements – particularly on such a divisive issue such as solar geoengineering. As time goes on and the climate crisis worsens, a rogue geoengineering project seems all the more likely.

Asteroid Mining

Shyla Robinson

Current Development Status

Recently transitioned from the realm of science fiction to a somewhat conceivable business proposition, the asteroid mining industry is still in its infancy. Nonetheless, research conducted by both the private sector and national space agencies over the past decade can help us envision two potential pathways asteroid mining could take. The first is mining Near-Earth Asteroids (NEAs) for precious metals like gold, silver, cobalt, and platinum group metals for export back to Earth or for use *in situ* which would mean that they are processed and utilised in space. While the latter admittedly sounds more far-fetched, there is good reason to expect that it is more likely to occur before metals are brought to Earth given that such a project would likely fail to yield long-term profit for investors as the increase in the supply of any given precious metal would drive down its market price. Thus, mind-numbing statistics of asteroids like 16 Psyche being worth $700 quintillion are unlikely to be valued as such when one accounts for the inevitable depreciation if even a fraction of the precious metals could be extracted. This scenario, however, assumes that aerospace technology has advanced to a level that would ensure the baseline cost of ferrying large quantities of mined materials back to Earth is low enough to encourage commercial use, an advancement that is yet to be realised and will likely take hefty long-term investments over the next few decades to materialise.

The second pathway asteroid mining could potentially take is that of harvesting water, an especially valuable resource in outer space. Aside from the possibility of using extracted water for human consumption or the construction of space infrastructure, scientists are particularly interested in the prospect of converting water to fuel. Through a process that would likely draw on solar energy or nuclear fission, water could be reduced to its component molecules of hydrogen and oxygen to produce rocket propellant. This would allow for refuelling in space thereby enabling humans to travel significantly further as a substantial amount of fuel is required to break through the Earth's initial gravitational pull after which the fuel is consumed at a relatively lower rate. Thus, when water begins to be extracted from asteroids -- a process less technically challenging than mining precious metals as simply heating the surface could release water vapour -- one can expect to see a significant jump in both scientific space exploration and commercial space industries like tourism.

So, how soon can we expect to see the first commodities mined from asteroids? Not unlike terrestrial mining, mining in space will require identifying potential mining targets, processing, and distribution which in this case would entail significant transportation costs.

As of now, the industry is firmly planted in its preliminary research phase with scientific samples being collected through space missions like NASA's *OSIRIS-REx* which collected a sample off the surface of asteroid Bennu and is due to return in 2023. Additionally, research is also being conducted on how machinery is likely to behave once landed on an asteroid. The first obstacle would be operating in a state of microgravity as the gravitational pull of asteroids is significantly lower than that of the planets or their moons. A second major challenge would be to understand how machinery interacts with regolith, a rocky substance that covers the surface of asteroids and behaves differently from soil on Earth. Of course, these challenges merely scrape the surface of what will need to be overcome before we see the first asteroid mine, however, as will be outlined next, there are many companies and countries that are willing to invest time and money into developing the necessary technology.

Key Developers and Beneficiaries

The initial boost in interest in asteroid mining over the past decade can be largely attributed to two US-based start-ups: Planetary Resources and Deep Space Industries. Both companies had the support of billionaire investors and raised funds in the millions which allowed them to conduct essential research that will form the base of the industry going forward. However, both companies have since been acquired, a development that illustrates the difficulty of maintaining investors' interest in asteroid mining-related projects that are unlikely to yield profits in the short term and demand exceedingly high R&D development budgets. Nonetheless, these companies helped plant the seed and the industry has since seen an increasing number of start-ups proliferate primarily in the USA and Luxembourg. Although the latter may come across as a surprising candidate, it has long been positioning itself to be the European hub for space mining and even launched its own Luxembourg Space Agency in 2018 which aims to focus on the business development related to space industries. Additionally, the state has also started a $225 million fund for space technology start-ups that choose to set up offices in the country.

In terms of national space agencies, NASA and the JAXA, the Japanese space agency, are the major players as of now with both conducting missions to collect samples off the surface of asteroids. Although both countries state that these missions are for scientific research, any insights gathered regarding the structural makeup of asteroids contribute to the efforts of the mining industry as it develops machinery and identifies worthy targets to mine. However, considering how lucrative asteroid mining could become once established in an increasingly resource-depleted world, these are unlikely to remain the only players for much longer and countries like the UAE, China, Russia, and India are already beginning to set their eyes on developing space mining capabilities.

What the government "controls"

Given that outer space is generally classified as 'global commons,' i.e., that its resources lie beyond national jurisdictions and are instead subject to international law, the regulation of asteroid mining is likely to shape up to be a significant global governance challenge. At the time of writing, the Outer Space Treaty of 1967 (OST), continues to be the first and primary guidelines when it comes to matters of outer space. Drafted during the Cold War, the OST's main objective was to emphasise that no nation can claim ownership over any celestial object. The treaty, however, is less specific when it comes to matters of commercial interest. The United States was the first to exploit the loophole in 2015 when President Obama signed the Commercial Space Launch Competitiveness Act that entitles US citizens to any space resource they obtain which means that US-based space companies have the right to use or sell the materials extracted from asteroids. Luxembourg soon followed with similar legislation; however, they extended the right to any company that has an office in the country thus essentially opening an avenue into the industry to anyone in the world if they have the financial means to establish a base in the country. It is expected that Japan and the UAE will soon follow suit and draft similar space property rights laws.

It is worth mentioning that although the OST is the most widely accepted international legislation, there have been more targetted attempts at regulating commercial activities in space. The 1979 Moon Agreement (MA) has more stringent rules regarding the use of space resources and limits commercial exploitation by states till an international regime is established which could keep "rational management" and "equitable sharing" at the forefront of its agenda. Unfortunately, the MA was a 'failed' attempt at regulation in terms of international law with only 18 countries ratifying the agreement and major players like the US, Russia, Japan, and China, rejecting it.

Political Implications & Potential Future (mis)uses

So far, the United States continues to be the most invested amongst the great powers with the recent Artemis Accords cementing its position at the forefront. Introduced in 2020 as a prerequisite for governments wishing to participate in NASA's Artemis Program which aims to return humans to the Moon by 2025, the Accords have been signed by 21 countries as of 2022 and have come to be recognized as an attempt to codify guidelines for space exploration more broadly. Their aim is to "provide for operational implementation of important obligations in the Outer Space Treaty …" and thus seek to reaffirm signatories' commitments to the extant ethical guidelines set out in the OST. Significantly, however, what the Accords are indirectly achieving under the guise of international cooperation is enhancing the US influence by strengthening its contentious interpretation of the OST which allows for commercial activities to become the unspoken norm. Naturally, the Accords have thus met with some pushback, the most significant of which has come from Russia whose official stance is that the US's interpretation of the OST is antithetical to its core aim of non-dominance and condemns the state for trying to develop international space law that unduly favours the US. Another notable absence from the signatories list is China who has likened the Accords to colonialism. Despite both the countries' rejection of the swiftly developing US-led space regime, it is worth underscoring that this stance is a result of them being political adversaries with the US and not their disinterest in asteroid mining or space exploration more generally as is evidenced by Roscosmos and the China National Space Administration collaboration on the International Lunar Research Station project. Thus, we are likely to continue to see tension amongst these superpowers as the quest for asteroid mining continues with significant technological advancement perhaps resulting in a space race like atmosphere if not adequately regulated.

In terms of other major players, we can expect to continue to see Luxembourg and Japan make great contributions to the establishment of an asteroid mining industry with their scientific research and business development efforts. They are likely to be soon joined by powerful actors from the Middle East, like the UAE and Saudi Arabia as they look to diversify their economies and pivot away from fossil fuels that become increasingly scarce. Indeed, this is precisely where the true benefit of asteroid mining comes into play: as the world progresses towards a green economy, the demand for cobalt and platinum group metals that are key components of cleaner technologies like solar panels or electric cars will inevitably rise. By outsourcing these precious metals, we could replace terrestrial mining and avoid the ecosystem destruction, toxic waste production, and community displacement that invariably follows it. Although this comes across as ideal, the key issue here would be that countries that rely on mining, as a key component of their GDP, especially those that are developing nations, will be disproportionately impacted as the price of these metals gets driven down. Thus, unless there are active measures taken for a more equitable distribution of benefits, we are likely to see global inequalities deepen to unprecedented levels. The need for such measures is compounded when one considers that those who are going to be directly benefiting are the wealthiest individuals in developed countries that have the surplus budget to spend on developing highly sophisticated technologies asteroid mining would demand. This will inevitably result in rich countries getting richer, at least in the short run. In the long run, one could argue that once economies of scale kick in and asteroid mining becomes profitable enough to adopt on a large scale, the boost in supply is likely to yield great advances in technology and increase accessibility as prices are driven down. This could potentially manifest into developing countries greatly boosting their human capital and lifting millions out of poverty. This, however, is a highly idealistic scenario which assumes that we have somehow configured a way to limit the supply so as to keep the market price stable while simultaneously developing technologies to drive down the fixed costs enough to yield profits and keep companies in business. Thus, in a future where asteroid mining becomes viable, there will need to be regulations on how much is to be imported as well as strong international legislation that allows for a more equitable distribution of benefits accrued – a complex, but ultimately worthwhile endeavour.

Space-based solar power

Issy Ronald

Development Status and Key Developers

Solar provides an important source of renewable energy, yet the sun is a fickle resource to harness, shining only during the day and when the weather is good, limiting the amount of energy produced. Space based solar power, which involves collecting solar power in space and transferring to Earth, can remedy this, allowing energy to be generated continuously to satisfy our growing demand. It involves launching a satellite equipped with solar panels into space, which wirelessly transmits the energy it generates back to Earth via high-frequency radio waves. The radio waves are picked up by a ground antenna, or rectenna, and then converted into electricity.

Space based solar power has yet to be fully realised. At the moment, both national governments and private industry are involved in its development. The British government commissioned Frazer-Nash, a consultancy, to investigate the viability of the idea. It concluded that the public sector may only need to fully fund the first phase of development, after which the private sector could be expected to begin investing in earnest. NASA in the US also announced in May that they were studying the theoretical and economic viability of space based solar power. In Europe, the European Space Agency is seeking to coordinate European academia and industry towards realising space based solar power.

The Asia-Pacific region has become the centre of the space based solar power, where it gathered the highest share of the revenue market in 2020. China and India, in particular, are important hubs. Beijing has begun constructing the 1-megawatt Bishan space solar energy station in the southwestern of Chongqing, with the aim of becoming operational by 2030 and expanding it to 1 gigawatt by 2049 – the same power capacity as the current largest nuclear power reactor. In Japan, researchers successfully transmitted electric power wirelessly using microwaves in 2015, a major step forward in realising the technology required for space based solar power.

A major obstacle to space based solar power is the environmental impact of space shuttle launches which produce vast emissions and cannot be reused. To combat this, SpaceX has developed Falcon 9, a reusable, two-stage rocket which allows the re-use of the most expensive parts of the rocket, reducing the costs and environmental impact of space access.

Supply chain

Like so many other industries, the development of space based solar power has been hindered by the supply chain crisis in the wake of the Covid-19 pandemic that temporarily halted production and import/export activity worldwide. Setbacks to research and development prompted by laboratory closures and insufficient funding also impacted upon its development.

80% of the global production of solar panels is currently concentrated in China where manufacturing costs are low. Many of the most important elements required to make solar panels, including polysilicon and wafers, are also manufactured in China, whose share of the industry in these materials is set to rise to 95%. A report by the International Energy Agency (IEA) published in July 2022 warned that this geographical concentration within the supply chain could create issues given the expanding trade restrictions which risk a slower deployment of solar panels, increasingly unstable geopolitical environment – particularly in Sino-US relations - and potential of disruptive events such as Covid-19. Given these pressures on the supply chain, the US Department of Energy issued a report concluding that the USA could re-establish a robust domestic solar manufacturing supply chain and become a competitive force within the global solar industry. This could be done by expanding production of thin-film modules, which don't rely on obtaining materials from Chinese companies, as well as redirecting existing polysilicon production towards the solar panel industry.

Uses

Global energy demand is projected to increase by nearly 50% by 2050. As countries around the world have also made commitments to reduce their emissions in response to the climate crisis, space based solar power could be an important alternative to produce renewable, cleaner energy. Solar panels situated in space could produce about 40x more energy than its counterparts on Earth, offering a much more efficient alternative.

By modelling costs on CASSIOPeiA, a prototype developed by International Electric, Frazer-Nash concluded that space based solar power could deliver between £35 MWh and £79 MWh - a relatively affordable renewable energy. In comparison, new onshore wind energy and large-scale solar plants now cost about £40MWh, while new coal-fired plants cost about £64MWh, according to Bloomberg. The falling costs of space launch and advancing technology in robotics and photovoltaics further enhance the financial viability of this project.

One of the major uses of space based solar power is its potential to deliver energy to any part of the world without the need for supply lines. A $100 million US military project, Arachne, is planned for launch in 2025 to deliver space based solar power to remote military bases with the hope of removing fuel supply lines which are vulnerable to attack. A US government report in 2007 pointed out that space based solar power "could also enable entirely new force structures and capabilities such as ultra-long-endurance airborne or terrestrial surveillance or combat systems to include the individual soldier himself." Such projects, therefore, could have a major strategic effect, altering the norms of engagement during interstate wars.

Moreover, beaming energy to other parts of the world may facilitate further international collaboration, including coordinating humanitarian responses as it could provide rapid and sustainable energy to areas affected by national disasters. Space based solar power also could create a new source of resource conflict. The materials required to build it polysilicon, ingots, wafers, cells and modules are predominantly produced in China at the moment, while there could be potential sources of tension once the satellites are in orbit.

Currently, the Outer Space Treaty of 1967 governs the use of space, limiting the number of available slots to place satellites, some of which are more valuable as they are situated above heavily populated areas. If space-based solar power becomes a genuinely viable source of energy, it is possible that interstate competition over these slots could increase, pressurising the existing treaties.

Green Hydrogen

Frank Stengs

Green hydrogen is emerging as one of the solutions to reduce global CO2 emissions. The element is derived through electricity from renewable sources and has the ability to store energy. Hence, it can be used as a fuel, especially for industries that are hard to electrify. If the global trend of decarbonisation picks up steam, green hydrogen is set to gain more prominence.

Current development status

According to Iberdrola, "green hydrogen technology is based on the generation of hydrogen — a universal, light and highly reactive fuel — through a chemical process known as electrolysis. This method uses an electrical current to separate the hydrogen from the oxygen in the water. If this electricity is obtained from renewable sources we will, therefore, produce energy without emitting carbon dioxide into the atmosphere".
Green hydrogen differs from other forms of hydrogen in the way it is produced. If the electricity used to produce hydrogen emits carbon dioxide, the hydrogen will be denominated grey. If the electricity used to produce hydrogen emits carbon dioxide, but the emissions are captured, the hydrogen will be denominated blue. These two methods are currently the most common ways to produce hydrogen.

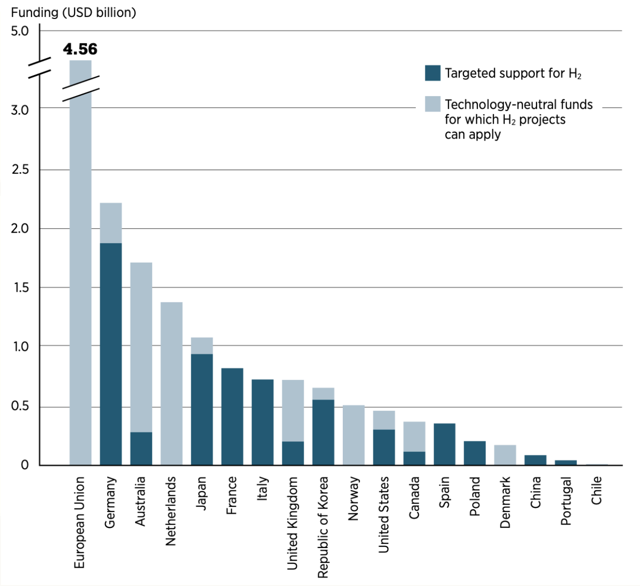
While hydrogen production seems like a straightforward process, yet there are several implications that limit its potential. Firstly, the production of hydrogen is not energy efficient. Secondly, it requires purified water, which is costly to produce. Thirdly, it is difficult to transport. Hence, harnessing the potential of green hydrogen will require innovations in energy efficiency, the usage of water, and modes of transport.
Developments point toward a positive outlook for the availability of water. Currently, hydrogen is produced from highly purified water, which is a precious resource that is costly to produce. The reason why it cannot be produced from salt water is because it limits the lifespan of the electrolyzer, due to corrosion. Researchers from Stanford University have found that coating the anode with a particular substance limits corrosion and increases the lifetime of the electrolyzer, making salt water hydrogen production a more feasible option. At Wageningen University, researchers are looking at the possibilities for offshore hydrogen production, which in theory could be more viable than offshore electricity production. Hence, water is becoming more available and cheaper for hydrogen production.
Efficient electrolyzers might also turn things around for mass-scale (green) hydrogen production. Current electrolyzers claim around 75% efficiency. This efficiency makes

mass-scale production of hydrogen particularly unattractive. This year, however, Australian company Hysata announced an electrolyzer with a record-breaking 95% efficiency. It would take the electricity from the inefficient production of hydrogen and make better use of it. As a consequence, (green) hydrogen production might become cheaper and available to produce mass-scale.

Key developers and beneficiaries

Global demand for hydrogen was around 90 Mt in 2020. Around 80% of hydrogen was produced from fossil fuels, with the remainder coming from residual gases in refineries and the petrochemical industry. The global green hydrogen market size is relatively small and was worth $1 billion in 2021. In comparison, the total hydrogen market was valued at $150.20 billion in 2021 and the total renewable fuel market accounted for $887.19 billion in 2021.

Over the next decade, USD 65 billion will be available for clean hydrogen funding, with Germany, Japan, and France leading the way (Figure 1). The total investment amounts to USD 160 billion, of which half is being planned for green hydrogen production.



Demand for hydrogen is set to grow, but is difficult to project. Projection models vary widely due to different assumptions in global energy demand, goals for reducing global temperature rise, development in the regulatory framework, use-case intensity in different sectors, among others. Most reports, however, project a limited but steady growth till 2030. This largely depends on hydrogen projects which are still under construction and the building of infrastructure, which will take many years to establish.

Figure 1. Average annual funding potentially available for hydrogen projects, 2021-2030

Use cases and political implications

Green hydrogen is emerging as one of the solutions to reduce global CO_2 emissions. Particularly, because it carries several advantages to other proposed solutions. Unlike electricity from renewable energy, its availability is not subject to patterns such as weather or day and night. Moreover, the resources to produce hydrogen are readily available. In comparison, to batteries which need e.g. lithium and/or cobalt, hydrogen can be produced wherever there is water and electricity. EV battery costs are expected to increase 22% and remain so till 2026, due to shortages in raw materials.

For industries such as aviation, shipping, long-distance trucking, fertiliser production, and concrete and steel manufacturing, hydrogen may be of particular importance. These industries require high density fuels or intense heat, which makes them difficult and expensive to electrify. In this case, hydrogen may be one of the options to substitute traditional fossil fuels that deliver those needs. Hydrogen combustion can achieve the full range of heat intensity needed for industrial processes, up to 2000°C. It makes hydrogen, among others, a more economical alternative than direct electrification.
Nevertheless, there is potential in other industries as well. Hydrogen can be used in fuel cells, which in turn can power anything that uses electricity. Unlike batteries, fuel cells do not need to be recharged and do not run down. Moreover, they can operate off the grid, are quickly refuelled and energy efficient. This makes hydrogen (fuel cells) particularly interesting for the military field and an alternative for electric vehicles.

Hydrogen along with other renewables have the power to reshape global energy relations. As a consequence, importance will shift from traditional fossil fuel exporting countries to countries with an abundance of green energy potential. That is, if the global trends are heading toward decarbonization. Moreover, hydrogen markets are likely to be regionalised. Due to transportation costs, use of pipelines will be more likely. A smaller segment of the market will be traded globally in other forms e.g. liquified, ammonia, or methanol.

Moreover, current events, which might increase or decrease demand and/or lower production costs, were not taken into account by projections models and growth reports. The war in Ukraine has created an energy crisis which made hydrogen an even more attractive alternative to natural gas and other fossil fuels. The conflict will increase demand and drive the global trade of hydrogen. Already power purchase agreements for renewable energy were up fivefold in Europe in 2022. Nevertheless, heightened energy prices threaten to weaken the economics of hydrogen in Europe, which will likely result in less investment and damage the

European hydrogen market. Countries with comparatively stable energy prices and lower production costs might profit as a consequence.

Military

Lethal Autonomous Weapons

Paloma Lier

A system is understood as "autonomous" when it has the ability to perform an intended task without human intervention using interaction of its sensors and computer programming with the environment. Whilst the number and importance of autonomous weapons have increased in recent years thanks to progress in AI and machine learning, their use and implementation in combat remains experimental and continues to pose problems of predictability.

Current development status

Autonomy is used to complete some of the weapons' different capabilities, such as mobility, targeting, intelligence, interoperability and health management. Lethal autonomous weapons (LAWs) also come as "decision aid" by gathering and providing sensitive data for human operators, notably when a target is too far or too fast for the operator to identify. SIPRI found that autonomy is used in at least 56 military systems to collect and process various types of information that might not be directly related to targeting but that might be of critical relevance from a command-and-control perspective. Apart from 'loitering' weapons, lethal autonomous systems are used mostly in a defensive capacity, to protect ships, ground installations or vehicles against incoming projectiles. Autonomous weapons without "humans in the loop" represent approximately a third of the existent lethal autonomous systems.

A few countries have demonstrated the existence or use of lethal autonomous systems in their weaponry. In 2021, the US army presented prototypes of robotic combat dogs that could be built with rifles attached. The Australian robotics maker GaardTech working for the Australian army announced the forthcoming presentation of the Jaeger-C, a bulletproof autonomous four-wheeled combat unit for use in suicide attacks. A CNA report prepared in 2021 for the Pentagon's Artificial Intelligence Center also presents how the Russian military is starting to implement Artificial Intelligence (AI) into its weapons, notably anthropomorphic robots capable of carrying multiple weapons and, possibly, of driving vehicles. According to the Russian minister Sergei Shoigu, the country has started the manufacturing of "killer robots" capable of fighting autonomously.

Key developers and beneficiaries

The USA has demonstrated the most advanced technology in lethal autonomous weapons to this day. With historic interest in AI technologies and on-the-ground robotic experience with unmanned aircraft systems and ground robots in Afghanistan and Iraq, the US remains the leader in autonomous systems. In 2015, the USA elevated the issue of autonomy to the highest strategic level with the publication of its new 'Defense Innovation Initiative', also referred to as the 'Third Offset Strategy'.

Numerous countries have shown lesser interest and deployed funding for the development of autonomous systems, notably the largest global arms producers such as the United Kingdom, Russia, France, Italy, Japan, Israel, South Korea, Germany, India and Sweden. Whilst information on the Chinese military is more limited, it is believed to be amongst the leading countries in the research and production of autonomous weapons, although remaining behind the leading United States.

European states and the EU have recognised the importance of autonomous weapons as a key strategic field but are believed to be less inclined than the US to pursue and dedicate large resources. Nonetheless, the EU has established the achievement of independence for AI and military production and supply chains as a strategic resilience objective.

A report established by Edsel Ing to predict the countries with the highest risk to use lethal autonomous weapons in the future identified Israel, USA, Saudi Arabia, Somalia, Russia, France, South Korea, the United Kingdom, Niger, Iraq, Jordan, Singapore, Italy, China, North Korea and Turkey are the States most inclined to exploit autonomous weapons.

The civilian sector is also a primary actor for lethal systems, with crucial research being conducted. The leading firms represented are information technology companies – Google, Amazon, and Baidu – as well the automotive and aerospace sectors. Armament companies are also important but the scale of resources they can deploy for autonomous systems is more limited than civilian infrastructures. Key players operating in the global autonomous weapons market include BAE Systems plc, Israel Aerospace Industries Ltd., Kongsberg Gruppen ASA, Lockheed Martin Corporation, MBDA, Northrop Grumman Corporation, Rafael Advanced Defense Systems Ltd., Raytheon Technologies Corporation, Rheinmetall AG, and Thales Group.

Supply Chain

As lethal autonomous weapons are still under-developed, an important part of the supply chain remains at the step of the research and development. Currently, progress in autonomous weapons often results from developments in both civilian and military industries – with the dual use of ECT and electronics as a paragon example.

The academic research is dominated by US universities most notably Carnegie Mellon University, Stanford University, MIT and the University of California, Berkeley. Outside of the USA, universities that are the most productive on these topics are based in Western Europe, South Korea and China.

In terms of materials, they do not require costly or hard-to-obtain raw materials, making them extremely cheap to mass-produce. Lethal autonomous weapons are also safe to transport and hard to detect. However, they require certain components, such as printed circuit boards, micro-chips and specific chemicals used for munitions which are mostly produced in Asia. Today, 90% of worldwide printed circuit board production is in Asia, over half of which occurring in China, whilst the US circuit board-market is aging and failing to keep up with its Asian counterpart. China is also the sole supplier for a number of specialty chemicals used in munitions and missiles. Beijing has previously said it wants to produce 70% of locally used chips by 2025. China's semiconductor-makers have been seeking out second-hand photolithography equipment to do this, buying up as much as 90% of available stock, according to a report in Nikkei Asia.

Other materials such as carbon fibre are mostly produced in Japan and Europe, creating dependencies for the defence manufacturing of other numerous countries, as few alternatives currently exist.

Use Cases and Political Implications

The first reported use of lethal autonomous weapons took place in Libya in March 2020. According to a UN report, Turkish autonomous drones tracked down a convoy from the opposing forces of General Haftar. The experts' report claims Haftar's forces "were hunted down and remotely engaged" by a Turkish Kargu-2 drone. Although it has not been explicitly stated that the drone killed the target, the Kargu-drone has the capacity to engage targets with or without human overlook. In 2021, a drone swarm, flying autonomously with artificial intelligence, was used by Israel in attacks on the Gaza strip.

Numerous political and military implications of lethal autonomous weapons have been identified. Advocates of the positive impact of LAWs argue that autonomous weapons will save soldiers' lives whilst avoid killing mistakes due to human miscalculations. However, the precision and rapidity brought by lethal autonomous systems also has implications for the barriers to war. Indeed, by reducing human cost, they may also reduce barriers to conflict, whilst their easy proliferation may increase the number of actors in conflicts. Lethal autonomous weapons risk to increase the scales of conflicts, as they are extremely scalable – meaning the level of damage you can deliver using autonomous weapons depends solely on the quantity of robots in your arsenal, which may also be increased by the AI arms race currently unfolding.

An important risk of lethal autonomous weapons is also their misuse – either by the wrong actors, such as terrorists or warlords, for unethical purposes like selective targeting of groups, or as a misconception of machines.

Finally, LAWs pose problems of accountability, at the individual, state and ethical level. According to Humans Rights Watch, "their use would raise a substantial accountability gap when it comes to removing human control from the use of force, finding that programmers, manufacturers and military personnel could all escape liability for unlawful deaths and injuries caused by fully autonomous weapons". At the state level, the potential lack of traceability of LAWs threatens concepts of deterrence and may lead to rapid escalations of violence. Morally, autonomous systems taking a human life undermine basic principles of human dignity and rights to life. As United Nations Secretary-General António Guterres has stated, "The prospect of machines with the discretion and power to take human life is morally repugnant".

Directed Energy Weapons

Shyla Robinson

Current Development Status

Long been a muse for science fiction authors and weapons developers alike, directed energy weapons (DEWs) have finally entered real-world military operations. There have been numerous attempts by nations to develop DEWs for their arsenal, notable examples of which include the British Air Ministry offering £1,000 in 1934 to anyone who could use 'rays' to kill a sheep at a 180 metres distance and the infamous Strategic Defense Initiative founded by President Reagan in 1983 which lasted a decade, cost $200 billion, and failed to yield any meaningful progress. DEWs are weapons systems built on electromagnetic or particle technology which allow for a directed beam of energy to be projected onto a target to yield fatal or nonfatal damage, as opposed to achieving the same impact through a physical projectile. Being a catch-all term for a range of highly sophisticated weapons, it is imperative to first outline the three main varieties of DEWs before delving into the potential risks and benefits posed by the technology.

Beginning with the most common variety, laser weapons are known for their speed and precision and work by emitting a beam of infrared light that heats a target till it combusts. They can be further classified into two main categories: chemical and solid-state lasers. The former runs off energy produced from reactions between two or more substances which it then transfers to the substance emitting the laser beam, while the latter is powered by an electric current which stimulates the production of a laser beam from a crystal. Although there were notable advances made in chemical-based laser technology, due to its use of highly corrosive chemicals like hydrogen peroxide and potassium hydroxide for the reaction and iodine for the laser beam production, the industry has since switched to favouring solid-state lasers that are less hazardous and bulky. On the battlefield, laser weapons can cut through materials like steel and aluminium in a matter of seconds and their level of lethality is adjustable thus allowing the flexibility to either degrade or destroy. Their performance is also determined by the distance of a target, the purity and concentration of the light, the ability to continuously focus a laser on the target, and crucially, the atmospheric environment as lasers cannot perform if obstructed by clouds or rain. Nonetheless, laser weapons' advantages are undeniable when one considers their deep magazines and low cost per shot which means they can be fired continuously as long as electricity is available.

The second major variety of DEWs are high-power microwave (HPM) weapons which emit beams of electromagnetic energy in a 10 megahertz to 100 gigahertz frequency range to penetrate electronic systems. These microwave emissions can enter a target's system via its antenna or sensor opening or more discreetly through cracks or trailing wires in the machinery. Thus, primarily used to degrade electric systems such weapons can be used against threats from uncrewed aerial systems like drones or to disrupt cellular devices at command posts. Their main advantage over laser weapons is that they can efficiently propagate regardless of weather conditions and due to their inherently dispersed nature can also be used to target multiple targets at once. HPMs can also be used as an 'anti-personnel area denial weapon' if adjusted to non-lethal levels at which they can produce a temporary burning sensation on the skin – the ethics of this, however, are murky and in all likelihood will be banned by international humanitarian law in the decades to come given what we already know of the adverse impacts of radiation on the human body. The final variety of

DEWs are particle beam weapons (PBWs) which project a beam of charged or uncharged atomic particles towards their targets at exceedingly high speeds. The kinetic energy that is released by the particles in this process produces 'super-heating' on impact resulting in the explosion of a target. Evidently lethal, it will still be a few decades till we see these weapons in mainstream military operations as the technology is still in its nascent stage with developers currently refining the design of such weapons with a specific key challenge being reducing the size of particle accelerators. Nonetheless, one interesting potential application of PBWs to keep an eye out for will be the ability of neutral particle beam systems to be used beyond the atmosphere thus opening the realm of space warfare through attacks on critical space-based infrastructure like satellites.

Key Developers and Beneficiaries

As is usually the case with emerging technologies, those most likely to benefit from the DEWs are countries with large enough military budgets to afford the development of such sophisticated weapons. Unsurprisingly, with the world's largest military budget the United States is leading the way for the DEW industry with many key developers like Lockheed Martin, Raytheon Technologies, BAE Systems, Northrop Grumman Corporation, and The Boeing Company all based in the country. Indeed, between fiscal years 2017 and 2019 the US military doubled its budget for DEWs from $535 million to $1.1 billion and even the "most conservative market projects" estimate that this spending will increase to nearly $30 billion in the next ten years. Thus, it comes as little surprise that the "breakthrough" for solid-state lasers came through on an American Navy vessel called the *USS Ponce* in 2014 with the weapon destroying the motors of nearby drones and boats. There have been rapid developments since, a notable example of which is the High Energy Laser with Integrated Optical-dazzler and Surveillance (HELIOS) weapon that the US Navy and Lockheed Martin have jointly developed that can burn down small boats and shoot down drones. Interestingly, the US Air Force has also started prepping for the age of DEWs with pilots receiving trainings which include deploying virtual laser weapons. However, given that these weapons systems are still not lightweight enough to be mounted on fighter jets, it will still be a few years till we see lasers in the sky.

In terms of other key players, Russia is an interesting case with the country reported to have been arming its military with vehicle-mounted combat laser systems since 2017. However, fast forward to the current war in Ukraine and we find that despite the Russian deputy prime minister Yury Borisov claiming that laser weapons are being deployed in Ukraine and that it has destroyed Ukrainian drones at the distance of 5km in five seconds, there has been no evidence found that validates this claim as the US Department of Defence reports.

Nonetheless, it would be naïve to think the Russians haven't been investing in developing the technology with firms like Almaz Antey and Rosatom leading the way. In particular, the Russian Sokol-Echelon laser-based Anti-Satellite Weapon Project is a key initiative to keep an eye on going forward for its implications for targeting critical assets in space. Another key player making great strides in DEW development is Israel with its development of a ground-based laser air defence system called the Iron Beam which has been designed to complement their extant short-range missile interception system, the Iron Dome. The difference between the two is that the new system would focus laser beams on the projectile till it combusts while the current system fires small, guided missiles to intercept projectiles. Given that the laser system would bring down the cost per shot to approximately $3.50 as opposed to the "tens of thousands of dollars apiece" for each Iron Dome interception, the initial investment is well worth the price and recognizing this the Israeli Defense Ministry has granted $100 million contract to the state-owned firm Rafael Advanced Defense Systems.

Not one to take a back seat when it comes to weapons technologies, China has also been reported to have been rapidly developing its DEW systems with its WB-1 active-denial system which can induce heating effects on skin and the 'Silent Hunter laser' which can reportedly cut through vehicle armour a kilometre away. Indeed, there is good reason to believe that the laser systems have already been integrated into the PLAN's fleets with the US Pacific fleet issuing a statement that they had detected a laser beam being used against them in the Philippine Sea in 2020. The Chinese Defence Ministry denies these allegations and dismissed the report, but this event nonetheless helps foreshadow what's to come. Another interesting case is that of Turkey who allegedly used laser weapons while fighting on the side of the Libyan government to shoot down a drone that was supplied by the UAE to the Libyan National Army – if true this would be the first time a combat laser destroyed another combat vehicle in field, however, this claim has been met with scepticism due to a lack of details and international coverage. Other countries making significant advancements in DEW development include France, Germany, the UK, Japan, and India.

What the government "controls"

Despite the rapid development of directed energy weapons technology, international regulatory bodies have been slow to catch up with the industry's progress. In terms of the supply chain, there has been no regulation at the international level and since DEW-related research and development is usually closely linked with national security programs, one can deduce that there is likely not enough regulation at the national level either as each country tries to push the bounds of the technology to attain a strategic advantage.

At present, the only piece of legislation pertaining to the use of DEWs is the Protocol on Blinding Laser Weapons (1995) which prohibits the use of such laser weapons against personnel as even the low-energy versions of such weapons can result in permanent blindness. This measure, however, does not account for blindness that results from collateral damage which despite all of their precision laser weapons are not immune to causing since their energy beams only stop once they come in contact with an object that either reflects or absorbs them and so there will always be the risk of civilians unknowingly crossing their path. Additionally, whether manually operated or supported through AI, laser weapons will need to be programmed to ensure that once the target infrastructure has been satisfactorily contended with, the beam is immediately turned off before it injures anyone or damages civilian infrastructure. It is worth noting that lower power lasers called dazzlers which serve to temporarily blind or disorient their target are legal and are used by both military and law enforcement. Between the lack of accounting for potential collateral damage and the permitted use of dazzlers, the 1995 Protocol will likely need to be updated soon before unscrupulous actors begin to take advantage of the grey areas as such lower-power technologies become more accessible to predatory governments and non-state actors.

For microwave-based technology more specifically, we are yet to see to what extent such weapons systems' implementation will be limited by the Additional Protocol I to the Geneva Conventions which prohibits the use of indiscriminate weapons that cannot be directed at specific military targets and thus might impact civilian objects without distinction. Finally, given that DEWs will be used in outer space to attack space assets such as satellites in the near future, it will be interesting to see to what extent the rules outlined in the 1967 Outer Space Treaty regarding the prohibition of military activities on celestial bodies applies to such operations and who will step up to ensure compliance.

Political Implications

The introduction of DEWs into modern warfare is bound to make combat more efficient – whether that's a good thing, however, is debatable. To begin with, one positive aspect of deploying laser weapons will be the reduction of collateral damage due to precision. However, when one considers that the cost per shot of using laser weapons is negligible and magazine essentially unlimited, there is the risk of actors using these weapons without as much care as they use kinetic weapons which could inadvertently increase the damage in the areas adjoining battlefields. In terms of HPVs, there will likely be an increased risk of radiation sickness for civilians living in the areas where these will be deployed. Additionally, if one expands their definition of collateral damage, radiation from HPVs will also negatively impact the biodiversity of a region and if chemical lasers see a resurgence, the use of highly corrosive toxic chemicals will also have adverse environmental effects. If these potential outcomes are acknowledged and real efforts are made to resist their occurrence, DEWs could potentially yield a net benefit as they would reduce the cost of conducting warfare which in the long run could result in a decrease in military spending and transfer of those funds into more productive industries – an admittedly idealistic scenario, but worth considering.

In terms of strategic advantage, we will likely see a reversal of the trend we have seen in recent decades wherein non-state actors or less militarily advanced states can put up a fight against more technologically advanced nations. This is because the former's strengths usually are in the number of low-cost attacks they can make, but with the advent of HPV systems, these will be easily intercepted at a minimal cost. A prime example of such a scenario would be in the Israeli-Palestinian conflict where if the Iron Beam is successful the power dynamics will likely tip even more so to the Israeli's favour. Thus, technologically advanced nations will gain leverage in the face of 'asymmetric threats.' This absolute power, however, is likely to be short-lived because unlike some other highly sophisticated technologies, low-power laser weapons could potentially be very easily proliferated as the technology gets better at developing smaller, sleeker models.

Anti-Satellite Weapons

Taha Tariq

Current development status

Anti-Satellite Weapons (henceforth ASAT) were never far behind the invention of satellites. The Soviet Union (USSR) launched the first satellite, Sputnik, in 1957, while also conducting the first successful ASAT test in 1970. The United States (US) launched its first satellite, Explorer, in 1958, and conducted a successful ASAT test as late as 1985. Despite this, after the Apollo moon landings in 1969, the US had already demonstrated technological superiority over the Soviet Union, and with its dissolution in 1991, the US had achieved hegemony in space. The Cold War had created the impetus behind the militarization of Space. The US and the USSR banked on their ballistic missiles that had provided them with the deterrent capability necessary to avert nuclear attacks. These missiles needed satellite guidance to stay on their trajectory and hit their targets. They also provided surveillance footage for reconnaissance.

Key developers and beneficiaries

With the dousing of the Cold War, ASAT development almost came to a halt. However, it has picked up in the last two decades, as Russia's conventional capabilities rebounded and as China became an economic mammoth with the ability to convert its wealth into weaponry. Consequently, the US conducted an ASAT test in 2006 from a navy ship, China destroyed a satellite using a mobile-launched missile in 2007, Russia conducted an ASAT test in 2015, and India joined this ASAT club in 2019. All ASAT tests conducted have been kinetic. They have physically destroyed satellites using missiles launched from the Earth. There have been no cases of 'satellite-launched' projectiles against other satellites, nor any development of such weapons for now. This section will mainly focus on the debris-producing kinetic ASATs fully deployed by the above-mentioned four nations. However, non-kinetic weapons are also being developed. These include High-altitude Electro-Magnetic Pulse (HEMP) weapons, that can permanently disable the internal electronic systems of a satellite or temporarily jam them, without any kinetic damage.

Supply chain (including what government "controls")

American ASAT capabilities can be seen as a remnant of the Cold War. The US has less incentives compared with other states to develop them. Most commercial satellites are American, and the US military relies heavily on its space infrastructure to run its military communications systems. Satellites provide a wide-range of tactical support, from Imaging Intelligence (IMINT) and Signals Intelligence (SIGINT) for operations such as drone strikes, to missile launch and nuclear explosion detection systems to catch and neutralise threats. The Global Positioning System (GPS), which is provided by the US, will also be at risk of destruction by ASATs. The US has 237 satellites with direct military utility. As such, just the military satellites of the US are greater than Russia's total number of satellites (172), though less than that of China (541). Russia and China have also employed military satellites with the same functions as the US. Additionally, Russia uses GLONASS, and China uses BeiDou, to avert dependency on the American-controlled GPS. This concern regarding dependency has led to the European Union also setting up the Galileo satellite constellation.

Russian and Chinese ASAT capabilities seem to grow in line with their overall military capabilities, which are aimed at reducing the strategic power disparity between themselves and the US. Russia and China can be seen as having more offensive utility for ASATs since they have less relative dependency on satellites. In a conventional war between them and the US, Washington has more to lose from ASATs. On the other hand, the sheer quantity of American satellites makes it harder for them to be completely targeted, or their debris to not inadvertently damage the satellites of other nations. Meanwhile, India's ASAT seems to be more defensive - its weapons project is aimed at neutralising Beijing's counterspace advantage in a potential conflict with New Delhi - rather than a revisionist programme aimed at displacing the American hegemony in space.

Use cases and political implications

Economic collapse

Use of ASATs against the satellite of major states would have global economic implications since all states depend upon outer space infrastructure. Even if a handful of satellites with only military utilities are destroyed, the ensuing wreckage circulating at high speeds (up to an estimated 25,000 km/h) in the orbit will collide with other satellites, which in turn will break apart and collide with others, thus creating a cascade effect. Apart from the 5,500 active satellites, there are some 3000 defunct satellites as well, bringing the total number of satellites orbiting the Earth to more than 8,500. Additionally, SpaceX's plan to put some 30,000 Starlink satellites will also massively contribute to the clutter susceptible to a cascade effect, causing massive economic disruption as communication and navigation networks come down, and global supply chains come to a halt. Without the time synchronisation provided by satellite networks, financial transactions will freeze, power grids will malfunction leading to mass blackouts, and a global economic collapse could ensue. The US by far will be the most affected state with 3433 satellites, followed by China with 541, the United Kingdom with 486, Russia with 172, Japan with 88, and India with 59. Other states disproportionately affected will be Canada, Germany, Luxembourg, Argentina, France, Spain and Italy, each with satellites between 60 and 20. With nearly 3,500 satellites, SpaceX will also be the single biggest private-actor to lose if a cascade effect were to begin today. Called the Kessler Syndrome, the prospect of satellites breaking down and colliding with each other may lead to the unusability of either huge parts of the orbit, or all of it. The ensuing and rapidly multiplying clutter would then block any attempts to put satellites into orbit, or escape to outer space, as transport rockets and vehicles get hit by the huge density of satellite wreckage circulating at high speeds across the orbit. This will abort plans for space tourism by companies such as Virgin Galactic, but more importantly, be it Roscosmos or NASA, all stakeholders and every future mission to escape Earth will be trapped in a field of debris.

Star Wars (But on Earth)

There is a possibility of misinterpreting collision and satellite destruction from the wreckage of even just one ASAT test as a preliminary attack on the defensive satellite infrastructure of the state whose satellite has been damaged. This can lead to mistaken retaliation on the satellite infrastructure of an unfriendly nation who is the suspected aggressor. Attacks on satellite infrastructure, especially kinetic, arguably open the door to legitimate armed retaliation. This can then spiral into a conventional war. Wreckage from ASAT tests accidently colliding with other satellites can also be mistaken for a preliminary attack on the affected state, in order to blind-sight defences, before a terrestrial offence begins. As such, even if there is no clear *casus belli*, in a belligerent geopolitical environment, as the one currently, the presence of ASATs can result in naturally-occuring collisions being mistakenly interpreted as the beginning theatre of a war, necessitating anticipatory self-defence i.e preemptive military operations on Earth.

Future prospects

The possession of ASATs does not create a novel situation. It is only an extension of the military capabilities of states, and only extends the range of aggressive military possibilities in space. It affords political power by extension of a state's military power - a leverage that will have to be taken into account when any future multilateral treaty to stall any race for space weapons is being negotiated. As in all treaties that attempt to limit an arms race, it is the states that possess the most amount of weapons or the most powerful or accurate of those weapons, that have the greatest bargaining power.

The 2022 US moratorium on kinetic ASAT tests can be seen as a testament of Washington's confidence in its counterspace capabilities. With the upper-hand, Washington has two paths to choose from. The first is to continue its ASAT development (especially non-kinetic), hoping that other states are unable to outpace its counterspace weaponry with the massive technological lead it has. The second is to negotiate a binding multilateral treaty with other ASAT powers, and eschew both the development and testing of all types of ASATs, similar to the Outer Space Treaty of 1967, which banned the placement of nuclear weapons outside of the Earth. Like any agreement between states in an anarchical system without an overarching authority, the risk of covert defection would be possible. In such a scenario, while one state complies with its treaty obligations, the other cheats. Indeed, to overcome such a dilemma, the rival parties would need to establish a level of trust, whose deficit is only increasing in a multipolar world, in the wake of Russia's invasion of Ukraine. For this reason, it is likely that the first path will be followed. The other reason is the concomitant development of missile systems, which form the bedrock of current kinetic ASAT technology. At the same time, experimentation with novel weapons systems is likely to continue. This is evident in the American moratorium: only Direct-Asecent Anti-Satellite Weapons (DA-ASATs) that produce debris, such as anti-satellite missiles, have been banned. The US is free to continue experimenting with weapons such as directed lasers or HEMPs that do not produce debris. In any case, weapons such as missiles and lasers need only be modified to become ASATs. On a technical level then, a holistic ban on the development of counterspace capabilities, cannot be undertaken without a wide-ranging ban on the development of other conventional capabilities that hold the potential of conversion into ASATs with minimal technological modification.

The threat posed by the politically destabilising and economically disastrous effects of ASAT use and development will remain constant for the coming years. What would be required to avert worst-case scenarios associated with their use, is the same sort of restraint states have hitherto shown in the use of weapons of mass destruction against each other in conventional warfare since the end of the second world war. This is a restraint that is increasingly being tested in a more polarised and multipolar geopolitical era.

Hypersonic weapons

Taha Tariq

Old Concepts, New Features:

Definitionally, hypersonic is a designation for speed. Commercial aircraft today are subsonic, i.e, less than Mach 1, below the speed of sound: calculated as 330 mps. Military fighter jets are supersonic, at Mach 2 or 3, while hypersonic vehicles travel more than five times the speed of sound (Mach 5), at more than 3800 mps. Weapons that end up partially traveling at hypersonic speeds have been present since the Cold War. Intercontinental ballistic missiles (ICBMs) also reach hypersonic speeds during some part of their flight. However, the race today for hypersonic weapons consists of three key features that have made states increasingly place a premium on their development. Firstly, hypersonic weapons are being developed for sustained hypersonic flight. From launch to strike, these weapons will travel at a hypersonic speed making them difficult to detect, and by extension intercept, at any point during their trajectory. Secondly, these weapons will be highly maneuverable, being controlled. This makes their flight path erratic and unpredictable, being subject to continuous change. Even if detected then, it would be difficult to predict their trajectory and intercept them, perhaps even with another hypersonic weapon. Lastly, the latest hypersonic weapons are being built with the aim of carrying nuclear weapons. This damages the deterrence credibility of states that have not acquired them, while making those that possess them theoretically trigger-happy. All three features are present in two weapons under the purview of this report: Hypersonic Cruise Missiles (HCMs), and Hypersonic Glide Vehicles (HGVs). They are at the forefront of emerging disruptive technologies with direct military applications.

Skyrocketing Development:

HGVs are composed of a ballistic missile with a glide-vehicle that separates and re-enters the atmosphere at hypersonic speeds after launch. The HGV then travels to its target, meandering its path through the use of thrusters or fins, the concept being akin to that of a glider. The trajectory is controlled while the HGV flies and strikes at hypersonic speeds. Russia deployed its HGV system, the Avanguard, as early as 2019, capable of launching multiple nuclear weapons, while China unveiled its own HGV, the DongFeng-17, the very same year. Five months later, the US conducted a successful HGV test off the coast of Hawaii in 2020.

HCMs on the other hand demands more technological prowess. At speeds around and above Mach 5, air molecules break apart. Combustion engines can not function if they are unable to utilize the air around them and in them at such speeds. HCMs have to be powered by a Supersonic Combustion Ramjet Engine (Scramjet), instead of the average rocket engine, in order to overcome the above mentioned physical challenge. The US successfully tested a Scramjet system called the Hypersonic Air-breathing Weapons Concept (HAWC) in 2021, it was reported that China had carried out a successful scramjet test in 2020, while Russia had successfully tested its Scramjet-powered missile, the Zircon, as early as 2017.

While successful tests do not automatically lead to production and deployment, they show the rapidly escalating development of hypersonic weapons by these states, with each successful test improving the operational capability of the weapons system, until parity in technology is reached upon new scientific barriers, leading to this slow process to begin again until the current phase of escalated development of weapons systems is seen again.

The Pentagon has requested $4.7 billion to spend on hypersonic research in 2023, a jump from the $3.8 billion requested 2022. Between 2015 and 2020, US research funding for hypersonics increased by a staggering 740%. Pentagon's research contracts have been awarded to both established and nascent companies. Military technology giants, Raytheon, Lockheed Martin, Boeing, and Northrop Grumman are at the forefront of developing Washington's hypersonic capability, while startups, geared specifically towards hypersonic technology, such as Hermeus have also raised funds in the hopes of making technological breakthroughs. The American model of using the private sector for military development is different from that of Russia and China. Moscow has used competing state-controlled design bureaus such as the Soviet-era NPO Mashinostroyeniya to select and fund the most promising hypersonic development plans, whereas Beijing is using the state-owned China Aerospace Science and Technology Corporation (CASC), and its various production labs, to develop its hypersonic weapons.

Proliferation Concerns:

Hypersonic weapons are concurrently being studied by other states such as India, Israel, North Korea, South Korea, Japan, Germany, Iran, France, and Brazil. Some of these states have conducted successful tests as well, albeit not at the scale of the three major powers. India tested a scramjet engine, the HSTDV, in 2020, Brazil tested another, the 14-X, in 2021, and North Korea tested a glide vehicle in 2022. Meanwhile, Australia has been jointly developing its program with American partnership. It is this scenario, that a 2017 report by RAND had forewarned, explaining that efforts at non-proliferation would no longer work within a few years. In a best-case scenario, the US, Russia, and China could today sign up to a comprehensive trilateral deal to stall the transfer of hypersonic technology to any other states, akin to the legally binding Non-Proliferation Treaty (NPT) of 1968. The current geopolitical climate and technical advancements by other states show that such a framework seems to be a foregone conclusion now. At a minimum then, what is more achievable is a formal understanding similar to the Missile Technology Control Regime (MTCR) of 1987. The three states in question pledge to not supply complete hypersonic weapons, subsystems, or any parts which are critical for hypersonic flight, such as Scramjets, to any other states. Subsequently, if any other states develop fully operational hypersonic weapons, they too must be pressurized by these original three to adhere to this anti-proliferation pledge.

Political Ramifications

While states which do not possess nuclear weapons may have more limited and conventional use of hypersonic weapons, those with nuclear weapons, namely India, Israel, and North Korea, would have augmented their offensive nuclear strike capability, upsetting deterrence stability in their respective regions, leading to states such as Pakistan, Iran, South Korea, and Japan, to aggressively pursue hypersonic weapons programs in an attempt rebalance. Since hypersonic weapons can escape radar detection due to their speed and maneuverability, states will have extremely limited response windows, diminishing their second-strike capability and credibility, since an adversary's first-strike may not be intercepted. Hypersonic nuclear states in conflict with a non-hypersonic nuclear state may become trigger-happy since their attack cannot be foiled with Anti-Ballistic air defense systems, while the latter may see a preemptive strike as their best chance at halting their own surprise destruction. Even if a state does not fear total nuclear annihilation, it would still be trigger-anxious due to the possibility of stealthy decapitation strikes taking out its government centre. This may result in a devolution of the launch command system of nuclear states in a bid to retain their second-strike capability to project credible deterrence. Indeed, the more individuals involved in this decision-making process, the higher the chances of a trigger-anxious launch team plunging the world into nuclear armageddon based on faulty intelligence such as an anomalous radar reading. As such, hypersonic weapons are on the verge of upending the balance based on Mutually Assured Destruction (MAD), bringing forth immense instability by disrupting current military calculations of the world's most powerful and aggressive states, and as such, recreating the anxieties found in the heyday of the Cold War.

Medical

Regenerative Medicine

Lewis Chapman

Regenerative medicine is the branch of medicine that aims to replace, regrow, or repair human organs, tissues, and cells. This is a broad, and rapidly evolving, field which has already made significant leaps and discoveries. The aim is essentially to stop the root cause of disease, rather than, as much of medicine is focused on, treating the symptoms of disease. Diseases being targeted by regenerative medicine include cancer, neurological conditions, cardiovascular disease, immune conditions, and genetic disorders. There is a real possibility that regenerative medicine could substantially extend human life expectancy.

Current development status

In 2021, investment into regenerative medicine reached $22.7 billion USD on the back of strong support from venture capital, more than triple the figure in 2017, and six new regenerative medicines were approved across the US, Europe and China. Regulation is still a barrier; however, progress here is being made. The US Food and Drug Administration (FDA) target of approving 10-20 cell and gene therapies per year by 2025 still appears possible, with significant progress in 2021 around gene therapy regulatory challenges. Currently, there are over 1,000 clinical trials currently being run in the regenerative medicine field, 97 of which are in the advanced Phase III stage.

Key developers and beneficiaries

The regenerative medicine sector is spread globally with many countries keen to be at the forefront of this emerging field. The US is currently home to 49% of regenerative medicine developers, Asia and Europe are too investing heavily with 31% and 18% respectively. Within cell and gene therapy, the UK has emerged a leader, in much part due to the Cell and Gene Therapy Catapult which is building a world-leading network of technology and innovation centres in the UK and bridging the gap between business, academia, research and government.

Although it is rapidly becoming less expensive with innovation and scale, regenerative medicine is not cheap. The beneficiaries, for the foreseeable future, will be those of wealthy, developed countries. Unfortunately, it seems that regenerative medicines will exacerbate health inequality globally since poorer, less developed nations lack the money, skills and infrastructure for regenerative medicine to be rolled out at scale. For example, the Middle East, Africa, and South America combined only account for 2% of regenerative medicine developers

Supply Chain

Most regenerative medicines, such as cell and gene therapy, do not require ingredients or supplies and hence have no physical supply chain. The constraint here is instead access to advanced, expensive, equipment. Stem cell therapy treatment, however, requires stem cells to be harvested from the body, but they are often difficult to extract and found mainly within bone marrow. Whilst this does complicate the process, sourcing stem cells is not a significant barrier to scaling up stem cell therapy. Indeed, alternative sources of stem cells are being explored such as reprogramming already developed cells – a preferable solution since this would not require invasive methods to harvest the cells required. Many regenerative medicines also require specialised supply chain capabilities including cold-chain or cryogenic product handing, storage, and distribution. This is not significant barrier to the growth of the industry but does complicate supply chains and add costs – most particularly for smaller companies which may not have the scale and experience of larger pharmaceutical companies.

Use Cases and Political Implications

There are a myriad of methods and technologies that are being researched in this area, perhaps the most well-known and advanced is that of stem cell therapy. This is when specialised stem cells are grown in a lab before being inserted into the body and instructed to behave like certain types of cells depending on the need. For example, patients with heart disease can be given these lab-made heart muscles cells to replace or repair damaged cells. Other types of regenerative medicine include artificial organs, gene therapy or editing and tissue engineering – where 3D-printed biomaterials are placed into the body where new tissue needs to grow, research here is ongoing but many people have already benefited from treatment. Cancer remains a leading target within the regenerative medicine industry, currently representing over 50% of all trials. Here, the ability to create artificial organs will also offer huge potential for cancer research capabilities. Overall, this is an industry with a huge opportunity set ahead and, although still at an early stage, initial products have demonstrated promise and thousands have already been treated, many of whom having no other viable treatment.

One major challenge that will have political implications, particularly in countries with nationalised healthcare, is that of payment. Traditionally, healthcare systems pay for "sick care" rather than "healthcare", hence the introduction of regenerative medicines – many of which are not curing diseases directly but rather just improving patients' broader health – requires a new approach to payment. Ideas being touted here include annuity-based payment and outcome-based payment. There will also be much political debate around the extent to which national healthcare systems will fund these treatments. A concern here is that if regenerative healthcare becomes entirely privatised, significant inequality will arise as the wealthy are, in effect, able to extend their own lives. There will also be demographic challenges if regenerative medicine is to become widespread and significantly extend life expectancy. This may be a greater problem in highly developed countries, many of which are already facing the challenge of aging populations such as Japan, Italy and Germany.

Genetic Engineering

Shyla Robinson

Current Development Status

Genetic engineering is the process of modifying DNA using biotechnology. Such changes can be achieved by altering a single base pair in the DNA (A-T or C-G), adding a new segment of DNA, or eliminating a section of the DNA altogether. The basic idea of selecting for desirable phenotypes has been around ever since agriculture first emerged and humans began selective breeding their livestock. The ability to physically modify an organism's DNA using technology, however, is relatively new with the first experiments on bacteria emerging in the 1970s. Nonetheless, the past several decades have seen a dramatic increase in our gene-editing capability – which has radicalized this age-old practice of selecting for desired traits. The bioethics debates that thus emerged first revolved around the proliferation of genetically modified crops across the globe, specifically the tensions between their ability to enhance food security by being disease-resistant with their ability to destabilise pre-existing ecosystems. This article will not revisit the GM crop issue pertinent as it continues to be, but instead focus on the latest breakthrough in the biotech industry: CRISPR-Cas9 genome editing.

The CRISPR tool (Clustered Regularly Interspaced Short Palindromic Repeats) is still in its early days but has proven to be revolutionary for genetic engineering due to its simplicity and precision. Previously, one could only edit DNA in blocks – a helpful analogy is to think of editing a book by changing pages at a time as opposed to words. Acting like a pair of genetic scissors, CRISPR now allows scientists to modify, exchange, or omit sections of the DNA with a level of specificity analogous to editing the very letters on a page. The power of such precision can be harnessed to treat a range of monogenic diseases that can be traced to a single defected gene like sickle-cell anaemia and cystic fibrosis. Oncologists have also sought to utilise CRISPR to treat the weaknesses in immune systems that allow cancer cells to evade the bodies' defences and spread. A key underlying factor in both the aforementioned cases is that applying CRISPR requires editing somatic cells which is significant as no altered genetic matter will be passed to the next generation. This is not the case for germline cells (sperm or egg cells), and here's where CRISPR's greatest controversy emerges: due to the tool's relative simplicity, any scientist trained in biotechnology can now alter hereditary genetic characteristics which in turn could eventually filter into the wider gene pool.

Key Developers and Beneficiaries

The key players in the commercialization of CRISPR are companies founded by the inventors themselves. However, pinpointing the primary 'inventor' has turned out to be a complex matter becoming the biggest biotech patent dispute in history. On the one side, we have Jennifer Doudna (UC Berkeley) and Emmanuelle Charpentier (University of Vienna) who authored the seminal paper in 2012 and won the Nobel Prize for their contributions and on the other side, we have Feng Zhang and his team at the Broad Institute (operated jointly by Harvard and MIT) who published a subsequent paper which further refined the theory. The source of the dispute can be traced to the fact that the first party conducted research on prokaryotes, i.e., single-celled organisms whose DNA is loose within a cell, while the second party tested the same CRISPR-Cas system on eukaryotic cells, i.e., cells in which DNA is contained within a membrane-bound nucleus. As nearly all CRISPR applications will require dealing with eukaryotic organisms, which includes all animals and plants, a patent that specifies eukaryotic cells is especially valuable. Recognizing this key distinction, as of 28 February 2022 the US Patent and Trademark Office ruled in favour of the Broad Institute. So how does this affect the development of the industry? To begin with, companies licensing the University of California patents like CRISPR Therapeutics (associated with Charpentier) and Intellia Therapeutics (associated with Doudna) are likely to face legal as well as financial challenges with the latter's stock reported to have fallen 21% after the news of the ruling despite making promising advances on their lead drug project. On the flip side, Editas Medicine (associated with Zhang) will naturally have its research capacity and market value bolstered by this ruling.

With the development of such a transformative technology, however, the US will not remain the only major player for long and we already see biotech companies in countries like Korea, Japan, China, France, and the UK pushing the limits of what is possible with the CRISPR. We are likely to see the initial benefits accruing to individuals within these countries who are wealthy enough to access cutting-edge healthcare to treat their genetic diseases or cancers as well as to those directly involved in such a lucrative industry. However, since beneficiaries are likely to only be people who can afford this, the risk of increasing health inequity both domestically and globally will need to be addressed by finding ways to democratise this therapeutic approach both at home and abroad so that people across the world suffering from genetic disease can be administered the therapies through their national health systems.

What the government "controls"

Extant international regulations on genetically modified organisms are primarily concerned with GM crops like the Cartagena Protocol on Biosafety which was adopted in 2003 and has 173 parties. This treaty concerns the movement of living modified organisms (LMOs) that have been genetically modified using modern technology and the risks they may pose to biological diversity and human health. Although the control measures put into place by the protocol will continue to be relevant in the age of CRISPR, there will be a need to expand the scope of international regulation beyond genetically modified plants, seeds, or fish to include pharmaceuticals and human beings themselves. Most countries already have additional regulatory bodies in place to regulate commodities obtained from GM sources, however, as the science develops the research sector will need to be regulated as any transgressions from international scientific norms, like avoiding editing germline cells, could lead to serious adverse effects. To cement such a status quo, scientists have called for a moratorium on CRISPR research related to germline edits until the scientific community has conducted adequate preliminary research. However, this attitude of caution is not the norm everywhere and its absence is most notably missed in China where they have not only proceeded to human clinical trials at an exceedingly fast pace but have also made headlines across the world for producing the first genetically altered babies. While the scientist concerned in this project defended his intentions by saying that he was trying the prevent the transfer of HIV to the twins from their HIV-positive father (an end to which he claims he was successful), other scientists question whether such an intervention was necessary at all and more importantly, worry about the door this premature development might have opened. While the Chinese government has made efforts to rectify this incident by sentencing the scientist to 3 years in prison, the regulatory controversies stemming from this case are far from over considering that as these twin girls grow up they may be subject to limitations on their reproductive rights to prevent the further spread of the modified DNA. This case thus exemplifies the need for lawmakers to catch up with the science and expand the mandate of extant GMO-related legislation.

Political Implications & Potential Future (mis)uses

CRISPR's greatest promise lies in its potential to revolutionise healthcare by eradicating genetic diseases and while the sentiment behind these efforts is undeniable, many in the disabled community worry that this will bring in a new wave of ableism and in the worst-case scenario, a comeback of eugenics. The fear is that as the technology advances, whatever the medical community deems as faulty genes will slowly be eradicated from the gene pool and while this comes across as a noble effort, when one considers that society has often been discriminatory towards those different and medical science is not independent of its influence, there is a real risk of harmfully impacting human diversity in this process 'improve' humanity. This will likely increase notions of ableism in society while further marginalising those who are disabled and without the financial means to treat their condition. Additionally, as this promotion of certain phenotypes over others continues, one can only expect looking at the historical record that those looking to leverage the technology to fulfil their malicious intentions will not be far behind.

However, with the memories of such eugenics still fresh in our minds this is likely to take a slightly different form some have referred to as 'velvet eugenics' which will ride the wave of commercialism instead of being enforced by the state and under the guise of patient autonomy and consent, begin nudging those with the financial means to enhance their offspring's intelligence or physical attributes. Prospective parents are already showing interest in genetic testing which would allow them to choose the embryo that is least susceptible to disease. One such company providing this service is Orchid Biosciences and their disease risk portfolio includes but is not limited to heart disease, breast cancer, prostate cancer, and type 1 or 2 diabetes. Many scientists are wary of the efficacy of their methods and argue that since we do not know enough about polygenic test scores and they are also based on statistical association, such predictions are hardly valid, especially when trying to approximate the risks for understudied populations. An even bigger issue, however, which brings us back to our discussion on eugenics is that polygenic risk scores can be developed to identify any trait with a heritable component and indeed there are already existing models that would potentially forecast academic capability, neuroticism, and homosexuality. The era of 'designer babies' may still be a few decades away, but once it comes it will likely result in increased economic inequity both domestically and between developed and under-developed nations in addition to cementing prejudiced behaviour towards those deemed abnormal.

But the power of CRISPR can also be harnessed to yield significant positive outcomes for society. Aside from the healthcare benefits, scientists have also found ways to apply the technology to increase the carbon sequestering capacity of plants to help fight climate change and are already working towards a genetically modified version of rice with enhanced photosynthesis mechanisms which would increase the amount of carbon captured by tissue by 30%. Understanding that it will take more than just enhanced carbon-capturing abilities for farmers to switch to this new variety, researchers working on this project also seek to apply CRISPR to boost crop yields and are looking to hold international field trials within the coming decade. Another potentially beneficial use would be to launch 'gene drives' to eradicate malaria by introducing mosquitos with specifically engineered genetic mutations which would pass on to the next generation and slowly eradicate the local population of mosquitoes. This same logic could also be applied to invasive plant species that are disseminating local ecosystems. Of course, the chief concerns of trying to play God and tampering with delicate ecological balances arise with all environment-centric genetic engineering projects, however, with enough preliminary research and controlled trials on uninhabited areas first, there is great potential to be realised. Thus, as with almost any emerging technology, the possibilities for the CRISPR-Cas system are endless provided we utilise and regulate it with great care.

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