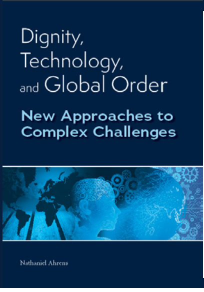

Excerpted from
Dignity, Technology, and Global Order
New Approaches to Complex Challenges
by Nathaniel Ahrens

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The Role of Technology in U.S.-China Futures and Global Order

It is not an exaggeration to state that a peaceful and prosperous 21st century depends to a great degree on how the United States and China manage their increasingly competitive relationship. The two countries' respective influence on the global economy, supply chains, finance, technology, global health, and environment and climate, not to mention their military power, means that each has the ability to throttle the ambitions and counter the interests of the other. Beyond the bilateral, this clout extends to their influence on other nations and the global order.

As such, addressing this challenge should be a major focus of politicians, military strategists, policy analysts, business leaders, public intellectuals, and other members of civil society. Yet despite this strategic imperative, over the last decade U.S.-China relations have become more strained and positions more deeply entrenched. Flying the flag of national interest, each country has dug in and focused on how to out-compete the other in geopolitical, economic, and military realms. Competition over emerging technologies and data is at the center of this dynamic.

U.S. and Chinese geostrategic futures are inextricably tied to technological innovation. Efforts to manage long-term relations between these two nations need to factor in the central role that new and emerging technologies play in creating interdependencies, increasing competition, exacerbating frictions, and stoking conflict.

Technology and Global Order

Over the last 70 years, rapid technological progress has played a major role in the pace and scale of globalization—not just the increase in global interaction and integration, but also the allocation of resultant economic gains.

In particular, the acceleration that began in late 1990s with advances in telecommunications, the internet, computing, and health innovation, contributed to broader levels of prosperity and connectivity across the globe. Yet these advances have also led to increases in inequality and unanticipated social stresses. The world is now on the cusp of far more rapid and extensive technological change, with the potential for much greater economic, societal, and military impact.

Technologies that have the ability to reshape economic and national security competition are the crown jewels of the emerging world order. In some circles, including in China, data is being referred to as the "fourth factor of production," with those organizations which can process, analyze, and utilize this data the most rapidly moving important steps ahead of their competitors. Innovations across a wide variety of emerging technologies will reshape almost every aspect of our economy, society, and military. Global and domestic politics will not be immune.

Since the end of World War II, U.S. leadership in science and technology research and development has served as the bedrock of American prosperity and security. This technological leadership position is likely to become eroded, as technological innovation becomes more diffuse and new players, especially China, compete for the commanding heights of these new technologies—technologies which will transform our economies, societies, and militaries. As such, competition over emerging technologies and their concomitant economic and national security benefits will be one of the most critical forces shaping the global order.

The Era of Techno-Sovereignty

Technological competition is already shaping the contours and boundaries of U.S.-China relations. The United States and China are not the only players in this dynamic, but they are at its core. The two largest economies are also the largest players in technological innovation, research and development, start-up company formation, and military technology spending. The U.S. National Intelligence Council captures the situation succinctly in their *Global Trends 2040* futures assessment: "The race for technological dominance is inextricably intertwined with evolving geopolitics and is increasingly shaped by broader political, economic, and societal rivalries, particularly those associated with China's rise."[5]

The American and Chinese governments increasingly view competition over emerging technologies as a zero-sum, first-mover, winner-take-all contest. The most powerful reason for this is the belief that the military applications of these technologies have the potential to offer decisive intelligence and battlefield advantage. A secondary reason is that the economic gains from technological innovations have historically accrued in overwhelming proportion to the innovators and standard-setters, with the rest of the world forced to adopt and follow. Early leads in emerging technologies also allow the locking-in of technology gains, further extending future advantage.

As such, the intense military push for technological advantage coincides with strong domestic economic and political pressures which have only increased in recent years. Beginning in the aftermath of the 2008 financial crisis and accelerating around 2016, in an effort to address festering economic imbalances and societal inequalities, governments have been retreating from globalization and turning inwards, adopting protectionist, neo-mercantilist policies that, on the surface, appear to align well with an indigenous technology development strategy. The upshot of this is that governments are taking an expansive view of national security, with economic security now seen as a key component of national security. Technologies that have the potential to reshape large swathes of military and economic activity have now become top political priorities.

Governments are therefore deeply concerned about the cross-border proliferation of key emerging technologies. The result is a movement towards the de facto nationalization of technology development, a trend we can call techno-sovereignty. Techno-sovereignty is *the emerging consensus among governments that they must assert greater control over technology and trade to ensure their respective national economic and military security*. It is now one of the most powerful geopolitical forces shaping the global order.

China has long been engaged in efforts to develop indigenous technological capabilities to decrease dependence on other countries and to grow

5 National Intelligence Council, *Global Trends 2040: A More Contested World* (Office of the Director of National Intelligence, March 2021), https://www.dni.gov/index.php/gt2040-home/gt2040-structural-forces/technology.

its economy and military. It has done this through industrial policy that forces technology transfer, restricts market access to foreign companies, and, in some cases, resorts to industrial espionage. Over recent years, however, the U.S. government approach to address the threat to American technological leadership has increasingly resembled that of China: build walls to prevent both leakage and penetration. In October 2020, the Trump Administration published a *National Security Strategy for Critical and Emerging Technologies*.[6] This national strategic document combined vague recommendations for strengthening the technology innovation base (such as "encourage public-private partnerships," "develop the highest quality workforce in the world," and "leverage private capital and expertise to build and innovate") with a litany of protective measures targeted at preventing other countries from illegally acquiring U.S. technology. It is clear that the authors spent much more time thinking about how to protect American advantage than how to extend it.

Politically this is the easiest approach, so it is unsurprising to see both China and the United States prioritize building protective walls rather than investing in key innovation ecosystems and infrastructure. It is still too early to see what approach the Biden Administration will take. There has been a greater focus on investing in American infrastructure and "building back better," but economic pressures, security tensions, and election cycles may result in a continuing emphasis on competing with China.

While governments focus on the economic and military implications of emerging technologies, technological change and innovation are impacting human lives and social structures across the globe, irrespective of national boundaries. This creates a dilemma, where incentives to innovate are being driven at the national and firm level, while social effects are shared across broader society. As governments and corporations pursue technological frontiers, who is considering the impact on society and individuals, on human flourishing? What is the social future towards which we are aiming with these innovations? Given the diversity of poitical systems and ideologies, how can societies develop universal norms for ethical technology use? If we take present day techno-sovereign competition to its logical conclusion, how does it affect the global order? How do nations co-exist in such an environment? Do we end up in a Balkanized world of incompatible technology regimes, like

6 White House, *National Strategy for Critical and Emerging Technology* (October 2020), https://www.hsdl.org/?view&did=845571.

that described by S.B. Divya in her visionary novel *Machinehood*?[7] Not taking other countries into account for the moment, in a world in which the United States and China refuse to allow the other access to core technologies, data, and markets, is there a plausible scenario where the two nations do not end up in conflict?

These are critical strategic questions. Yet analysts and policymakers are focused almost exclusively on the near-term national impacts of strategic competition, ignoring or discounting the global spillover costs and long-term sociatal implications. Without a vision for the future and a better understanding of the forces shaping it, technology will drive the future in unanticipated and difficult-to-control ways. Put simply, the unforeseen consequences of technology will have a greater impact on the future of society and world order than governments' best efforts to direct them.

Technology Taxonomy and Military and Societal Implications

It is not enough to talk about emerging technologies in the abstract. A vision for an inclusive global order that promotes human flourishing and reduces the likelihood of conflict needs to start with a clearer understanding of the nature of these technologies and their potential impacts on both strategic competition and broader society. A better understanding of the technologies and their military and societal impacts will also help us appreciate the urgency and complexity of the challenge.

In an effort to think about and visualize these technologies and their impacts in more specific terms, we created an emerging technology taxonomy. We first separated the technologies into five areas: information and communications technology, space technology, biotechnology, advanced materials technology, and earth and energy technology. We then broke these down into specific technologies, derivatives, general applications, and military applications, and looked in detail at their military and societal impact (summarized in Figure 1, page 14, and detailed in the tables in Appendix A).

For military impacts, we focused on force multiplication, advanced weaponry and defense, information advantage, energy advantage, and labor

7 S.B. Divya, *Machinehood* (New York: Saga Press, 2021).

Figure 1. Military & Societal Impacts of Emerging Technologies

	Artificial Intelligence	Augmented & Virtual Reality	Cloud Computing	Distributed Ledger Technolo	Electromagnetic Spectrum	Internet of Things	Neuromorphic Engineering	Quantum Technology	Social Media	Alternative Propellants	Satellite Technology	Genomic Engineering	Synthetic Biology	Additive Manufacturing	Advanced Synthetics	Metamaterials	Nanotechnology	Advanced Energy Storage	Advanced Renewables	Hypersonic Technology
Military Impact																				
Force Multiplication	●	●	●	●	●	●	●	●		●	●	●	●	●	●	●	●	●	●	●
Advanced Weaponry & Defense	●	●	●	●	●	●	●	●		●	●	●	●	●	●	●	●	●		●
Information Advantage	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		
Energy Advantage												●	●			●	●	●	●	
Labor & Cost Reduction	●	●	●	●	●	●	●	●	●	●		●	●	●	●	●	●	●		
Societal Impact																				
Privacy	●		●			●	●	●	●		●	●	●		●					
Alienation	●	●	●			●			●			●			●					
Nature of Humanity	●											●	●				●			
Justice & Equality	●							●	●			●	●	●	●		●			
Labor	●	●	●			●	●	●				●	●	●	●		●			
Autonomy	●		●			●	●	●				●	●		●					

Information & Communications Technology (Artificial Intelligence through Social Media) · **Space Technology** (Alternative Propellants, Satellite Technology) · **Biotechnology** (Genomic Engineering, Synthetic Biology) · **Advanced Materials Technology** (Additive Manufacturing through Nanotechnology) · **Earth & Energy Technology** (Advanced Energy Storage through Hypersonic Technology) and cost reduction (Appendix D). For societal impacts, we looked at privacy, alienation, nature of humanity, justice and equity, labor, and autonomy (Appendix C).

As we categorized and explored the military and societal implications of each technology, a two-pronged conclusion became clear: first, since each of these technologies brings military advantage (with a first-mover advantage to most of them), nations will be strongly incentivized to pursue dominance in each domain. Second, this pursuit will coincide with, and likely overshadow, the negative impacts these technologies may have on society and human flourishing. As F. Daniel Davis observed while serving on the President's Council on Bioethics, "...the claim that all these impressive achievements make positive contributions to human flourishing is misguided and even dangerous... the quest for new knowledge, and for new applications of that knowledge, can be perverted so as to inflict egregious harm on our fellow human beings..."[8]

In light of the lopsided incentives, it is unrealistic to expect governments to prioritize technology governance over development and deployment. *Political, military, and economic advantages accrue in the near-term at the national level, while social ramifications are felt globally and are evident only on a longer time horizon.* This necessitates new approaches to technology governance.

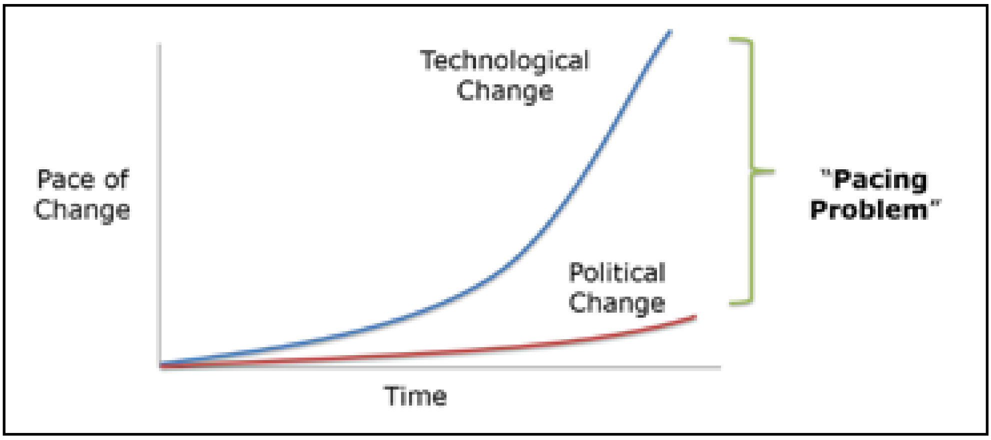
The Challenges to Effective Governance

One challenge to effective technology governance, as discussed above and demonstrated in detail in Appendix A, is that governments, research organizations, and private enterprise have strong incentives to pursue technological frontiers. But another key challenge is a structural conundrum, often described as either the pacing problem or the Collingridge Dilemma (Figure 2, page 16).

The pacing problem refers to the fact that technological development happens much faster than bureaucratic structures and regulators can adapt. The current regulatory approaches from Congress with regard to cryptocurrencies are a prime example. It is unlikely that members of Congress can get up to speed fast enough on regulating cryptocurrencies, let alone understand

8 F. Daniel Davis, "Human Dignity and Respect for Persons," in Adam Schulman, F. Daniel Davis, and Daniel Dennett, et al., *Human Dignity and Bioethics* (The President's Council on Bioethics, March 2008), 31-32.

Figure 2. The Pacing Problem Created by Technological Development



Source: Thierer, Adam. "The Pacing Problem, the Collingridge Dilemma & Technological Determinism," *The Technology Liberation Front,* August 16, 2018.

the technical details of distributed ledger technologies and their broader ramifications. Industry representatives lobby legislators to refrain from regulation for the present, and by the time the technology is entrenched, regulatory efforts are hamstrung.

The pacing problem is not new; it is part and parcel of the nature of technological change. Adam Thierer, of George Mason University's Mercator Center, lists key drivers contributing to the pacing problem as follows:[9]

- Technological driver: The power of "combinatorial innovation," which is driven by "Moore's Law," fuels a constant expansion of technological capabilities.
- Social driver: As citizens quickly assimilate new tools into their daily lives and then expect that even more and better tools will be delivered tomorrow.

9 Adam Thierer, "The Pacing Problem, the Collingridge Dilemma & Technological Determinism," *The Technology Liberation Front*, August 16, 2018, https://techliberation.com/2018/08/16/the-pacing-problem-the-collingridge-dilemma-technological-determinism/. For a more detailed discussion by Thierer, see "The Pacing Problem and the Future of Technology Regulation," at https://www.mercatus.org/bridge/commentary/pacing-problem-and-future-technology-regulation.

- Political driver: Government has grown increasingly dysfunctional and unable to adapt to those technological and social changes.

This conundrum was explored in detail by David Collingridge in his 1980 book *The Social Control of Technology*. The essence of what is now known as the Collingridge Dilemma (which Collingridge himself referred to as the "dilemma of control") is that the social consequences of technologies are hard to predict early in the development stage, and by the time they are better known the technologies have already become too economically, socially, and politically entrenched to control and govern. As Collingridge summarized, "… attempting to control a technology is difficult, and not rarely impossible, because in its early stages, when it can be controlled, not enough can be known about its harmful social consequences to warrant controlling its development; but by the time these consequences are apparent, control has become costly and slow."[10]

We are facing this dilemma with respect to both existing and emerging technologies. Microsoft President Brad Smith was quoted in *LiveScience* as saying that "Artificial intelligence could lead to an Orwellian future if laws to protect the public aren't enacted soon." Smith goes on to state "If we don't enact, now, the laws that will protect the public in the future, we're going to find the technology racing ahead…and it's going to be very difficult to catch up."[11]

Who is responsible for technology governance? Part of the innovator ethos is that innovation happens first, and regulation and governance can be sorted out later, either by government or industry. The attitude in Silicon Valley has been, in essence, "it is our job to build the technology, and, when and only when it is absolutely necessary, it is the government's job to regulate it." Given what we know about the pacing problem and Collingridge Dilemma, and the incentives for technology firms to "move fast and break things," pushing half-baked products to market before someone beats them to it, it does not bode well for taking these broader societal impacts into account. Technology companies will continue to stoke the fires of development, catering to voracious appetites on Wall Street and the military-industrial complex. Pres-

10 David Collingridge, *The Social Control of Technology* (New York: St. Martin's Press, 1980), 19.

11 Stephanie Pappas, "Expect an Orwellian future if AI isn't kept in check, Microsoft exec says," *Live Science*, June 7, 2021, https://www.livescience.com/orwellian-artifical-intelligence-future.html.

sures to innovate, both independently and in service of national interests, will trump thoughtful development in service of human flourishing.

The following pages
Appendix A
Appendix B
Appendix C
Appendix D
are also available for download as separate files.

Appendix A
Emerging Technology Taxonomy

What do we mean by new and emerging technologies? While this should be straightforward, we were unable to find a comprehensive taxonomy of new and emerging technologies and their potential impacts. We therefore created one in the hopes that it could serve as a useful framework through which to better understand the individual and collective impacts on the military and societal spheres.

We compiled a list of key technologies, dividing them into five technology areas.[124]

Table 2. Major Technology Areas and Technologies

<table>
<tr>
<td rowspan="2">Information & Communications Technology
• Artificial Intelligence
• Augmented/Virtual Reality
• Cloud Computing
• Distributed Ledger Technology
• Electromagnetic Spectrum
• Internet of Things
• Neuromorphic Engineering
• Quantum Technology
• Social Media</td>
<td>Space Technology
• Alternative Propellants
• Satellite Technology</td>
<td>Biotechnology
• Genomic Engineering
• Synthetic Biology</td>
</tr>
<tr>
<td>Advanced Materials Technology
• Additive Manufacturing
• Advanced Synthetics
• Metamaterials
• Nanotechnology</td>
<td>Earth & Energy Technology
• Advanced Energy Storage
• Advanced Renewables
• Hypersonic Technology</td>
</tr>
</table>

124 We attempted other approaches to categorizing technologies, such organizing technologies by their underlying function, but this did not result in as clear a picture of the technologies' pragmatic impacts. Appendix B provides background on our methodology.

We then subdivided those five areas of technology into technology components, derivatives, and capabilities. We listed applications for each, in both the public and military realms. Finally, we attempted to categorize the impacts of these technologies and applications, broken down into military and societal.[125] There is an apparent incongruity to this approach, in that we focus on the potential positive military benefits and the negative social consequences. This is intentional, however, as the political drivers of technology development are, to a great extent, military applications, whereas governance concerns are driven primarily by the potentially negative social consequences. This approach naturally obscures or ignores the enormous societal benefits that stem from new technologies, including benefits to health, security, communications, efficiency, equity, productivity, access to information, and addressing climate challenges, among others. Our argument is simply that those benefits are self-evident; the potential societal benefits and military applications drive technology development.

One of the additional challenges we faced was how to best catalogue and visualize this data. We ended up with an enormous workbook containing multiple spreadsheets that, while useful for providing a holistic digital view and keeping all our data, sources, and iterations in one place, was not conducive to displaying in print format. It also had more data than we needed for the purposes of this paper. Ultimately, a single comprehensive view of the data eluded us, so we have provided in the pages that follow detailed breakdowns of each major technology.

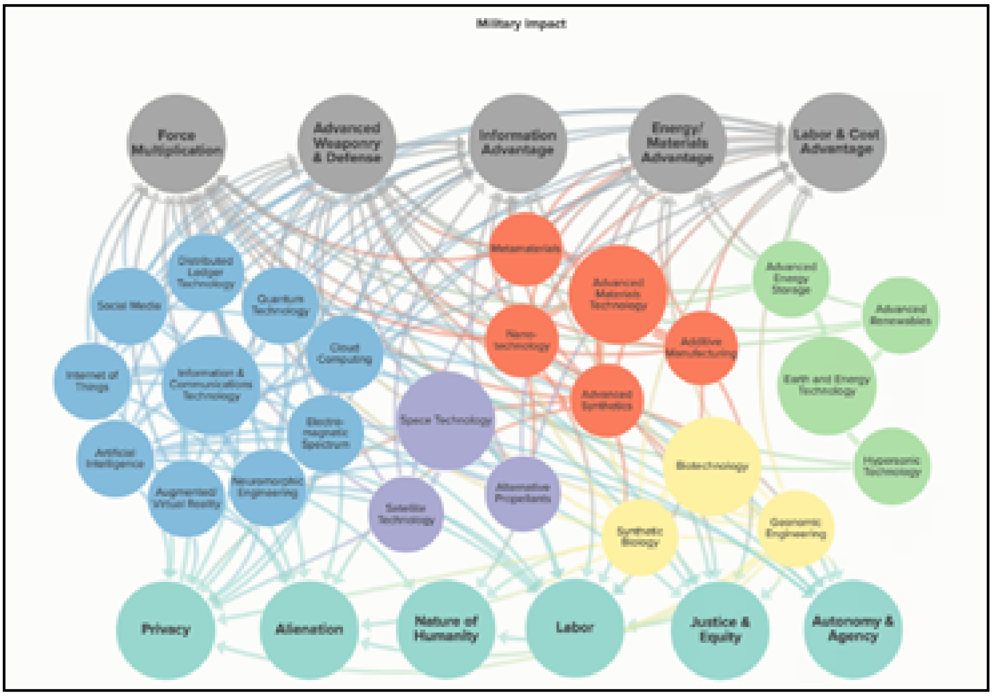
We also experimented with a variety of methods and tools for visualizing the military and societal impacts. We found the clearest to be the chart presented earlier in the main body of the paper (Figure 1, page 14), but also found the Kumu.io platform to be a useful way to interact with the data and relationships in a more dynamic fashion (Figures 3 and 4, page 73).

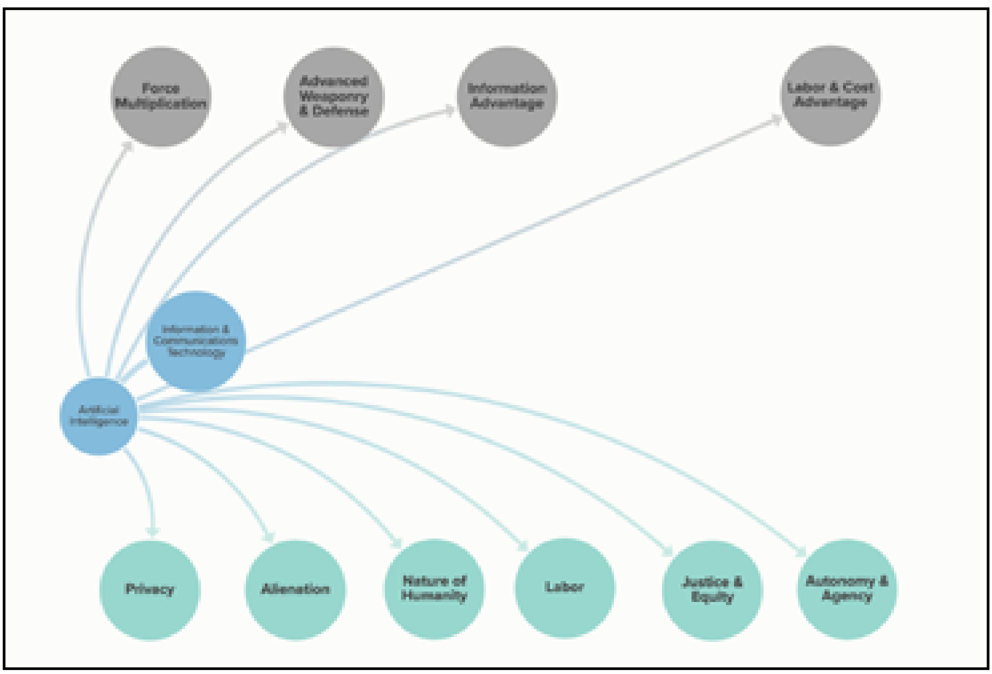
Detailed Technology Breakdowns

The tables on the following pages present a detailed breakdown of each area of the technology taxonomy, organized according to the major technologies in each technology area.

125 In this project we use the term "societal impact" to cover and encompass "human impact."

Figures 3 and 4. Kumu enables dynamic visualizations of the entire system of relationships (Figure 3, top), as well as the ability to isolate individual technologies or impact areas (Figure 4, bottom).





Technology Area	**Information & Communications Technology**
Technology	**Artificial Intelligence**
Components, Derivatives, Capabilities	Machine Learning, Computer Vision, Artificial Neural Networks, Natural Language Processing, Robotics, Speech Recognition, Expert Systems, Big Data Processing, Predictive Analytics, Automation, Reinforcement Learning, Cognitive Computing, Sensing and Perception, Deep Learning
General Applications	Autonomous Vehicles, Autonomous Systems, Gaming, Chat Bots, Search Engines, Sentiment Analysis (Opinion Mining), Text Analysis, Facial Recognition, Stock Market Analysis, Health Monitoring, News Categorization, Weather Prediction, Language Comprehension and Interface, Spam Filters, Derivatives Training, Software Testing and Automatic Cyber-Vulnerability Testing, Machine Translation, Medical Diagnosis, Hearing Aids, Mood Analysis, Brain-Machine Interfaces, Recommendation Systems, Robotic Locomotion, Targeted Advertising and Customer Segmentation, DNA Sequence Classification, Computer-Vision Object Recognition, Bioinformatics and Chemical Analysis, Legal Case Research, Space/Underwater Exploration, Resource Extraction
Military Applications	Autonomous Vehicles and Weapons, Information Operations, Human-Machine Teaming, C4ISR, Internet of Military Things/Internet of Battlefield Things, Anti-Access/Area-Denial (A2/AD) Operations, Simulation Modeling and Synthetic Environments, Biometrics, Cyber Operations and Defense, Decision and Planning Support, Defense Logistics and Supply Chain, Predictive Analytics
Military Impact Categories	Force Multiplication, Advanced Weaponry & Defense, Information Advantage, Labor & Cost Reduction
Societal Impact Categories	Privacy, Alienation, Nature of Humanity, Justice & Equality, Labor, Autonomy

Technology Area	**Information & Communications Technology**
Technology	**Augmented/Virtual Reality**
Components, Derivatives, Capabilities	Spatial Augmented Reality, Simulations, Mixed Reality
General Applications	Smart Glasses, Heads-Up Display/ Head-Mounted Display, Film and Media, Entertainment, E-Sports, Mobile Gaming, Mobile Holographic Display, Biometric Identification, Spatial Augmented Reality, Industrial Manufacturing, Commerce and Retail Marketing, Simulated Training Environments, Simulation Modeling, Navigation, Social Interactions Platforms, Education
Military Applications	Autonomous Vehicles and Weapons, Information Operations, Human-Machine Teaming, C4ISR, Internet of Military Things/ Internet of Battlefield Things, Anti-Access/ Area-Denial (A2/AD) Operations, Simulation Modeling and Synthetic Environments, Biometrics, Cyber Operations and Defense, Decision and Planning Support, Defense Logistics and Supply Chain, Predictive Analytics
Military Impact Categories	Force Multiplication, Advanced Weaponry & Defense, Information Advantage, Labor & Cost Reduction
Societal Impact Categories	Alienation, Labor

Technology Area	Information & Communications Technology
Technology	**Cloud Computing**
Components, Derivatives, Capabilities	Hybrid Cloud, Multi Cloud, Cloud Storage, Big Data Analytics
General Applications	Enterprise Resource Planning, Testing and Development, Disaster Recovery, Data Backup, Mobile Cloud Computing, Anti-Virus Applications, E-Commerce, Cloud Gaming, Application Services
Military Applications	Autonomous Vehicles and Weapons, Information Operations, Human-Machine Teaming, C4ISR, Internet of Military Things/ Internet of Battlefield Things, Anti-Access/ Area-Denial (A2/AD) Operations, Simulation Modeling and Synthetic Environments, Biometrics, Cyber Operations and Defense, Decision and Planning Support, Defense Logistics and Supply Chain, Predictive Analytics
Military Impact Categories	Force Multiplication, Advanced Weaponry & Defense, Information Advantage, Labor & Cost Reduction
Societal Impact Categories	Privacy, Alienation, Labor, Autonomy

Technology Area	**Information & Communications Technology**
Technology	**Distributed Ledger Technology**
Components, Derivatives, Capabilities	Smart Contracts, Consensus, Anonymity and Privacy, Shared Ledger
General Applications	Cryptocurrency, Digital Assets, Provenance in Supply Chain Management, Smart Contracts, Cyber Security, Identity Authentication, Financial Management and Banking, Intellectual Property, Management, Cross-Border Payments, Internet of Value, Art
Military Applications	Global Data Sharing and Coordination, Critical Infrastructure Control, Secure Data Control and Exchange, Weapons Release, Defense Logistics and Supply Chain Operations, Security, and Validation, Procurement Auditing, Contract Management
Military Impact Categories	Force Multiplication, Advanced Weaponry & Defense, Information Advantage, Labor & Cost Reduction
Societal Impact Categories	N/A or Unclear

Technology Area	Information & Communications Technology
Technology	**Electromagnetic Spectrum**
Components, Derivatives, Capabilities	Radio Waves, Microwaves, Infrared, Ultraviolet, X-Rays, Gamma Rays, LIDAR
General Applications	Data Transmission, Video and Teleconferencing, Satellite Communications, Navigation, Meteorological Services, Spectroscopy, Mobile Phones and Applications, Streaming, Wi-Fi, Broadcast, Lasers (Laser Isotope Separation, Electrical Switching, Remote Sensing, Imaging and Diagnostics, Optical Communications, Plasma Chemistry, Chemical Analysis for Nuclear Security and Energy Applications)
Military Applications	Communications, Situational Awareness, Intelligence, Surveillance, Reconnaissance (ISR), Command and Control (C2), Radar and LIDAR, Signals Intelligence (SIGINT), Environmental Sensing, Early Missile Detection, Air and Missile Defense, Missile Guidance, Precision Targeting and Strikes, Electronic Warfare, Spectrum Manipulation and Signature Management, Directed Energy Weapons, Anti-Access/Area-Denial (A2/AD), Space Defense and Weaponry, Non-Intrusive Aircraft Inspection, 5G Communications, Weapons System Datalink
Military Impact Categories	Force Multiplication, Advanced Weaponry & Defense, Information Advantage, Labor & Cost Reduction
Societal Impact Categories	N/A or Unclear

Technology Area	Information & Communications Technology
Technology	**Internet of Things**
Components, Derivatives, Capabilities	Edge Computing, Smart Sensing Systems, Peer-to-Peer Networks
General Applications	Smart Devices, Systems, and Applications, Disease Monitoring and Prevention, Therapeutic Delivery, Smart Manufacturing, Agriculture, and Industry Applications, Smart Grid and Energy Management, Surveillance, Control Systems, Logistics and Supply Chain Management, Intelligent Transport Systems, Media and Entertainment
Military Applications	Autonomous Vehicles and Weapons, Information Operations, Human-Machine Teaming, C4ISR, Internet of Military Things/ Internet of Battlefield Things, Anti-Access/ Area-Denial (A2/AD) Operations, Simulation Modeling and Synthetic Environments, Biometrics, Cyber Operations and Defense, Decision and Planning Support, Defense Logistics and Supply Chain, Predictive Analytics
Military Impact Categories	Force Multiplication, Advanced Weaponry & Defense, Information Advantage, Labor & Cost Reduction
Societal Impact Categories	Privacy, Alienation, Labor, Autonomy

Technology Area	**Information & Communications Technology**
Technology	**Neuromorphic Engineering**
Components, Derivatives, Capabilities	Interpretation and Autonomous Adaptation, Massively Distributed, Parallel Information Processing, Analog and In-Memory Computing, Memory-Processor Co-Localization, Deep and Covolutional Neural Network Accelerator, Embedded Intelligence
General Applications	Pattern Recognition, Classification, Prediction, Object Identification and Change Detection, Autonomous Control, Edge Computing, Robotic Vision and Control Sensors, Biomedical and Biosignal Engineering, Perception Engineering, Medical Assistive Applications (incl. Retinal Implant and Sensory Substitution), High-Speed Serial Interfaces, Electronic Design Automation, Authentication System, Cybersecurity
Military Applications	Autonomous Vehicles and Weapons, Information Operations, Human-Machine Teaming, C4ISR, Internet of Military Things/ Internet of Battlefield Things, Anti-Access/ Area-Denial (A2/AD) Operations, Simulation Modeling and Synthetic Environments, Biometrics, Cyber Operations and Defense, Decision and Planning Support, Defense Logistics and Supply Chain, Predictive Analytics
Military Impact Categories	Force Multiplication, Advanced Weaponry & Defense, Information Advantage, Labor & Cost Reduction
Societal Impact Categories	Privacy, Labor, Autonomy

Technology Area	**Information & Communications Technology**
Technology	**Quantum Technology**
Components, Derivatives, Capabilities	Computing, Sensing, Communication, Cryptography, Measurement
General Applications	Artificial Intelligence, Computational Chemistry, Quantum Encryption, Secure Communication, Quantum Teleportation and Networking, Financial Modeling and Arbitrage, Weather Forecasting, Particle Physics, Cybersecurity & Cryptography, Logistics Optimization (Quantum Annealing), Distributed Sensor Networks, Drug Design, Protein Folding
Military Applications	Autonomous Vehicles and Weapons, Information Operations, Human-Machine Teaming, C4ISR, Internet of Military Things/ Internet of Battlefield Things, Anti-Access/ Area-Denial (A2/AD) Operations, Simulation Modeling and Synthetic Environments, Biometrics, Cyber Operations and Defense, Decision and Planning Support, Defense Logistics and Supply Chain, Predictive Analytics
Military Impact Categories	Force Multiplication, Advanced Weaponry & Defense, Information Advantage, Labor & Cost Reduction
Societal Impact Categories	Privacy, Justice & Equality, Labor, Autonomy

Technology Area	**Information & Communications Technology**
Technology	**Social Media**
Components, Derivatives, Capabilities	Social Networking, Wikis, Media and Content Sharing, Blogs and Microblogs
General Applications	Digital Marketing, E-Learning, News and Information Sharing, Digital Marketplace, Community Building
Military Applications	Autonomous Vehicles and Weapons, Information Operations, Human-Machine Teaming, C4ISR, Internet of Military Things/ Internet of Battlefield Things, Anti-Access/ Area-Denial (A2/AD) Operations, Simulation Modeling and Synthetic Environments, Biometrics, Cyber Operations and Defense, Decision and Planning Support, Defense Logistics and Supply Chain, Predictive Analytics
Military Impact Categories	Information Advantage, Labor & Cost Reduction
Societal Impact Categories	Privacy, Alienation, Justice & Equity

Technology Area	**Space Technology**
Technology	**Alternative Propellants**
Components, Derivatives, Capabilities	Solar Electric Propulsion, Electrothermal, Ion Drive, Arcjet, Pulsed Plasma, Hall-Effect, Microsatellite Propulsion
General Applications	Space Access and Exploration, Micro-propellants, Orbital Propulsion, Human Space Flight, Payload Delivery, Deep Space Propulsion and Probe, Proximity Operations, Noncooperative Capture and Deflection
Military Applications	Similar to general applications
Military Impact Categories	Force Multiplication, Advanced Weaponry & Defense, Information Advantage
Societal Impact Categories	N/A or Unclear

Technology Area	**Space Technology**
Technology	**Satellite Technology**
Components, Derivatives, Capabilities	Intelligence, Surveillance, and Reconnaissance (ISR), Space Command, Control, and Communications, Remote Space Sensing, Earth Observation, Cubesats
General Applications	Positioning, Navigation, and Timing (PNT), Space Traffic Management, Space Situational Awareness, Space Search and Rescue, Space Sustainment Operations, Image Gathering on Planetary Probes and Rovers, Structural Deformation Detection, In-Orbit Spacecraft Surface Damage Analysis, Failure Diagnostics, Temperature Monitoring, Radiation Measurement, Space-Based Kill Assessment, Debris Management, Solar Radiation Management
Military Applications	Missile Warning Systems, Space Flight Safety/Collision Avoidance, Antisatellite Weapons, Communication Jammers, Sensor Dazzler Detection, Space Battle Management, Visual Spacecraft Monitoring, Smart Instrumentation Point (SIP)
Military Impact Categories	Force Multiplication, Advanced Weaponry & Defense, Information Advantage
Societal Impact Categories	Privacy

Technology Area	**Biotechnology**
Technology	**Genomic Engineering**
Components, Derivatives, Capabilities	Conditional Gene Expression Control
General Applications	CRISPR, Drug Discovery, Therapeutics, Diagnostics, Disease Models, GMO, Gene Drives, Biomaterials
Military Applications	Commodities Materials, Specialty Materials, Sensing, Biological and Chemical Weapons, Sensor-Active Materials, Clandestine Sensors, Distributed Tag, Track, and Trace Systems, High-Strength Polymers, Stealth Materials, Corrosion-Resistant Coating, Biological Computing, Data Storage, Cryptographic Materials, Cognitive, Physical, and Socio-Emotional Performance Enhancement, Cybernetic Replacement, Healing Enhancement
Military Impact Categories	Force Multiplication, Advanced Weaponry & Defense, Information Advantage, Energy Advantage, Labor & Cost Reduction
Societal Impact Categories	Privacy, Alienation, Nature of Humanity, Justice & Equity, Labor, Autonomy

Technology Area	**Biotechnology**
Technology	**Synthetic Biology**
Components, Derivatives, Capabilities	Biological Sensing, Therapeutics, Synthetic Genomics
General Applications	CRISPR, Human Modification and Augmentation, Artificial Tissue Engineering and Regeneration, Cryogenics, Biomimetics, Cybernetics, Enhanced Mechanical Integrity and Restoration, Genetically Engineered Crops, Reflective Crops, Synthetic Bio-Fuels and Materials, Fine Chemicals Production, Drug and Vaccine R&D, Production, and Delivery, Bioremediation, Disease Mechanism and Drug Target Identification, Pharmaceuticals
Military Applications	Commodity Materials, Specialty Materials, Sensing, Biological and Chemical Weapons, Sensor-Active Materials, Clandestine Sensors, Distributed Tag, Track, and Trace Systems, High-Strength Polymers, Stealth Materials, Corrosion-Resistant Coating, Biological Computing, Data Storage, Cryptographic Materials, Cognitive, Physical, and Socio-Emotional Performance Enhancement, Cybernetic Replacement, Healing Enhancement
Military Impact Categories	Force Multiplication, Advanced Weaponry & Defense, Information Advantage, Energy Advantage, Labor & Cost Reduction
Societal Impact Categories	Privacy, Nature of Humanity, Justice & Equity, Labor, Autonomy

Technology Area	**Advanced Materials Technology**
Technology	**Additive Manufacturing**
Components, Derivatives, Capabilities	Rapid Prototyping, Rapid Tooling, Rapid Manufacturing, Direct Digital Manufacturing (DDM), Part Consolidation
General Applications	Industrial Parts and Equipment Manufacturing (plus localization), Medical Implants and Prosthetics, Architectural Design and Parts, Modeling
Military Applications	Supply Chain Management and Responsiveness, Sustainable Military Operations, Contingency Resupply Operations and Parts Availability, Prosthetics
Military Impact Categories	Force Multiplication, Advanced Weaponry & Defense, Information Advantage, Labor & Cost Reduction
Societal Impact Categories	Justice & Equity, Labor

Technology Area	Advanced Materials Technology
Technology	**Advanced Synthetics**
Components, Derivatives, Capabilities	Synthetic Polymers, Synthetic Alloys, Plastic Composites, Synthetic Crystals, Self-Healing Polymers, Smart Polymers, Electron Conducting Polymers, Shape Memory Polymers and Alloys, Piezoelectric Materials, Self-Sensing Composite Materials, Embedded Fibers
General Applications	Synthetic Rubber, Lightweight Sensors, Batteries, Scaffolding, Fault-Tolerant/Wear-Resistant Coatings, Electronics, Transport, Flexible LED, Conductive Ink, Smart Textile, Embedded Electronics and Semiconductors, Synthetic Gels, Polymer Supercapacitor, Radioactive Waste Storage and Disposal
Military Applications	Protective Gear, UAVs, Sensor Systems, Vehicles
Military Impact Categories	Force Multiplication, Advanced Weaponry & Defense, Information Advantage, Labor & Cost Reduction
Societal Impact Categories	Privacy, Alienation, Justice & Equity, Labor, Autonomy

Technology Area	Advanced Materials Technology
Technology	**Metamaterials**
Components, Derivatives, Capabilities	Meta-surfaces, Transformation Optics, Electromagnetic Cloak, Optical Data Processing, Quantum Chips and Processors
General Applications	Neuro-regeneration, Tumor-Targeted Imaging, Electrical Field Stimulation Therapies, Electrochemical and Optical Biosensors, Photonic Chips, Optical Coating Technologies, Geoengineering
Military Applications	Aeronautic Acoustics, WMD Materials Manipulation, Healing Enhancement
Military Impact Categories	Force Multiplication, Advanced Weaponry & Defense, Information Advantage, Energy Advantage, Labor & Cost Reduction
Societal Impact Categories	N/A or Unclear

Technology Area	**Advanced Materials Technology**
Technology	**Nanotechnology**
Components, Derivatives, Capabilities	Nanomaterials, Nano-Energetics, Nano-Manufacturing, Nano-Metrology, Nano-Bioengineering
General Applications	4D Printing, Electronics & IT: Transistors, Magnetic Random Access Memory, Quantum Dot Ultra-HD Displays and Television, Flexible Electronics (Ultra-Responsive Hearing Aids, Semiconductor Nanomembranes, Antimicrobial Coating, Photovoltaics, Conductive Ink), Medical & Healthcare (Nanomedicine, Imaging and Diagnostics, Gene Sequencing Technology, Therapeutics, Vaccine Delivery), Energy (Fuel Production & Consumption, Energy Harvesters, Batteries, Carbon Nanotubes, Desalination, Pollutant Cleaner, Mechanical Filtration, Chemical and Biological Agents Detection, Thin Film Solar Panels, Fuel Additives, Catalytic Converters), Nanoengineered Infrastructure and Construction Materials, Nanosensors, Manufacturing and Structural Material, Cellulose Conversion, Bone and Neuro Tissue Engineering, Bio-Printing, Molecular Motors, Nanomachines, Nanoengineered Brain-Machine Interfaces (BMI), Smart Dust, Geoengineering
Military Applications	Nano-Explosives, Chemical & Biological Weapons, Bioterrorism, Nuclear Activity Monitoring and Detection, Electromagnetic Stealth Technology, Nano-Engineered Land, Air, Space Structures
Military Impact Categories	Force Multiplication, Advanced Weaponry & Defense, Information Advantage, Energy Advantage, Labor & Cost Reduction
Societal Impact Categories	Privacy, Nature of Humanity, Justice & Equity, Labor, Autonomy

Technology Area	**Earth and Energy Technology**
Technology	**Advanced Energy Storage**
Components, Derivatives, Capabilities	Harvesting, Storage, and Generation Technologies, — Solid-State Batteries, Photovoltaics, Perovskite-Structures, Piezoelectric Materials, Salt-Based Energy Storage, Distributed Systems, Carbon Capture and Sequestration, Direct Air Capture,
General Applications	Electric Vehicles, Pacemakers, Wearables, Wireless Sensor Networks
Military Applications	Endurance Drones, Lightweight, Flexible Solar Panels
Military Impact Categories	Force Multiplication, Advanced Weaponry & Defense, Information Advantage, Energy Advantage, Labor & Cost Reduction
Societal Impact Categories	N/A or Unclear

Technology Area	Earth and Energy Technology
Technology	**Advanced Renewables**
Components, Derivatives, Capabilities	Geothermal Energy, Biomass and Biofuels, Hydro and Ocean Power, Wind, Solar, Hydrogen, Green Ammonia, Synthetic Fuels, Electrofuels, Next-Generation Nuclear Technology (Fusion, Thorium, Advanced Light and Heavy Water Reactors, High-Temperature Gas Reactors, Molten Salt Reactors, Sodium-Cooled Fast Reactors, Lead-Cooled Reactors, Tristructural-Isotropic-Fueled Reactors, Fast-Neutron-Spectrum Reactors, Advanced Pressurized Water Reactors, Pebble Bed Reactors)
General Applications	Next-Generation Energy Conversion and Power Generation Systems, Advanced Fuel Cells and Battery Technologies, Catalytic Chemistry and Biochemistry, Waste and Carbon Dioxide Remediation, Efficient Energy Management Systems, Nuclear Powered 3D Printing
Military Applications	Next-Generation (Resilient and Mobile) Energy Conversion and Power Generation Systems, Advanced Fuel Cells and Battery Technologies, Efficient Energy Management Systems, Nuclear: Small and Micro Nuclear Reactors, Directed-Energy Weapon Power Systems, Space Flight and Naval Propulsion Systems, 3D Printing, Hydrogen: Vehicles and Transport Systems, Stealth Submarines, Ballistics, UAVs
Military Impact Categories	Force Multiplication, Energy Advantage
Societal Impact Categories	N/A or Unclear

Technology Area	**Earth and Energy Technology**
Technology	**Hypersonic Technology**
Components, Derivatives, Capabilities	N/A or Unclear
General Applications	Payload Delivery, Space Access, Time-Critical Targets, High-Speed Transportation
Military Applications	Hypersonic Glide Vehicles, Hypersonic Cruise Missiles, Conventional Prompt Global Strike, Tactical High-Speed Strike Capability
Military Impact Categories	Force Multiplication, Advanced Weaponry & Defense
Societal Impact Categories	N/A or Unclear

Appendix B:
Background & Methodology

At the outset of this project we recognized that emerging technologies will have significant impacts on both national security and on society and human flourishing. But in order to determine which technologies would have the greatest impact, and in which areas, we needed to create a more standardized technology taxonomy.

We reviewed the literature and compiled technology categories used across various think tank, research, and government documents, expecting natural categories to emerge. We ended up facing several challenges:

- There is no standardized way of talking about and organizing technologies across different organizations and documents. Variations in the usage of terms like applications, capabilities, enablers, and core technologies made compilation and side-by-side comparisons difficult.
- Individual documents lacked a systematic method for categorizing different technologies. For example, lethal autonomous weapons might be placed alongside biotechnology, or big data alongside artificial intelligence. However, technologies of interest are not necessarily directly comparable. Some serve as core underlying capabilities while other sit closer to the application layer.
- The sources that do succeed in creating more structured categories begin in the outer layer with end uses, applications, and component technologies. As a result, there are numerous overlaps between categories. For example, supply chain management crosscuts the Internet of Things, blockchain, artificial intelligence, and nanotechnology among others. This resulted in a crowded picture of the technologies involved.

For these reasons, we could not easily delineate the relationships and implications of these technologies with the existing categories available in the literature.

To solve this, we used technical and scientific papers, academic journals, and information from national laboratories to decompose each technology of interest into its components, derivatives, and applications. This gave us the borders of each technology and a map of relationships to organize the technologies into the broadest categories for comparison without sacrificing details or precision of our categories. In this way, we created a tree that shows the boundaries between technologies and the many branches of applications while grouping them into families, or bundles of technology domains.

Despite our best efforts, our categorization still has limitations, and throughout the progress of our work we gained an appreciation for the existing literature and the attempts of our predecessors. To situate the landscape of technologies in a more comprehensive but precise way, we had to identify and decompose the broadest categories of technology into component capabilities or technologies, derivative capabilities, and applications. This posed another set of challenges:

- The ways in which certain technologies have entered the public discourse raised significant obstacles. An ideal taxonomy would break down each technology into a common set of components. Unfortunately, familiarity with and interest in these details are uneven across the technologies and resist standardization. For example, under quantum technology, we have the components computing, sensing, and communication, which form the core of quantum capabilities. Approaching genomic engineering in this manner would give us something along the lines of computational modeling, genetic logic, DNA synthesis and assembly, and directed evolution. Most of our audience is far less familiar–and interested–in the latter. On the other hand, the literature on artificial intelligence and its related technologies has become widely dispersed in the public discourse, which may explain why components of artificial intelligence such as big data analytics and machine learning are frequently given equal status to artificial intelligence.
- Some technologies don't lend themselves well to neat partitions between capabilities and applications. The capabilities and applications themselves may be ambiguous. This may be because the scholarly discourse and research has not yet matured or that capabilities have not made their way into clear use-cases and applications. For synthetic biology and genomic engineering, in particular, genomic engineering is both a technology of interest and a component capability of synthetic biology.

- The decomposition of the technologies allowed us to capture and organize much of the existing literature, but this doesn't mean that we have exhausted every technology that may have an impact on military and society/human flourishing. We were bound to make a trade-off between the depth and the breadth of this taxonomy.

Despite these many challenges, by starting from the underlying technology rather than use-cases or applications, we were able to create a practical technology taxonomy that is closer to "mutually exclusive, collectively exhaustive" (MECE) principles. We have attempted to create minimal overlap between the combined components and derivative capabilities across the technologies. By grouping families of technologies in technology areas, we have also situated cross-cutting applications squarely within the context of a single technology domain without losing sight of their cross-domain effects.

Our goal was not to create a taxonomy simply for taxonomic purposes, but we put significant thought and energy into identifying and organizing the technologies of interest such that the taxonomy reflects the technical contours and relationships in order to achieve a level of systematic accuracy. This taxonomy isn't complete or depth-intensive, nor was it intended to be. Our purpose was simply to look for a way to better understand and visualize the military and societal implications of technologies in order to inform the rest of this project.

Appendix C:
Societal Impact Categories

Privacy: Privacy allows for the expression of our individuality. It is necessary for freedom of expression, thought, association, creativity, and experimentation. It also allows us to engage with each other socially in an autonomous fashion.

Alienation: Humans are social creatures. While technology can make certain tasks more efficient, it can also increase social isolation and alienation. Alienation results from the inability to control significant and basic aspects of our lives, a feeling of estrangement from the social forces that dictate our lives, and the breakdown of social ties and cohesion.

Nature of Humanity[126]: What makes a person a person? At what point does artificial and biological augmentation push a being to become post-human? At what point does artificial intelligence take on roles traditionally occupied by humans? Redesigning human biological structure alters our definition of humanity. Artificial intelligence gives some human qualities to non-human entities and objects.

Justice and Equity: Access to technology and its resultant benefits will not be spread equally or equitably. This has ramifications for economic distribution, societal structure, justice, and political representation and resilience.

Labor: Technology will cause large numbers of workers to become irrelevant. This threatens not only the individuals themselves, but society and political structures—particularly democratic ones. The nature of much labor will also change, leaving humans less connected with final products and lacking in productive, meaningful, and satisfying work.

Autonomy and Agency: Autonomy and agency refer to our existence as something more than biological shells and automatons; we make our own choices about ourselves and have the moral freedom to do as we see right. Autonomy and agency are threatened when we feel like mere instruments of something beyond our control.

126 The question of whether to include "nature of humanity" is worth further consideration. Despite seeming like an obvious area of impact, to what extent would we care about the nature of humanity if it didn't impact any of the other categories?

Appendix D
Military Impact Categories

Force Multiplication: This amplifies capabilities through a combination of synergetic attributes without requiring greater mass or volume of resources. It enables numerically inferior forces to prevail through elements such as leadership, morale, new strategy and tactics, and relative combat effectiveness. New measure and countermeasure dynamics will emerge. Innovations in organizational logic and strategic doctrines can produce game-changing tactical and strategic advantages. Force multipliers include: surprise, stealth, range extenders, all-condition capabilities, low-visibility capabilities, counter-electronic defense, coordination mechanisms, trust, alliances, energy efficiency, and efficient defense production.[127]

Advanced Weaponry and Defense: The integrated battlefield will demand seamless interoperability and system resilience. Advanced battle systems and platforms will reflect this shift with increasing autonomy and connectivity of new and legacy technologies across a common architecture. The next generation of weapons and defense applications enhance stealth, non-kinetic, precision, and autonomous capabilities aimed at securing or disrupting integrated, multi-domain command and control targets and operations.

Information Advantage: Information advantage involves securing multi-domain command and control, battlefield awareness, and decision dominance over the networked environment while denying, degrading, corrupting, or destroying the enemy's information assets. This includes the ability to project a fusion of kinetic and non-kinetic power through means of electronic warfare, psychological operations, deception, information and physical attacks on information targets. To a large extent, future wars will be fought over control and integrity of data and information. War and peace will become increasingly indistinguishable.[128]

127 Vinod Anand, "Impact of Technology on Conduct of Warfare," *Strategic Analysis* 23, no. 1 (April 1999), https://ciaotest.cc.columbia.edu/olj/sa/sa_99anv02.html.

128 *Strategic Appraisal: The Changing Role of Information in Warfare* (Santa Monica: RAND Corporation, 1999), https://www.rand.org/pubs/monograph_reports/MR1016.html; and "Information Warfare," *Naval Postgraduate School Center for Information Warfare and Innovation*, https://nps.edu/web/ciwi/info-warfare.

Energy Advantage: Energy is both a strategic weapon and a resource. Developments in energy technology seek to minimize the requirements of mission operations and delivery and maximize performance and power for infrastructure and weapons systems. Advancements in energy production, storage, and generation technology seek to close supply vulnerabilities by optimizing output, efficiency, and resilience. The maturation of directed energy weapons adds a new dimension to kinetic and non-kinetic warfare.

Labor and Cost Reduction: Cost- and labor-reducing technology enhances either input or output. Technology promises new materials, energy sources, computational and machine capabilities, and cutting-edge weapons and defense applications that reduce human and non-human capital and costs to achieve superior results. Efficiencies may include new concepts in logistics, force employment, and force structure enabled by cost-cutting innovations in equipment, weaponry, and infrastructure.