The Global Race for Future Power

Critical Technology and the Strategic Development of Talent

A report by the International Cyber Policy Centre at the Australian Strategic Policy Institute (ASPI) presents an insight into how critical technologies play a crucial role in the global economy, society, green energy production, medical breakthroughs, and military capabilities. A key theme is that the Covid-19 pandemic, geopolitical tensions, and changes in global supply chains have disrupted international collaboration. In future, countries may wield critical materials as economic coercion weapons, leading to an energy crisis.

The ASPI report, along with the Critical Technology Tracker website, identifies leading countries, universities, and businesses in scientific research and innovation. China is ahead in 37 of the 44 evaluated technologies, often producing over five times as much high-impact research as its closest competitor. The US leads in advanced semiconductor devices, high-performance computing, advanced integrated circuit design, quantum computing, and vaccines. The UK and India closely compete for the next most important technological powerhouse, followed by South Korea, Germany, and Australia. The Critical Technology Tracker also highlights leading organizations in various technologies, such as the University of California system, the Chinese Academy of Sciences, and the Indian Institute of Technology.

Dominance in most technology categories by the US and China highlight the fact that any development of long-term domestic technology leadership by a country requires a holistic viewpoint of how that country fits into the global competition for talent, resources, and market share. A broader perspective is that nations seeking to develop local technology leadership must compete with the US and China for graduates, irrespective of their country of origin. Understanding the human dimension of technology development is crucial, as innovations come from skilled researchers. China's lead in high-impact research is due to its majority of researchers being trained domestically and its ability to attract talent from democratic countries. However, translating high-impact research into manufacturing reliable products requires a different skill set, which China is also striving to develop.

These findings are apparently intended to serve as a wake-up call for those nations who are not leading the rankings. Urgent policy changes, increased investment, and global collaboration are needed to close the growing gap.

Critical Technologies in the Conventional and Renewable Energy Industries

Two themes have dominated social media and professional conferences for anyone connected to the ‘Energy Transition’ space in recent years:

- **Data Analytics / AI / Machine Learning / High Performance Computing**: Computationally intensive challenges that formerly relied upon some of the world’s largest supercomputers are increasingly augmented by cloud computing, machine learning is being integrated into all stages of the ‘E&P Life cycle’, and interest is slowly growing in quantum computing opportunities. Efforts to reduce the carbon impact of marine seismic surveys and improve their HSE performance now also rely upon AI solutions.

- **Access to Critical Minerals and Global Electrification**: Current mining efforts and known reserves of many metals and minerals necessary to replace hydrocarbons as the global energy base are deficient. Nevertheless, the development of battery technology, attracts vast investment in R&D and industrialization. Nuclear, hydrogen, solar, and wind, all consume vast natural resources to bring online, and each has a carbon impact at different stages of their lifecycle.

The relevance of these themes to this newsletter is that a 'global technology competition' between developed nations is underway to develop relevant technologies, attract highly educated graduate talent, and build competitive market share. Furthermore, those countries with strategic leadership in key technology arenas can exploit that leadership to gain economic and political advantage over other countries seeking to catch up or compete.

Although I summarize the overall content of the ASPI report and Critical Technology Tracker website, the examples chosen are deliberately relevant to the two broad themes just mentioned.

ASPI's Critical Technology Tracker (The Global Race for Future Power)

The ASPI study focused on research quality over quantity to rank countries and organizations by analyzing quality metrics, such as the proportion of papers in the top 10% most highly cited research reports, the H-index, and the number of top-performing research institutions. Quality metrics distinguish high-impact research papers from low-quality ones, providing insight into a nation's technical capability.

Citations reflect a paper's impact, and only papers of similar age should be compared using citation counts. The H-index combines quantity and impact measures and performs better than other single-number research quality summaries. The study uses both the top 10% and the H-index as neither is perfect and both offer unique insights.

ASPI's Critical Technology Tracker offers insights into strategy, intent, and potential future capabilities, as well as the spread and concentration of global expertise. The claim is made that countries can use the tracker to support strategic planning, targeted investment, and global partnerships. Research papers published between 2018 and 2022 were analyzed in 44 technology areas using custom search queries for the Web of Science database. The database is heavily used by researchers studying scientific trends and has well-understood performance characteristics. Most reports (98.7%) were in English, limiting the dataset but capturing research papers published in high-profile journals.

'Technology Monopoly Risk' Metric: Highlighting Concentrations of Technological Expertise

The study used large-scale data analytics to place quality metrics within a geographical context by summarizing the institution and host country for each author's affiliation address. The "technology monopoly risk" metric highlights concentrations of technological expertise in a single country, considering the lead the top country has over the next competitor and the number of the world's top 10 research institutions in the leading country. This metric serves as a leading indicator for potential future dominance in technology capability.

Researchers also tracked the global flow of human talent by identifying the countries where authors obtained their undergraduate and postgraduate degrees, revealing brain gains and brain drains for each country. Talent-flow charts in the report track a sample of authors from high-impact papers, providing insights into the global competition for research talent.

Technology Deep Dives

The ASPI report includes a "Technology deep dives" section that provides in-depth analysis in three technology areas: **artificial intelligence**, **quantum technologie**s and **advanced materials and manufacturing**. For each technology area, a table is included of the top five ranked countries and the technology monopoly risk, insights, and context from the top 20 institutions, and key points from the talent tracker.

Table 1 summarizes the Top 5 countries for ten technologies sit within the artificial intelligence, computing, and communications category in ASPI's Critical Technology Tracker.

AI, more than any other technology, continues to dominate the public debate. In the related field of *advanced data analytics*, China leads, claiming 13 of the top 20 institutions, which is crucial for deriving valuable insights from large datasets and maintaining a competitive edge in industries like search engines. Top institutions in this field include the Chinese Academy of Sciences, the University of California system, and Huazhong University of Science and Technology. The University of California system is the only institution to rank among the top 20 in all AI categories, benefiting from its location in California's vibrant tech ecosystem. Other notable institutions in AI include Tsinghua University, Zhejiang University, the Indian Institute of Technology, and Singapore's Nanyang Technological

University and National University of Singapore. Major US tech companies, such as Google, Microsoft, Facebook, Hewlett Packard Enterprise, and IBM, are also well represented in AI research.

Technology	Top 5 countries					Technology monopoly risk
Advanced radiofrequency communications (incl. 5G and 6G)	29.65%	9.50%	5.18%	4.89%	4.83%	8/10 3.12 **high**
Advanced optical communications	37.69%	12.76%	5.64%	3.88%	3.48%	8/10 2.95 **medium**
Artificial intelligence (AI) algorithms and hardware accelerators	36.62%	13.26%	4.20%	4.15%	3.48%	7/10 2.76 **medium**
Distributed ledgers	28.38%	11.32%	8.94%	5.54%	4.81%	6/10 2.51 **medium**
Advanced data analytics	31.23%	15.45%	6.02%	4.19%	3.92%	8/10 2.02 **medium**
Machine learning (incl. neural networks and deep learning)	33.20%	17.93%	4.87%	3.87%	3.32%	7/10 1.85 **low**
Protective cybersecurity technologies	23.33%	16.80%	7.67%	5.71%	5.20%	5/10 1.33 **low**
High performance computing	29.31%	25.57%	6.34%	4.68%	3.98%	3/10 1.15 **low**
Advanced integrated circuit design and fabrication	24.18%	21.19%	7.16%	4.46%	3.57%	4/10 1.14 **low**
Natural language processing (incl. speech and text recognition and analysis)	25.73%	23.57%	5.74%	4.55%	3.37%	5/10 1.09 **low**

Table 1. Top 5 countries for artificial intelligence, computing, and communications. From Table 3 in Gaida et al. (2023).

Regards employment trends, the US is generally good at attracting migration from overseas into its postgraduate training programs in all technology areas within the AI, computing, and communications category. Significant talent pools migrate from India and China to work in the US. **Figure 1** uses the Critical Technology Tracker to [compare how well the US is going against China in the flow of talent for the machine learning category](#).

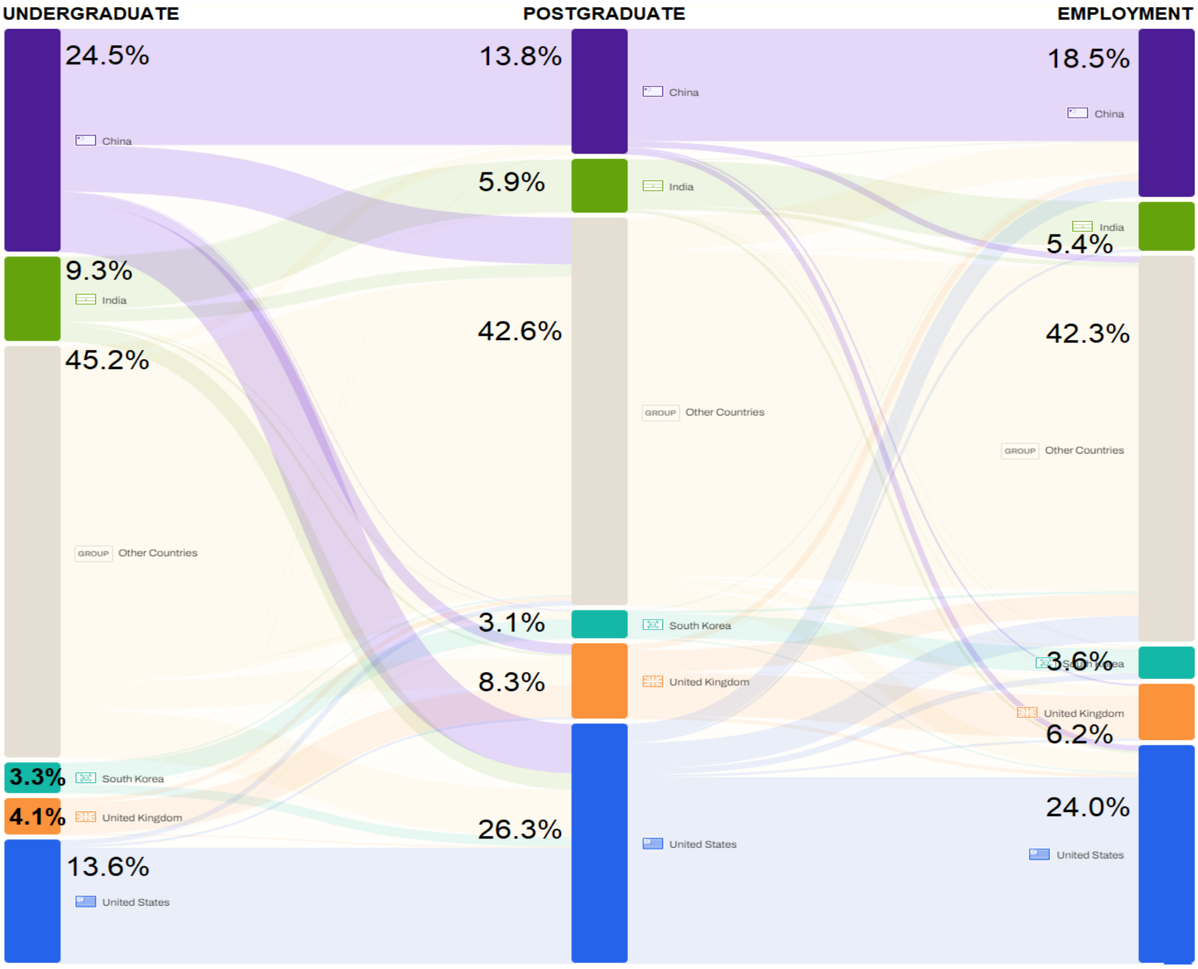

Figure 1. Critical Technology Tracker comparison of China, India, Other Countries, South Korea, UK, and US (from top to bottom) in the ***flow of machine learning talent*** *across undergraduate, postgraduate, and employment categories*.

Inflows to China at the employment level are greater than outflows at the postgraduate level. The US attracts significant talent from overseas, particularly from India and China, into its postgraduate programs in AI, computing, and communications. However, after the postgraduate level, the US loses a considerable portion of this talent to China, South Korea, the EU, and other countries. China gains talent in AI across all technologies and manages to attract foreign talent for employment. The UK and Australia excel in attracting and retaining talent in AI categories. India faces brain drain in AI algorithms and hardware accelerators but retains most of its machine learning talent.

The US and China have comparable employed talent in advanced data analytics and protective cybersecurity. The US leads in advanced integrated circuit design, high-performance computing, and natural language processing. A US-Europe alliance in advanced integrated circuit design and fabrication could hinder China's aim for supremacy in this area. Europe is on par with or exceeds China's global talent in advanced radiofrequency communications and distributed ledgers and could play a more significant role in these critical technologies.

Appendix 1.1 (Top 5 country visual snapshots) in the ASPI report also provides a visual snapshot showing the top 5 countries ranked by their (%) proportion of high-impact research output across 44 technologies. The column on far right of the *energy and environment* categories in **Table 2** called "Technology monopoly risk" seeks to highlight concentrations of technological expertise in a single country. China again dominates most categories.

Technology	Top 5 countries					Technology monopoly risk
Hydrogen and ammonia for power	60.43%	6.74%	4.71%	2.83%	2.80%	9/10 8.97 **high**
Supercapacitors	64.19%	7.28%	4.89%	4.78%	2.03	10/10 8.81 **high**
Electric batteries	65.44%	11.87%	3.81%	2.80%	2.43%	10/10 5.51 **high**
Photovoltaics	39.33%	9.18%	5.40%	4.90%	3.30%	7/10 4.28 **medium**
Nuclear waste management and recycling	35.95%	16.55%	6.51%	4.51%	4.39%	8/10 2.17 **medium**
Directed energy technologies	39.09%	19.08%	5.88%	5.34%	2.85%	7/10 2.05 **medium**
Biofuels	23.15%	15.48%	5.48%	4.42%	3.65%	5/10 1.50 **low**
Nuclear energy	26.83%	20.45%	6.11%	4.39%	4.26%	4/10 1.31 **low**

Table 2. Top 5 countries in various energy and environment categories.

Summary

China has clearly established itself as a leading science and technology superpower in critical and emerging domains. ASPI's research shows that China leads in 37 out of 44 tracked technologies, excelling in defense, space, robotics, energy, biotechnology, AI, advanced materials, and quantum technology. A second-tier group of countries includes India, the UK, South Korea, Germany, Australia, Italy, and occasionally, Japan. China's dominance is the result of deliberate policy planning and strategic investment. Every other nation seeking to attain technology leadership must take notice and similarly invest with long-term mindsets.

Further Reading

Gaida, J., Wong-Leung, J., Robin, S., and Cave, D., 2023, ASPI's Critical Technology Tracker (The global race for future power): Australian Strategic Policy Institute, International Cyber Policy Centre, Policy Brief, Report No. 69/2023, 84 p. https://www.aspi.org.au/report/critical-technology-tracker