*Shows newly added technologies and new data

AUKUS RELEVANT TECHNOLOGIES: Top 10 country snapshot

Below is a snapshot showing data from ASPI's *Critical Technology Tracker* (techtracker.aspi.org.au/). It sets out the top 10 countries, ranked by their (%) proportion of high-impact research output, across 23 critical technologies. In ASPI's view, these technologies are integral to the advanced capability areas likely to be important to AUKUS Pillar 2 as the trilateral security partnership (United States, United Kingdom, Australia) builds over the coming years. For example:

Technology	Technology monopoly risk	Lead institution	AUKUS rank (total %)	Top 10 countries									
Hypersonic detection, tracking, and characterization*	9/10 5.20 high	Northwestern Polytechnical University (China)	2nd 18.7%	73.3%	14.1%	4.1%	1.0%	1.0%	0.7%	0.6%	0.6%	0.6%	0.6%

ASPI's Critical Technology Tracker: focuses on a key performance measure of scientific and technological capability—high-impact research—and reveals where countries, universities, national labs and companies around the world have a competitive advantage in this measure across (now) 52 technologies. Another feature on the website is a 'talent tracker' which reveals the flow of global talent in these technologies and highlights brain gains and brain drains for each country. To measure 'high-impact research' we collected and analysed the top 10% of the most highly cited papers (2.2million papers published 2018-2022) to generate insights into which countries and organisations are publishing the greatest share of high-quality and innovative research in critical technology and defence fields (see more on page 6).

New findings: this AUKUS Pillar 2 focused research reveals that China is leading in high-impact research in 19 of these 23 technologies and has a commanding lead in hypersonics, electronic warfare and in key undersea capabilities. But in other key technologies such as autonomous systems operation technology, advanced robotics, adversarial AI-reverse engineering and protective cyber the collective strength of the AUKUS countries shifts this picture, and they take the global lead. A slightly larger grouping of countries would change the picture even further. But across a number of technology areas China's lead is so great that no aggregation of countries exceeds its share - highlighting the importance of the accelerating effect of greater collaboration between like minded partners. For some technologies at least 9 of the world's top 10 research institutions are based in China (for autonomous underwater vehicles it's 10/10) and they are collectively generating 8 times more high-impact research than the second-ranked country (in all cases the US). In these 23 technologies, ASPI's talent tracker dataset shows 14.2% of high-impact authors working in China completed postgraduate training in an AUKUS country (US = 8.5%, UK = 3.8%, Australia = 1.9%), while 4.3% trained in the EU, 1.9% Canada, 1.6% Singapore and 1.1% Japan. That knowledge import is highest in defence categories like hypersonic detection (AUKUS 19.5%) and electronic warfare (AUKUS 17.6%).

Potential future technological capability: What ASPI's Critical Technology Tracker provides - beyond datasets showing research performance - are unique insights into strategy, intent and potential future capabilities. It also provides valuable insights into the spread and concentrations of global expertise across a range of critical areas. Sometimes countries are leading because they are well ahead across the entire technology (research, commercialisation, manufacturing, supply: for example China's stunning lead in electric batteries). In other cases, a country is leading in high impact research output because they (and their institutions: universities, national labs and companies) are seeking to catch-up through significant investment, typically incentivised by government funding and policy directives.

AUKUS RELEVANT TECHNOLOGIES: Top 10 country snapshot

Why high-impact research is important: Scientific and technological innovation is typically underpinned by high impact research and there are clear links between 1) high-impact research; 2) scientific and technological breakthroughs and 3) commercialisation. Our report discusses this in depth (and see page 6 below): www.aspi.org.au/report/critical-technology-tracker. But whether the focus is hypersonics or autonomous underwater vehicles, actualising research performance, no matter how impressive, into major technological gains can be a difficult and complicated step that requires other inputs in addition to high quality research, such as investment, an effective manufacturing sector and the right policy and regulatory frameworks.

The technology monopoly risk traffic light

This metric (see column below) seeks to highlight *concentrations of technological expertise in a single country*. It incorporates two factors: 1) how far ahead the leading country is relative to the next closest competitor, and 2) how many of the world's top 10 institutions that produce high-impact research are located in the leading country. Naturally, these are related, as leading institutions are required to produce high-impact research. This metric, based on high-impact *research output*, is intended as a leading indicator for potential future dominance in technology capability. The default position is low. To move up a level, **both** criteria must be met.

- High risk = **8+/10** top institutions in no. 1 country and at least **3x research lead**
- Medium risk = **5+/10** top institutions in no. 1 country and at least **2x research lead**
- Low risk = medium criteria not met

Example: If a country has a 2.5 times research lead but 'only' four of the top 10 institutions, it will rate low, as it fails to meet *both criteria* at the medium level.
The two metrics along with the traffic light are given in the left hand column of the *top 10 country rankings* tables.

Undersea capabilities

Technology	Technology monopoly risk	Lead institution	AUKUS rank (total %)	Top 10 countries									
Coatings	8/10 7.96 high	Chinese Academy of Sciences	2nd 10.2%	58.5%	7.3%	6.0%	3.2%	2.8%	1.8%	1.8%	1.6%	1.5%	1.3%
Autonomous underwater vehicles*	10/10 6.00 high	Harbin Engineering University (China)	2nd 14.3%	56.9%	9.5%	3.3%	3.0%	2.9%	2.8%	2.4%	2.3%	2.1%	2.1%
Advanced undersea wireless communication*	8/10 4.08 high	King Abdullah University of Science & Technology (S.A.)	2nd 16.2%	44.9%	11.0%	7.1%	6.5%	3.9%	3.0%	2.6%	2.4%	2.3%	1.5%

*Shows newly added technologies and new data

Sonar and acoustic sensors*	9/10 4.01 high	Harbin Engineering University (China)	2nd 20.2%	49.6%	12.4%	6.2%	3.8%	2.9%	2.8%	2.5%	1.6%	1.6%	1.5%
Air-independent propulsion (focused on compact energy generation)*	5/10 3.75 medium	Chinese Academy of Sciences	2nd 14.3%	41.6%	11.1%	7.6%	4.3%	3.7%	3.3%	2.7%	2.4%	2.1%	1.5%
Autonomous systems operation technology	3/10 1.25 low	University of California System	**1st** 29.6%	26.2%	21.0%	5.3%	5.1%	3.5%	3.2%	3.1%	2.9%	2.4%	2.0%
Advanced robotics	4/10 1.13 low	University of California System	**1st** 33.0%	27.9%	24.6%	5.5%	4.8%	3.8%	3.6%	2.8%	2.5%	2.1%	2.0%

Quantum technologies

Technology	Technology monopoly risk	Lead institution	AUKUS rank (total %)	Top 10 countries									
Quantum computing	8/10 2.26 medium	University of Maryland	1st 42.8%	33.9%	15.0%	6.2%	5.5%	4.1%	4.0%	3.3%	3.0%	2.8%	2.7%
Post-quantum cryptography	4/10 2.33 low	University of Science and Technology China	2nd 20.8%	31.0%	13.3%	6.8%	4.7%	3.7%	3.7%	2.7%	2.5%	2.5%	2.2%
Quantum communications	5/10 1.89 low	University of Science and Technology China	2nd 26.4%	31.5%	16.7%	7.7%	6.5%	3.8%	3.8%	3.6%	3.0%	2.6%	2.2%
Quantum sensors	2/10 1.02 low	Chinese Academy of Sciences	1st 30.4%	23.7%	23.3%	7.8%	4.3%	4.3%	3.9%	2.7%	2.7%	2.6%	2.5%

*Shows newly added technologies and new data

Artificial Intelligence and Autonomy

Technology	Technology monopoly risk	Lead institution	AUKUS rank (total %)	Top 10 countries									
Drones, swarming and collaborative robots	5/10 3.50 medium	Beihang University (China)	2nd 16.9%	36.1%	10.3%	6.1%	5.1%	4.6%	2.6%	2.4%	2.1%	2.0%	1.9%
Artificial intelligence (AI) algorithms and hardware accelerators	7/10 2.76 medium	Tsinghua University (China)	2nd 19.3%	36.6%	13.3%	4.2%	4.2%	3.5%	3.4%	3.0%	2.9%	2.5%	2.5%
Advanced data analytics	8/10 2.02 medium	Chinese Academy of Sciences	2nd 23.0%	31.2%	15.4%	6.0%	4.3%	3.9%	3.3%	3.1%	2.9%	2.5%	2.1%
Machine learning (incl. neural networks and deep learning)	7/10 1.85 low	University of California System	2nd 24.5%	33.2%	17.9%	4.9%	3.9%	3.3%	2.8%	2.7%	2.5%	2.5%	2.0%
Advanced integrated circuit design and fabrication	4/10 1.14 low	University of California System	1st 28.4%	24.2%	21.2%	7.2%	4.5%	3.6%	3.5%	3.1%	3.0%	2.7%	2.6%
Natural language processing	5/10 1.09 low	Google (US division)	1st 32.9%	25.7%	23.6%	5.7%	4.6%	3.4%	2.6%	2.5%	2.4%	2.2%	2.2%

Advanced cyber

Technology	Technology monopoly risk	Lead institution	AUKUS rank (total %)	Top 10 countries									
Protective cybersecurity technologies	5/10 1.33 low	University of New South Wales (Australia)	**1st** 27.8%	22.3%	16.8%	7.7%	5.7%	5.3%	3.3%	3.2%	2.8%	2.7%	2.3%

*Shows newly added technologies and new data

Adversarial AI - reverse engineering*	7/10 1.23 low	University of California System	1st 33.7%	30.9%	25.1%	5.0%	4.3%	3.5%	3.5%	3.1%	2.9%	2.1%	2.0%

Hypersonic and counter-hypersonic capabilities

Technology	Technology monopoly risk	Lead institution	AUKUS rank (total %)	Top 10 countries									
Hypersonic detection, tracking, and characterization*	9/10 5.20 high	Northwestern Polytechnical University (China)	2nd 18.7%	73.3%	14.1%	4.1%	1.0%	1.0%	0.7%	0.6%	0.6%	0.6%	0.6%
Advanced aircraft engines (incl. hypersonics)	7/10 4.15 medium	National University of Defense Technology (China)	2nd 17.2%	48.5%	11.7%	7.0%	3.9%	3.6%	2.5%	2.2%	2.2%	2.1%	2.1%

Electronic warfare

Technology	Technology monopoly risk	Lead institution	AUKUS rank (total %)	Top 10 countries									
Electronic warfare*	9/10 3.25 high	National University of Defense Technology (China)	2nd 19.9%	46.5%	14.3%	3.9%	3.5%	3.3%	3.3%	2.8%	2.3%	2.0%	1.4%
Directed energy technologies	7/10 2.05 medium	Northwestern Polytechnical University (China)	2nd 26.3%	39.1%	19.1%	5.9%	5.3%	2.8%	2.4%	2.4%	2.0%	1.9%	1.8%

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What is ASPI's Critical Technology Tracker?

The Australian Strategic Policy Institute is the Indo-Pacific's leading defence, national security and technology think-tank. ASPI's *Critical Technology Tracker* (techtracker.aspi.org.au/) provides the public with a rich new dataset that allows users to track technologies foundational to modern economies and societies' national security and defence, energy production, health and climate security. This research seeks to assess the potential future capability of nations within each critical technology and to highlight long-term strategic trends, including areas of focus for each country. Another feature on the site is a 'talent tracker' which reveals the flow of global talent in these technologies and highlights brain gains and brain drains for each country. The *Critical Technology Tracker* and accompanying report (www.aspi.org.au/report/critical-technology-tracker) provide decision-makers with a new evidence base to make more informed policy and investment decisions. This effort goes further than previous attempts to benchmark research output across nations by focusing on individual institutions and technologies rather than on total research output.

Brief Methodology

ASPI analysed the top 10% of the most highly cited papers to generate insights into which countries are publishing the greatest share of high-quality, innovative and high-impact research. Credit for each publication was divided among authors and their affiliations and not assigned only to the first author (for example, on a five-author paper, each author was attributed 20% credit). Fractional allocation of credit is a better prediction of individuals who go on to win Nobel Prizes or fellowship of prestigious societies. The contact address for each author was provided in the data downloaded from Web of Science. Web of Science (Core Collection) is heavily used by researchers who study scientific trends and it has well understood performance characteristics. We then built a bespoke data-processing pipeline to identify both the country of affiliation and the unique research institution name for each author. Building this pipeline and cleaning this large dataset took many months of work by dedicated data scientists before the data analysis could begin. For each technology, a custom search query was developed for the Web of Science database. This identified 2.2 million research papers subsequently used for analysis (the size of each technology category dataset analysed depends upon the technology being examined). For example, there were 526,738 research papers to analyse for machine learning (2018-2022), whereas post-quantum cryptography yielded a much smaller dataset of 4,416 papers. For the full and detailed methodology please visit (from page 10): aspi.org.au/report/critical-technology-tracker.

Why research is vital for scientific and technological advancements

To build the Critical Technology Tracker, ASPI selected one of many potential methodological approaches (citations of scientific publications) over many other potential data sources examined for inclusion. Analysis of patent citations and patent ownership according to country is a rich source of insight, for example, but determining the country of origin and ownership is a complicated process so data reliability is a problem. Similarly, analysis of venture capital funding could provide valuable insight into the intensity of technical innovation. Unfortunately, obtaining consistent and trustworthy data is extremely challenging, especially at the international level. We selected research publications because we knew we could build a high quality, reliable and global dataset and high-impact research is a major contributor to technological, scientific and commercial strength. The effect is most pronounced for high-quality papers (that is, the most highly cited). For example, 80% of research papers in the top 0.01% of high-quality research are referenced in patents. This drops to 60% for the top 0.1% and 40% for the top 1%. This known connection between the most cited research and patented technical breakthroughs has been used as a proxy to measure relative institutional and national standing. In stark contrast, those research reports in the bottom 50% are almost never cited in patents. Patents that directly reference research papers deliver 26% more commercial value than otherwise comparable patents that are disconnected from research. For more analysis please visit (from page 9): www.aspi.org.au/report/critical-technology-tracker.