



# NO HANDS ON DECK: US AND AUSTRALIAN PROGRESS IN AUTONOMOUS WARFARE AT SEA

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## POLICY BRIEF

### Key takeaways

- As competition with China intensifies, future unmanned warfare can address key strategic and anti-access challenges for the United States, Australia and like-minded partners in the Indo-Pacific.
- The United States and Australia have undertaken promising experimentation in unmanned systems beneath, on and above the ocean, but more investment and experimentation is required in realistic scenarios.
- Recent updates to the defence and technology ecosystems in the United States and Australia have been sensibly predicated on fostering and harnessing innovation, though both still face limitations and concerns.
- Moving from unmanned experiments to actual capability production will require overcoming political and institutional hurdles to retiring legacy systems and making radical changes to existing force structures.

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### Introduction

As artificial intelligence (AI) and robotics technologies progress, the increasing autonomy of unmanned military systems will drive new operational concepts with the potential to transform modern war. The Indo-Pacific's contested littoral sandboxes and maritime proving grounds will be a decisive test for the future of autonomous warfare at sea. Here, the success of the United States, Australia and like-minded partners in unmanned warfare will depend on sustained, smart and collaborative investments in fundamental research, operational concept development and systems deployment. Yet, just how transformative these systems will be remains unclear owing to significant

political and institutional hurdles. In the face of these barriers to changing force structures and phasing out legacy systems, the United States FY2020 defence budget will provide a useful indicator of American intention to move experimental prototypes off the shelf and into production.

China enjoys a home court advantage in the Indo-Pacific's maritime environment. Autonomous systems, however, offer the United States and its regional allies the potential to address strategic and operational challenges posed by Chinese anti-access capabilities. The United States and Australia have undertaken promising experimentation in unmanned

sea warfare beneath, on and above the ocean's surface. Some projects, like DARPA's Sea Hunter, have achieved relatively quick success. Other concepts, like an unmanned carrier-launched combat aircraft or GPS-like maritime networks, require further research and development. As the United States and Australia modernise their naval systems, they must realistically assess what future unmanned warfare at sea will look like in terms of threats, operational challenges and new concepts and capability needs. If serious budgetary commitments are made to shift experimental systems to production, US-Australian coordination on technology development and integration can establish the basis for interoperable and collective defence in the Indo-Pacific.

## A contested Indo-Pacific

China's military strategy in the Indo-Pacific is designed to deny US power projection and access across the region. The Chinese military employs anti-ship ballistic missiles, long-range cruise missiles, conventional and nuclear submarines, integrated air defences, electronic warfare, cyber, and counter-space capabilities in an anti-access area-denial (A2/AD) strategy that is designed to increase the risk to US forces operating in China's maritime surrounds. China has also pursued 'grey-zone activities' between war and peace to coerce and pressure its neighbours and prosecute its territorial claims. It has built, seized and militarised features in the South China Sea, reignited territorial disputes and disrupted freedom of navigation and overflight in violation of regional norms and international law. In the world's most densely populated undersea environment, the result is a physically congested and militarily contested arena.<sup>1</sup>

Technologically, China seeks predominance. Its 2017 National Artificial Intelligence strategy called for technological parity with the West in homegrown AI research and development (R&D) by 2020, major breakthroughs by 2025 and global leadership by 2030.<sup>2</sup> China is operationalising AI and unmanned warfare systems in the Indo-Pacific. Undersea, the China State Shipbuilding Corporation, the chief shipbuilder for China's Navy, has proposed an 'Underwater Great Wall' to track enemy submarines. Modelled after America's Cold War-era sound surveillance system, an array of active and passive acoustic sensors would line the sea floor listening for submarines and transmitting

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information to unmanned surface vehicles (USVs) 3000 metres above on the ocean's surface.<sup>3</sup> China's Yunzhou-Tech is aggressively pursuing swarms of USVs with the ability to team with manned surface ships and, in the case of one prototype, to carry arms.<sup>4</sup> In the air, China is developing High Altitude, Long Endurance Unmanned Aerial Vehicles (UAVs), including the Soaring Dragon and Divine Eagle, for aerial reconnaissance and targeting. The former has been deployed to Hainan Island in the South China Sea, and there are reports that the latter may be operational as well.<sup>5</sup> If successful, these developments will buttress China's peripheral anti-access/area denial strategy.

## The autonomous advantage

For the United States and its allies in the Indo-Pacific, unmanned sea warfare has the potential to confer military advantages that could remain effective in the face of looming resource, manpower and anti-access challenges. While the Global Hawk UAV has often been presented as a case study for how unmanned operations can lead to greater overall human involvement, future iterations of unmanned systems may free up personnel and reduce mission, training, supply, operation and design costs.<sup>6</sup> Insofar as China's grey-zone activities have succeeded due to an unwillingness to put allied lives on the line to defend distant geographical features, unmanned operations could offer a partial solution by reducing the risk of casualties in protecting territorial claims, exclusive economic zones, international law and freedom of navigation.

In information-denied environments, allied militaries must develop new ways to establish and maintain a common operating picture. If successful, unmanned systems could enable key assets to deploy in difficult situations for prolonged periods of time, such as

nuclear-powered drones or UUVs that employ fluctuating buoyancy to propel forward motion.<sup>7</sup> With dynamic re-tasking, stealth and the ability to perform intelligence, surveillance and reconnaissance (ISR) tasks at far higher levels than existing manned systems if costs can be kept low, UUVs could form the basis of an Indo-Pacific undersea information network.<sup>8</sup> Swarms of inexpensive UUVs, USVs and UAVs could harness the 'power of the many' to wreak havoc on costly military assets or execute complex jamming or bombing missions. Since swarms are more resilient to losses, they may be less vulnerable to traditional anti-air defences such as those fielded by China on military facilities in the South China Sea.<sup>9</sup>

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In anti-access zones, projecting power from outside the range of anti-aircraft and anti-surface systems has never been more important. In order to maintain mission effectiveness, alternate concepts and tactics must be employed that allow manned submarines or surface ships to stand off from the fray. To this end, unmanned systems functioning as forward-facing 'scouts' or persistent attack assets could extend the effective range of submarines, aircraft carriers and traditional fighters.<sup>10</sup>

## **Application to sea warfare in the Indo-Pacific**

The United States and Australia are already pioneering new concepts for sea warfare that utilise unmanned systems to improve current operational capabilities. To remain relevant in the Indo-Pacific, their goals should be to defeat anti-access challenges, uphold freedom of navigation and build a strong, regional networked defence across all three naval domains: subsurface, surface and above surface. Both countries will need to couple investments in unmanned systems with

changes to force structure, budgets, and operational planning if they are to effectively transition prototypes into production.

### **Under the sea**

Below the surface of the sea, the Indo-Pacific harbours the world's densest concentration of submarines.<sup>11</sup> As China increases its fleet from 56 to "between 69 and 78" submarines by 2020, this region will grow more congested.<sup>12</sup> UUVs of all sizes under development allow manned submarines to avoid the fray and optimise their utility for operations where they are absolutely necessary.<sup>13</sup>

At the largest scale, the United States and China are developing Extra-Large UUVs (XLUUVs) for missions such as gathering intelligence, deploying underwater mines, scouting and decoying for manned submarines, blocking geographical chokepoints and destroying high-value targets via 'suicide' attacks.<sup>14</sup> In the Indo-Pacific, strategic maritime chokepoints govern China's access to open waters in the Pacific and Indian Oceans; they also facilitate US and Australian access to the South China Sea and waters closer to China.<sup>15</sup> Commanding these chokepoints — the Strait of Malacca, the Taiwan Strait, the Straits of Karimata and Makassar and the Ryukyu Islands — thus determines mobility into, out of and through the region.<sup>16</sup> By the 2040s, when XLUUVs are projected to come online, these chokepoints will likely be contested. Teams of UUVs may be running 'zone defence' — patrolling specific geographical areas — and monitoring chokepoints, allowing the United States and its allies to compete for the control of chokepoints in a crisis, while freeing manned submarines to fulfil other strategic missions.

XLUUVs may also form the basis of an 'underwater aircraft carrier' concept, where larger sea drones deploy smaller counterparts or other advanced payloads undersea.<sup>17</sup> The United States is pursuing this concept through DARPA's Hunter Program.<sup>18</sup> In 2017, the Navy hosted a competition to develop an XLUUV that could deploy modular payloads (including smaller UUVs) after a 2000-nautical mile undersea transit.<sup>19</sup> Such developments, if realised in practice, would allow stealth and undersea power projection in contested waters.

At the smaller end of the spectrum, the US Navy employs UUVs for mine detection and ocean surface



Sailors assigned to Unmanned Undersea Vehicle Squadron 1 (UUVRON 1) perform maintenance on a Bluefin-12D, an unmanned underwater vehicle (Photo: US Navy)

mapping, with neutralisation and anti-submarine warfare missions in mind.<sup>20</sup> In 2017, the Navy fielded its first undersea drone squadron, UUVRON-1, under the Pacific Fleet's Submarine Command.<sup>21</sup> Looking ahead, swarms of UUVs could spoof the acoustic signature of submarines to confuse opposing submarines, harass adversary navigation or sink enemy ships at a standoff distance.<sup>22</sup>

### On the surface

On the water, competition is also intensifying to develop USVs for swarming operations and asymmetric attacks on high-value surface assets. Australian robotics start-up Aquabotix has developed SmartDiver, a micro UUV/USV hybrid that can dive to a depth of 50 metres and communicate with other members of its swarm to execute complex missions.<sup>23</sup> SmartDiver is designed for ISR and "sophisticated, coordinated assaults through tracking, trailing and overwhelming targets".<sup>24</sup> In June of 2018, Aquabotix signed a contract with the US Navy for counter-mine operations and received an explosives license from the US Bureau of Alcohol, Tobacco and Firearms in October.<sup>25</sup> Such US-Australian collaborations strengthen existing efforts towards building networked defence in the Indo-Pacific.

USVs with links below the surface are also being developed for anti-submarine warfare hunting and tracking operations. In 2018, DARPA's Anti-Submarine Warfare Continuous Trail Unmanned Vessel (ACTUV) program, otherwise known as the 'Sea Hunter' submarine tracker, successfully transitioned to the Office of Naval Research for development and possible inclusion in operations with the US Navy.<sup>26</sup> A twin-diesel engine USV capable of autonomous patrolling for 60-90 days at a time, the Sea Hunter was designed to detect, track and identify quiet, modern diesel-electric submarines like those China is fielding, using advanced sonar and magnetometer arrays. If fully deployed, this capability will revolutionise situational awareness and undersea dominance.

The Sea Hunter will also save money. DARPA has estimated that the cost of operations by the Sea Hunter will be US\$15,000-\$20,000 per day as opposed to the US\$700,000 per day that an Arleigh Burke-class destroyer would require. Accordingly, the Navy is considering the Sea Hunter's ability to field modular payloads for additional missions. In the words of Fred Kennedy, director of DARPA's Tactical Technology Office: "ACTUV represents a new vision of naval surface warfare that trades small numbers

of very capable, high-value assets for large numbers of commoditised, simpler platforms that are more capable in the aggregate... The US military has talked about the strategic importance of replacing 'king' and 'queen' pieces on the maritime chessboard with lots of 'pawns', and ACTUV is a first step toward doing exactly that."<sup>27</sup> Given the added risks in a congested environment and the threats to high-value assets from China's own area-denial capabilities, a 'pawns' strategy is shrewd. This strategy, however, relies on overcoming significant political and institutional resistance to making radical changes in the US Navy's current force structure. Signalling support for legacy systems, in January the Navy signed a US\$15.2 billion order for two additional Ford-class carriers despite growing concerns about the carrier's vulnerability to Chinese and Russian anti-ship missiles and submarines.<sup>28</sup>

### **Above the sea**

Overhead, UAVs may prove valuable in the Indo-Pacific for establishing a common operating picture, extending the range of manned aircraft and evading anti-aircraft systems via swarms and decoys. The US Navy's MQ-4C Triton UAV was scheduled to deploy to Guam by the end of 2018 to conduct broad area maritime surveillance over the Pacific. Triton's first mission is to track maritime targets from up to 60,000 feet above the sea and report their whereabouts to naval air and ground stations in the United States or to manned P-8A Poseidon anti-submarine aircraft nearby.<sup>29</sup> DARPA's Sea Hunter is also designed to communicate with both systems. Beyond the maritime ISR mission, Triton is intended to perform signals intelligence by 2021, when it is scheduled to reach initial operational capacity.<sup>30</sup>

Australia has ordered the Triton UAV as part of a Memorandum of Understanding with the US Navy, partnering to influence its future design.<sup>31</sup> With Royal Australian Air Force (RAAF) Base Tindal 3,700 kilometres from the South China Sea, Australia could theoretically fly surveillance missions over the contested region and high above the range of air defences.<sup>32</sup> The Australian Navy has also commissioned 822X, an experimental UAV squadron exploring new approaches to the ISR mission.<sup>33</sup> Furthermore, in February 2019 Boeing unveiled plans for an Australian-built, multi-mission "Loyal Wingman" UAV which is expected to fly alongside manned fighters to enhance their combat

effectiveness. A prototype of this semi-autonomous system is expected to fly in 2020.<sup>34</sup>

The US Navy is making advancements in aerial manned-unmanned teaming, having recently demonstrated the ability to conduct aerial refuelling of a manned F-18 fighter with an unmanned MQ-25 Stingray UAV tanker prototype. The Stingray, which takes off and lands on an aircraft carrier, will eventually replace the use of other F-18s for 'buddy refuelling', freeing up pilots and platforms for other functions. The US\$805 million award projects that the development of this UAV by 2024 will extend the combat range of F/A-18 Super Hornets, EA-18G Growlers, and F-35C fighters.<sup>35</sup> The Stingray program's precursor, the Unmanned Carrier-Launched Surveillance and Strike (UCLASS) program, has also considered developing unmanned fighters to penetrate enemy airspace and hunt down air defences.<sup>36</sup> Going forward, the US Navy could develop this more challenging follow-on concept in the 2040s to extend the combat range of carrier-based aircraft themselves. In the Indo-Pacific's challenging anti-access environment where long-range anti-ship missiles such as the Chinese DF-21D ballistic missile are proliferating, increasing the ability of carrier-based fighters to operate effectively far away from shorelines may be crucial to their ongoing relevance and power projection mission.

## **US and Australian innovation engine**

None of these programs are guaranteed. The operational success of autonomous naval capabilities will require budgetary commitments to support large-scale production and a willingness to make radical change to existing force structure. Sustained investments in the research and development of core technologies — such as machine learning, autonomous undersea and surface navigation, and underwater data links communication — will also be crucial. With a rapidly growing quantity of defence-relevant inventions now coming from outside government laboratories, building and harnessing a robust culture of innovation is a military imperative.

The Pentagon's 2014 Third Offset Strategy recognised this shift and laid the foundations for the US military to better harness private sector technology and foster an

innovation culture within the Department of Defense.<sup>37</sup> Today, the Defense Innovation Unit (DIU) scouts the private sector for breakthrough technologies and employs new acquisition authorities to bring these into the defence ecosystem. The Strategic Capabilities Office repurposes existing weapons systems to counter new threats. And the Defense Innovation Board serves as an outside advisory arm to the Secretary of Defense, bringing a Silicon Valley mindset and development expertise to issues of technology, culture and innovation within the department. Each of these entities has identified AI as a technological priority area. The Pentagon has also launched a Joint Artificial Intelligence Center for which details are sparse.<sup>38</sup>

Australian policymakers, too, have seized on the need to innovate more effectively. Recognising Australia's strong national foundation for R&D versus its limited ability to translate innovation into defence-relevant applications, the Turnbull Government's 2015 National Innovation and Science Agenda brought venture capital investment into Australia — to the tune of more than A\$1 billion in FY 2017 — by providing an attractive tax climate for angel and early-stage investors.<sup>39</sup> This was followed by the establishment of a Next Generation Technologies Fund (NGTF) for defence-related research investments and a Defence Innovation Hub for late-stage technology development.<sup>40</sup> Crucially, Canberra has also invested in multilateral initiatives around autonomous systems and operations. In November 2018, the Australian Navy hosted Autonomous Warrior 18 (AW18), bringing Five Eyes partners together in Jervis Bay for a joint technology trial of autonomous command and control systems.<sup>41</sup> Such exercises provide crucial opportunities for testing new systems and help to foster interoperability among close partners at an early stage of autonomous integration.

Yet, despite the promise inherent in both governments' efforts, these developments face very real challenges.<sup>42</sup> In the United States, the success of Third Offset Strategy programs remains to be seen and has many teething problems to overcome. DIU, for instance, has encountered challenges to its wide-ranging use of Other Transaction Authorities (OTAs) to acquire new technology and has already been reorganised once.<sup>43</sup> While Congress has loosened restrictions on using OTAs for the purpose of engaging non-traditional innovation sources, it remains reticent to heavily invest in new systems. Nearly two-thirds of the US\$20.8

billion awarded in OTA contracts between 2015 and 2017 has gone to traditional contractors with pre-existing relationships with the department.<sup>44</sup>

In Australia, R&D expenditures have declined over the past decade and some fear innovation initiatives will suffer from a lack of follow-through effort and long-term political will as a result of inconsistent bureaucratic leadership.<sup>45</sup> Moreover, despite a growing need to harness the Australian technical research community to “prevent [long-term] technological surprise”, as per DARPA's role, the NGTF focuses primarily on shorter-term military objectives.<sup>46</sup>

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Cultural issues around innovation also plague both nations. In Australia, a fear of failure may be stifling innovation;<sup>47</sup> in the United States technical program managers who fear budget pressures from Congress are disincentivised from taking the risks that many think are necessary to deliver breakthroughs.<sup>48</sup> Furthermore, Silicon Valley and Washington do not see eye-to-eye. Highlighting the extent of this rift, Google pulled out of Pentagon AI initiative, Project Maven, due to employee protests about working on combat-related programs, even as the company was poised to launch a politically censored search engine in China. These problems, coupled with superior access to data, lower ethical resistance to lethal autonomy, a taut civil-military fusion, and a robust workforce may give China advantages in the application of intelligent-systems.<sup>49</sup>

One encouraging sign of the emphasis Washington is now placing on the US research enterprise is DARPA's effort to field and invest in the infrastructure that will support unmanned systems in the future.

The Positioning System for Deep Ocean Navigation (POSYDON) program, for example, seeks to develop GPS-like positioning information for autonomous undersea systems, providing “omnipresent, robust positioning across ocean basins”.<sup>50</sup> Similarly, DARPA’s ‘Oceans of Things’ program aims to achieve “persistent maritime situational awareness over large ocean areas by deploying thousands of small, low-cost floats that could form a distributed sensor network”.<sup>51</sup> Australian firm OCIUS is developing a similar ‘Satellites of the Sea’ concept with its Bluebottle USVs.<sup>52</sup> If proof-of-concepts are successful, such infrastructure enablers may be vital to establishing regional superiority.

## Implications for Australia

In the future, Australia will need to be a developer, integrator and consumer of unmanned naval technology. And as China closes the technological gap, Washington will need to cast a wider net on innovation sources, including by relying on trusted allies like Australia.

### Innovation

As a developer, Australia could fill gaps in its defence innovation ecosystem by more effectively connecting the technical research community and private sector with the defence mission. New organisations modelled on DARPA and DIU could bridge these divides. In particular, Australia’s position in the region presents an advantage for cooperation with DARPA on developing and testing undersea infrastructure enablers like POSYDON and the Satellites of the Sea programs. As an integrator, Australia should host joint unmanned warfare exercises with a coordinated development plan. Specifically, a follow-on to AW18 could include the integration of command and control systems in more realistic and contested scenarios.

### Naval modernisation

As policymakers plan today for the Australian Navy of the next 50 years, unmanned technology and operational concepts must become a larger part of the conversation. Australia’s acquisition of Triton has strong implications for interoperability and joint technology development with the United States. Indeed, the

Triton’s potential to communicate with the P-8A Poseidon and future DARPA Sea Hunter opens the door for further partnership on unmanned command-and-control across all three domains of naval warfare.

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Debates over the future of Australia’s submarine force, on the other hand, have paid relatively little attention to the unmanned future. The Shortfin Barracuda, Australia’s choice to replace the aging Collins-class submarine, is scheduled to go online in the 2030s, with all 12 submarines to be operational by the mid-2050s. In the contested maritime arena of the 2050s — which will be far different from today’s relatively benign environment — manned undersea operations near an adversary’s littoral shoreline will prove extremely challenging. With UUV swarms blocking off key access chokepoints, the future submarine will need to act from a large standoff distance and deploy its own UUV payloads for close-in missions.<sup>53</sup> Whether long-endurance, nuclear-powered submarines are necessary for such operations or advanced diesel-electrics, such as the Shortfin, are sufficient depends on how they are used. Absent the development of plausible operational concepts for the use of manned submarines in contested and UUV-rich environments, the most expensive project in Australian history may be unsustainable at an acceptable cost. A more realistic assessment of the future undersea operating environment of the 2050s and beyond is required before the Shortfin’s design decisions are finalised.

### Interoperability

Interoperability between US and Australian forces is a precondition for achieving a robust and coordinated approach to regional defence. At some operational and tactical levels, allied forces are already highly

interoperable, owing to years of joint deployments, the Five Eyes partnership and bilateral training exercises.<sup>54</sup> Many developments in unmanned systems will integrate with this existing joint force architecture. Looking to the future, however, interoperability cannot be assured in the face of radical changes in tactics, operational concepts, force structures and strategy. As autonomy increases, the four elements of command — authority, communication, situational awareness and situational understanding — will all change radically.<sup>55</sup>

Maintaining interoperability will require discipline at all phases of development and integration. To this end, AW18, Triton and SmartDiver are a promising start, but Australia should actively seek additional opportunities to build interoperability with US and allied forces. For example, Australia could pursue integrated operational planning with US forces as part of joint capability developments in unmanned systems like Triton and Loyal Wingman. Australia should also host exercises, competitions, technical workshops on unmanned sea infrastructure and a Five Eyes combined centre of excellence for autonomous systems in the Indo-Pacific. Given its strategic position at the heart of the region, Australia is well poised to lead such efforts.

Changes in the Indo-Pacific strategic environment demand collective defence through mutual participation. By bringing allies and partners together around unmanned warfare and operational concept development, the United States and Australia can begin to build a networked defence that secures allied military presence into the future. Failure to align budgets and force structures with the emerging technologies integral to future warfare will place the United States and Australia at a growing disadvantage in an increasingly contested region.



## Endnotes

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  13. While not currently at play in the Indo-Pacific, in the nuclear domain, a Russian Autonomous Underwater Vehicle (AUV) capable of carrying a 100-megaton nuclear warhead was reportedly detected by US intelligence in November of 2016. According to Russian media, the "Status-6," which more closely resembles an oversized torpedo, has a range of 6,200 miles and can be launched from two different nuclear submarines. See: Steve Weintz, "Why Russia's Status-6 Torpedo Is Really a 100-Megaton Cruise Missile," *The National Interest*, 7 July 2018, available at: <https://nationalinterest.org/blog/buzz/why-russias-status-6-torpedo-really-100-megaton-cruise-missile-25272>. According to the 2018 Nuclear Posture Review, "Russia is also developing ... a new intercontinental, nuclear-armed, nuclear-powered, undersea autonomous torpedo." See: Office of the Secretary of Defense, "The Nuclear Posture Review," *Department of Defense*, 2018, available at: <https://media.defense.gov/2018/Feb/02/2001872886/-1/-1/1/2018-NUCLEAR-POSTURE-REVIEW-FINAL-REPORT.PDF>. The torpedo is designed to cause radioactive tsunamis in ports after launching from submarines in open water. While easily detectable by sonar, anti-submarine warfare options are limited for engaging such a torpedo, highlighting the need for defensive weapons that can stop UUVs in the water. See: Dave Majumdar, "Just How Much of a Threat is Russia's Status-6 Nuclear Torpedo?" *The National Interest*, 16 January 2018, available at: <https://nationalinterest.org/blog/the-buzz/just-how-much-threat-russias-status-6-nuclear-torpedo-24094>.
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## About the author



### Lindsay Gorman

Lindsay Gorman has more than a decade of experience at the forefront of technology innovation and in the trenches of policy formation. She is the Fellow for Emerging Technologies at the Alliance for Securing Democracy. Previously, she ran a technology consulting firm, Politech Advisory, working with start-up companies and venture capital firms in artificial intelligence and FinTech. She was also an adjunct fellow in CSIS's Technology Policy Program.

A quantum physicist by training, she has built her policy career in the Office of US Senator Mark Warner, the White House Office of Science and Technology Policy, and the National Academy of Sciences on 21st century innovations and their societal consequences.

In addition to bipartisan legislation, Lindsay crafted policy guidance on FinTech, cybersecurity, autonomous vehicles, smart cities, financial regulation, artificial intelligence, disease surveillance, manufacturing, and the internet of things. She has spoken on FinTech, space, and cybersecurity at international technical and policy conferences worldwide and engaged in bilateral scientific dialogues with China and Russia.

Lindsay's technical expertise lies in artificial intelligence, data analysis, and quantum computing. She has published a *Nature Physics* paper on topological insulators, built a prototypical self-driving car for the Defense Advanced Research Projects Agency (DARPA), and operated a nuclear reactor.

Lindsay holds a physics degree from Princeton University, where she graduated magna cum laude, and a master's degree in applied physics from Stanford University.

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Cover: DARPA completed its Anti-Submarine Warfare Continuous Trail Unmanned Vessel program and has transferred the technology demonstration vessel, christened Sea Hunter, to the Office of Naval Research (Photo: DARPA)

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