RAND AUSTRALIA

Research Report

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Prioritising Critical Technologies of National Interest in Australia

Developing an Analytical Approach

Prepared for the Defence Science and Technology Group, Department of Defence

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About This Report

The Australian government has embarked on a plan to shape and coordinate national policy around those technologies deemed critical to the national interest. Central to this is the ability to balance the sometimes competing needs for security, prosperity and social cohesion. Associated to these three pillars is the level of sovereignty a nation like Australia requires to ensure it can benefit from those critical technologies when it needs to, particularly in the face of external threats. Given the rapid global growth in technological development, Australia cannot reasonably maintain control over all aspects of technologies. Rather, it needs to determine where it must own sovereign capability and intellectual property for particularly critical technologies, where it can collaborate with trusted allies and partners to gain the necessary access to technologies and capture the benefits of collaboration, and where technologies are readily accessible on the open market.

RAND Australia was tasked by the Defence Science and Technology Group (DSTG) with developing an analytical framework for identifying critical technologies of national interest; determining how this can be employed to identify technologies critical to achieving national policy priorities; and then determining a small list of technologies, the criticality of which would require a dedicated policy response.

This work was sponsored by the Joint and Operations Analysis Division of DSTG and led by the RAND Australia Office. Significant support was provided by staff from RAND Europe, with a focus on identifying potential lessons for Australia from international approaches to critical technologies. DSTG staff provided significant information and contributed with many fruitful discussions. This work may be of interest to policymakers who are involved in technology policy, commercialisation strategic planning, and resource management. Researchers who wish to understand how criticality and the national interest impact prioritisation may also be interested. For more information about RAND Australia, see www.rand.org/australia or contact the RAND Australia director listed on that webpage.

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Summary

To obtain and maintain a competitive edge, many nations constantly monitor and assess technological developments. Such developments not only contribute to national security, but also to economic advantage and international influence; they also can have societal benefits. As such, the policy environment needs a robust evidence base for emerging technologies and their potential impacts. With such an evidence base, the Australian government will be able to make timely policy decisions regarding investment in critical technologies of national interest (CTNI).[1]

The Australian government recently established the Critical Technology Policy Coordination Office (CTPCO) within the Department of the Prime Minister and Cabinet (PM&C). Its mission is to provide coordinated, whole-of-government advice on technology developments, opportunities and risks, and to recommend actions to promote and protect critical technologies. The CTPCO is working with the Defence Science and Technology Group (DSTG), who are providing the analytical and technology forecasting expertise. RAND Australia was engaged by DSTG to develop an analytical framework to support the prioritisation of CTNI. The framework is built around responding to two key questions:

- How might Australia design an analytical approach to prioritising CTNI in a manner that balances national security, economic prosperity, and social cohesion requirements?
- Given its capacity limitations, how can Australia develop policy that effectively balances the development of a broad range of technology capabilities over the long term while investing in more immediate programs to accelerate CTNI?

To do this, we collected, reviewed and analysed information from a range of sources, including Australia's domestic (federal) policy environment as well as the rich history of other national and multinational efforts. From this, we identified a number of contextual factors that need to be considered in the development of the analytical framework for making strategic investment choices around critical technologies. They include the following:

- Technology represents only one critical enabler for the national interest. Others include infrastructure, workforce, and supply chains. Given these are often interdependent, the CTNI assessment cannot occur without due consideration of them.
- Many bodies in Australia have identified technologies that are important to their policy area (e.g., health, agriculture). Prioritising CTNI must look across all sectors to evaluate their impact.

[1] The Australian government has defined CTNI as 'current and emerging technologies with the capacity to significantly enhance, or pose risk to, our national interests (economic prosperity, social cohesion and/or national security)' (Department of the Prime Minister and Cabinet [PM&C], 'Protecting and Promoting Critical Technologies', Australian Government, 2021e, p. 1).

- International competition is a major driver of technology development. Australia does not have the resources to be competitive in all technologies that might be critical to the national interest. It therefore needs the ability to analyse where it must control technology, where it is better to collaborate with trusted partners, and where it can rely on the international market for access. The present analysis is centred around risk.
- Competing priorities across policy sectors and between the goals of security, prosperity and social cohesion necessitate a consistent, transparent and functional decision framework. This will allow evidence-based decisionmaking that is optimised to the circumstances of the day.
- As this environment is data-rich, the analytical approach must strike a balance between efficiency and timeliness, with the need to continually ingest large amounts of data and reflect them meaningfully to a broad array of stakeholders. The analytical approach should recognise this in how it delivers and caveats its outputs.

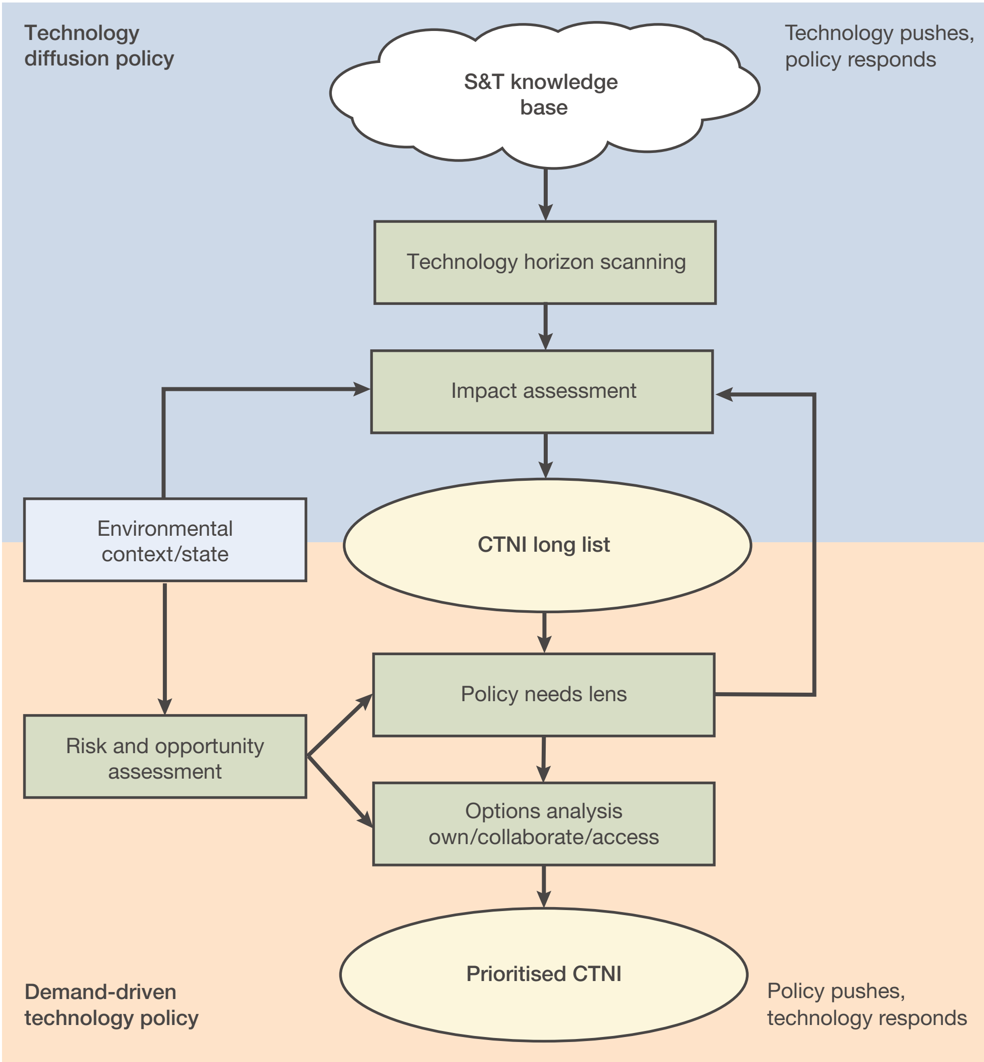
Using this as a basis, we develop an analytical framework (see Figure S.1) where the top half (blue sector) seeks to develop a list of CTNI (which we will refer to hereafter as the 'CTNI long list') based on their broader impact, while the bottom half (pink) takes the CTNI long list and, in response to some policy drivers, develops a prioritised list. While Figure S.1 appears linear, in reality there would be feedback throughout the model. For clarity, we have, for the most part, left these feedback loops out of the figure. However, the feedback loop between policy needs and impact assessment is included, as it emphasises the fact that any significant policy changes (e.g., commitments in relation to carbon neutral emissions) may require an assessment against the Australian government's three pillars of national interest, namely, economic prosperity, social cohesion and/or national security.[2]

The details for each component of this framework are discussed in the course of this report. In broad terms, the logic is that the Australian government use a combination of technology horizon scanning and an environmental scan to perform a technology impact assessment. The impact assessment would assess candidate technologies in terms of the three national interest pillars (security, prosperity, social cohesion) situated in the broader technological and national policy context. Through this assessment, the government would be positioned to establish Australia's capacity to innovate, undertake technology transfer, and understand the characteristics of those technologies.

The government might also have specific policy issues where CTNI offer a solution. This kicks off a second activity whereby CTNI are considered in terms of their capacity to support that policy requirement. The first step is to further prioritise the CTNI list into a set of candidate technologies. To capture value, the government would need to understand whether each candidate technology provides a tangible benefit (opportunity) or positions Australia to counter a potential threat (risk), based on the internal and external factors driving this policy

[2] Department of the Prime Minister and Cabinet (PM&C), 'Protecting and Promoting Critical Technologies', Australian Government, 2021e, p. 1.

FIGURE S.1
High-Level CTNI Prioritisation Framework



need. Potential solutions (options) could then be analysed, particularly in terms of the capacity to own critical technologies, have collaborative relationships with trusted partners, or to simply access that technology from the market (hereafter referred to as the own-collaborate-access model).[3] Taken together, these can enable Australia to develop and prioritise solutions in the national intent and cognisant of the timeline for delivering the required outcome.

[3] This is derived from the UK approach. See UK Cabinet Office, *Global Britain in a Competitive Age: The Integrated Review of Security, Defence, Development and Foreign Policy*, UK Government, 2021a.

We observe that the successful and effective implementation of such an analytical framework must reflect the realities of the decision environment. Key considerations include the following:

- The competing policy objectives of security, prosperity and social cohesion suggest the need for a technology assessment for CTNI that is distinct from (but related to) parallel efforts in the Department of Defence, which primarily focuses on security.
- It is important to distinguish between diffusion- and mission-based technology policy approaches. While Australia needs some capacity to utilise a range of technologies, its limited resources means prioritising those that meet the threshold to be competitive or for which there is an incontestable security need.
- Strategic patience is needed to ensure policy and investment decisions have the opportunity to succeed. Policy decisions must be cognisant of the time lag between the identification of CTNI priorities and the delivery of the anticipated benefit.
- There must be recognition that Australia requires the ability to respond rapidly when disruptive breakthroughs in novel science and technology (S&T) emerge. This ensures that major disruptions can be identified early and policy pivoted rapidly, when necessary, so as to minimise strategic surprises and maintain competitiveness.
- Social cohesion assessment metrics are a work in progress, not only in Australia but also in other nations and international institutions considered in the course of this study. It will take time to develop and mature the measures used for integrating the consideration of broader social factors into CTNI policy.

Based on our analysis, we make the following recommendations:

- The prioritisation approach should develop a longer list of critical technologies and use this to establish a smaller set that offer practical responses to current policy needs.
- Use an own-collaborate-access model to determine where there is choice on viable policy options.
- While CTNI might be the policy focus, impacts of other critical functions such as infrastructure, workforce and supply chain must be considered when prioritising.
- A monitoring and evaluation (M&E) regime should be established to support the continued evolution of this approach and the priorities it identifies.

Ultimately, CTNI prioritisation is a wicked problem[4] given that the nature of the policy environment is highly interdependent and both context- and time-dependent. There is no single optimal solution. Rather the result will be a 'best fit', given the circumstances of the day and the shifting perspectives of those making the assessments.

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4 A 'wicked problem' from a public policy perspective is one where the policy issue exists in a highly dynamic, socially complex environment with significant interdependency across many policy sectors. As such, optimal policy solutions ae not assured, as they involve behavioural changes that cannot be readily predicted. See Australian Public Service Commission, *Tackling Wicked Problems: A Public Policy Perspective*, Australian Government, 2007.

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Abbreviations

ACOLA	Australian Council of Learned Academies
AI	artificial intelligence
CapTech	capability technology group
CDP	Capability Development Plan
CET	critical and emerging technologies
COVID-19	coronavirus disease 2019
CSIRO	Commonwealth Science and Industrial Research Organisation
CTNI	critical technologies of national interest
CTPCO	Critical Technology Policy Coordination Office
DG DEFIS	Directorate-General for Defence Industry and Space
DIS	Defence Industrial Strategy
DSIS	Defence and Security Industrial Strategy
DSTG	Defence Science and Technology Group
EDA	European Defence Agency
EPTA	European Parliamentary Technology Assessment
EU	European Union
FOA	freedom of action
GDP	gross domestic product
HILDA	Household, Income and Labour Dynamics
IAF	Impact Assessment Framework
IIER	Institute for Integrated Economic Research
IISA	Industry Innovation and Science Australia
IOT	Internet of Things
IP	intellectual property
IR	Integrated Review of Security, Defence, Development and Foreign Policy
ISR	innovation, science and research
KET	key emerging technology
KIC	Knowledge and Innovation Community
M&E	monitoring and evaluation
MEP	member of the European Parliament
MOD	Ministry of Defence (UK)
MS	Member States
NATO	North Atlantic Treaty Organisation
NIAA	National Indigenous Australians Agency

OA	operational advantage
OECD	Organisation for Economic Co-operation and Development
OSRA	Overarching Strategic Research Agenda
PFRA	publicly funded research agencies
PM&C	Department of the Prime Minister and Cabinet
pMS	participating Member States
R&D	research and development
RD&I	research, development and innovation
S&T	science and technology
SIA	Strategic Innovation Agenda
SME	subject matter expert
STREAM	Systematic Technology Reconnaissance, Evaluation and Adoption Method
TA	technology assessment
TRL	technology readiness level

CHAPTER ONE

Introduction

As society seeks to deliver better outcomes for people, communities and nations, there is an increasing reliance on scientific and technological developments.[1] Discovery, development and utilisation of new technologies are also providing a strategic edge to those entities who are investing in them, as well as spillovers to other stakeholders and sectors.[2] To attain and/or maintain a strategic advantage, it is important for nations to be constantly monitoring and assessing scientific and technological developments. At the same time, it is important to understand and adapt to the strategic environment by responding to immediate opportunities, threats and risks in order to maximise benefits from technologies that may emerge over the next decade or so. This is particularly important for key enablers such as technology, infrastructure, and workforce, which take many years of investment to mature.

Like many developed nations, Australia needs to actively address these opportunities and challenges. From a policy perspective, Australia has articulated the need to develop a set of critical technologies of national interest (CTNI), that is, 'current and emerging technologies with the capacity to significantly enhance, or pose risk to, our national interests (economic prosperity, social cohesion and/or national security)'.[3] This may include beneficial outcomes for the national interest such as genetic engineering for increasing food crop yields,[4] robotics for automating production,[5] or new materials that enable new

[1] Y. Dong, H. Ma, Z. Shen and K. Wang, 'A Century of Science: Globalization of Scientific Collaborations, Citations, and Innovations', *Proceedings of KDD 2017*, Halifax, NS, Canada, 13–17 August 2017.

[2] K. Radinsky and E. Horvitz, 'Mining the Web to Predict Future Events', *WSDM 2013—Proceedings of the 6th ACM International Conference on Web Search and Data Mining*, Rome, Italy, 4–8 February 2013.

[3] Department of the Prime Minister and Cabinet (PM&C), 'Protecting and Promoting Critical Technologies', Australian Government, 2021e, p. 1.

[4] J. Fernandez-Cornejo and M. F. Caswell, *The First Decade of Genetically Engineered Crops in the United States*, Economic Information Bulletin No. 11, 2006, p. 36.

[5] A. R. Patel, S. Azadi, M. H. Babaee, N. Mollaei, K. L. Patel and D. R. Mehta, 'Significance of Robotics in Manufacturing, Energy, Goods and Transport Sector in Internet of Things (IoT) Paradigm', *Proceedings of the 4th International Conference on Computing, Communication Control and Automation*, Pune, India, 16–18 August 2018.

forms of propulsion, such as hypersonic flight.[6] Conversely, recent events have highlighted the relevance of CTNI to challenges to the national interest; current examples include the national capacity to cope with pandemics such as COVID-19,[7] concerns over the security of the National Broadband Network (NBN) in relation to the provision of 5G services,[8] and the increasing dependence on rare earth materials (also an area of opportunity for Australia given its deposits[9]). Finally, there is the recognised need to manage and control access to sensitive (often dual-use) technologies, generally through legislative and regulatory means (e.g., export controls on the Defence and Strategic Goods List).[10]

A key challenge is to determine how and where to invest in a manner that can address immediate issues while also positioning Australia such that its innovation capacity can continue to contribute to its success over the long term. The international nature of research means that Australia also needs to strike a balance between collaborating to accelerate technology development with protecting national developments. Australia is a middle economic power with a limited capacity to build and sustain expertise across all technology fields, or even all the components that contribute to many technologies. As such, critical technology sovereignty has been recognised as an issue of concern,[11] suggesting that Australia must determine those critical technologies that need to be owned domestically, those that can be established through collaboration with trusted partners, and those where Australia is comfortable accessing them from any source.[12] The benefits from technology lie in its application, which relates closely to the policy, legal, regulatory, social, economic, and cultural contexts of technology adoption.[13] Finally, while security is a major determinant, this perspective should not inhibit Australia's ability to grow its prosperity and enhance its social cohesion, which, in turn, directly contribute to national security.

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[6] W. G. Fahrenholtz and G. E. Hilmas, 'Ultra-High Temperature Ceramics: Materials for Extreme Environments', *Scripta Materialia*, Vol. 129, 2017.

[7] Shannen Higginson, Katarina Milovanovic, James Gillespie, Andrew Matthews, Christopher Williams, Laura Wall, Naomi Moy, Madeline Hinwood, Adrian Melia and Francesco Paolucci, 'COVID-19: The Need for an Australian Economic Pandemic Response Plan', *Health Policy Technology*, Vol. 9, No. 4, 2020.

[8] Tom Uren and Danielle Cave, 'Why Australia Banned Huawei from Its 5G Telecoms Network', Australian Strategic Policy Institute, 30 August 2018.

[9] Luke Brown, 'Australia Needs to Back Itself on Rare Earths', *The Strategist*, 8 November 2019.

[10] Department of Defence, *The Defence and Strategic Goods List 2021*, Australian Government, 2021.

[11] See, for instance, Department of Home Affairs, *Critical Technology Supply Chain Principles*, Australian Government, 2020b.

[12] UK Cabinet Office, *Global Britain in a Competitive Age: The Integrated Review of Security, Defence, Development and Foreign Policy*, UK Government, 2021a.

[13] Camilla D'Angelo, Anna Knack, Calum MacLure and Jon Freeman, *Evidence Synthesis on the Conditions Needed to Translate Research and Drive Innovation*, Santa Monica, Calif., and Cambridge, UK: RAND Corporation, RR-2610/2-RS, 2018.

RAND Australia was engaged by Defence Science and Technology Group (DSTG) within the Department of Defence to develop an analytical framework to support a key deliverable in their collaborative program with Critical Technology Policy Coordination Office (CTPCO). Particular emphasis was put on helping develop a broad understanding of the totality of functions of the Australian government and how CTNI can be identified and prioritised in a structured and repeatable manner. This report outlines our support to this program in terms of model development and testing.

Two major questions drove this study:

1. How might Australia design an analytical approach to prioritising critical technologies of national interest in a manner that balances national security, economic prosperity, and social cohesion requirements?
2. Given its capacity limitations, how can Australia develop policy that effectively balances the development of a broad range of technology capabilities over the long term while investing in more immediate programs to accelerate critical technologies of national interest?

In response to this, we propose an analytical framework for the identification and prioritisation of CTNI suited to Australia's particular circumstances. We commence by exploring how other nations approach CTNI and drawing lessons from their collective experiences (Chapter Two). We then situate this within the Australian policy context to identify some of the key factors that will shape CTNI identification and prioritisation (Chapter Three). Next, we design an analytical framework to support the establishment of a CTNI prioritisation process (Chapter Four). This is followed by discussing the implementation of this analytical framework (Chapter Five). We conclude with some observations and recommendations as to how the framework should be developed and applied (Chapter Six). We also include three appendixes detailing international case studies (Appendix A), different approaches to assessing social cohesion (Appendix B), and an exemplar application of an element of the approach (benefits mapping) for the Australian agriculture sector (Appendix C).

CHAPTER TWO

International Experiences for Establishing CTNI Policies

The Australian government's pursuit of prioritised CTNI to guide its policy and investment decisions is not unique. There is a long history of other governments and multinational bodies seeking to shape their policy decisions around technology through the identification and prioritisation of those technologies that are critical to their national objectives. We undertook a review of international approaches to understand how nations define and adopt CTNI.[1] In total, we investigated 38 approaches using publicly available information to identify broader trends or examples of practices potentially suitable for Australia.[2] We have focused primarily on Europe (including the United Kingdom) as many of the challenges these countries face are similar to Australia. For instance, Australia has a strong research sector, which supports a wide range of technology areas, and a technically skilled workforce. However, its relatively small size in population and economic terms means it may not be able to gain a competitive advantage in all the technology areas it desires. We have considered both the pan-European institutions (such as the European Union [EU]) and national approaches, as these provide a diversity of approaches applied to institutions of a similar scale to Australia's. In recognition of Australia's close relationship with the United States, we also considered the US government's recent National Strategy for Critical and Emerging Technology.

2.1. Management Responsibilities for Critical Technology Policy

Most countries in Europe have a dedicated agency of some kind for technology assessment; some indeed have several, with one for defence and at least one civilian agency. However, there is often at least a partial disconnect between how countries in the EU define critical technologies, critical sectors, and critical infrastructure, and different government departments or agencies may be responsible for each. For example, in some countries the national ministry of defence may be responsible for setting CTNI priorities, whereas in others, ministries of justice or security, or those responsible for industry policy and innovation, may

1 We focused on governmental institutions because these align with how Australia is approaching this.

2 See Appendix A for a complete list as well as a summary of these approaches.

take a leading role on CTNI. Parliaments often have a direct role, if with a different focus to the executive, with specialist secretariats for assessing science and technology (S&T) and explaining the relevance of new developments to legislators and the public. Furthermore, defence departments may have different priorities compared with other departments and agencies focused on dual-use or civil applications, both in terms of the technologies classified as CTNI and the assessment criteria and process used to come to that classification.

Though there is no universal approach to classifying CTNI, different national agencies collaborate at the European level or feed into EU initiatives. Many technology assessment (TA) agencies at the national level are also involved in pan-European organisations, such as the European Parliamentary Technology Assessment (EPTA) network that promotes information exchange and a common method of TA. The EPTA is a network whose objective is to advance the establishment of TA as part of decisionmaking in European Parliament and more widely. The EPTA includes a mix of supranational, national and subnational agencies as full members and offers associate membership to a mix of European and non-European equivalents.

Moreover, since most European countries are also part of the EU and hence participate in its various CTNI-related strategies and initiatives, many nations also participate in frameworks such as the European Defence Agency (EDA)'s Overarching Strategic Research Agenda (OSRA), the European Commission's Smart Specialisation Strategy and program of work on key emerging technologies (KETs), and the European Institute of Innovation and Technology's Strategic Innovation Agenda (SIA). Since many countries already participate in these pan-European institutions and initiatives, there is a reduced need for individual EU Member States (MS) to have extensive national TA strategies and agencies—especially for those smaller nations with limited financial, organisational and technical resources for S&T policy.

2.2. Monitoring and Evaluating CTNI Programs

Measuring the success of CTNI initiatives is critical for understanding whether the government is getting the policy outcomes it desires. Publicly available sources yielded little information on the monitoring and evaluation (M&E) regimes of most TA initiatives, but the data suggest many TA initiatives do not have mature systems in place or at the very least do not report on these openly. Although some multinational institutions such as the EDA and the North Atlantic Treaty Organisation (NATO) have well-documented monitoring regimes in place to track developments against their specified CTNIs, publicly available information suggests this is the minority of initiatives. TA processes in some countries such as Estonia and Denmark are reportedly inhibited by a lack of resources to develop and maintain monitoring regimes. Other countries, such as Austria, revise their assessments every one or two years.

Given this lack of public information on M&E processes or outcomes, as well as the inherent challenge of assessing the counterfactual (i.e., Would a nation have been better or worse off in a hypothetical world where it prioritised a different set of CTNI?), it is difficult to offer a robust assessment of how effective international TA initiatives are in identifying, assessing and securing CTNI. Based on a review of public sources, some of the most granular and transparent CTNI strategies in Europe have been developed by the EU institutions and the United Kingdom, with national authorities in the Netherlands and France having published relatively detailed strategies. Selected case studies are described in Appendix A, with a focus on their inputs, activities/processes and outputs, but more limited information available on the extent to which these contribute to beneficial long-term outcomes in terms of protecting the most relevant CTNI.

2.3. Classification and Assessment of Technology

Not surprisingly, given the diversity of national interests and capacities of nations to sustain CTNI, different nations have adopted a variety of priorities, definitions and approaches. Typically, different CTNI approaches classify their areas of focus based on one or more of the following—often overlapping—categories:

- **Critical technologies:** defined area(s) of technology where there is an interest in retaining security of supply and use, including a national innovation base.
- **Critical sectors:** defined segment(s) of national industry where there is an interest in retaining sovereign industrial capability and capacity (including skills, facilities, prime contractors and lower-tier supply chains, and potential limits on foreign ownership).
- **Critical (national) infrastructure:** defined aspect(s) of physical or digital infrastructure that underpin broader governmental, military, economic and/or societal functions.

Technology assessments apply a variety of criteria to classify CTNI, including a technology's novelty and contribution to security, prosperity or influence. Common examples include indicators of

- **unfamiliarity, novelty or innovativeness of S&T breakthroughs:** such as the extent to which developments in a given technology area offer the prospect of more 'disruptive' and 'game-changing' advances
- **strategic importance for security capabilities:** a technology area's contributions towards relative advantage, freedom of action, and supply chain security
- **contribution to prosperity:** a given technology's potential to contribute towards economic competitive advantage, job creation, increases in productivity, exports, foreign direct investment, etc., defined either in a narrow sense (e.g., financial and commercial benefits) or in terms of broader 'net social value' (e.g., to include wellbeing, happiness, etc.)
- **contribution to international influence:** the technology area's contributions towards projection of both 'hard' and 'soft' power, and maintenance of a strong and open political discourse in line with democratic values
- **specific relevance for mitigating non-traditional or hybrid threats:** combating issues such as disinformation, pandemics and climate change, which are beyond the more traditional conception of national security threats

- **interdependencies with wider critical infrastructure and functions:** the technology area's contributions towards enabling critical national infrastructure; or underpinning other technologies, processes and systems used widely across government, the military or society.[3]

Different institutions define CTNI at varying levels of granularity, depending on their purpose and the evaluation criteria employed. For example, the Finnish Defence Forces Research Agenda applies categories such as 'governance technologies' and 'sustainable technologies'.[4] These broad areas help guide strategy and policy. Other TA institutions require more specificity for their purposes. For example, the EDA's OSRA has 139 'technology building blocks', each described at a granular level (e.g., 'Enabling Components for Advanced Antennas', 'Ignition Systems of Energetic Materials'). These building blocks are then combined to describe a capability technology group (CapTech) of relevance to military tasks and long-term capability development priorities, or to guide research, development and innovation (RD&I) investments. The technology building blocks also feed into various strategic foresight, analysis and planning activities, such as the EU Capability Development Plan (CDP).[5]

2.4. Sovereign Choices for Critical Technology

Sovereignty issues are often a key factor in how individual nations consider critical technology. As part of its recent integrated review of security, defence, development and foreign policy,[6] the UK government introduced an 'own-collaborate-access' framework to help government agencies ascertain their true sovereignty requirements.[7] This framework aims to guide decisions about when to 'own' (i.e., retain indigenous capability), when to 'collaborate' with allies and partners through multinational research and equipment programs, and when to 'access' certain technologies from the market (e.g., by procuring off-the-shelf solutions or seeking to acquire access to foreign intellectual property [IP]).[8] Figure 2.1 provides specific definitions based on RAND's interpretation of this policy framework (see Table A.1 for more detail).

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3 This focus on those technologies that enable a wide range of other technologies, systems and processes is most explicit in the EU's program of work on KETs. See European Commission, *KETS for a Competitive Europe*, 2014a; Interreg Europe, 'Key Enabling Technologies (KETs): A European Priority for Industrial Modernisation', webpage, 2021.

4 Finnish Defence Forces, *The Finnish Defence Forces' Research Agenda 2015*, 2015.

5 Marta Kepe, James Black, Jack Melling and Jessica Plumridge, *Exploring Europe's Capability Requirements for 2035 and Beyond: Insights from the 2018 Update of the Long-Term Strand of the Capability Development Plan*, EDA, 2018.

6 UK Cabinet Office, 2021a.

7 UK Cabinet Office, 2021a.

8 UK Ministry of Defence (MOD), *Defence and Security Industrial Strategy*, UK Government, 2021.

FIGURE 2.1
UK Government 'Own-Collaborate-Access' Framework

Own	"where the UK has leadership and ownership of new developments, from discovery to large-scale manufacture and commercialisation."
Collaborate	"where the UK can provide unique contributions that allow us to collaborate with others to achieve our goals."
Access	"where the UK will seek to acquire critical S&T from elsewhere through options, deals, and relationships."

SOURCE: Adapted from UK Cabinet Office, 2021a.

Clearly there is alignment with Australia's sovereignty aspirations, and so this framework is readily adaptable to CTNI. Of particular importance is the fact that the complexity of most modern systems (e.g., aircraft, ships, satellites, machinery, networks) means that they are composed of many subsystems, components and technologies. As such, it is unlikely that a single nation (particularly a middle power like Australia) can gain and maintain sovereign control over all constituent technologies of such a 'system of (technological) systems'. Even the Department of Defence, despite the significant investments made in developing leading-edge capabilities, has systems that are typically a combination of sovereign, collaborative and off-the-shelf elements, developed and delivered by domestic and multinational partners, industry suppliers and research organisations. However, the potential for foreign interference needs to be an explicit consideration.

2.5. Mission and Dispersion Approaches to Technology Investment

International practices have shown that there are generally two approaches national and multinational institutions take to considering CTNI: they compile either an extensive and enduring list, which encapsulates the totality of critical technologies; or shorter lists often focused on addressing immediate issues such as security risks, economic opportunities or regulatory controls. It is useful to consider the longer list as representative of capability enhancing that is supported by 'diffusion-oriented' policy design.[9] Conversely, to address immediate issues, a 'mission-oriented' policy design may be required, which inevitably results in a smaller number of technologies being considered for a specific task, setting or

[9] Lewis M. Branscomb, 'U.S. Scientific and Technical Information Policy in the Context of a Diffusion-Oriented National Technology Policy', *Government Publication Review*, Vol. 19, No. 5, 1992.

sector, but which still most likely draws from the underlying technologies identified in the (diffusion-based) long list.[10]

Both long and prioritised lists build up the national RD&I ecosystem (people, infrastructure, knowledge and experience, IP, etc.) and cannot be considered in isolation from that. And both lists are important, representing a policy dilemma of how a nation can invest its limited resources in the best way possible given the possible tensions between potentially competing sets of priorities.

Before discussing the relationship between the two approaches within the Australian context, it is instructive to examine the key characteristics of each. As Table 2.1 shows, diffusion-oriented approaches take a broader perspective, seeking to provide the greatest coverage of technology building blocks, and lead to a long list of CTNI (hereafter referred to as the 'CTNI long list'). Given that investment spread, it is more difficult to be a technology leader in all areas; rather, the aim is to situate oneself to be a 'fast follower', utilising (long list) CTNI investment as a springboard. This necessitates a sophisticated technology horizon-scanning capability to identify the signals of impactful emerging technologies used in combination with a national intelligence function (security, business, etc.) that scans the environment to determine how those technologies might be employed within that nation's context. As such, the market is a driving force and, at least in an open economic system, the private sector, cognisant of the incremental improvements technology offers, should be situated to drive investments. This implies that diffusion approaches typically drive government policy ('trickle up') because the relevant industries align economic opportunity with the markets in which they operate.

TABLE 2.1
Key Characteristics of Diffusion- and Mission-Oriented Approaches

Diffusion-Oriented Policy Design	Mission-Oriented Policy Design
• Capability enhancing	• Disruptive change
• Typically 'smart follower'	• Typically 'first movers'
• Market-pull dominates	• Technology push dominates
• Industry driven investment	• Government driven investment
• Incremental innovation focused on 'value-add'—building on existing technologies	• Generate/exploit 'radical' innovation for a technology leap forward
• Covers a broader spectrum of technologies	• Selects fewer technologies in attempt to address major opportunities/challenges
• Anticipates trickle up/'spin-ons' from industry to government	• Anticipates trickle down/'spin-offs' to industry

SOURCES: Branscomb, 1992; Chiang, 1999; Coccia 2019.

[10] Mario Coccia, 'Why Do Nations Produce Science Advances and New Technology?', *Technology in Society*, Vol. 59, 2019.

In contrast, mission-oriented approaches focus on a smaller set of technologies where the assessment suggests there is the potential for significant disruption to the operational environment, either in terms of what the technology can do or where there is a major issue that may fundamentally change the environment. As such, it is a more proactive approach, with investments seeking to create a world-leading position. Technology is the driver and, given the level of risk, government is generally the funder. In essence, governments seek to select a few technologies that will radically alter and improve their (relative) position or will defend and maintain an existing advantage. Given this, the future exploitation of that technology tends to trickle down, with the outcomes of the government investments leading to spin off opportunities in adjacent areas.

The policy challenge then becomes one of balance between these two perspectives. Clearly, Australia needs to have a minimum viable level of capability in a range of critical technologies. However, choices need to be made as to which critical national needs are best served by having additional resources allocated.

2.6. Summary

Australia is far from unique in trying to establish a comprehensive policy approach to identifying and prioritising CTNI. In this chapter, we identified that other comparable nations tend to establish a centralised agency to manage this, and generally provide some level of resourcing to support implementation of the agenda. The relationship between all national interest criticalities (technology, infrastructure, workforce, supply chain) is generally acknowledged, as is the interplay between protecting critical technologies and seeking to achieve economic benefit. Societal benefit appears to be implied from these. This often then leads to sovereignty considerations, from which it is recognised that technologies generally develop in an international RD&I environment. This will require strategic choices about benefits (economic, security, social cohesion) of owning a technology, where it is it more effective and/or less risky to access externally, and the best risk-mitigation strategy to collaborate with trusted partners. Somewhat related to this is whether the investment would be better focused on a few areas where there is the greatest likelihood of realising the desired benefit or whether a more conservative approach involving hedging investments across a broader range of technologies should be pursued.

CHAPTER THREE

Critical Technology and Australia's National Interest

To be able to develop an approach suitable to support the Australian government's CTNI policy, it is important to identify and explore the underpinning factors that will frame the underlying analysis. While the basis for establishing policy on CTNI within Australia is unique to its national circumstances, there are a number of lessons that can be drawn from other experiences. Having considered how other nations approach this, we can now situate CTNI within the Australian context, identifying some of the key factors that will inform the policy development and prioritisation.

3.1. Critical Technology Context

Critical Technology Program Coordination Office

The Australian government established the CTPCO within the Department of the Prime Minister and Cabinet (PM&C) 'to provide coordinated, whole-of-government advice on technology developments, opportunities and risks, and to recommend actions to promote and protect critical technologies',[1] with aims to

- ensure Australians have access to cost-effective, safe, secure and inclusive technologies;
- promote Australia as a trusted partner for investment, research, innovation and collaboration;
- support regional resilience and competitive, trusted and diverse technology innovation and international markets; and
- maintain the integrity of our research and capabilities, enable Australian industries to thrive and maximise our sovereign IP.

The establishment of the CTPCO is a recognition of the need to build a comprehensive and connected policy environment to develop, manage and derive benefit from CTNI.

[1] PM&C, 'Critical Technology Policy Coordination Office', Australian Government, 2020.

Clearly this will need to utilise and build on existing national S&T programs and policies, particularly those with responsibilities that span Australia's RD&I ecosystem (e.g., the Office of the Chief Scientist, Industry Innovation and Science Australia (IISA), Australian Academy of Science, and Australian Council of Learned Academies (ACOLA); as well as Australia's publicly funded research agencies (PFRAs) such as Commonwealth Science and Industrial Research Organisation (CSIRO), DSTG, Australia's Nuclear Science and Technology Organisation, and the Australian Institute of Marine Science). This will provide the capacity to identify what parts of the RD&I are most critical, and then identify national policy priorities. The CTPCO is working with the DSTG, who are providing the analytical and technology forecasting expertise, which is critical to this policy endeavour.

Summary of RD&I Expenditure

Given this 'whole-of-nation' policy coordination aspiration, it is worth quantifying the scale and balance of Australia's domestic RD&I ecosystem. Australia makes a significant investment, from basic research through to technology delivery. The most recent figures from the Bureau of Statistics (FY 2019–2020) sets it at $35.6 billion, split among the private sector (for-profit) ($18.1 billion), academia ($12.7 billion), government agencies such as PFRAs ($3.4 billion) and private non-profit research institutes ($1.3 billion).[2] This represents a significant fraction of gross domestic product (GDP) (1.79 per cent) and compares favourably with other Organisation for Economic Co-operation and Development (OECD) nations[3] (e.g., Canada [1.59 per cent], EU [2.11 per cent] and the United Kingdom [1.76 per cent]), though not the United States (3.07 per cent). However, in absolute terms it is significantly lower than these entities (e.g., between 75 per cent and 80 per cent of Canada's expenditure and approximately 40 per cent of the United Kingdom's expenditure).[4]

In terms of workforce numbers, the annual effort (averaged over the period 2017–2019) is academia (81,717; 46 per cent), private sector (74,991; 42 per cent), government (14,521; 8 per cent) and private non-profit (7,205; 4 per cent).[5]

Finally, it is insightful to look at where business invests in RD&I. This occurs predominately in the manufacturing sector (30 per cent), information and communication services (20 per cent), and commercial services and tourism (12 per cent), with smaller efforts in health (9 per cent), energy (5 per cent) and mineral resource (5 per cent).[6]

2 Australian Bureau of Statistics, 'Research and Experimental Development, Businesses, Australia', Australian Government, 2021.

3 OECD, 'Gross Domestic Spending on R&D', webpage, n.d.

4 OECD, n.d.

5 Australian Academy of Science, 'How Is Science Funded in Australia?', webpage, n.d.

6 Australian Bureau of Statistics, 2021.

Technology Assessments

The CTPCO does not need to start from a blank slate, as there already exist many technology lists that can contribute to CTNI prioritisation. These 'technology lists' are generally focused on specific policy agendas (often contained in strategy or roadmap documents). Some of these appear to be developed cognisant of other lists, while others appear to be developed independently. Some are one-offs, whereas others are updated over time. Furthermore, PFRAs, academia and industry can also develop comparable lists, generally around a technology domain (for the former) and business demands (for the latter). As such, the lists in their totality represent both technology-push and policy/sector-pull drivers.

The national security sector has a long history of continuously monitoring technologies for threats and opportunities—and institutionalising these in terms of lists of critical technology. These can be as a response to

- **drivers of future change:** for example, the Department of Defence foresight study *Forward 2035*,[7] which posits itself 15–20 years into the future, seeks to inform strategic planning and prevent strategic surprise
- **identified operational risks:** for example, the Defence Strategic Goods List[8] and Sensitive Technologies List,[9] which identify technologies that require monitoring or protection from a security perspective
- **emerging technology opportunities:** for example, the Next Generation Technology Fund[10] and the StaR Shots program,[11] which identify research priority areas that have the potential to create leap-ahead capabilities
- **national security challenges:** for example, the National Security Science and Technology Priorities[12] and the National Security Science and Innovation Strategy,[13] which seek to align emerging challenges with technology domains of relevance.

This range of responses is symptomatic of the deep linkages between technology and security concepts and capabilities; the sometimes rapidly changing nature of technology and Australia's strategic environment, which combine to create threats and opportunities over

7 Seng Boey, Peter Dortmans and Joanne Nicholson, *Forward 2035—DSTO Foresight Study*, Australian Government, 2014.

8 Department of Defence, *Defence and Strategic Goods List 2019*, Australian Government, 2019.

9 Given its security classification, it will not be discussed here. Some general information can be found in Department of Defence, 2021.

10 DSTG, 'Next Generation Technologies Fund', Australian Government, n.d.-a.

11 DSTG, 'Strategy: Science, Technology, and Research (STaR) Shots', Australian Government, n.d.-b.

12 Department of Defence, *National Security Science and Technology Priorities 2020*, Australian Government, 2020b.

13 PM&C, *The National Security Science and Innovation Strategy*, Australian Government, 2009.

time; an appreciation that technology developments can be pushed from below by research discoveries, or pulled from above by objectives or requirements; and a realisation that Australia has limited resources and cannot achieve its objectives alone.

Other sectors undertake similar measures. For example, in health there are the Medical Research Future Fund, which ‘aims to transform health and medical research and innovation to improve lives, build the economy and contribute to health system sustainability’;[14] and the National Health and Medical Research Fund, which prioritises investments that aim to both ‘create knowledge and build research capability’ and ‘drive the translation of health and medical research into clinical practice, policy and health systems and support the commercialisation of research discoveries’.[15]

There are also mechanisms that explicitly focus on academic research, such as

- the Australian Research Council, which has a number of funding mechanisms that are selected competitively across a range of technology areas[16]
- the Australian Council of Learned Academies, which undertakes various initiatives ‘to analyse the future, navigate change and highlight opportunities for the nation’ in technology and policy domains, and so identify priority technologies.[17]

Finally, the business sector also identifies a mix of technology needs and priorities. While these tend to be focused on more immediate commercial opportunities, they also capture some longer-term needs and ambitions. By way of example, we identified eight relevant industry bodies in the agricultural sector.[18] Across these there were a number of common technology opportunities, such as data and digitisation, automation, information and communications technology (ICT) connectivity, sensors, environmental sciences, various biological and chemical sciences, and food safety.

3.2. Key Factors for CTNI Policy and Prioritisation

In order to develop the analytical framework, we must first understand those factors that will shape how critical technologies are conceived, how they relate to the national interest, and how they are to be realised. While we do not claim to have uncovered the totality of these, we have identified a small set of particular importance.

[14] Department of Health, ‘Medical Research Future Fund’, webpage, n.d.

[15] National Health and Medical Research Centre, *NHMRC Corporate Plan 2020–21*, Australian Government, p. 4.

[16] Australian Research Council, homepage, n.d.

[17] ACOLA, ‘Horizon Scanning Series: An Overview’, webpage, n.d.

[18] The industry bodies identified were National Farmers Federation, Dairy Australia, Australian Egg Corporation, Cotton Australia, Meat and Livestock Australia, AUSVEG, Australian Wool Innovation and Sugar Research Australia.

Critical Technologies Are Only One Critical Enabler of National Interest

This statement recognises that while we focus on CTNI, it forms part of a broader government security agenda; namely, ensuring the security of key enablers that are critical to the national interest. For instance, the Australian government is also focused on protecting critical infrastructure[19] and cybersecurity, as underscored by its Cyber Security Strategy 2020.[20] The Australian government also released its updated National Security Science and Technology Priorities in 2020, which seek to

> drive a strategic advantage by clearly articulating the national security community science and technology challenges, therefore assisting to shape and influence programs of work across both the national security agencies and the broader science and technology ecosystem . . . [and] provide the science and industry community with visibility of the endorsed national security science and technology areas.[21]

These six priorities are described in terms of applications (technology foresight; intelligence; preparedness, protection, prevention and incident response; cybersecurity; border security and identity management; and investigative support and forensic science) and are divided into 26 subcategories, with examples of S&T research identified against each.

But this is not just a concern for the security sector. Much of Australia's economic prosperity relies on the digital economy, the resources sector and the agricultural sector, particularly from an exports perspective. There has been much recent activity across all these sectors from a critical technology perspective:

- For instance, the Digital Economy Strategy 2030 is aimed at 'building a modern and resilient economy to drive Australia's future prosperity', recognising that to do this, Australia must keep 'at the forefront of emerging technologies',[22] in particular artificial intelligence (AI), the Internet of Things (IoT), data analytics, blockchain technology and quantum computing. It also identifies that national infrastructure assets are critical to the delivery of the outcome needs.
- In the resources sector, the recently released National Manufacturing Priority Road Map has a vision of Australia becoming 'a global centre for commercialising and manufacturing cutting-edge technology products and services for the global resources sector that benefit a range of other industries'.[23]

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[19] Department of Home Affairs, *Protecting Critical Infrastructure and Systems of National Significance*, Australian Government, 2020d.

[20] Department of Home Affairs, *Australia's Cyber Security Strategy 2020*, Australian Government, 2020a.

[21] Department of Defence, 2020b, p. 1.

[22] PM&C, *Digital Economy Strategy: A Leading Digital Economy and Society by 2030*, Australian Government, 2021b, p. 2.

[23] Department of Industry, Science, Energy and Resources, *The Resources Technology and Critical Minerals Processing National Manufacturing Priority Road Map*, Australian Government, 2021, p. 7.

- The most recent *Delivering Ag2030* report identifies technology as key to maintaining and advancing Australia's global prosperity, supporting the domestic economy and making Australia more resilient.[24]

In all these cases, critical technologies represent key enablers, particularly when effectively integrated with critical infrastructure and a productive and skilled workforce. As such, CTNI are prerequisites for strategic advantage, but are not sufficient to deliver this on their own without wider investment in innovation, infrastructure, people and skills.

Technology Assessment for CTNI Is Distinct from but Related to Parallel Efforts in Defence

Similar to other nations, Australia has a relatively mature approach to technology assessments within the Department of Defence. However, the defence context is quite different to that of the rest of government, given its long-term focus, the size of its capability development budget, its close security ties with allies (including in S&T), and the primary importance of security in maintaining a capability edge over potential adversaries. That is not to say that critical technologies for defence are independent of those across the remainder of government; there are many opportunities for dual usage. Rather, the basis for the TA and prioritisation for defence differs in a way that risks subverting a broader whole-of-nation perspective. As such, the appropriate scope and organisational structure for any TA capability depends on the stated objective, primary audience(s) and relevant policy timeframes.

Given this, consideration could be given to the establishment of distinct (though interlinked) defence and non-defence CTNI assessment programs to ensure other drivers, such as prosperity and social cohesion, are properly considered. For example, in the EU, the EDA strategy prioritises defence and dual-use technologies in granular detail, while non–defence-focused strategies cover other strategic technology areas at a higher level.

Across Government, Societal, Security and Economic Considerations Are Commonly Used to Prioritise Technologies

There is a clear message from the Australian government around the importance of considering national security implications in relation to technologies. This is often balanced by seeking to realise the economic benefit that can be derived from such technologies. However, the broader societal benefits are also (and perhaps increasingly) being recognised as an important consideration as to whether a given technology is critical to the national interest.

Indeed, one could argue that society does not just benefit from (critical) technology development, it also provides the basis that underpins the development of critical technologies by creating the human capital and social conditions conducive to its development. Indeed, the

[24] Department of Agriculture, Water and the Environment, *Delivering Ag2030: May 2021*, Australian Government, 2021c.

World Economic Forum's most recent *Global Risks Report* assesses 'social cohesion erosion' as one of the greatest threats facing the world both from an economic and security perspective.[25] The Australian government recognises this, emphasising the societal impacts in many key strategies. For instance, the Cyber Security Strategy will be 'delivered through complementary actions by governments, businesses and the community'[26] wherein 'everyone—governments, businesses and the community—has a role to play in creating a more cyber secure Australia'[27] and, in particular, to 'empower the community to practise secure online behaviours'.[28] Similarly, within the critical technology policy environment, the government notes that 'everyone has a role to play to ensure Australia can safely, securely and efficiently adopt critical technologies'.[29]

These considerations of security, economic and societal benefits have, for some time, been articulated by various government departments, albeit with subtly different characterisations:

- **PM&C** defines the national interest and consisting of 'economic prosperity, social cohesion and/or national security'.[30]
- **Home Affairs** is structured around the three global goals of prosperous ('contribute to Australia's prosperity by enabling a globally connected and open economy and society'), secure ('protect Australia and Australians from key national security and criminal threats') and united ('building community resilience and engendering respect for Australia's shared values and institutions, our way of life and the rule of law').[31]
- **Department of Industry, Science, Energy and Resources** noted in its 2015 Science and Research Priorities noted that 'Australia depends on science and research to increase productivity, achieve sustainable economic growth, create jobs, and improve national wellbeing'.[32]
- **Foreign Affairs and Trade** emphasised in its 2017 Foreign Affairs White Paper the themes of opportunity, security and strength through 'a flexible economy, strong defence and national security capabilities and resilient democratic institutions within a cohesive society'.[33]

[25] World Economic Forum, *The Global Risks Report 2021—16th Edition*, 2021.

[26] Department of Home Affairs, 2020a, p. 6.

[27] Department of Home Affairs, 2020a, p. 7.

[28] Department of Home Affairs, 2020a, p. 8.

[29] PM&C, 'Critical Technologies Discussion Paper: Agriculture', Australian Government, 2021a.

[30] PM&C, 2021a.

[31] Department of Home Affairs, *Blueprint for Home Affairs*, Australian Government, 2018, p. 11.

[32] Department of Industry, Science, Energy and Resources, 'Science and Research Priorities', Australian Government, 2015, p. 1.

[33] Department of Foreign Affairs and Trade, '2017 Foreign Policy White Paper', Australian Government, 2017, p. 2.

- **Department of Defence** states that 'it is essential that countries pursue their interests in ways that are mutually respectful and supportive of stability, prosperity and security' in its recent strategic update.[34]

Clearly, in developing its policy agenda (at least in those sectors that have a strong focus on security), the Australian government is cognisant of the fact that 'new applications of technology must consider economic opportunities, national security risks, and impacts on social cohesion'.[35] Other strategic partners are also taking a similar perspective (see, for instance, the United Kingdom[36] and New Zealand[37]). As such, and consistent with PM&C policy position that the national interest be considered in terms of prosperity, security and social cohesion, these three pillars will be the basis against which an evaluation framework will assess if and how candidate technologies support the national interest.

Differing Priorities Across Policy Sectors Requires a Consistent, Transparent and Repeatable Decision Process

The CTPCO was established within the PM&C in July 2020 with the stated goal 'to provide coordinated whole-of-government advice on technology developments, opportunities and risks, and to recommend actions to promote and protect critical technologies'.[38] Its two key functions are to 'coordinate critical technologies-related policy across government and to provide a strategic foresight capability and policy overview to Government'.[39] This includes assuring access to technologies, building trusted collaborative partnerships, supporting trusted technology innovations, enhancing Australia's international competitiveness, and creating a supportive environment across the RD&I ecosystem (e.g., academia, PFRAs and industry).[40]

The dependency on critical technologies might suggest a need to protect them (e.g., limiting access to IP, reducing risk of foreign interference). However, the nature of that protection needs careful balancing with the benefits that collaboration can offer. Indeed, there will be little benefit to Australia if security concerns stymie their use, either nationally or by international allies and partners, and limit their further development, because 'access to secure critical technologies is fundamental to a prosperous and resilient Australia'.[41] How-

[34] Department of Defence, *2020 Defence Strategic Update*, Australian Government, 2020a, p. 11.

[35] PM&C, 2021a.

[36] UK MOD, 2021.

[37] New Zealand Ministry of Defence, *Defence Capability Plan 2019*, New Zealand Government, 2019, p. 7.

[38] PM&C, 2020.

[39] PM&C, 'Protecting and Promoting Critical Technologies', Australian Government, 2021e.

[40] PM&C, 2020.

[41] PM&C, 2021e.

ever, the observation by IISA that 'there have been few long-term and truly transformative ISR [innovation, science and research] programs'[42] suggests the current system is suboptimal. IISA has recommended 'a strategically balanced, whole-of-government ISR investment plan . . . [to] ensure there are returns in the short, medium and long term'.[43] This emphasises the need for a joined-up approach that selects a set of technologies ('winners') that will best meet Australia's security, prosperity and societal wellbeing aspirations, while being cognisant of the global security and economic environment within which Australia finds itself, and the domestic constraints of the resources it can apply.

Securing the National Base for CTNI Must Be Balanced Against Other Policy Objectives and Australia's Finite Resources

The Australian government must specifically strike a delicate balance between using broader industrial policy and defence procurement decisions to shape the development of sovereign industrial and technological capability. Concurrent with this, it must promote affordability, value-for-money, and other objectives such as interoperability within the international system. While it is neither possible nor desirable for Australia to become fully self-sufficient in all technology areas, given the cost implications and unnecessary duplication, there may be opportunities for Australia to work more closely with key strategic partners and identify opportunities to develop a multilateral approach to CTNI.[44]

Sovereignty can be understood, then, in terms of what is essential for Australia to 'own', where the benefits of 'collaboration' with like-minded and trusted partners are best realised, and the conditions under which Australia should seek to 'access' technologies in the global marketplace. Such an approach assumes deliberative policy decisions on partnerships based on accepting some level of mutual dependence between like-minded countries in terms of CTNI. It also assumes that those allies are willing to take collective action to secure certain technologies of common interest to all participating nations in the event of an external threat.

Industry Is a Major Contributor to the Research Commercialisation Pipeline

Despite the examples noted in the previous section, it is important to note that the Australian government (and by inference those academic and other PFRAs) is not the only active player. It is worth emphasising that in formulating policy around critical technology, the expectation is that 'industry and Government will invest in and use critical technologies

[42] IISA, *Driving Effective Government Investment in Innovation, Science and Research*, Australian Government, 2021, p. 5.

[43] IISA, 2021, p. 6.

[44] Daniel Kliman, Ben FitzGerald, Kristine Lee and Joshua Fitt, *Forging an Alliance Innovation Base*, Center for a New American Society, 2020.

that are secure to protect Australians, their data, and our national interests'.[45] As noted earlier, the most recent data from the Australia Bureau of Statistics show that business investment in RD&I represents approximately half of all investments. When broken down against the 'research commercialisation pipeline',[46] some 60 per cent of business investment was expended on experimental research, with a further 32 per cent on applied research.[47] In comparison, academia expended significantly less on experimental developmental research in comparison with business (about a seventh) and a similar amount on applied research.[48] From a workforce perspective, academia and industry contribute at a similar level (46 per cent for academia compared with 42 per cent for the private sector).[49] What this suggests is that academia plays a major part in the discovery of new S&T breakthroughs, while industry is most heavily involved in commercialising these good ideas into novel products and services. It is noteworthy that PFRAs play a role in both of these, although their entry point tends to be applied translational research. Given its emphasis on the application and use of CTNI, industry therefore plays a critical role, and getting the balance between security and prosperity is paramount.[50]

International Competition Sets Constraints on Sovereignty Choices for Critical Technologies

As with all nations operating in the global marketplace, international competitiveness is a crucial success factor. For example, exports from the resources sector continue to be a major contributor to the Australian economy, and maintaining Australia's position in a competitive international marketplace is seen as critical to prosperity, and through that, to security and social cohesion.[51] Indeed, 'the Australian resources sector is sophisticated and one of the most technologically advanced in the world, with strong long-term growth potential'.[52] Maintaining international competitiveness requires 'commercialising and manufacturing

[45] PM&C, 2021a.

[46] The research commercialisation pipeline types are (in increasing levels of maturity): pure basic research, strategic basic research, applied research, and experimental developmental.

[47] Australian Bureau of Statistics, 2021.

[48] Australian Bureau of Statistics, 'Research and Experimental Development, Higher Education Organisations, Australia', 2020.

[49] Australian Academy of Science, n.d.

[50] See, for instance, Lucia Retter, Erik J. Frinking, Stijn Hoorens, Alice Lynch, Fook Nederveen and William D. Phillips, *Relationships Between the Economy and National Security: Analysis and Considerations for Economic Security Policy in the Netherlands*, Santa Monica, Calif., and Cambridge, UK: RAND Corporation, RR-4287-WODC, 2020.

[51] Department of Industry, Science, Energy and Resources, *Responsible, Reliable, Ready for the Future—Australia's Global Resources Statement*, Australian Government, 2020.

[52] Department of Industry, Science, Energy and Resources, 2020, p. 7.

cutting-edge technology products'.[53] The Australian government has recognised this and developed the National Manufacturing Priority Road Map to prioritise investment in and support the delivery of critical resource-sector technologies.[54]

However, while there are different sectoral focuses on critical technologies, 'there is no whole-of-government approach to evaluating ISR investments despite the existence of effective domestic and international models'.[55] Given this, the IISA's recommendation that 'the development of whole-of-government ISR priorities could be used to drive investment decisions'[56] suggests the need for a more coordinated national approach to policy development and national investment in key critical technologies.

This is not a new criticism of the current state of policy on RD&I, with Professor Ian Chubb noting in 2014 (in his role as Australia's Chief Scientist), that 'the reality is when you can't do everything, you've got to pick where you spend your money'[57]—in effect 'pick winners' and then build better collaborative relationships between academia and industry, an area where Australia has, historically, underperformed.[58] One could argue that there have been some recent efforts to select technologies that offer a competitive advantage through the ACOLA horizon-scanning series.[59] This series identified and undertook a deep analysis of six technologies deemed to be critical to Australia's long-term success, namely, IoT, synthetic biology, precision medicine, energy storage, AI, and agricultural technologies. Crucial to the current conceptualisation of CTNI (i.e., security, prosperity and social cohesion), they used 'economic, social, cultural and environmental perspectives to provide well-considered findings that inform complete policy responses to significant scientific and technological change'[60] in each of the six key technology areas.

Any Analytical Approach Must Strike a Balance Between Efficiency and Engagement with Multiple Relevant Stakeholders

Resources permitting, the Australian government could consider approaching the identification of CTNI through a highly systematic approach involving multiple inputs, rounds of analysis, and stakeholders, similar to the EDA's OSRA process. This first identifies a set of key

[53] Department of Industry, Science, Energy and Resources, 2020, p. 19.

[54] Department of Industry, Science, Energy and Resources, 2021.

[55] IISA, 2021, p. 5.

[56] IISA, 2021, p. 6.

[57] Tim Dodd, 'Chief Scientist Urges Strategic Research Funding', *Australian Financial Review*, 1 December 2014.

[58] Office of the Chief Scientist, *Benchmarking Australian Science, Technology, Engineering and Mathematics*, Australian Government, 2014, p. 31.

[59] ACOLA, n.d.

[60] ACOLA, n.d.

strategic areas with technology gaps, then identifies individual technologies in those technology gaps, and then uses experts to score the individual technologies. Having a systematic process improves transparency and ensures that all potential technology areas are considered, leading to a more comprehensive list and clear traceability to the original evidence base and analysis used to generate it. This all takes time, resource and stakeholder buy-in, of course, necessitating a balance. As demonstrated through the European experiences, there are several methods that may also be applied, and there is no 'one size fits all' methodology.

To define the most appropriate approach, Australia should consider its audience, tailor the outputs to them, and ensure they receive and understand the outputs and use them. For example, the European Parliament's Science and Technology Options Assessment function provides briefings to inform policymaking, while the EDA and European Commission ensure that the OSRA and technology building blocks feed into the CDP and the research and capability funding windows of the European Defence Fund. These coordinated efforts aim to avoid establishing a list of CTNI without appropriate mechanisms to respond.

Strategic Patience Is Needed to Ensure Policy and Investment Decision Have the Opportunity to Realise Their Benefits

Given the nature of technology development, there will be a time lag between the government identifying CTNI priorities, the development of policy instruments to respond, and those instruments delivering the anticipated benefit. Managing expectations, particularly as events emerge in the daily news cycle, may be challenging, as the government may seek to adjust their policy instruments to respond. This risks perverse outcomes, wherein CTNI priorities deliver too late to effectively deal with those issues.

Further, institutionalising CTNI policy development will take time. Most approaches we reviewed have been built over many years, even decades. Australia should accept that it will take time to build a mature approach to policy development around CTNI. This can be characterised as the need to 'crawl, walk, run', building up an 'intelligent customer' function across government, industry and the research sector, and, over time, becoming more ambitious as the understanding of the key technology areas develops. However, if a major incident arises, the government must retain the capacity to adjust its policy settings, with agile processes in place so it can act quickly when it needs to.

CTNI Prioritisation Must Respond Rapidly When Disruptive Breakthroughs in Novel S&T Emerge

Any potential assessment and prioritisation approach should also recognise that priorities shift over time and that the technology and threat landscapes are both developing at a fast pace and subject to significant uncertainty. As novel S&T developments emerge, what was considered CTNI in the past may not be critical in five- or ten-years' time. The approach taken to developing and maintaining the CTNI lists should consider how often they should be refreshed, how to introduce challenge (e.g., through red-teaming, gaming, participatory methods) into the process to avoid 'group think' about CTNI, and how Australia could be forward-leaning in actively monitoring 'weak signals' to try and detect possible new technology trends and understand their possible future projections.

3.3. Summary

In this chapter we have considered the Australian context and international experiences to define the CTNI policy environment. There are considerations and lessons to be learned if one wishes to develop and prioritise CTNI in a consistent, transparent and ultimately repeatable manner. We have identified ten such factors that provide a basis for devising a suitable analytical framework that supports CTNI prioritisation.

CHAPTER FOUR

An Analytical Framework for CTNI Prioritisation

In this chapter, we develop an analytical framework that supports the identification and prioritisation of CTNI. We show how this framework both contributes to maintaining national innovation capabilities and supports technology acceleration to address emerging issues.

4.1. High-Level Framework

Having considered both national and international issues and approaches, we are now in a position to develop an analytical framework that can take a range of existing and emerging S&T, overlayed with a national policy agenda, to develop and prioritise CTNI. Clearly there is a set of attributes the model needs. As noted earlier, many others have sought to do this and structured their approach to their particular need. For instance, similar work focused on the future transport sector[1] identified the requirement to assess and compare technology against strategy goals; derive needs based on functions (or missions); recognise that no single metric is sufficient and multiple may be required; use a common analytical framework; focus on the effect the technology can deliver; utilise, as much as possible, practical, current agency functions; recognise information is incomplete and capture uncertainties; and allow flexibility to accommodate technology and contextual disruptions.

In Figure 4.1, we display a high-level analytical framework to support this. Here, the top half (blue sector) seeks to develop the CTNI list based on the technologies' broader impact, while the bottom half (pink) takes that list and, in response to some policy drivers, develops a prioritised list. While the details for each are discussed later in this chapter, it is worth highlighting some features of the model:

- Essentially, the model is a combination of technology horizon scanning and an environmental scan to perform a technology impact assessment.

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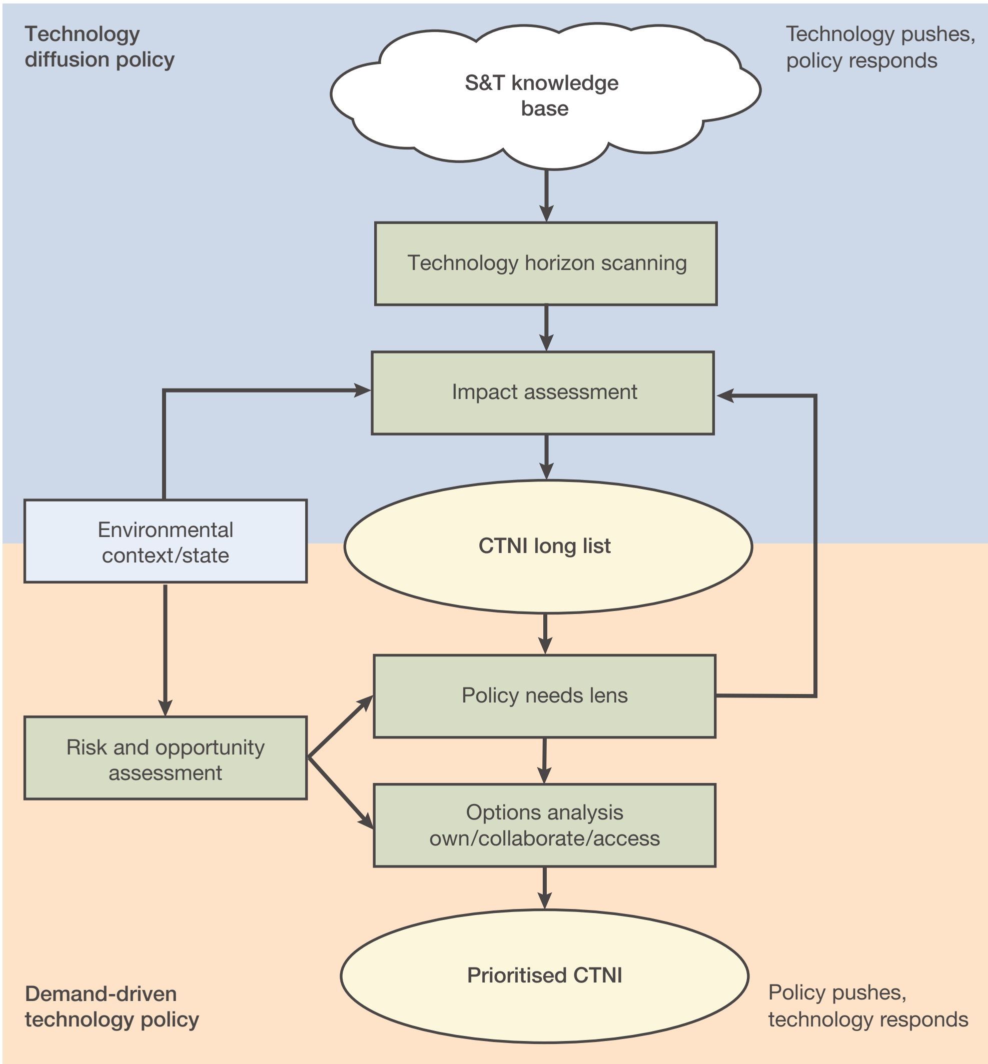
[1] Stephen W. Popper, Nidhi Kalra, Richard Silberglitt, Edmundo Molina-Perez, Youngbok Ryu and Michael Scarpati, *Strategic Issues Facing Transportation, Volume 3: Expediting Future Technologies for Enhancing Transportation System Performance*, National Academies of Sciences, Engineering, and Medicine, Washington, D.C.: National Academies Press, 2013.

FIGURE 4.1

High-Level CTNI Prioritisation Framework



- The impact assessment assesses candidate technologies in terms of the three national interest pillars situated in the broader technological and national policy context.
- The model recognises the utility in applying both diffusion- and mission-oriented approaches, with the top half covering the former, and the bottom half the latter.
- While this figure appears linear, in reality there would be feedback throughout the model. For clarity, we have left most of the feedback loops out of the figure. However, the feedback loop between policy needs and impact assessment is included because it emphasises the fact that any significant policy changes (e.g., commitments in relation to carbon neutral emissions) may require an assessment against the three pillars.

In addition, the government might have specific policy needs that require addressing through CTNI. This kicks off a second activity whereby CTNI are considered in terms of their capacity to support those specific policy requirements. The first step is to winnow down the CTNI list into a set of candidate solutions. To assess value here, we would need to understand how it provides a national benefit (opportunity) or represents a potential threat (risk), based on the factors driving this policy need. Potential solutions (options) could then be analysed, particularly in terms of the capacity to own-collaborate-access to develop solutions given the national intent and the timeline for delivering the required outcome. Taken together, this process delivers two different types of cascading lists: a broader list that captures all technologies that are critical to the national interest and a prioritised list of CTNI that cuts across all policy sectors.[2]

4.2. CTNI Long List Development

Technology Horizon Scanning

Central to our analytical approach is to have a comprehensive, dynamic database of current and emerging technologies. Currently, this is achieved through a software-enabled technology horizon–scanning approach that DSTG has developed and is delivering to a number of defence and national security organisations, as well as international partners.[3] The DSTG approach aims to provide 'a systematic examination of information to identify potential threats, risks, emerging issues and opportunities'[4] and is seen as a contributor to considerations of the national interest by detecting and identifying future sources of opportunity and threat. This provides the basis for the systematic framework for capturing, assessing and curating technologies in a manner to winnow that full spectrum into a more manageable set.

Of course, technology policy is not constructed in isolation of the broader policy environment. The inertia of the existing technology ecosystem and the time required to make changes mean that if there are significant changes to be made (in the national interest), then these need to be considered and built from the existing edifice. This can be complicated by the rapid nature of technological development, on the one hand, and the difficulty in imagining how that will be manifest as a functional product, on the other. As such, we need a

[2] The Productivity Commission recently released a report on supply chain vulnerability where they employed a three-step analytical framework transitioning from 'vulnerable to disruption' to 'essential to the well-being of Australians' to 'criticality to production'. This was released after our analysis was complete and has not been considered in detail. However, there may be merit in investigating whether framing the CTNI long list in terms of *essential* rather than *critical* to the national interest, based on the Productivity Commission's definitions, might be more appropriate. See Productivity Commission, *Vulnerable Supply Chains*, Australian Government, 2021b.

[3] D. L. Bongiorno, N. Prakasan, J. Truswell, M. Posadowski and J. Walsh, 'AiCE: Automating Horizon Scanning for the Detection of Emerging Technologies', *2020 IEEE Symposium Series on Computational Intelligence*, Canberra, ACT, Australia, 1–4 December 2020.

[4] UK Cabinet Office, *Review of Cross-Government Horizon Scanning*, UK Government, 2021b, p. 2.

systematic assessment approach that builds on top of the discoveries and critical factors that emerge from the technology horizon scanning, while being cognisant of the (policy) environment within which it will mature. In order for the discipline and stability needed for policy changes and investments to realise their benefits, this approach must be repeatable, minimise ‘bias’, and be able to manage large volumes of data.

When making assessments, caution is required given the potential for overestimation of a technology’s capabilities and underestimation of its time-to-impact. These may lead to poor policy outcomes as the hype around an emerging technology may distort decisionmaking, funding distribution, acquisition cycles, and policy implementation. As such, the analytical approach for prioritising critical technologies needs to understand technological risk. A common approach is technology readiness levels (TRLs), which focuses on the characteristics of the technology itself.[5] However, consideration should be given to more contemporary approaches such as STREAM (Systematic Technology Reconnaissance, Evaluation and Adoption Method),[6] which goes beyond TRLs by considering the organisational context in which any given technology must be absorbed and applied (e.g., barriers/enablers in terms of regulation, funding, training, standards); see Table 4.1. This type of analysis, informed by

TABLE 4.1
Summary of STREAM Approach

Phases	Key Questions
Frame	What is the function that technologies are to affect?
	What is the agency context within which the function is carried out?
	What are the goals and metrics associated with the context?
Identify	What technologies are or will be available to affect an agency’s ability to perform a particular function?
	What is the maturity of these technologies, and when are they likely to be available?
Characterise	For each technology, how does it affect the agency’s ability to meet the goals associated with the function?
	What are the costs, drivers and barriers to technology adoption?
Compare	What are the trade-offs between adopting a technology or bundle of technologies now or in the future?
	What are the likely outcomes, both direct and indirect, on the target functions as well as other agency functions?
Decide	What action should an agency take with respect to these technologies (monitor, shape, adopt, . . .)?

SOURCE: Adapted from Popper et al., 2013, p. 2.

5 NASA, ‘Technology Readiness Level’, webpage, 29 October 2012.

6 Popper et al., 2013.

intelligence from the business sector, allows for a deeper understanding of the time it will take for technology commercialisation.

As noted, the technology ecosystem can be slow to change and has many actors with vested interests in pursuing particular technologies. Any approach that seeks to limit that scope in the establishment of a critical technologies list will be confronted with some resistance to change. These actors may have valid cases. As such, the possibility of change must be explored and left as a series of possible options, at least in the early part of any analysis. Other factors may also create some resistance. For instance, ethical considerations cannot be ignored, as the use of a technology that may be unethical for one group of people may be acceptable by others. As such, the computer-enabled data-driven approach must work in tandem with a more qualitative descriptive approach. This will be a key factor in the design of the data system that underpins these processes.

It should be noted that it is unlikely that a single domain of science will deliver a complete solution to a single problem or opportunity of national interest. Indeed, history suggests that it is the convergence of various technologies that will ultimately create the outcome required.[7] Because of this, *we recognise the need to consider technology convergence*, which represents the aggregation of multiple other technologies, non-technological aspects that underpin them, and technological or non-technological aspects that facilitate their adoption. In essence, any technology can be broken down into multiple levels of more specific technologies or subunits of knowledge. This will allow insights into those technologies that have wide-ranging opportunities and/or are critical elements to realising the benefits of aggregations of technologies.

Impact Assessment Through National Interest Lenses

An impact assessment represents the entry point for the national policy agenda to be considered. Clearly, not all RD&I programs represent CTNI, at least from a policy perspective. That is not to diminish the importance of technologies that do not meet these criteria. Rather, it is a recognition that, from a national policy perspective, there are certain technologies that have a particular relevance to addressing specific national issues, challenges and opportunities, and where the government therefore cannot simply leave things to market forces and the private sector to solve. In terms of the CTNI agenda, this relates to their impact on security, prosperity and social cohesion. The mechanism for addressing this is through an impact assessment; that is to say, an evaluation of the potential for technologies to affect current and future issues of national significance.

Technology Characteristics

In establishing what technology characteristics matter, it is instructive to seek insights on how other nations have addressed this, given their legacy of differing approaches over the

[7] For instance, the US National Science Foundation has established the Convergence Accelerator Program ‘solve societal challenges through convergence research and innovation’. See National Science Foundation, ‘Convergence Accelerator’, webpage, n.d.

past two decades. In terms of capturing balance and value, a similar approach to the Australian pillars is employed (although security and prosperity are generally the focus, with the occasional consideration of societal impact). For instance, the UK MOD's 2012 'National Security Through Technology' white paper defines these as a balance between an open procurement principle (recognising market forces offer a greater chance for successful innovation) and a technology advantage principle (which recognises the need to protect some sensitive technologies).[8] Further, when considering technologies within a policy context, impact assessments have considered such factors as

- whether the technology is game changing or disruptive to 'normal' business practices
- the strategic impact of its application, generally in terms of security, prosperity and international influence
- its capacity to mitigate the impact of non-traditional threats (both from a security and prosperity perspective)
- the level of convergence with other technologies and other enablers (e.g., critical infrastructure), particularly in terms of the complexities of these inter-relationships.

Therefore, in addition to the information captured in the technology horizon scanning, we have identified the following characteristic as useful:

- **Nature of impact—**the manner in which the technology is expected to make an impact. A candidate CTNI must be categorised in at least one (but can fit into more than one) of the following:
  - *Disruptive:* game-changing technologies that enable developments in capability that unfold faster than an entity's ability to adapt to their consequences. Game changing generally refers to a significant step forward in innovation or capability that would require a complete rethink of how we approach something. These conditions may arise through 'technology surprise' or through the failure or inability to adapt in a timely manner.
  - *Converging:* delivers innovations or capabilities that create new efficiencies and opportunities when distinct technologies are combined. These technologies can be existing or emerging S&T developments.
  - *Emerging:* new or previously undeveloped technologies that are experiencing growth through increased attention and/or funding during early-stage development. These technologies may deliver innovation that expand on current functions due to breakthroughs within a technology domain in areas of importance within Australia. The technology may offer tangible benefits across a range of critical national sectors.
  - *Enduring access and sovereign capability:* maintaining existing critical technologies within Australia or ensuring access to a trusted partner.

[8] UK MOD, *National Security Through Technology*, UK Government, 2012.

- **Realisation timeframe**—the timeframe of candidate CTNI must also address a policy timeframe in at least one of the following areas:
  - *Immediate*: able to address a significant change underway that requires the government to rapidly respond on behalf of the Australian people and where specific technologies have been identified as central to that response.
  - *Emerging:* an emerging threat/opportunity has been identified whereby technology offers options for government to invest in innovation and/or adjust policy levers to optimise the outcomes.
  - *Long-term:* able to respond to where future critical risks/prospects are forecast that will, if unaddressed, diminish Australia's relative global standing and/or national productivity.

Policy Context

Candidate critical technologies cannot be considered in isolation from the national policy context. As such, policy attributes need to be attached to the technologies. This takes the form of linking technology attributes across all government sectors. This is possible through the linking of department and agency objectives and desired outcomes (currently captured in a relatively consistent manner through the use of the Department of Finance's logic model),[9] and injecting academia, PFRA and industry perspectives to those functions and hence those technologies. Factors, such as where technologies offer cross-cutting solutions (affecting many government sectors) and the broader RD&I infrastructure, would automatically be captured through this data-tagging process.

Evaluation Criteria

Understanding the value of a candidate technology is an implicit requirement for assessing its impact. The UK MOD's recent Defence and Security Industrial Strategy (DSIS) emphasises 'critical success factors' for investment decisions (of which critical technologies are a major component) in terms of strategic fit (addressing priority national functional requirements), potential value for money, and the value to the broader national enterprise.[10] While criteria are, as yet, not clearly defined, they are underpinned by HM Treasury's *Green Book*[11] and *Public Value Framework*,[12] which is built around the four pillars of pursuing goals (including vision and level ambition), managing inputs, engaging users and citizens (including legitimacy, experience and participation), and developing system capacity (supply chains, resource capacity, sustainability and institutional interdependencies).

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[9] Department of Finance, *Developing Good Performance Information*, Resource Management Guide No. 131, Australian Government, 2020a.

[10] UK MOD, 2021.

[11] HM Treasury, *The Green Book: Appraisal and Evaluation in Central Government*, UK Government, 2020.

[12] HM Treasury, *Public Value Framework: with Supplementary Guidance*, UK Government, 2019, p. 6.

Aside from managing inputs, which is largely associated with governance, the remaining three pillars offer some insights into how value might be identified. Using these criteria, in conjunction with identified government needs, we have formed a series of statements against which candidate CTNI could be considered:

- **Supply chain:** CTNI will be supported by a resilient supply chain and able to manage foreseeable challenges to that, so that it cannot be 'held hostage' to internal pressure and external competition.
- **National base:** CTNI will have the capacity to effectively operate with the necessary enabling capabilities such as accessible national infrastructure and a sufficiently skilled and sized workforce, and within an appropriate ethical, legal and regulatory framework.
- **Resource utilisation:** CTNI should represent an efficient and effective utilisation of national resources whereby the costs incurred are proportionate to the benefits derived from that investment. This includes consideration of foregone costs in other areas through the utilisation of these resources.
- **Long-term sustainability:** CTNI will continue to be supported and supportable at the required level for an extended period after the initial policy and investment activities conclude.
- **Sovereign interest:** CTNI will demonstrate, through their application, a level of Australian interest to maximise the national economic benefit in the short term and positions Australia for success in the longer term.
- **International leverage:** CTNI should be able to be leveraged to Australia's benefit when engaging with international partners, including offering 'trade goods' that can facilitate access to other technologies, applications and skilled workers, and help facilitate Australia's preferred position within the international environment.
- **Social benefit:** CTNI should maintain and potentially enhance the standard of living for all Australians in a manner that does not impose undue restrictions on them. In doing so, it would contribute to the resilience of Australian institutions.

While these may not be mandatory, clearly meeting them does offer a basis for making the CTNI list.

Assessment

Using the technology characteristics and policy criteria, we can build the criteria against which CTNI are identified, as well as the evidence base used to support these. This is likely to require input from subject matter experts (SMEs) for assessment, which would be facilitated through the coordinating body. Further, it should be recognised that there will be overlap across and between the assessment elements mentioned above. We contend impact assessment includes implicit feedback loops that develop throughout the process. Given this, the approach taken would be subject to resources and system maturity. As such, we cannot advocate the manner in which it should be undertaken. However, we do recognise that the outcome of that assessment must be characterised in terms of the national interest pillars listed below and describe the propensity for impact across them:

- **prosperity:** the potential to create new markets, maintain an existing one, and/or eventually, disrupt existing markets and value networks where Australia has (or has the potential for) a competitive advantage
- **security:** the potential to create new threats, disrupt Australia's capacity to meet its security objectives, and eventually render existing capabilities redundant
- **social cohesion:** the potential to enable national stability, to realise a benefit or cause challenge in the immediate term and/or cause significant and rapid societal changes in the longer term, and to affect the Australian way of life.

We then undertake an analysis to determine whether the level of coverage afforded by the current CTNI long list is sufficient. This will allow action to be taken, if necessary, to manage any gaps, including amending the CTNI list.

Environmental Context

A parallel input into this initial TA is a recognition of the broader context and how that might enable or inhibit technological development. This is the art of 'policy-orientated foresight'; that is, 'the process of developing a range of . . . possible ways in which the future could develop and understand these sufficiently well to be able to decide what decisions could be taken today'.[13] In our case, it is important to situate the environment within which the technology might develop and be employed, as this can affect the developmental path. It also helps to identify risks and opportunities for the application of that technology into the future. There are a number of examples where the Australian government has developed descriptions of the strategic environment that capture the broader issues of national importance, albeit in slightly different forms:

- *Forward 2035:*[14] a Department of Defence publication that posited a future around complexity, change, opportunity and demands to identify four policy-oriented drivers, namely, mastering complexity, trust in technology, smart power, and innovative enterprise.
- *Australian National Outlook 2019:*[15] a publication by the CSIRO that explores the economic, social and environmental challenges for Australia out to 2060 through different policy positions

[13] Averil Horton, 'A Simple Guide to Successful Foresight', *Foresight*, Vol. 1, No. 1, 1999, p. 5.

[14] Boey et al., 2014.

[15] CSIRO, *Australian National Outlook 2019*, Australian Government, 2019.

- *Australia 2030: Prosperity Through Innovation:*[16] a publication by Innovation and Science Australia (now IISA) that identifies five imperatives that will deliver better social, economic and security outcomes through a more innovative culture (particularly in terms of S&T).

4.3. CTNI Priorities Development

Technology has the propensity to significantly change the policy environment with which it interacts. For instance, changes in digital technologies have created major changes in how business is conducted, created new security challenges from those seeking to penetrate digital systems, and raised issues of public interest such as privacy and safety. As such, understanding if, where, how and to what extent technology is likely to affect the national interest is essential to determining technology criticality, priority and the associated policy requirements. As the Australian government has recently noted, through the Office of Best Practice Regulation, 'strong evidence-based impact analysis is a powerful tool when applied intentionally and consistently. . . . [It] ensures that decision makers are supported with the necessary evidence base, and that policy options are well-designed, well-targeted and fit-for-purpose.'[17] Furthermore, 'almost every Government proposal being considered is within scope of the Government's impact analysis requirements', and an Impact Assessment Framework (IAF) has been introduced to help 'policymakers develop the evidence base for well-informed decision making'.[18]

With this in mind, we have identified the following steps to be followed when developing a prioritised list, based on current policy needs and how the CTNI (through the long list) might offer solutions (in effect, the bottom half of Figure 4.1):

1. **Policy needs lens:** derive sectoral and/or cross-cutting technology lists from specific government policy priorities.
2. **Risk and opportunity assessment:** review technology priority in terms of risk/opportunity to capture value in a consistent manner.
3. **Options development:** determine viable technological options, together with their strengths and limitations.
4. **Establish CTNI priorities:** assess technologies against established criteria to determine which are of most importance to the national interest.

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[16] Innovation and Science Australia, *Australia 2030: Prosperity Through Innovation*, Australian Government, 2017.

[17] PM&C, 'The Office of Best Practice Regulation: Developing the Evidence Base for Decision Making', webpage, 2021d.

[18] PM&C, 'The Impact Analysis Process', Australian Government, 2021c.

Policy Needs

Throughout its time in office, a government will articulate its policy priorities. These might be in response to an emerging threat, be aimed at realising a national benefit, or be associated with a political imperative or a change in the domestic environment (e.g., regulatory obligations that arise from an international agreement). They might be aligned to a particular policy sector (e.g., agriculture) or an issue that cuts across multiple sectors (e.g., climate change). And they might be directed at certain segments of society, such as the business sector, community groups and/or older Australians. Irrespective of who, why and where these policy priorities are focused, they each present a policy need against which technological solutions can be identified and prioritised. That is to say, there is the potential for a dedicated priority technology list to be developed for each.

The decision to develop such lists will fall to different actors depending on the nature of the policy priority. For instance, if the government falls largely within the remit of a single sector (e.g., if it wishes to improve the productivity of the agriculture sector), it is likely that the relevant department will be responsible. If the issue is cross-cutting, such as achieving net zero-carbon emission by 2050 or seeking options to decouple Australia from another nation's economy, it might fall to an interdepartmental task force, a central agency or even a PFRA. If it focuses on a single national interest pillar (e.g., regional security), then the relevant department might be responsible, with some level of accountability shared with other departments.

However, if we are to develop a list of CTNI priorities, then it is important that those narrower technology priorities are articulated in a consistent manner. At a minimum, they should use (and indeed be on) the CTNI long list. Taking that into account, in this step we would undertake a review of these policy needs and associated technology priorities to ensure that they are captured in a manner suitable for the later steps of options analysis.

In addition to using the technology taxonomy of the CTNI, other key factors need to be captured. While the IAF is focused only on regulatory issues, given its use across government, it does provide a useful basis (and potential guidance) to impose this consistent policy needs lens. Notwithstanding the fact that it does not explicitly consider security, the framing questions for the IAF Preliminary Assessment provide a starting point:[19]

- What is the potential scale of the problem?
- What is the nature of the proposed options?
- How many stakeholders are affected?
- What is the impact on individuals, businesses and community organisations?
- *What are the potential cost burdens or savings?* [emphasis added]
- Who is the decisionmaker?

[19] PM&C, 2021c.

We add a further question to cover the security pillar, and adjust the italicised question above as follows:

- What are the security implications of the proposed options?
- What are the potential implications for national prosperity?

We then map to the broad government policy agenda that is data-tagged to the CTNI with the national needs identified in the technology priority lists to ensure consistency and manage inconsistencies and data gaps.

This information is also important as part of the development of the CTNI long list, since it can help inform the impact assessment against which the sufficiency of that list can be assessed.

Risk Assessment

While it is important to collect and collate the set of technology lists developed to address specific policy priorities, we cannot simply overlay the lists to identify the subset that is of greatest importance. Simply selecting those that appear the most often might miss the importance of each technology to the policy response. Similarly, the interdependency between technologies in delivering a solution would be missed. Finally, not all policy problems are equal—some will offer greater benefits than others, be that mitigating an emerging threat or realising an emerging opportunity. As such, we need the capacity to align these lists in a consistent manner. To understand and compare these policy needs and technology responses, a risk assessment is undertaken as a basis for comparison. A nuance here is that, for consistency purposes, opportunities are defined in terms of opportunities missed in order to allow a consistent framing between risk and opportunity.[20] This will provide a consistent basis to compare the different technology priority lists.

It is important to note that risk here is not just from an external threat or failing to realise an economic benefit. It might be in terms of the ability to realise within the desired timeframe or the knock-on effect on the broader system as resources are diverted to (or from) this technology. It might be the need to maintain currency in national capabilities in order to preserve a global or national market, or the ability to supply and sustain critical systems that support national wellbeing. As such, a number of assessments will be required and compared. Some level of weighting across these might be needed if it is determined that some of these risk types are more important than others.

Options Assessment

Having captured and mapped a range of (policy-driven) technology priority lists, we are now positioned to explore whether there is a subset of CTNI that require greater attention. Of

[20] This is broadly consistent with the UK approach.

course, developing such a list does not occur in a vacuum. The national capacity and capabilities need to be considered, as does the cost (in terms of benefit) and the scale and timing of the risk or opportunity. Australia's need to retain (or obtain) sovereign control needs to be balanced against its ability to leverage trusted partners for access, or even approach the open market for access. To evaluate these competing pressures, we recommend establishing what the realistic trade-offs are and then developing options that are compared through an appropriate analytical approach.

Assuming the analyses that led to the policy priority lists are robust, those options would derive from technologies on that list. Some viable policy options might consist of other types of solutions, such as critical infrastructure, or a mixture of types. What is critical is understanding how (and how well) the options can deliver the required outcome given the system constraints, such as resources, governance and regulatory issues, national capacity, and foregone benefits. Further complicating this is balancing the national aspiration to own as much of those critical technologies as possible against the reality that Australia cannot expect to maintain the necessary leading edge given its size and that of potential competitors.

The evidence base for any technology option would build upon the information developed in the impact assessment. The additional information required would include any (significant) changes to technological characteristics, as well as more explicit consideration of the particular policy need under consideration. Further, the nature of the solution (disruptive vs evolutionary change), the timeframe to respond (both decision and delivery) and/or the downstream impacts need to be captured explicitly. Finally, the risk appetite, as captured in the risk/opportunity assessment, needs to be incorporated.

Having developed these detailed options, government can bring together appropriate SMEs to consider these options against the policy context. While a variety of techniques can be employed, it is important that the criteria used align with the statements identified earlier in this chapter and against the national interest pillars. The product would be a prioritised list for critical technologies for that particular policy issue.

National Capacity Characterisation

The complexity of a whole-of-nation approach to prioritising CTNI is not to be underestimated. The number of technologies that might be considered and their continued evolution, the number of sectors that are potential users and how that policy environment evolves, the importance of the three national pillars (security, prosperity, social cohesion), and the underlying national capacity versus sovereign choice conundrum (own, collaborate, access), when combined, will make any prioritisation intractable without some capacity to reduce the option set down to a manageable level.

It is useful, then, to understand criticality from a national capability/capacity level, which removes technologies that are essential for Australia to own as well as those that are easily accessible through international sources. Such a distinction means that technologies deemed essential to own will automatically make the prioritised list. Then, subject to available national capacity, what remains are those critical technologies that are not readily accessible.

Integration of Diverse Policy Demands

It is easy to envisage that the government would establish priority critical technology lists for national policy issues. However, this might look quite different depending on the issue. For instance, a priority list for addressing climate change (such as seeking to achieve zero-net emissions) would in all likelihood be quite different from one that was designed to help decouple Australia's economy from China. As such, there is the potential for a final step whereby the priority technology lists across major policy agendas could be compared. This would allow a more holistic focus on CTNI that have wider applications, ensuring better alignment between these areas in terms of if, where and how they are invested in. In a manner of speaking, this has the potential to bring us full circle to selecting a few technologies that have potential for the greatest impact.

CHAPTER FIVE

Employing the Analytical Framework

Developing an analytical framework is only part of the challenge, as the complexity of the whole-of-nation CTNI policy coordination requires a dedicated effort. In this chapter, we identify the attributes for a successful application and then discuss some of the challenges when determining a suitable way in which to manage them. There are many challenges that could be considered. We have identified seven that are, at this time, the most pertinent when applying the analytical framework.

5.1. Attributes for Successful Application

Establishing a consistent, transparent and fit-for-purpose analytical framework for CTNI prioritisation is a challenging endeavour. There are a large number of disparate policy sectors whose requirements need to be defined in an internally consistent manner.[1] Technologies continue to evolve, and their evolution paths have uncertain timelines, particularly for those that have low technological maturity, critical interdependencies with other technologies, or a history of challenges in their commercialisation. The national interest goals of security, prosperity and social cohesion have different (and sometime conflicting) motivations that require a level of choice over how to balance them. And there is the reality of the global market for a middle power like Australia.

While the framework described in Chapter Four (see Figure 4.1) would appear relatively straightforward to apply, the reality is that CTNI assessment and prioritisation is complex, contested and dynamic. For the analytical framework to be successful, it must be able to deliver certain outcomes. We have identified four key attributes:

- **Identifying emerging and potentially disruptive technologies.** These disruptions can represent either an opportunity or threat (or in some cases both) and offer the greatest challenges to the current modes of operation.
- **Identifying those technologies that are essential to the national interest.** These may be existing technologies or emerging ones and are most likely to represent opportunities for (or risks to) greater efficiency or effectiveness.

[1] For instance, agriculture, health, education and mining.

- **Supporting operationally urgent requests from government.** In this case, the immediacy of the response requires a capacity to filter for those CTNI on the list that offer the most promising potential solutions.
- **Uncovering the potential implications of policy initiatives and/or changes for CTNI.** This is not exclusive to initiatives around technology and might also include critical infrastructure, workforce, regulatory and community issues.

This leads to a second consideration, in that while our approach is to start with the technology and winnow down to a CTNI list and then prioritise, there must also be windows for national policies to interact with those lists. At one level, when developing the long list, this focuses on the potential impact of candidate CTNI on the three national interest pillars (security, prosperity and social cohesion). From a prioritisation perspective, this focus on exploring response options where value is established and compared in a transparent and repeatable manner is essential.

Finally, when applied, the framework must capture the technology's context, including

- its maturity and the pathway to achieving this (including the projected timeline)
- the potential application and the broader environment of that application
- issues around commercialisation and value chains
- the broader global trends that might affect development and applications
- dependencies on raw materials, other technologies, infrastructure, knowledge and skills
- any sustainability issues around the development and application, including the supporting supply chain.

5.2. Implementation Considerations

An Optimised Solution May Not Be Practical

A typical optimisation approach is not feasible given that many value assessments will be subjective and context-dependent. In essence, it is a 'wicked problem':

- It is highly interdependent with multiple drivers,
- The consequences of choices are often unforeseeable given the uncertainty of how technologies will be realised and employed in an evolving national environment.
- It seeks to address issues that cut across all aspects of government.
- It has no optimal solution.
- It exists in an environment of continual change.
- It is socially complex and will involve changes in behaviour.[2]

[2] A 'wicked problem' from a public policy perspective is one where the policy issue exists in a high dynamic, socially complex environment with significant interdependency across many policy sectors. As such, optimal policy solutions ae not assured, as they involve behavioural changes that cannot be readily predicted.

Given the complexity for the CTNI context, both from a technology and policy perspective, developing such an optimised solution is not feasible. Indeed, much of the information underpinning the ultimate choice will come in the form of expert opinion. Furthermore, as the issue at hand is examined and solutions derived, it may be that different and distinct technology options could be developed to address a priority issue. There are also the legislative and regulatory instruments in place to protect specific technologies, such as through export and access control on sensitive (particularly dual-use) technologies. Finally, CTNI cannot be treated in isolation from other critical national capabilities, such as infrastructure and workforce, as it is highly likely that it will be a combination of these that will deliver the require outcome.

One approach to dealing with this that is commonly used by Australian government departments is multicriteria decision analysis. This supports decisionmaking by establishing objectives and criteria to allow for trade-offs between alternatives. Through a facilitated analytical activity, SMEs are used to compare these alternatives, with each providing an assessment of the relative benefit between, and ordering of, the alternatives. These are then combined to establish an overall preference. Depending on the specific analytical method used, the results can be interrogated to determine their sensitivity to small changes.[3]

Balancing Between Mission- and Diffusion-Based Approaches Is Not a Binary Choice

The policy choice between diffusion- and mission-based initiatives will likely be contested. However, it is possible, and perhaps necessary, to support both types of initiatives. We can think of them, respectively, as technology diffusion policy, where it is (generally) the technology that institutes the change and policy responds, and demand-driven technology policy, where the policy environment sets the requirements and technology solutions offer the response. Australia has generally taken a diffusion-oriented policy approach when considering technology investment as a whole. We observe that both have their place—that is, Australia needs to develop and utilise both list types. However, given resource limitations, a policy mechanism that determines how to balance diffusion- and mission-oriented policy responses is necessary. It may be useful to adopt an approach that considers not only the potential impact of the technologies (be that threat or opportunity), but also the likelihood of that impact (the threat or opportunity) becoming real. This can be achieved through separate and different scanning activities that identify and quantify emerging events or issues. From this a more refined, temporal-based set of critical technologies would be identified as potential candidates to address the issues. It is this set that would comprise 'win-

See Australian Public Service Commission, *Tackling Wicked Problems: A Public Policy Perspective*, Australian Government, 2007.

[3] We observe that DSTG has extensive experience in designing and employing these approaches. As such, we have not provided a detailed review.

ners' for those issues at hand or most likely to occur. This aligns more with a mission-oriented policy design process.

It is important to emphasise this does not mean that the technologies only on the CTNI long list are not important now or in the future. Rather, these underwrite the innovative capacity necessary to position Australia to meet emerging challenges in a more effective and efficient way, one that is focused on successfully delivering actionable (operationalised) results of that investment in the appropriate timeframe. A further set of criteria should be applied when considering CTNI. These relate to whether Australia owns (or needs to own) the technology, needs to collaborate to develop the technology, or requires access to it.[4]

Metrics Should Be Demand-Driven

Fundamentally, any approach to prioritising CTNI must respond to national needs, whether that be related to security, prosperity, social cohesion, or a combination of these. Given the cross-cutting nature of CTNI, that prioritisation process must be able to consolidate policy drivers from across all sectors in a consistent manner. The first step is to bring together the supply side (critical technologies) and demand side (national interest) to determine the level of coverage the current investment affords. In the first instance, this gap analysis can be built around existing data sets, using measures adapted from those which relevant government departments report against. However, given the breadth and quantity of data available, we need to build confidence in the results by designing a consistent, repeatable and measurable approach. Within the government sector, one approach to identify what should be measured (as opposed to what can be measured) is to use a logic model that links the flow of resources (inputs), activities (actions) and products (outputs) to the desired policy objectives and strategic goals.[5] As noted earlier, M&E is a necessity to ensure success. Measures can be established at each point in the logic model, although ideally one should be measuring the outputs and outcomes rather than the inputs, supporting this M&E requirement.

The Department of Finance approach to program design and reporting is useful here.[6] This approach is mandated to ensure government investment (through New Policy Proposals, for example) delivers their promised outcomes. Thus, we can map government objectives (the promised outcomes) to the existing national research agenda (as a representative of the investment). Once complete, cross-correlating the investments each sector contributes for particular technologies and then considering these technologies against CTNI priorities could be used to identify underinvestment (policy gap) or overinvestment (inefficiencies).

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4 UK Government, *Global Britain in a Competitive Age: The Integrated Review of Security, Defence, Development and Foreign Policy*, March 2021; White House, 'U.S.-EU Summit Statement', US Government, 2021.

5 Department of Finance, 2020a. See also Scott Savitz, Miriam Matthews and Sarah Weilant, *Assessing Impact to Inform Decisions: A Toolkit on Measures for Policymakers*, Santa Monica, Calif., and Cambridge, UK: RAND Corporation, TL-263, 2017, and references contained therein.

6 Department of Finance, *Corporate Plans for Commonwealth Entities*, Resource Management Guide No. 132, Australian Government, 2021.

The internal workings of the department (their program of work) are captured as activities and outcomes, and so can be identified, prioritised and resourced.[7] Departments and agencies are advised to use a logic model to

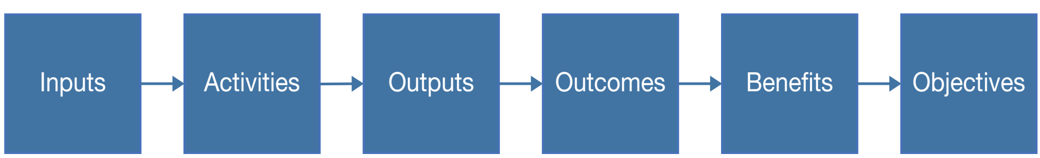
- help create a theory of change that connects efforts within an entity's direct control (e.g., processes or outputs) to high-level outcomes of that effort (outcomes over which the entity has little influence);
- provide a useful tool for program planning, implementation and evaluation (including testing the validity of assumptions about how change occurs);
- identify appropriate performance measures to measure success.[8]

In effect, such a logic model will contain strategic objectives or outcomes that may reside beyond any one government department and lie in the national interest. It is conceded that when one is seeking to assess performance of a program and compare this in a consistent manner with other programs, the problem becomes complicated, but if a similar line of reasoning is used (as shown in Figure 5.1) and best practice in program management followed,[9] the benefits derived show the real difference achieved by pursuing these strategic objectives. An illustrative example on deriving this for the agriculture sector is provided in Appendix C.

Assessing Social Cohesion Needs Further Development

Comparing the three national interest pillars of security, prosperity and social cohesion in a manner that is both consistent in level and intent across the three and useable around the range of sectors under consideration is a key determinant. Of the three, social cohesion is more difficult to quantify in a manner consistent with security and prosperity. However, its importance is clearly recognised. The World Economic Forum has identified social cohesion

FIGURE 5.1
Generic Logic Model



SOURCES: Adapted from Department of Finance, 2020a; The Stationery Office, 2011.

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7 Department of Finance, 2020a, p. 5.

8 Department of Finance, 2020a, p .9.

9 See, for instance, AXELOS, *Managing Successful Programmes*, 4th ed., London: The Stationery Office, 2011, p. 20.

risk as a major global risk.[10] This appears to be, in part, a consequence of a lack of consistency in what constitutes social cohesion. The CTPCO has defined social cohesion as

> the combination of common purpose, shared values (including overarching ethical, regulatory and social frameworks), shared challenges, equal opportunity, and a sense of community. In the context of critical technology, how does the identified technology contribute to, create or enhance the sense of community and shared purpose for all Australians.[11]

While there are measurable elements of this pillar, it may be difficult to do so a priori. Given the contextual nature of social cohesion, we have considered a range of sources to help illuminate key features. We note there are some approaches that seek to describe social cohesion in a measurable manner (see Appendix B for details on each):

- The Institute for Integrated Economic Research (IIER) Australia recently released a report on the relationship between trust, social cohesion and resilience, whereby social resilience is an outcome from effective national culture around social cohesion.[12]
- The Australian Productivity Commission, in its review of Government Services, aligned the logic of its approach to that mandated by the Australian government for program development and reporting.[13]
- The National Indigenous Affairs Agency (NIAA), with its measures under the Closing the Gap program, takes a longer-term perspective, uses measurable data, and looks across several policy sectors, all within an Australian context.[14]
- The Melbourne Institute administers the Household, Income and Labour Dynamics (HILDA) survey, a longitudinal instrument for collecting 'information about economic and personal well-being, labour market dynamics and family life'.[15]
- The Scanlon-Monash Index of Social Cohesion is an annual national survey administered by the Scanlon Foundation that measures attitudes across five themes: belonging, worth, social justice, political participation, and acceptance of diversity. It is longitudinal in nature, having commenced in 2007.[16]

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[10] World Economic Forum, 2021.

[11] See, for instance, PM&C, 2021a. This was derived from Tim Soutphommasane, 'The Challenge of Social Cohesion', ANU Research School of Psychology Annual Lecture, 2 September 2016; and Department of Home Affairs, 'About Social Cohesion', webpage, 2021.

[12] Institute for Integrated Economic Research Australia, *Trust, Social Cohesion and Resilience: A Conversation Starter for Australia*, 2021.

[13] Productivity Commission, *Report on Government Services 2021*, Australian Government, 2021a.

[14] NIAA, 'National Agreement on Closing the Gap: At a Glance', webpage, 2020b.

[15] Melbourne Institute, 'HILDA Survey', webpage, n.d.

[16] Andrew Markus, *Mapping Social Cohesion 2020: The Scanlon Foundation Surveys*, Monash University, 2021.

- The New Zealand Treasury's Living Standards Framework covers the breadth of what constitutes social cohesion and comes from a policy environment similar to that of Australia.[17]
- HM Treasury has added societal benefits as a criterion for defence procurement as part of its broader Public Value Framework for investment.[18]

Before seeking out the common characteristics, it is worth reiterating the definitions for social cohesion within the context of CTNI. As noted earlier, it relates to common purpose, shared values, shared challenges, equal opportunity, and a sense of community, with the emphasis for CTNI on shared purpose and a sense of community.[19] Each of the examples above has been derived for different purposes. Indeed, we deliberately sought to have such diversity. As such, there is an understandable degree of divergence. However, there are generally two camps—those that take a more social capital[20] perspective (e.g., Productivity Commission, Melbourne Institute, New Zealand Treasury) and those taking a values-based[21] perspective (e.g., IIER Australia, Scanlon Foundation, NIAA, HM Treasury). The former is likely to be easier to measure in a quantitative sense, while the latter aligns more closely with the CTPCO definition of social cohesion.

Fundamentally, incorporating social cohesion within the typical cost-benefit/value-for-money measurement paradigm is challenging.[22] Unlike security and prosperity, social cohesion does not easily fold into traditional approaches to prioritisation that governments employ because efficiency and effectiveness are not as easy to quantify.[23]

Technology Development Pipeline Needs to Be Explicitly Considered

Time and timing are critical factors when deciding to invest resources in a critical technology, particularly if there is a pressing need—that is to say, there is a requirement to take a mission-based policy approach. This represents a key determinant in any decision government makes around prioritisation, since the ability to decide, act, deliver and then exploit will shape whether a technology solution is viable, particularly in term of timeliness, suitability and cost, given the assessed threat or opportunity. As such, choosing which technologies are critical needs to be forward-looking because benefit realisation takes time.

A schematic rendition of the delivery cycle of a critical technology is provided in Figure 5.2 and is based around a model of mobilising national resources to achieve the required capabil-

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[17] The Treasury, *The Treasury Approach to the Living Standards Framework*, New Zealand Government, 2018.

[18] HM Treasury, 'Public Value Framework: with Supplementary Guidance', UK Government, 2019.

[19] PM&C, 2021b.

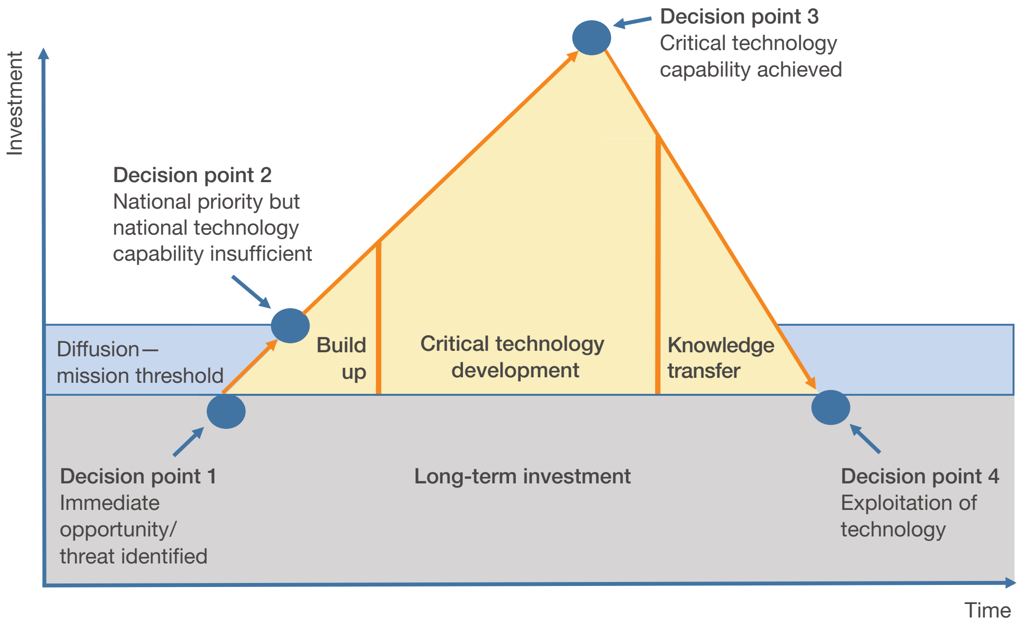
[20] That is, the functional efficiency of the social system.

[21] That is, the wellbeing and resilience of individuals and groups.

[22] Department of Finance, 'Value for Money: Considering Value of Money', webpage, 2020b.

[23] Department of Finance, 2020a.

FIGURE 5.2
Delivery Cycle of a Critical Technology



SOURCE: Adapted from Layton, 2021.

ity in a chosen critical technology.[24] This model identifies four decision points, with implementation taking the form of stepping through each decision point and, if the predetermined threshold is exceeded, undertaking activities. The process commences, as described earlier, when an immediate threat or opportunity is identified (decision point 1). If it is decided that the issue is of sufficient priority to warrant a response where technology can play a crucial role, then the question arises as to whether existing national technology capabilities exist (or at least are accessible)—decision point 2. If that is not the case, then government would invest in developing the selected critical technology (or technologies) to a specific level and commence developing the process for doing this (e.g., source selection, business case development, governance arrangements, government approval, development of enabling capabilities [e.g., workforce, infrastructure]). This can take some time. As such, there is a requirement to consider the investment of both resources and time into the planning, particularly if this is subject to a cost-benefit analysis.

Once those hurdles are passed, activities to develop the critical technology can begin. Importantly, given the risk assessment, the level of capability required needs to be identified and worked towards to ensure the efficient and effective use of resources. As such, the metrics

[24] This is adapted from Peter Layton, *Being Prepared for Unprecedented Times: National Mobilisation Conceptualisations and Their Implications*, Griffith University, 2021.

within the business case must be explicit and solution-oriented. Once that level is achieved, the investment in critical technology development can start to transition into turning that technology into functional solutions (decision point 3). Without this, there is the risk that the technology will not deliver on its potential. This technology transfer, together with the upskilling of researchers, the engagement with industry, the development of necessary infrastructure, and the lessons learned through this cycle, represents an activity of knowledge transfer. This should be pursued even in circumstances where the technology capability has not been achieved.

This leads to the final decision point, that of whether there is any further role for the government in helping those within the RD&I ecosystem develop solution to exploit the technology. Clearly, if there is a security requirement, then the government may wish to invest in supporting industry innovation. However, a solution that provides opportunities for greater prosperity might be left to the entrepreneurial nature of industry, with the government helping to support and shape things through mechanisms such as regulation.

Sovereignty and Sovereign Risk May Require Compromise

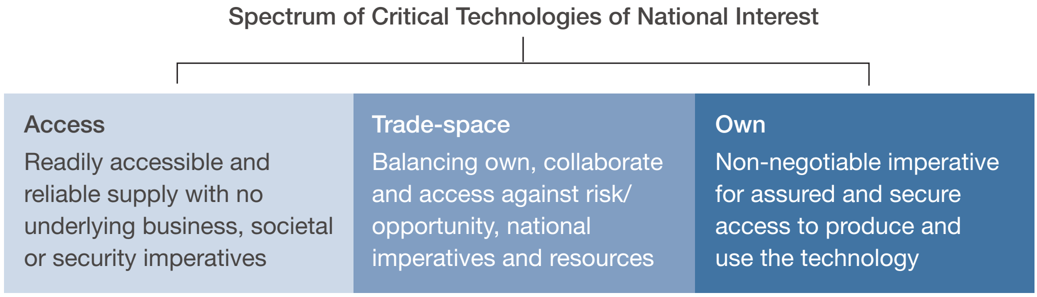
As noted in Chapter Three, the United Kingdom's Own-Collaborate-Access framework has some level of overlap with Australia's sovereignty aspirations. It is assumed that most nations (particularly those middle powers like Australia) cannot hope to gain and maintain sovereign control over all the technologies they would like. This is true for the sectors with the largest levels of research investments, such as defence and health. As the Department of Defence foresight study *Forward 2035* notes, there is an opportunity for 'smart power'—that is to say, the ability to work with like-minded partners to codevelop technology solutions.[25] Ultimately, capacity limitations and international competition necessitate some compromises over sovereignty.

This suggests a key factor in developing policy for CTNI is determining the balance of ownership, collaboration and accessibility that can simultaneously deliver the best national benefit (against the three pillars) while also ensuring Australia has the capacity to respond in a timely manner to new opportunities and/or threats. A consequence of this is that while Australia may desire the ability to own a particular technology set, it will have to make compromises and trade-offs that result in accepting less sovereign control for some CTNI. While international collaboration is an essential part of RD&I, the risks of interference by foreign actors must also be a consideration. Finally, this balance of CTNI across the own-collaborate-access continuum highlights the need for government to balance diffusion- and mission-driven policy levers centrally and in a consistent manner across all relevant sectors.

Concurrent consideration of a complete set of technology solutions is likely to overwhelm any such balance of investments assessment. An initial winnowing process is necessary as a step towards a more manageable trade-space (see Figure 5.3). Such a process is premised upon three broad criteria: essential, accessible and feasible to develop.

[25] Boey et al., 2014, p. 3.

FIGURE 5.3
CTNI Trade-Off Spectrum



In the first instance, a determination can be made as to which CTNI are of such fundamental importance to prosperity, security and social cohesion that Australia cannot risk not having sovereign control over them. This may be in terms of an underlying stated strategic imperative or a need to be able to operate independently.[26] Ownership does not necessary equate to owning the underlying IP; rather, it is the capacity to access and employ that technology. The policies underpinning ownership might be a mixture of both government and commercial control and use.

At the other end of the spectrum, there are critical technologies that are readily available from a number of sources and whose supply chain can be counted upon to deliver in a timely manner. It may be that this technology can be maintained through a stockpile of componentry (e.g., semiconductors) that can be readily assembled into useable products with manageable adaptation of the industry base. As such, there is little need to seek sovereign control over these CTNI. What remains is the trade-space within which a smaller set of CTNI is considered against the national base (reduced due to commitments to the CTNI that must be owned).[27] The assumption here is that the resources for owning a critical technology will be higher than if it was achieved through collaborative arrangements, which, in turn, will be higher than if it was simply accessed as required.

Ultimately for the decisionmaker, it comes down to a determination of where something is essential, accessible and/or feasible to develop. To help navigate the way through this, we have created a decision tree (Figure 5.4), adapted from one developed for the UK MOD in the space domain.[28] In this case, the government will make initial choices that exclude those

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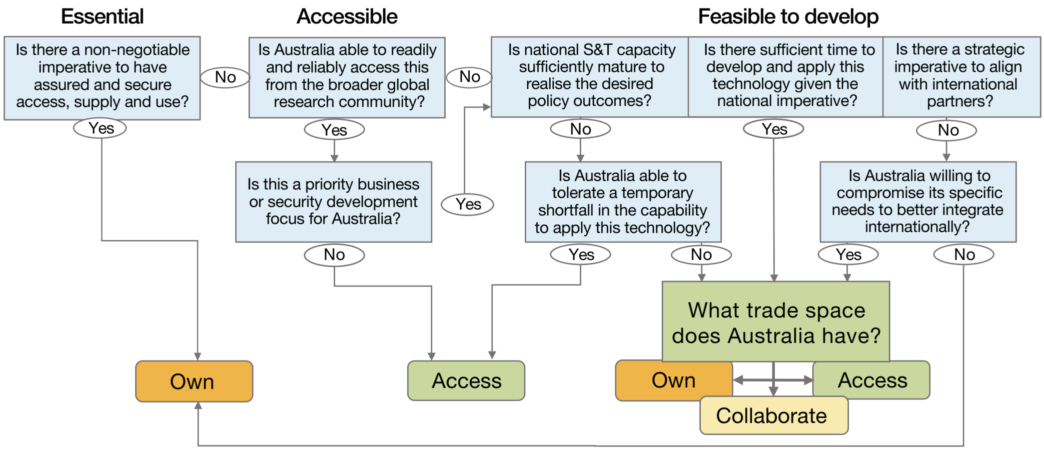
[26] See Table A.1 and UK MOD, 2021, for descriptions from a security perspective.

[27] Opportunity cost is a consideration here. For instance, if the cost of owning those CTNI outstrips national capacity, the government would need to revise its policy levers to ensure demand did not outstrip national capacity.

[28] Lucia Retter, James Black and Theodora Ogden, *Realising the Ambitions of the UK's Defence Space Strategy: Factors Shaping Implementation to 2030*, Santa Monica, Calif., and Cambridge, UK: RAND Corporation, RR-A1186-1, 2022.

FIGURE 5.4
Critical Technology Decision Tree



SOURCE: Adapted from Retter et al., 2022.

technologies where ownership is imperative and those that can be readily (and acceptably) accessed. What remains is the CTNI trade-space where the remaining resources can be prioritised and ownership aspirations (or at least collaboration plans) can be selected.

Repeatability and Traceability Provide Credibility

A successful analytical approach must have the following characteristics:

- It must be repeatable to allow a regular cycle for priorities to be identified and policy responses to be developed.
- In must be delivered in a structured way so that data and information can be effectively managed and reused where possible.
- The outputs must be traceable to the inputs in order to allow stakeholders to have confidence in those outputs.

While these might seem obvious, in such a contested, complex and potentially politicised environment credibility with stakeholders and the public is important. Each of these will ask questions of the approach taken to implementation. For instance, the ability to repeat the approach on a regular drumbeat will allow better planning of resources and ensure expectations of stakeholders are managed. Efficiency through the reuse of existing data and knowledge gained from previous cycles will ensure better outcomes as the process matures. Notwithstanding resource limitations, the decision will be on the length of the cycle. The continuous injection of technologies might require a frequent cycle, whereas the slower moving pace of policy change (development and implementation) might suggest a longer cycle. The need for a structured approach is important. While there might be a need to adapt the approach, this should be only in the detail of the components. This ensures those providing the data understand the type of data they are required to provide and when, what level of fidelity is required, and how to capture any uncertainties associated with it. This is particularly important given the uncertainty over technology delivery. Finally, it must be traceable to build confidence. If it appears that the results come out of a single area of government and/or have not incorporated information from a particular area, then those stakeholders may not support the approach.

CHAPTER SIX

Conclusion

This research activity sought to develop an analytical approach for CTNI prioritisation. Building on lessons from other international programs and recognising the breadth (all government sectors) and depth (all technology domains) of the problem, we have developed an analytical framework suited to Australia's unique domestic context. Built around the national interest lenses of security, prosperity and social cohesion, we have developed a broad two-step approach that first seeks to identify a long list of CTNI and then uses a policy lens to develop a smaller prioritised CTNI list that cuts across all policy sectors.

In developing this analytical framework, we established the following:

- The competing policy objectives of national security, economic prosperity and social cohesion require a technological assessment of critical technologies that are distinct from those undertaken elsewhere within the Australian government, particularly the Department of Defence, which primarily focusses on security.
- It is important to distinguish between diffusion- and mission-based technology policy approaches. While Australia needs some capacity to utilise a range of technologies, its limited resources dictate the need to prioritise those that meet the threshold to be competitive or for which there is an incontestable security need.
- Strategic patience is needed to ensure policy and investment decisions have the opportunity to succeed. Policy decisions must be cognisant of the time lag between the identification of CTNI priorities and the delivery of the anticipated benefit.
- There must also be recognition that the ability to respond rapidly when disruptive breakthroughs in novel S&T emerge is required. This ensures that major disruptions can be identified early and policy pivoted rapidly when necessary so as to minimise strategic surprises and maintain competitiveness.
- The development of metrics for each of the pillars requires a consistent structure to allow for compatible evaluations between them.
- Social cohesion assessment metrics will need to be developed for this context as one of the priorities for advancing this framework. It will take time to develop and mature the measures used for integrating the consideration of broader social factors into CTNI policy.

Based on our analysis, we make the following recommendations:

- The prioritisation approach should develop a longer list of critical technologies and use this to establish a smaller set that offer practical responses to current policy needs.
- Use the own-collaborate-access model to determine where there is choice on viable policy options.
- While CTNI might be the policy focus, impacts of other critical functions such as infrastructure, workforce and supply chain must be considered when prioritising.
- An M&E regime should be established to support the continued evolution of this approach and the priorities it identifies.

Ultimately, CTNI prioritisation is a wicked problem, given the nature of the policy environment is highly interdependent, and both context- and time-dependent. There is no single optimal solution. Rather the result will be a 'best fit', given the circumstances of the day and the shifting perspectives of those making the assessments.

APPENDIX A

Selected Case Studies

This appendix contains an overview of the various approaches to identifying CTNI taken by a number of international institutions. These are displayed in Table A.1. In reviewing these, we sought to answer the following four questions as far as possible based upon the information available:

- What are deemed to be their critical technologies?
- How are these linked to critical functions within those societies? (This would be characterised in terms of security, prosperity and societal impacts.)
- What approach do they use to identify critical technologies, and what criteria do they use to define criticality?
- How (if at all) do they assess progress in these programs?

TABLE A.1
European Information Sources

Nation	Approach/Organisation
International	• EU-US Trade and Technology Council (2021)
EU	• European Parliament's Panel for the Future of Science and Technology (commenced 1987) • European Commission's Key Enabling Technologies (commenced 2009) • European Commission's Smart Specialisation Strategy (2011) • European Institute of Innovation and Technology's Strategic Innovation Agenda (2014) • EDA's OSRA (2019) (2019) • European Commission's Flagship Projects (2019)
Austria	• Austrian Institute of Technology Assessment's Medium-Term Research Programme (commenced 1994) • Austrian Council's Strategy 2020 (2009)
Denmark	• Danish Board of Technology Foundation (commenced 1995)
Estonia	• Research, Development and Innovation Strategy (2014)
Finland	• Sitra (The Finnish Innovation Fund) (1967) • Committee for the Future (commenced 1993) • Defence Forces Research Agenda (2015) • Securing the Finnish Defence Technological and Industrial Base (2016)

Table A.1—Continued

Nation	Approach/Organisation
France	• Ministry of Research and Innovation's Conseil Stratégique de Recherche (commenced 2013) • Defence Procurement Agency's Presentation de l'Orientation de la S&T: 2014–2019 (2014) • Ministry of the Armed Forces' Document de Référence de l'Orientation de l'Innovation de Défense (2019)
Germany	• Office of Technology Assessment's Tasks and Goals (commenced 1991) • High Tech Strategy (commenced 2006) • Commission of Experts for Research and Innovation's Mission Statement (commenced 2006)
Italy	• Programma Nazionale per la Ricerca: 2015–2020 (2015)
Netherlands	• Hague Security Delta's Securing Critical Infrastructures in the Netherlands (2015) • Defence Industry Strategy (2018)
Spain	• Estrategia Española de Ciencia, Tecnología e Innovación 2021–2027 (2020)
Sweden	• Evaluation and Research Secretariat (2006) • Innovair (2010)
United Kingdom	• Parliamentary Office for Science and Technology (commenced 1989) • National Institute for Health and Care Excellence (established 1999) • Defence Industrial Strategy (2005) • Government Office for Science (set up 2007) • National Security Through Technology (2012) • Eight Great Technologies (2013) • Combat Air Strategy (2018) • Defence Technology Framework (2019) • MOD Science and Technology Strategy (2020) • Research and Development Roadmap (2020) • Integrated Review of Security, Defence, Development and Foreign Policy (2021) • Defence and Security Industry Strategy (2021)
United States	• National Strategy for Critical and Emerging Technologies (2020)

A.1. UK Approaches

The United Kingdom's approach to CTNI has evolved in recent decades, shifting towards a broader conception of how critical technologies deliver value to the nation. How it classifies CTNI and integrates thinking about sovereign industrial and technological capability into defence strategy, policy and procurement decisions has changed in fits and starts over the last 20 years. Major developments since 2005 are summarised in the paragraphs below, with a focus on describing the different evaluation criteria used as part of TA for CTNI.

Defence Industrial Strategy (2005)

In 2005, the Labour government published a Defence Industrial Strategy (DIS). This had three aims:[1]

- promoting an overall business environment that is attractive to defence companies and investors
- identifying key technological and industrial capabilities that are important to retain in the UK industrial base and to maintain appropriate sovereignty, with sustainment strategies where these seem at risk
- explaining how, in decisions on individual acquisition programs, the UK MOD would account for industrial and other factors.

In line with these aims, the DIS also defined 'appropriate sovereignty' to mean 'indigenous industrial and technological capability required for retention for national security reasons'. This concept was defined and assessed in terms of several evaluation criteria, as summarised below:[2]

- **Strategic assurance:** Industrial capabilities that are to be retained onshore as they provide those technologies or equipment important to safeguarding the state. This includes technologies used within the United Kingdom's nuclear deterrent, high-grade cryptography, or as a 'key tenet of counter-terrorism capability'. Retention of sovereign industrial capabilities can be required when
  - the technology is of such strategic importance that the risk of offshoring is unacceptable
  - military requirements dictate that there must be minimal or no risk of the capability failing (e.g., as with the nuclear deterrent)
  - there is a need to prevent an adversary from acquiring knowledge through the proliferation of sensitive technology
  - procuring or sourcing the technology overseas is prohibited for legal reasons (e.g., contravening treaty obligations and export controls).
- **Defence capability:** This could include industrial capabilities of particular operational importance or aspects of more generic battlefield systems or subsystems, where failure could present particular danger to the UK Armed Forces. Retention of sovereign capabilities can be required when
  - there is a specific need to ensure security of supply (e.g., where there is a viable global market for a given technology but risks to the availability and reliability of equipment in a crisis, or where there are constraints on IP rights that make it difficult for the United Kingdom to provide confidence in its own ability to understand a given technology's true performance or to maintain and update equipment over time)

1 UK MOD, 'Defence Industrial Strategy', white paper, UK Government, 2005.

2 UK MOD, 2005, pp. 21–22.

  - failing to sustain the capability in the United Kingdom would lead to reliance on a single overseas source; this may in itself present a risk of adverse political interference from the relevant overseas government at the point that the United Kingdom seeks to procure from the relevant supplier
  - it is important to ensure that associated IP within the United Kingdom is protected and not transferred to a potential adversary
  - it is particularly important that the UK Armed Forces have secure priority access to the industrial base needed to enable effective equipment acquisition, support and upgrade when and where needed for Urgent Operational Requirements. (This is closely related to the broader concept of security of supply but focuses more on the ability rather than the will of the overseas supplier, who may not be able to deliver on time due to physical distance or because their domestic customer has first call on the supplier's capacity.)
- **Strategic influence:** Technology areas where sovereign UK capabilities, including niche areas of expertise, provide influence in military, diplomatic or industrial terms. Collaborative or complementary RD&I and acquisition programs may often be relevant here, providing potential benefits in terms of cost sharing, value-for-money and interoperability. Retention of sovereign capabilities can be required when
  - they provide continuing access to a niche UK capability that is highly valued by international allies and partners, providing influence in the context of coalition operations
  - the United Kingdom possesses certain 'cutting-edge' capabilities that ensure that due weight is placed on its requirements and it can achieve an equitable workshare and technology access when partnering with other nations on collaborative research or equipment programs
  - it is especially important to ensure access to a particular collaboration project, for example due to broader political and diplomatic considerations.
- **Technology benefits:** Those capabilities where there is considerable opportunity for the MOD to benefit from spillovers from innovation into other technology areas, application areas or sectors, including civil markets. These may provide broader economic and societal benefits, but also directly benefit the MOD by driving economies of scale. (Notably, however, the DIS did not identify any sovereign capability which was assessed to be important to retain for this reason alone.)

Based on these detailed evaluation criteria and a series of horizon-scanning and capability audit activities, the MOD identified a range of S&T priorities, including those areas relating to nuclear; cryptography; submarines and surface ships; armoured fighting vehicles; fixed-wing aircraft, including unmanned aerial vehicles; helicopters; general munitions; complex weapons; and command, control, computers, communications, intelligence, surveillance, target acquisition and reconnaissance (C4ISTAR) systems.[3]

[3] UK MOD, 2005, p. 17.

National Security Through Technology (2012)

In 2012, the UK government published a white paper entitled 'National Security Through Technology'. This built upon and supplanted the guidance provided in the 2005 DIS, and was built around two key principles:[4]

- **The Open Procurement principle:** Wherever possible, the MOD would seek to fulfil the United Kingdom's defence and security requirements through open competition in the domestic and global market.
- **The Technology Advantage principle:** The Open Procurement principle is qualified by the need for the United Kingdom to take action to protect its operational advantage (OA) and freedom of action (FOA), but only where this is essential for national security.

Collectively, these two principles sought to guide policy, research, capability development and procurement decisions, and to deliver overall value for money. The white paper recognised the need to identify and monitor CTNI that were essential from an OA and FOA perspective, as well as to protect the MOD's ability to evaluate independently the effectiveness of technologies; work closely with allies, partners, industry and academia to develop new technology; clearly communicate future requirements to the research base; and preserve a 'lean but effective group of highly skilled people' within the MOD capable of acting as an 'intelligent customer' function for new technologies.[5]

Unlike the 2005 DIS, the 2012 white paper did not make public any priority areas or CTNI, instead providing a conceptual framework for unpublished and classified initiatives within the MOD.

Eight Great Technologies (2013)

In 2013, the UK government published its 'Eight Great Technologies' industrial strategy, comprising critical technologies that were selected to receive special funding because they were identified as areas where the United Kingdom was set to be a global leader. The aim of the strategy was to accelerate the commercialisation of these technologies and its focus was dual-use rather than defence-specific. The technologies were funded to the tune of £600 million over a period of three years.[6]

The factors considered in defining these eight priority technologies were 'UK growth opportunities', 'multiple applications', 'UK industrial capability' and 'UK research strength'. These criteria resulted in the following short list of technology areas: big data, space, robot-

4 UK MOD, 2012, pp. 19, 25.

5 UK MOD, 2012, p. 14.

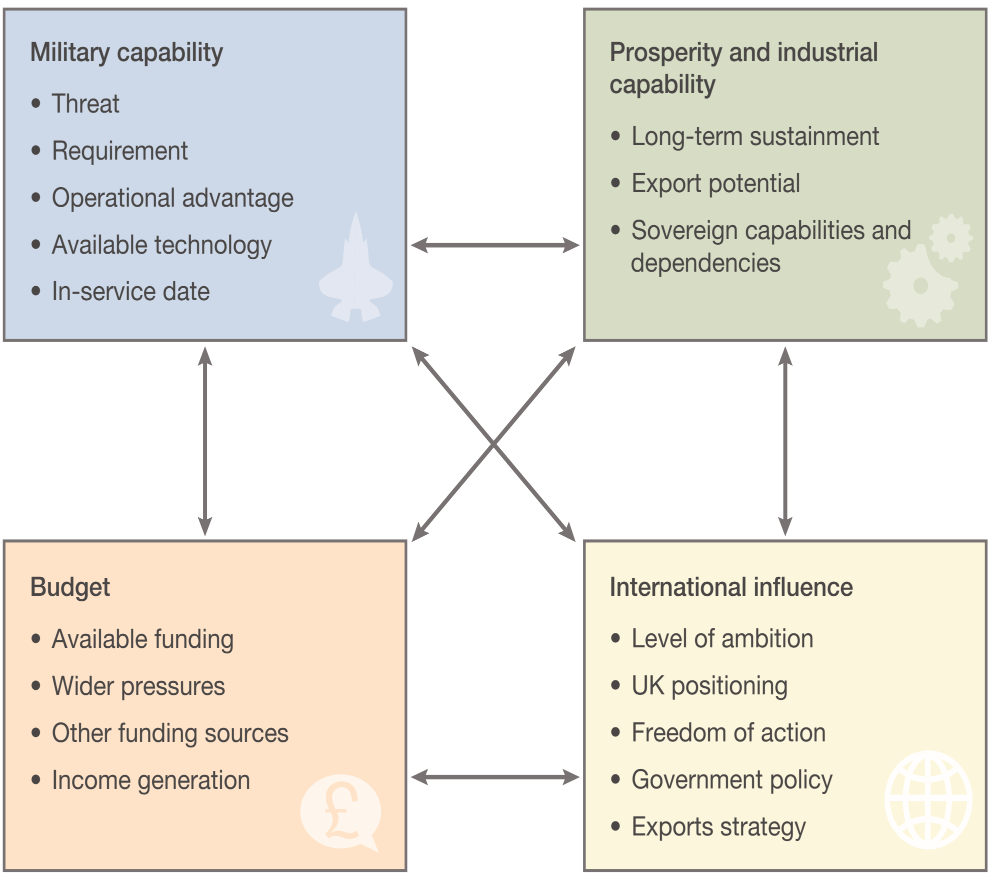
6 HM Treasury 'Autumn Statement 2012', UK Government, 2012.

ics and autonomous systems, synthetic biology, regenerative medicine, agriscience, advanced materials, and energy.[7]

Combat Air Strategy (2018)

In the absence of any formal published replacement for the 2005 DIS, the late 2010s saw the MOD shift its focus towards defining sectoral or domain-specific strategies and policies to ensure continuing access to the necessary technologies and industrial capacity and capability. Published examples include the 2017 National Shipbuilding Strategy and the 2018 Combat Air Strategy, which both addressed areas that had previously been identified as priorities in the DIS. The latter outlined an approach to developing and retaining sovereign industrial and technological capability in terms of a National Value Framework (see Figure A.1).

FIGURE A.1
National Value Framework in the UK Combat Air Strategy



SOURCE: UK MOD, 2018.

[7] UK Government, 2013.

This focused on balancing the different benefits, costs and risks associated with sovereign versus collaborative programs in terms of OA, FOA, influence and affordability to deliver overall value for money. The framework was supported by the development of technology lists within MOD to identify detailed requirements in terms of retaining FOA, along with industrial and skills analysis to understand areas of potential risk and shortfall where the United Kingdom might need to invest in sovereign capacity and capability, or else trade its way into collaborative programs (e.g., the new Tempest future combat air program with Italy and Sweden).[8]

The Integrated Review and the Defence and Security Industrial Strategy (2021)

Most recently, the concept of technological advantage outlined in the 2012 'National Security Through Technology' white paper has been supplanted by the new own-collaborate-access model introduced in the Integrated Review of Security, Defence, Development and Foreign Policy (IR)[9] and the associated new DSIS (2021).[10] This model aims to guide decisions about when to *own* (i.e., retain indigenous capability), when to *collaborate* with allies and partners through multinational research and equipment programs, and when to *access* certain technologies from the market (e.g., by procuring off-the-shelf solutions or seeking to acquire access to foreign IP). The potential logic behind selecting each of these three approaches is discussed at a high level in the public version of the IR, as shown in Figure A.2 below.

FIGURE A.2
Own-Collaborate-Access Framework

Own	"where the UK has leadership and ownership of new developments, from discovery to large-scale manufacture and commercialisation."
Collaborate	"where the UK can provide unique contributions that allow us to collaborate with others to achieve our goals."
Access	"where the UK will seek to acquire critical S&T from elsewhere through options, deals, and relationships."

SOURCE: Adapted from UK Cabinet Office, 2021a.

[8] UK MOD, *Combat Air Strategy*, UK Government, 2018.

[9] UK Cabinet Office, 2021a.

[10] UK MOD, 2021.

This new approach bears some similarities to earlier ones in terms of the evaluation criteria employed to define critical technologies and areas of industrial capability that might need to be retained in the United Kingdom. Nonetheless, it also signals a shift in UK policy towards emphasising that when developing a strategy for CTNI or making a specific investment decision, it is rarely a simple binary choice between 'sovereign' and 'non-sovereign'.[11] Indeed, the fact that modern defence capabilities form part of a 'system of systems' means that they typically combine a mix of sovereign, collaborative and off-the-shelf elements, with different multinational partners, industry suppliers, and research organisations involved at different stages in the capability life cycle.

In this complex setting, the UK government should seek to own technology where necessary, collaborate where possible, and access where prudent in an effort to maximise the use of finite national resources and support the wider policy ambition to develop 'Global Britain' as a 'science superpower' and promote societal resilience against possible shocks (e.g., disruptive new technology, pandemics, climate change).[12]

The new DSIS released alongside the IR in March 2021 provided additional guidance on how the MOD should navigate the trade-offs between different options available within the own-collaborate-access framework, and thereby how to classify CTNI. The DSIS acknowledged that the concept of technological advantage introduced in the 2012 white paper had 'proved difficult to apply in practice', given 'the link between national security requirements and procurement strategies may not be so straightforward'.[13]

In its place, the DSIS introduced a new multitiered approach to making decisions about when to maintain technological and industrial capabilities onshore that applied the following concepts:[14]

- **Strategic Imperatives:** This describes areas of capability that are 'so fundamental to . . . national security, and/or where international law and treaties limit what [the United Kingdom] can obtain from overseas'. For the United Kingdom, this entails a need to protect sovereign capability for CTNI relating to 'nuclear deterrence capabilities, submarines, cryptography and offensive cyber' because 'there are no safe, credible and/or legal ways' to otherwise meet the nation's security needs.
- **Operational Independence:** This principle applies in those capability areas that are needed to continue to conduct 'military operations as [the United Kingdom] choose[s] without external political interference and to protect the sensitive technologies that underpin those capabilities'. This dictates a need to retain sovereign access not only to IP and technology, but also the 'systems engineering skills and design knowledge' to

[11] UK MOD, 2021.

[12] UK Cabinet Office, 2021a.

[13] UK MOD, 2021, p. 20.

[14] UK MOD, 2021, pp. 20–21.

adapt technologies and deliver new capabilities in response to unforeseen and urgent operational requirements.

The DSIS also presented new guidance on the minimum criteria to be applied when making investment decisions, known as 'critical success factors':[15]

- **Strategic fit:** whether the option meets national security requirements and other business needs.
- **Potential value for money:** what the option entails in terms of whole-life costs.
- **Public value evaluation:** how and the extent to which the option might deliver broader public or social value. This newly introduced criterion ensures that the MOD considers the effect of different investment options on wider policy objectives, such as 'helping local communities manage and recover from the impact of COVID-19; increasing supply chain resilience and capacity; responding to climate change; equal opportunity through reducing the disability employment gap and tackling workforce inequality; improving health and wellbeing including the physical and mental health in the contract workforce' and also 'creating new businesses, jobs and skills'. For the first time, a minimum 10-per-cent weighting is now applied in all competitions under the United Kingdom's Public Contract Regulations, and the MOD will apply the same policy to all launched under the Defence and Security Public Contract Regulations from 1 June 2021. This mandatory 10-per-cent weighting for broader public and social value reflects the current government's emphasis on 'levelling up' disadvantaged regional economies and supporting communities across the United Kingdom, including reinforcing the bonds within the political union of England, Scotland, Wales and Northern Ireland.

Along with the IR and DSIS, the United Kingdom has also recently introduced a new regime for monitoring foreign investment in critical sectors, enhancing the government's powers to scrutinise or block acquisition of certain businesses or technologies.[16] These are codified through the National Security and Investment Act, which sets out a new mandatory notification regime for transactions in certain sectors and a voluntary notification regime for all other sectors, while also allowing the secretary of state to 'call in' investments for review (in any sector) and to assess and address any national security risks they might entail.[17]

The 17 critical sectors (and therefore areas of CTNI) that are subject to the new mandatory notification regime are advanced materials, advanced robotics, AI, civil nuclear, com-

[15] UK MOD, 2021, pp. 38–39.

[16] UK Parliament, 'National Security and Investment Act 2021', UK Government, 2021.

[17] Decisions over when to exercise the 'call-in' power are driven by target risk (the nature and activities of the target of a given transaction), trigger event risk (the type and level of control being acquired by the investor and how this could be used), and acquirer risk (the extent to which the acquirer may represent national security risks, e.g., given origin).

munications, computing hardware, critical suppliers to government, critical suppliers to the emergency services, cryptographic authentication, data infrastructure, defence, energy, military or dual-use technologies, quantum technologies, satellite and space technologies, synthetic biology, and transport.[18]

A.2. European Union Approaches

The EU's approach is complex, given the need to resolve tensions between promoting European strategic autonomy and addressing national priorities. As with the United Kingdom, the EU's approach has evolved over time. The EU currently has multiple CTNI strategies and initiatives that have different areas of focus and are overseen by different agencies. Critical technologies for defence have traditionally been the domain of the EDA,[19] which created the OSRA in 2016 to harmonise European defence research priorities.[20] More recently, a new Directorate-General for Defence Industry and Space (DG DEFIS) has been established within the European Commission with a remit to foster security, competitiveness and innovation across the EU by promoting the 'strategic autonomy' of the European Defence Technology and Industrial Base (EDTIB). The president of the European Commission since 2019, Ursula von der Leyen, has expressed her ambition to realise a more 'geopolitical' Commission with a muscular approach to strengthening 'technological sovereignty', competitiveness and resilience.[21]

Beyond defence, the Commission's 2011 Smart Specialisation Strategy focuses on regional growth: it provides a framework for regions around the EU to identify their own local critical technologies, with an emphasis on building prosperity.[22] The European Institute of Innovation and Technology's SIA, launched in 2014, also aims to support economic growth and competitiveness, but has eight broad S&T priorities that apply at an EU-wide level.[23] Another approach is the Commission's six KETs, published in 2009, which seek to strengthen the European industrial base and promote sovereignty and security of supply.[24] Finally, the Panel

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[18] Department of Business, Energy, and Industrial Strategy, 'National Security and Investment: Sectors in Scope of the Mandatory Regime', UK Government, 2020.

[19] The membership of the EDA overlaps heavily with that of the EU MS, but Denmark has opted out of being an EDA-participating MS.

[20] EDA, 'Overarching Strategic Research Agenda (OSRA)', 2019.

[21] Jean-Pierre Darnis, *The European Union Between Strategic Autonomy and Technological Sovereignty: Impasses and Opportunities*, Fondation pour la Recherche Stratégique, 16 April 2021.

[22] European Commission, 'Smart Specialisation', webpage, n.d.-a.

[23] Council of the European Union, 'European Institute of Innovation and Technology and Strategic Innovation Agenda: EU Co-Legislators Reach Political Agreement', press release, 28 January 2021.

[24] Interreg Europe, 2021.

for the Future of Science and Technology provides expert assessments on critical technologies to members of the European Parliament (MEPs) to inform policy and decisionmaking.[25]

The various published EU strategies and related documentation are well developed, providing extensive details on the criteria and approach that should be taken to identify CTNI, lists of CTNI, and evaluation regimes. Between them, the strategies also address the key areas of the security, sovereignty/autonomy, prosperity, influence, and social cohesion of the EU and its MS. Given their pan-European remit, they involve a large range of stakeholders, such as national governments, regional and local governments, EU-wide industry, academia, and EU policymakers. Despite this emphasis on consultation, the EU approach to CTNI inevitably reflects enduring tensions and compromises between the EU institutions and national capital: on the one hand, promoting collaboration and mutual dependence among MS ('pooling and sharing' of resource to minimise duplication of effort and enhance competitiveness with the United States, China and others); on the other hand, needing to address political sensitivities and the desire of MS to retain certain technological and industrial interests at the national level.[26] Each of these EU strategies and initiatives is described in more detail below.

The EDA's Overarching Strategic Research Agenda

The EDA adopted the OSRA to bring together the various programs within the EDA responsible for critical defence technologies, known as CapTechs, and ensure their actions align with military tasks and long-term capability needs.[27] The 12 CapTechs cover different domains, such as 'Components and Modules' and 'Materials and Structures' (see Figure A.3). Each one has its own strategic research agenda that feeds into the OSRA framework in an effort to drive coherence across the various CapTechs, which are run by the EDA and bring together experts from the participating Member States (pMS), industry and academia.[28]

The OSRA further identifies 139 'technology building blocks' that are technologies key to defence that would benefit from EU collaborative support.[29] The technology building blocks are identified first by establishing priority technology gaps; these gaps then guide a combined top-down and bottom-up approach to select individual technologies.[30] In the top-down approach, technologies are selected that would support operational requirements. In the bottom-up approach, basic technologies are selected from a so-called Technology Taxonomy maintained by the EDA, a large database of defence-related technologies.[31]

[25] Panel for the Future of Science and Technology, 'History and Mission', webpage, n.d.

[26] Darnis, 2021.

[27] EDA, 2019.

[28] EDA, 'EDA CapTech Materials & Structures', 2018.

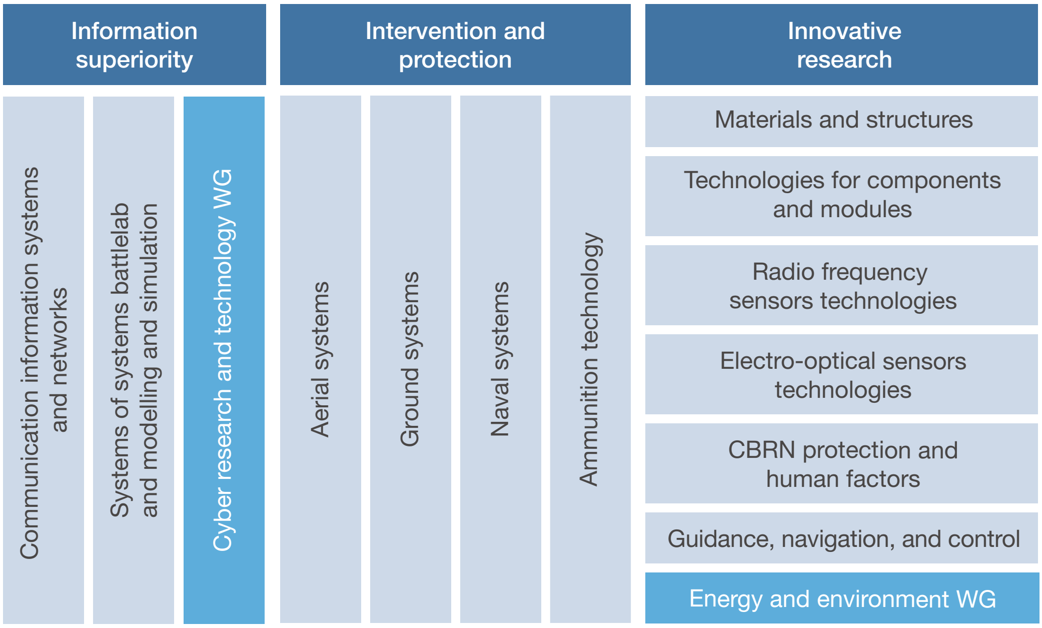
[29] EDA, 2019.

[30] EDA, 'OSRA—Overarching Strategic Research Agenda and CapTech SRAs Harmonisation', n.d.

[31] EDA, n.d.

FIGURE A.3

EDA CapTechs Used to Frame the OSRA and Technology Building Blocks



SOURCE: EDA (n.d.).
NOTE: There are also two working groups (WG) for ‘Cyber Research and Technology’ and ‘Energy and Environment’ that do not have the full status of a CapTech.

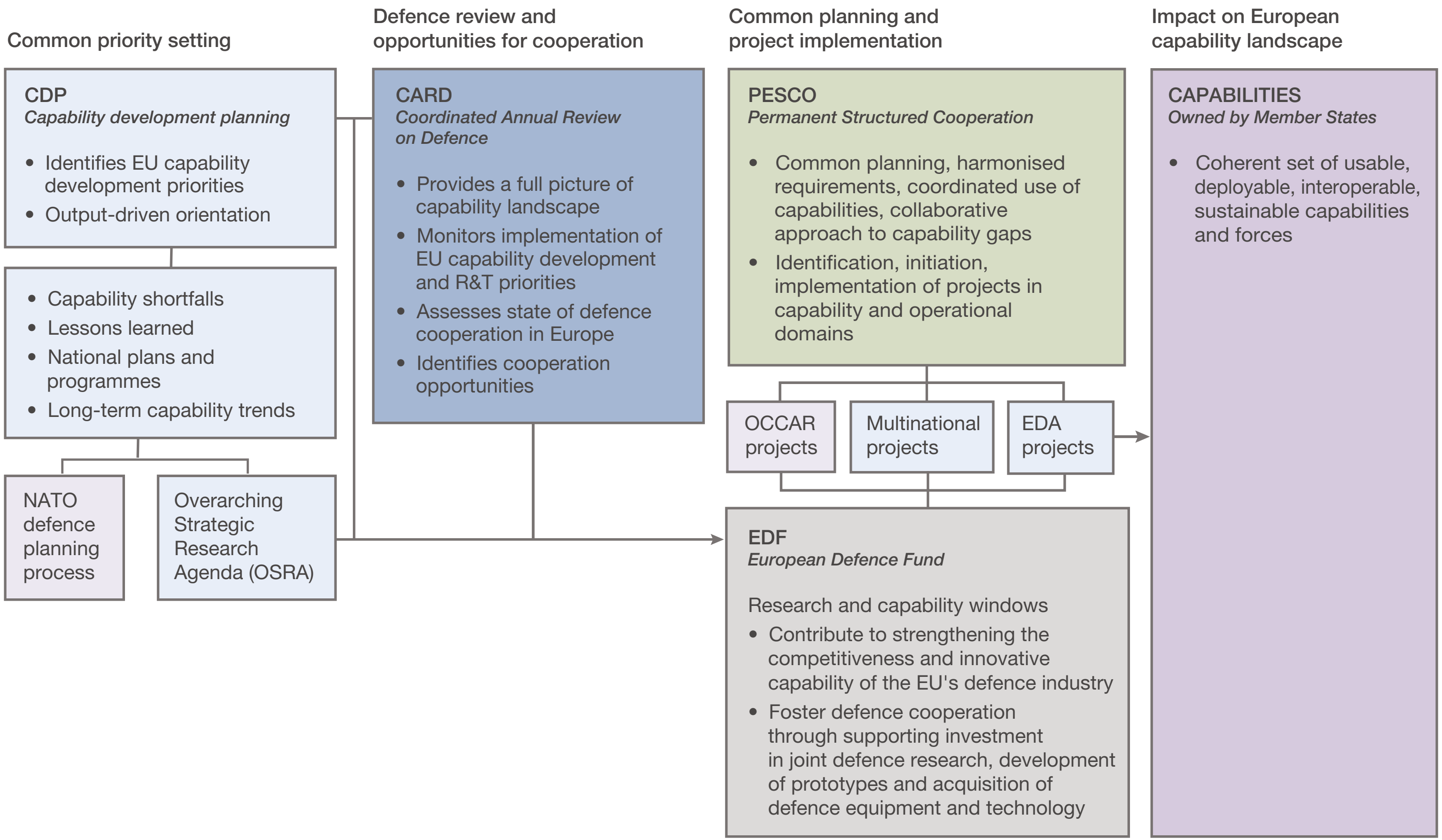
The CapTechs and associated strategic research agendas each oversee technology building blocks that are relevant to them. They select the final list of technology building blocks from the long list identified in the top-down/bottom-up selection phase through a scoring process, where technology building blocks that are the most relevant to the technology gaps in the field are selected.[32] Through the OSRA, the same technology identification process is applied across the groups. The CapTechs then prepare development roadmaps and funding plans for their technology building blocks. The groups meet three times a year and update and review their technology building blocks.[33]

The OSRA process and technology building blocks also inform other major European defence policy, planning and investment initiatives, such as the EU’s CDP, Permanent Structured Co-Operation (PESCO) or the research and capability windows of the new European Defence Fund (EDF). This enables the EDA and Commission to prioritise the allocation of resources based on a combination of capability requirements, strategic and policy priorities, and industrial and security of supply considerations, cognisant also of NATO Defence Planning Processes and initiatives by EU MS (see Figure A.4).

[32] EDA, 2018.

[33] EDA, 2018.

FIGURE A.4
EU Initiatives to Deliver Priority Capabilities



SOURCE: EDA, n.d.

The European Commission's Key Enabling Technologies

Alongside the focus of the EDA on detailing technology building blocks within the OSRA process, the EU also considers high-level strategic priorities for CTNI. The European Commission published its KETs strategy in 2009 with the overall aim of supporting European industry and the research base to promote economic growth, competitiveness and strategic autonomy in technology areas upon which many essential capabilities, systems and value chains rely.[34] This strategy has relevance to defence and security but is firmly dual-use in focus, not least because it predates the creation of DG DEFIS and the move towards a greater role for the EU institutions in defence policy—reforms that only began in earnest after the United Kingdom's vote to exit the EU.[35]

KETs are generic technologies that are knowledge-intensive, have high research and development intensity, high capital expenditure, and require highly skilled employees. The Commission also describes KETs as being 'of systematic relevance, multidisciplinary and trans-sectorial, cutting across many technology areas with a trend towards convergence, technology integration and the potential to induce structural change'.[36] The six KETs are advanced manufacturing, advanced materials, life-science technologies, micro/nano-electronics and photonics, AI, and security and connectivity.[37]

KETs were integrated into the EU's previous Horizon 2020 framework program, the multiyear financial instrument with a €77 billion budget that aimed to support European innovation. The KETs program received €30 billion of funding from Horizon 2020.[38] The funding for KETs was directed at supporting prototypes, product validation in pilot schemes, and large-scale pilot schemes.[39] Depending on the TRL, researchers could receive up to 100-percent funding for KET projects, and businesses could receive business innovation grants up to €2.5 million.[40] Mapping exercises have also been undertaken to identify relevant technology centres across Europe to understand capacity and capability and help drive cross-European collaboration. The current multiyear framework, the Horizon Europe program, which started in 2021, has again given KETs a key role.[41]

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34 Maurits Butter, Noëlle Fischer, Govert Gijsbers, Christian Hartmann, Marcel de Heide and Frans van der Zee, *Horizon 2020: Key Enabling Technologies (KETs), Booster for European Leadership in the Manufacturing Sector*, Directorate-General for Internal Policies, 2014.

35 James Black, Alexandra Hall, Kate Cox, Marta Kepe and Erik Silfversten, *Defence and Security After Brexit: Understanding the Possible Implications of the UK's Decision to Leave the EU – Compendium Report*, Santa Monica, Calif., and Cambridge, UK: RAND Corporation, RR-1786-RC, 2017.

36 European Commission, 2014a.

37 Interreg Europe, 2021.

38 Butter et al., 2014.

39 Butter et al., 2014.

40 Butter et al., 2014.

41 Interreg Europe, 2021.

The European Commission's Smart Specialisation Strategy

The Smart Specialisation Strategy is a framework that can be adopted by European regions to identify and support CTNI in their local areas. It encourages regions to support technologies where the region has a competitive advantage and where the technologies can support economic growth and social cohesion.[42]

The strategy provides six steps that regions should follow to identify and promote CTNI:

- Analyse the regional context through SWOT (strengths, weaknesses, opportunities, and threats) analysis, regional profiling studies, targeted surveys, and expert assessments.
- Set up a dedicated Steering Group or Management Team.
- Design a shared vision for the region.
- Select a limited number of strategic priorities for the region.
- Create an action plan or roadmap for achieving the strategic priorities.
- Create integration and evaluation mechanisms, to evaluate whether the strategic objectives are being met.[43]

The Smart Specialisation Strategy thus allows a common framework to be adapted to suit regional needs, ensuring bottom-up involvement in supporting CTNI. The strategy also provides funding to regions and provides online resources and a self-assessment tool.[44]

The European Commission's Flagship Program

In 2019, the Commission launched its Flagship program, which was supported by the Horizon 2020 program.[45] The Flagship program involves large-scale research initiatives (over €1 billion) related to a selected set of emerging technologies. Taking a high-risk, high-reward approach, these seek to ensure long-term investment (around ten years). The technologies chosen are intended to align with the RD&I agendas of the EU and its national bodies. The intent it to mobilise academia, industry and national programs to 'tackle major challenges in science and technology'. Horizon 2020 currently has four Flagship initiatives:

- Battery 2030+, which aims to 'develop high-performance, safe and sustainable batteries'
- Graphene, which is focused on 'taking graphene and related two-dimensional materials and applying them in European technology'
- Human brain project, which seeks to mobilise 'neuroscientists, computer and robotics experts . . . [to support] understanding of the human brain'
- Quantum technologies, which aims to 'accelerate the development and uptake of quantum technologies'.

[42] European Commission, 'What Is Smart Specialisation?', webpage, n.d.-b.

[43] European Commission, *Guide to Research and Innovation Strategies for Smart Specialisations (RIS 3)*, 2012.

[44] European Commission, *The Programming Period 2014–2020: Guidance on Monitoring and Evaluation*, 2014b.

[45] European Commission, 'Shaping Europe's Digital Future: Flagships', 2019.

The European Institute of Innovation and Technology's Strategic Innovation Agenda

The SIA, like the Smart Specialisation Strategy, aims to support sustainable economic growth and address societal challenges by enhancing European capabilities in priority technology areas.[46] However, rather than supporting regions to create their own CTNI strategies like the Smart Specialisation Strategy, the SIA supports eight key areas at a pan-European level, which are known as Knowledge and Innovation Communities (KICs). The KICs cover climate, digital, sustainable energy, health, raw materials, food, manufacturing, and urban mobility.[47] KICs bring together universities, research labs and private enterprise from across Europe with the aim of supporting innovators and entrepreneurs in their respective areas to commercialise their products and services. The European Institute of Innovation and Technology offers financial support to KICs and regularly evaluates their performance.[48]

The Panel for the Future of Science and Technology for the European Parliament

Besides the various CTNI strategies and initiatives at the executive level, the European Parliament also has a specialist TA function to support the EU's legislature. Set up in 1987, the Panel for the Future of Science and Technology provides scientific assessments of technology developments for MEPs. It aims to consider the longer-term impacts of new CTNI technologies to support relevant legislation, cutting across defence, dual-use and civil applications. Its members are 27 serving MEPs.[49]

Technologies are proposed to the panel by parliamentary committees or MEPs; the panel then carries out TA and scientific foresight projects to assess long-term impacts of the technologies before identifying potential legislative pathways to protect, promote and responsibly deploy emerging CTNI.[50]

The EU-US Trade and Technology Council

A recent development was the announcement on 15 June 2021 of the establishment of the EU-US Trade and Technology Council (TTC), which aims to 'strengthen trade, investment

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[46] Council of the European Union, 2021.

[47] Council of the European Union, 2021.

[48] Council of the European Union, 2021.

[49] Panel for the Future of Science and Technology, n.d.

[50] EPTA, 'Panel for the Future of Science and Technology (STOA) for the European Parliament', webpage, n.d.

and technological cooperation'.[51] Importantly for CTNI, the TTC aspires to 'seek common ground and strengthen global cooperation on technology, digital issues and supply chains; to support collaborative research and exchanges; . . . [and] to promote innovation and leadership by US and European firms'.[52] To kick things off, the TTC is establishing working groups focused on 'technology standards cooperation (including on AI, IoT, among other emerging technologies), climate and green technology, Information and Communication Technology (ICT) security and competitiveness, data governance and technology platforms, the misuse of technology threatening security and human rights, export controls, investment screening, promoting SMEs access to, and use of, digital technologies, and global trade challenges . . . [as well as] critical supply chains'[53] particularly associated with semiconductors. The EU and the United States are also looking at policy drivers associated with technology competition and cooperation that focuses on 'competition policy and enforcement, and increased cooperation in the tech sector, . . . support[ing] collaborative research and innovation exchanges, . . . [and] developing a new research initiative on biotechnology and genomics'.[54]

While this arrangement is only just commencing, it does demonstrate that the global nation of technology development and applications requires cooperation, even for major powers.

A.3. The US Critical and Emerging Technologies List

The US National Strategy for Critical and Emerging Technologies (2020)[55] observes that a market-oriented approach provides key advantages over a state-directed one, thus positioning liberal democracies to better realise the benefits of technologies, both from a security and prosperity lens. The strategy defines critical and emerging technologies (CET) as 'those technologies that have been identified and assessed by the National Security Council (NSC) to be critical, or to potentially become critical, to the U.S.'s national security advantage, including military, intelligence, and economic advantages'.[56] The US government focuses its CET strategy around two pillars: promoting the National Security Innovation Base (NSIB) and protecting technology advantage (security).[57]

[51] White House, 2021, para. 3.

[52] White House, 2021, para. 17.

[53] White House, 2021, para. 18.

[54] White House, 2021, para. 19.

[55] US Government, 'National Strategy for Emerging and Critical Technologies', 2020.

[56] US Government, 2020, p. 2.

[57] US Government, 2020, p. 4.

There are 13 priority actions under promoting the NSIB (equivalent to Australia's prosperity pillar).[58] Of interest to Australia are:

- Attract and retain inventors and innovators.
- Leverage private capital and expertise to build and innovate.
- Rapidly field inventions and innovations.
- Support the development of a robust NSIB, to include academic institutions, laboratories, supporting infrastructure, venture funding, supporting businesses, and industry.
- Increase priority of R&D in developing government budgets.
- Develop and adopt advanced technology applications within government, and improve the desirability of the government as a customer of the private sector.
- Encourage public-private partnerships.
- Build strong and lasting technology partnerships with like-minded allies and partners, and promote democratic values and principles.
- With the private sector, create positive messaging to increase public acceptance of CET.

There are nine priority actions under protecting technology advantage (equivalent to Australia's security pillar).[59] The following are of interest of Australia:

- Require security design early in the technology development stages, and work with allies and partners to take similar action.
- Protect the integrity of the R&D enterprise by fostering research security in academic institutions, laboratories and industry, while balancing the valuable contributions of foreign researchers.
- Engage with the private sector to benefit from its understanding of CET as well as future strategic vulnerabilities related to CET.
- Assess worldwide S&T policies, capabilities, and trends, and how they are likely to influence, or undermine, American strategies and programs.
- Ensure secure supply chains, and encourage allies and partners to do the same.
- Message to key stakeholders the importance of protecting technology advantage, and offer practical assistance whenever possible.

The US government has also identified 20 CET:[60]

- advanced computing
- advanced conventional weapons technologies

[58] US Government, 2020, pp. 7–8.

[59] US Government, 2020, pp. 9–10.

[60] US Government, 2020, p. A-1.

- advanced engineering materials
- advanced manufacturing
- advanced sensing
- aero-engine technologies
- agricultural technologies
- AI
- autonomous systems
- biotechnologies
- chemical, biological, radiological, and nuclear (CBRN) mitigation technologies
- communication and networking technologies
- data science and storage
- distributed ledger technologies
- energy technologies
- human-machine interfaces
- medical and public health technologies
- quantum information science
- semiconductors and microelectronics
- space technologies.

A.4. Lessons from International Practices

Those European nations that are MS and/or EDA pMS participate in the EU CTNI approaches discussed above. In many cases, they also have their own national approaches to CTNI, although these often draw on elements of the EU strategies like KETs and KICs. Many national and some regional parliaments around Europe also have TA units that are often, like the European Parliament's Panel for the Future of Science and Technology, part of the EPTA network.

Some common themes emerging from a review of publicly available information on different European national approaches are discussed below.

Common Aims and Scope

Many national approaches to identifying and supporting CTNI are relatively broad in terms of aims and scope. In general, national approaches aim to support CTNI with a view to

- supporting national security, for instance, by maintaining strategic autonomy in certain sectors
- stimulating national (or regional/local) economic growth
- benefiting society more widely (e.g., supporting communities, promoting influence, helping to address policy priorities such as climate and environmental change).

These elements may be covered by different agencies and strategies, or some countries may consider only one or two of these aims. For example, the Danish Board of Technology[61] focuses solely on societal development, whereas Germany's Office of Technology Assessment and separate Commission of Experts for Research and Innovation focus on economic and social benefits from CTNI.[62] Other countries, like France and the Netherlands, have agencies and strategies that cover security, economic and social issues.[63]

National approaches to CTNI also often have a wide scope. For example, Austria's Institute of Technology Assessment identifies four general themes: information society, technology and sustainability, governance and emerging technologies, and participatory approaches.[64] Spain's Advisory Council for Science, Technology and Innovation has identified six varied themes: health; culture, creativity and inclusive society; security for society; digital world, industry, space and defence; climate, energy and mobility; and food, bioeconomy, natural resources and environment.[65]

As discussed earlier, many European countries also define a related category: critical infrastructure.[66] The approach taken to critical infrastructure may or may not involve explicit links to CTNI policy and classifications. Links can also be made between CTNI and national approaches to enhancing societal resilience, preparedness and contingency planning. Finland, for example, maintains national stockpiles and works closely with

61 Danish Board of Technology, 'About DBT', webpage, n.d.

62 Commission of Experts for Research and Innovation, 'Mission Statement', webpage, n.d.; Office of Technology Assessment at the German Bundestag, 'Tasks and Goals', webpage, n.d.

63 Ministère de la Défense, *Document de Presentation de l'Orientation de la S&T*, French Government, n.d.; Conseil Strategique: Ministère de l'Enseignement Supérieur, de la Recherche et de l'Innovation, *Stratégie Nationale de Recherche 2020*, French Government, 2020; Government of the Netherlands, *Defence Industry Strategy*, 2018; Rathenau Instituut, 'What We Do', webpage, n.d.

64 Austrian Institute of Technology Assessment, 'Medium-Term Research Programme', 2017.

65 Government of Spain, *Estrategia Española de Ciencia, Tecnología e Innovación 2021–2027*, n.d.

66 The Netherlands, for example, defines Category A infrastructures as those that reach a certain threshold in one of four criteria: economic impact (potential for damage or drop in GDP), physical impact (potential for casualties), societal impact (potential for threats to survival or emotional problems), or cascading effects. Category B infrastructures have lower thresholds applied to the first three criteria. Category A includes national transportation and distribution of electricity; natural gas production; oil supplies; storage, production or processing of nuclear materials; drinking water supplies; and water management. Category B includes regional distribution of electricity and gas; flight and airplane management; maritime and inland shipping management; large-scale storage, production or processing of petrochemical resources; financial sector; communication with and between emergency services; police mobilisation; and government services that depend on reliable, available digital information and data systems. See Hague Security Delta, *Securing Critical Infrastructures in the Netherlands*, 2015.

industry and civil society to ensure the maintenance of certain essential societal functions in a crisis.[67]

Common Selection Criteria

Most published strategies from national agencies do not specifically list the evaluation criteria they use to identify CTNI. Among those that do list selection criteria, however, there are several common themes.

One common approach is to consider areas where the country has a competitive economic advantage, as in Italy's National Research Program[68] and France's Strategic Research Council.[69] Another important consideration is whether the technology would contribute to strategic and operational advantage from the perspective of national defence and security. For example, the Netherlands' Defence Industry Strategy selects technologies based on the impact they will have on the Netherlands' ability to perform military tasks in the next five to ten years.[70] Similarly, the French government has stated that the ability of a technology to contribute to national strategic autonomy is an important consideration.[71] A third common criterion is unfamiliarity or novelty, which refers to the perceived quality and originality of the technology—as included in Austria's Strategy 2020[72] and Germany's High-Tech Strategy.[73]

Common Methods

Different European countries provide varying levels of insight into their methods for selecting CTNI. Most countries use a combination of different methods to ensure an interdisciplinary approach, engage a variety of stakeholders (both across national government or the military, and externally across industry, academia and international allies and partners), and seek to capture 'weak signals' of emerging S&T developments that might become a national priority in the future.

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[67] For more examples, see Joanne Nicholson, Peter Dortmans, Marigold Black, Marta Kepe, Sarah Grand-Clement, Erik Silfversten, James Black, Theodora Ogden, Livia Dewaele and Pau Alonso Garcia-Bode, *Defence Mobilisation Planning Comparative Study: An Examination of Overseas Planning*, Santa Monica, Calif., and Cambridge, UK: RAND Corporation, RR-A1179-1, 2021.

[68] Government of Italy, *Programma Nazionale per la Ricerca: 2015–2020*, n.d.

[69] Ministère de l'Enseignement Supérieur, de la Recherche et de l'Innovation, *Stratégie Nationale de Recherche*, French Government, 2015.

[70] Government of the Netherlands, 2018.

[71] Ministère de la Défense, n.d.

[72] Austrian Council, *Strategy 2020*, n.d.

[73] European Commission, *Case Study Report: The German High-Tech Strategy*, 2018.

Examples from this methodological toolkit include[74]

- horizon scanning[75]
- ongoing monitoring of current technologies (technology watch and market intelligence functions)
- literature reviews and rapid evidence assessments
- internal workshops and external workshops with scientific experts and policymakers
- citizen participation
- requests for proposals for government funding for promising initiatives (e.g., grand challenges)
- exploratory studies
- metanalyses (including scientometrics, patent analysis)
- attention analyses (e.g., Google Trends, investment and venture capital trends).

Commonly Identified CTNI

Given the variety of TA methodologies, the evaluation criteria employed, and the relative weighting between different criteria, each European country has its own slightly different definition of CTNI. Nonetheless, there are recurring themes in terms of the technology areas that feature in CTNI lists.

Dual-use examples are listed below in alphabetical order:

- advanced materials
- advanced or additive manufacturing
- aerospace
- agriculture technologies and research
- AI
- big data
- biotechnology
- energy
- health
- information and communication technology
- maritime technologies
- mobility and transport
- nanotechnology

[74] Based on the methods listed in the accompanying spreadsheet.

[75] In the United Kingdom, for example, the Defence Science and Technology Laboratory maintains a multiyear program for S&T horizon scanning, supported by RAND Europe's horizon scanning tool and database. This monitors and assesses the relevance of new and emerging S&T developments around the globe based on a series of evaluation criteria.

- novel materials
- optical technologies
- quantum technologies
- robotic and autonomous systems
- space
- sustainable technologies.

Additional defence-specific examples are listed below:

- chemical, biological, radiological, and nuclear
- combat aircraft
- command and control systems
- cryptography
- cyber and electronic warfare
- effectors (i.e., complex weapons and, increasingly, directed energy weapons)
- force protection (armour, protection systems, etc.)
- sensors
- submarines and surface ships.

APPENDIX B

Different Approaches to Assessing Social Cohesion

There are a number of approaches various groups have taken to assess the impact of policy on society. While they employ different terms (such as 'wellbeing', 'social resilience', etc.), we assess these as being broadly equivalent to the CTPCO definition of social cohesion (see Chapter Four). While each approach tends to seek a quantitative output, the data is often subjective, with some level of interpretation used to determine what characterises 'good' social cohesion. We have identified seven cases that can be used to help the formulation of appropriate criteria for a CTNI policy context.

The Institute for Integrated Economic Research Australia Study on Social Cohesion and Social Resilience

A recent report by the Institute for Integrated Economic Research Australia looked at the relationship between trust, social cohesion and resilience within the Australian context.[1] What it observes is the strong interdependency between trust and social cohesion; and how it is the combination of these that underpin national resilience across each of the community, civil and whole-of-society levels. They note that 'a society in which people feel they have a stake will be one where cohesion and trust are higher. Individuals become citizens rather than subjects and, consequently, are likely to develop shared norms, values and rules'.[2] To realise such a society, they observe the need for the 'capacity to act . . . and a will to cooperate',[3] in effect a combination of engagement and investment. Based on this, they introduce social resilience as a surrogate measure for social cohesion, defining it as 'the capacity of a community or society to adapt to, recover, and grow from the threats and challenges faced, and create a better future where citizens can thrive. Furthermore, a resilient community or society will do so without harm to other communities or societies, or the sustainability of the planet'.[4]

1 Institute for Integrated Economic Research Australia, 2021.

2 Institute for Integrated Economic Research Australia, 2021, p. 4.

3 Institute for Integrated Economic Research Australia, 2021, p. 5.

4 Institute for Integrated Economic Research Australia, 2021, p. 5.

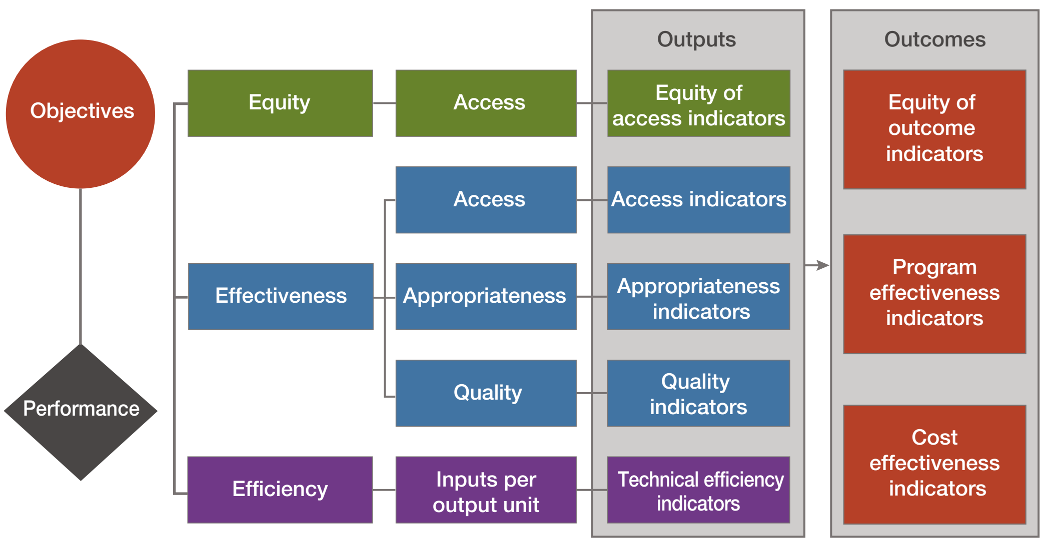
From a public policy perspective, one can see how these factors are important when seeking to prioritise in terms of the national interest, at least from a social cohesion perspective. In particular, they suggest national interest factors such as a capacity to act, a willingness to cooperate, a benefit realised across all levels of society, a minimisation of detrimental side effects on others, and a sense of a belonging. These factors can provide scaffolding against which critical technologies can be assessed to establish the basis for them being CTNI.

The Productivity Commission's Review of Government Services

The Productivity Commission's recent review of government services seeks to assess 'the equity, efficiency and effectiveness of government services in Australia, which contributes to the wellbeing of all Australians'.[5] The Commission assesses the delivery of government services in child care, education and training; justice; emergency management; health; community services; and housing and homelessness. As Figure B.1 shows, they build their evaluation methodology around equity of access, effectiveness (appropriateness, access and quality) and efficiency (input per output unit). Clearly, this approach is consistent with the Department of Finance's logic model.[6] Importantly, the Commission measures comparative performance rather than performance in absolute terms. It also seeks to consider all jurisdictions, in doing so incorporating consideration where there are significant differences in scale and delivery.

FIGURE B.1

General Performance Indicator Framework



SOURCE: Productivity Commission, 2021, pt. A, sec. 1.

5 Productivity Commission, 2021a.

6 Department of Finance, 2020b.

While not explicitly for social cohesion, it does seek to have a common approach that considers a range of relevant enablers and sectors. It also quantifies outputs in a manner that can be related to outcomes and benefits. However, it takes a retrospective approach to measurement, which may not be easily translated to an analytical approach that is more prospective in nature.

The National Indigenous Affairs Agency's Closing the Gaps Program

In 2008, the Australian government established the Closing the Gap program, which sought to reduce disadvantage for Aboriginal peoples. This program sought to focus policy and investment in seven key areas in order to close the gap between indigenous and non-indigenous Australians: life expectancy, childhood mortality, early childhood education, literacy and numeracy, school attendance, school completion, and employment outcomes.[7] Despite significant efforts from the governments of both major parties, this approach has been seen to have limited success, with the prime minister calling it 'wrong-headed'.[8] The NIAA responded by developing a broader set of 16 new targets that seek to 'overcome the inequality experienced by Aboriginal and Torres Strait Islander people, and achieve life outcomes equal to all Australians'.[9] The targets, developed in partnership with the National Coalition of Aboriginal and Torres Strait Islander Peak Organisations, each describe a policy outcome, metric and target data. Through these, the government will have the evidence base to design, deliver and evaluate policy. Significantly for our focus on metrics for social cohesion, they are to be assessed against measurable data, across several policy sectors, and over many years. The targets currently include the following:[10]

- Everyone enjoys long and healthy lives.
- Children are born healthy and strong.
- Children are engaged in high quality, culturally appropriate early childhood education in their early years.
- Children thrive in their early years.
- Students achieve their full learning potential.
- Students reach their full potential through further education pathways.
- Youth are engaged in employment or education.
- Strong economic participation and development of people and their communities.
- People can secure appropriate, affordable housing this is aligned with their priorities and need.

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7 John Gardiner-Garden, 'Closing the Gap', in *Parliamentary Library Briefing Book—44th Parliament*, Parliament of Australia, 2013.

8 Isabella Higgins, Sarah Collard and Brad Ryan, 'Closing the Gap Agreement Reset with 16 New Targets to Improve Lives of Aboriginal and Torres Strait Islander Australians', *ABC News*, 16 July 2020.

9 NIAA, 2020b.

10 NIAA, 'Closing the Gap Targets and Outcomes', webpage, 2020a.

- Adults are not overrepresented in the criminal justice system.
- Young people are not overrepresented in the criminal justice system.
- Children are not overrepresented in the child protection system.
- Families and households are safe.
- People enjoy high levels of social and emotional wellbeing.
- People maintain a distinctive cultural, spiritual and economic relationship with their land and waters.
- Cultural and languages are strong, supported and flourishing.
- People have access to information and services enabling participation in informed decisionmaking regarding their own lives.

Clearly, these are specific to the indigenous community; however, there are some themes that are relevant, namely, life expectancy and quality; education leading to opportunity; equality of access; personal, familial and community safety; emotional and psychological wellbeing; and respect for diversity.

The Melbourne Institute's HILDA Survey

Commencing in 2001, the HILDA survey annually collects data on 'many aspects of life in Australia, including household and family relationships, income and employment, and health and education' from a cohort of over 17,000 Australians.[11] Funded by the National Centre for Longitudinal Data within the federal Department of Social Services, the survey collects and reports on approximately 150 data elements.[12] From a social cohesion perspective, this includes social capital (8 measures), health and disability (22 measures), employment (15 measures), and life abilities and satisfaction (17 measures). These are synthesised into annual reports to measures changes over time.

One area of synthesis that might be relevant to social cohesion is 'subjective wellbeing',[13] 'an umbrella term that generally refers to the concepts of positive and negative affect (with "affect" including mood and emotions such as happiness), domain satisfactions and life satisfaction'.[14] One result is a single life satisfaction measure, which is the aggregation of six 'life domains': job, finances, housing, safety, leisure, and health.[15] While these are collected from the individuals surveyed and hence not practical for our purposes, they do provide a

[11] Melbourne Institute, *The Household, Income and Labour Dynamics in Australia Survey: Selected Findings from Waves 1 to 18*, University of Melbourne, 2020.

[12] Department of Social Services, 'Household, Income and Labour Dynamics in Australia (HILDA) Survey Fact Sheet', Australian Government, 2017.

[13] Melbourne Institute, 2020.

[14] Melbourne Institute, 2020, p. 105.

[15] Melbourne Institute, 2020, p. 110.

set of criteria against which subjective assessments on the implications of CTNI in terms of social cohesion might be made.

The Scanlon-Monash Index of Social Cohesion

The Scanlon Foundation, in collaboration with Monash University, has undertaken 24 annual surveys 'to track public opinion on social cohesion, immigration and population issues . . . [and] provide insight into the resilience of Australian society when faced with a major crisis'.[16] With a large sample size (5,883 participants in the 2020 survey) and a comprehensive set of questions (148 in the 2020 survey), the Scanlon-Monash Index tracks 'constant and changing elements of Australian opinion over time: in a broad perspective, from 2007 to 2020, over a three year period, from 2018 to 2020, and during the current year'.[17] It then identifies five domains of social cohesion against which change is noted:[18]

- **Belonging:** Indication of pride in the Australian way of life and culture; sense of belonging; importance of maintaining Australian way of life and culture.
- **Worth:** Satisfaction with present financial situation and indication of happiness over the last year.
- **Social justice and equity:** Views on the adequacy of financial support for people on low incomes; the gap between high and low incomes; Australia as a land of economic opportunity; trust in the Australian government.
- **Participation (political):** Voted in an election; signed a petition; contacted a Member of Parliament; participated in a boycott; attended a protest.
- **Acceptance and rejection, legitimacy:** The scale measures rejection, indicated by a negative view of immigration from many different countries; reported experience of discrimination in the last 12 months; disagreement with government support to ethnic minorities for maintenance of customs and traditions; feeling that life in three or four years will be worse.

Given these five domains have been used consistently for measurement over 14 years, they represent an approach that would appear to operate in the longer timeframes typical of technological development. While the high-level domains do cover much of what would be covered under the definition of social cohesion, the characteristics under each would require further work as they come from a context where there is a strong link between social cohesion, national identity, immigration, and multiculturalism. That is to say, the Scanlon-Monash Index is aligned with how the Department of Home Affairs defines social cohesion.[19]

[16] Markus, 2021, p. 1.

[17] Markus, 2021, p. 1.

[18] Markus, 2021, p. 28.

[19] Department of Home Affairs, 2021.

New Zealand Government's Living Standards Framework

In 2018, The New Zealand government established the Living Standard Framework as 'a way to support government agencies to be more cohesive so public policy on wellbeing, spending and other government interventions is aligned to improving intergenerational wellbeing'.[20] Broadly based upon the OECD's wellbeing framework, the Living Standard Framework 'includes many dimensions addressing the factors that can expand people's choices and opportunities to live the lives they value—including health, education and income'.[21] It is described in terms of four key elements:[22]

- **Domains of current wellbeing,** which reflect the outcomes of importance to New Zealanders' wellbeing and are divided into[23]
  - current—broken into 14 categories with a total of 75 metrics attached
  - future—broken out in terms of the 'four capitals' with a total of 37 metrics
  - international impact—considers the impact on people in other countries and is broken into six categories and eight metrics.
- **The four capitals,**[24] which each have a set of specific metrics:
  - Human: 'the skills, knowledge, and physical and mental health that enable people to participate fully in work, study, recreation and society more broadly . . . [with] a direct link to key elements of wellbeing including employment, income and social connection'
  - Social: 'social connections, attitudes, understandings and formal rules or institutions that contribute to societal wellbeing'
  - Natural: 'all aspects of the natural environment needed to support life and human activity
  - Financial and physical: 'financial and physical assets that support incomes and material living conditions'.
- **Risk and resilience**: risks to wellbeing and the nations' capacity to respond.
- **Distribution**: in essence, equality defined in terms of people, places and generations.

The Living Standards Framework takes a comprehensive approach to measuring wellbeing, which, in the context of this work, aligns closely with social cohesion. While this level of detail is unnecessary for assessing CTNI, the high-level elements shown above might provide a useful heuristic with which to make consistent, comprehensive, transparent and repeatable (qualitative) technology impact assessments.

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20 The Treasury, 2018.

21 The Treasury, *The Living Standards Framework: Dashboard Update*, New Zealand Government, 2019b, p. 3.

22 The Treasury, 2019b, pp. 3–4.

23 Statistics New Zealand, 'Wellbeing Data for New Zealanders: Contextual Indicators', New Zealand Government, n.d.

24 The Treasury, 'Budget Policy Statement 2019', New Zealand Government, 2019a.

The UK MOD's Defence Value Proposition

The UK whole-of-government Public Value Framework[25] seeks to expand the traditional considerations of balancing capability, schedule and cost. While its definition for 'social or public value' employs a financial lens ('welfare economics'), it does observe that this 'includes all significant costs and benefits that affect the welfare and wellbeing of the population, not just market effects. For example, environmental, cultural, health, social care, justice and security effects are included'.[26] Taking this a step further, a recent report focusing on developing a 'Defence Value Proposition' derived six ways the UK MOD contributes to the nation:[27]

- protecting our people
- insuring against future uncertainty
- protecting our global influence
- contributing to international security
- supporting our national economy
- contributing to national identity and social welfare.

The last of these contributions defines value in terms of 'the role of defence as a vital part of the United Kingdom's national identity, social cohesion and local communities',[28] which includes shared identities, local communities, and promoting civic and social integration.

25 HM Treasury, 2019, p. 6.

26 HM Treasury, 2020, p. 5.

27 James Black, Richard Flint, Ruth Harris, Katerina Galai, Pauline Paille, Fiona Quimbre and Jess Plumridge, *Understanding the Value of Defence Towards a Defence Value Proposition for the UK*, Santa Monica, Calif., and Cambridge, UK: RAND Corporation, RR-A529-1, 2021, p. 29.

28 Black et al., 2021, p. 39.

APPENDIX C

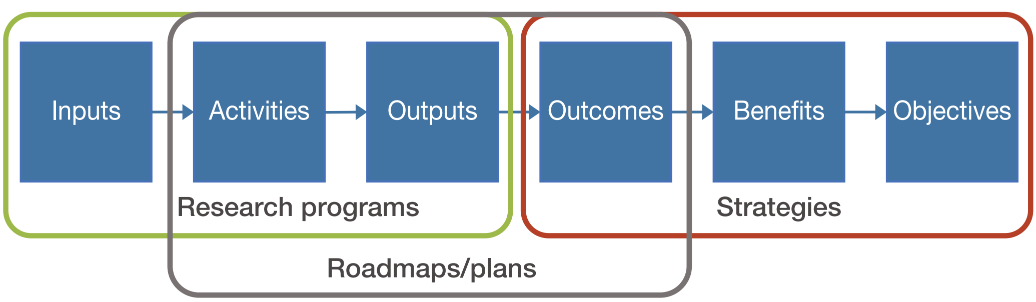
Developing the Agriculture Benefits Map

In this appendix, we provide a case study for the application of the logic model suggested to link the government's policy agenda with the national research program. Using a uniform approach across all policy sectors will allow greater consistency when seeking to integrate the priorities of the various sectors. Figure C.1 describes the benefits map logic model that the Australian government uses to set policy directions and build research (and other) programs to achieve them. As the 'owner' of the policy agenda, the government sets the demand (i.e., the national objectives). From a supply perspective, the RD&I ecosystem delivers research programs that seek to transition technologies into functional outputs. However, in reviewing various documentation, we observe that these do not align well, and that their connection is not well articulated. We determined that the various technology roadmaps and plans often (and sometimes inadvertently) provided the connections (as displayed in Figure C.1). We tested this approach across a number of sectors to gain an understanding of how best to apply it. We use the agriculture sector to show how to apply this as part of the framework.

We commenced with a desktop activity where we reviewed the relevant policy documents from the Department of Agriculture, Water and the Environment, specifically their annual report[1] and corporate plan.[2] These allowed us to determine the (enduring) national objec-

FIGURE C.1

Relationship Between Data Sources and Benefits Map



[1] Department of Agriculture, Water and the Environment, *Annual Report 2020–21*, Australian Government, 2021a.

[2] Department of Agriculture, Water and the Environment, *Corporate Plan 2020–21*, Australian Government, 2021b.

tives and outcomes. These reports also identified specific benefits the government is seeking to achieve—that is to say, how outcomes support the achievement of the objectives. We then reviewed the Decadal Plan for Australian Agricultural Sciences 2017–26,[3] adapting its outputs to align with those desired by the department, given the decadal plan's focus on how S&T solutions for the future. We also incorporated the findings of the Australian Council of Learned Academies report *The Future of Agricultural Technologies*,[4] which we used in combination with the decadal plan to determine a set of RD&I outputs. For completeness, we captured the technology domains that they identified as key inputs. These were all brought together on a benefit map, which is reproduced in Figure C.2. This mapping was then used to provide a consistent basis for discussion between the various stakeholders and SMEs. Aside from refining the content, the relationships between the boxes across each step are established and reasoning captured.

3 Australian Academy of Science, *Grow. Make. Prosper. Decadal Plan for Australian Agricultural Sciences, 2017–26*, 2017.

4 ACOLA, *The Future of Agricultural Technologies*, 2020.

FIGURE C.2

Illustrative Benefits Map for the Agriculture Sector

Inputs (technology domains)

- Genomics
- Metabolic engineering
- Agri-intelligence technologies
- Big data
- Biochemistry
- Climate sciences
- Robotics and automation
- Nanotechnology
- Distributed ledger technology

Activities/programs

Outputs

- Increased productivity through improved farm management
- Evidence informed timely and efficient use of inputs on farms
- Enhanced tracking through the value and supply chain
- Crop adaptations that increase resilience to drought, pests and weeds
- Increased animal resilience to drought and pests
- Reduced cost and increased on-farm efficiencies through automation
- Improved soil and crop health through nano-fixing of nitrogen
- Improves crop yields through ML-enabled decision making
- Responsiveness to changing environmental/meteorological conditions
- Enhanced consumer confidence/ minimised safety breaches through secure tracking and tracing of products
- Streamlined certification across the supply chain

Outcomes

- Increased value through quality and market advantage
- Increased productivity through integrated farming systems
- Enhanced biosecurity
- Maintenance of a sustainable resource base

Benefits

- Outcomes are consistent with forecasts, allowing for unforeseeable events
- Average annual productivity growth for the past ten years is equal to or exceeds average annual market sector productivity growth over the same period
- The national biosecurity system meets the agreed national goals and objectives of the Intergovernmental Agreement on Biosecurity
- A reduction in nutrient, sediment and pesticide loads consistent with meeting agreed national targets

National Objectives

- **Agriculture** Assist industry to grow to a $100 billion agricultural sector by 2030
- **Biosecurity** Manage biosecurity risks to Australian agriculture, the environment and our way of life
- **Environment** Support stewardship and sustainable management to enhance Australia's environment

NOTE: ML = machine learning.

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RAND AUSTRALIA

The Australian government has embarked on a plan to shape and coordinate national policy around technologies deemed critical to the national interest. Central to this plan is the ability to balance the three pillars of national interest identified by the government: national security, economic prosperity, and social cohesion. Associated with these pillars is the level of sovereignty a nation like Australia requires to ensure it can benefit from those critical technologies when it needs to.

In this report, the authors develop an analytical approach for identifying and prioritising critical technologies of national interest (CTNI) to Australia in a manner that balances national security, economic prosperity, and social cohesion requirements. Information from a range of sources, including Australia's domestic (federal) policy environment as well as the rich history of other national and multinational efforts, is reviewed and analysed.

The authors describe a broad, two-step analytical approach that first seeks to identify a long list of CTNI and then uses a policy lens to develop a smaller prioritised CTNI list that cuts across all policy sectors. Although CTNI might be the policy focus, impacts of other critical functions, such as infrastructure, workforce and supply chain, also need to be considered when prioritising. The authors recommend that a monitoring and evaluation regime be established to support the continued evolution of the analytical approach and the priorities it identifies.

This report will be of interest to policymakers who are involved in technology policy, commercialisation strategic planning, and resource management.

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