Visions of ARPA

Policy Exchange

Embracing Risk, Transforming Technology

Edited by Iain Mansfield and Geoffrey Owen

Foreword by Dr William Schneider, Jr

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Contents

Foreword

William Schneider, Jr.
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The Soviet Union shocked the world with three technological surprises during 1957 and 1958; the successful orbiting of its 56 cm/88-kg *Sputnik* artificial earth satellite in 1957, followed in less than a year by adapting its space launch vehicle to the ICBM, and its breach of the nuclear testing moratorium in March 1958.

These events constituted both intelligence and technological surprise which imparted an outsized impact on the US governmental leadership that galvanized the Congress to act, but the government response developed more slowly.

Adapting to the nuclear and space age had been initiated in 1953 by President Dwight Eisenhower's *Solarium Studies*. The newly established national intelligence agencies and the Department of Defense (1947) would need to exploit modern scientific advances to adapt the US defense and intelligence posture from its World War II and Korean conflict legacy. One recommendation to support the DoD's capacity to adapt the US defense and intelligence posture was the effort to provide the Secretary of Defense with independent scientific advice on the technologies largely developed in by the defense industry. This recommendation made by the Hoover Commission in 1955 led to the establishment of the Defense Science Board in 1956.

The US had been institutionally unprepared, and politically unwilling to accept the concept of "technological surprise" although the notion of "surprise" was a well-established dimension of military planning and operations for millennia. Following the dramatic events of 1957-58, the Congress created ARPA in 1958 (and since 1996, DARPA). For its six decades of operation DARPA has been held to a singular and enduring mission:

> *Make pivotal investments in breakthrough technologies for national security, and through its investment to catalyze the development of new capabilities that give the Nation technology-based options for preventing – and creating – technological surprise.*

DARPA $3.8 billion budget accounts for less than 3% of the DoD's budget. However, the Agency contributes to extensively to US military capability development in an institutionally complex, but productive R&D ecosystem. DARPA has no laboratories, test ranges, or long-term career employees associated with DARPA programs. The core of DARPA's enduring capacity to innovate are its cadre of ~ 100 program managers and a professional staff of ~ 220 who typically serve for 3-5 years before returning to their parent academic, research organizations, or industrial institutions. They bring new ideas about how to address known as well as anticipated DoD mission needs coupled to a sense of urgency to support the timely development of the enabling technologies to do so, and to establish links with other elements of the DoD R&D ecosystem to facilitate their adoption by military users.

The enduring simplicity of DARPA's structure and organization belies the difficulty in replicating DARPA-like institutions in other settings. Efforts elsewhere in the US government's R&D apparatus to establish DARPA-like institutions have not been successful in producing DARPA-like outcomes. For example, the Department of Energy (DoE) – despite its existing 11-laboratory infrastructure – sought to create its own version; ARPA-E in 2007. While useful research is undertaken, its work has not been associated with the scale and scope of technological advance that has characterized DARPA since its founding. It seems likely that with similar funding, other DoE laboratories could have created similar results.

The UK has an extraordinary scientific infrastructure supporting both basic and applied research in the physical as well as the life sciences. However, institutional constraints have limited the ability of the UK to 'punch-its-weight' in coupling these national assets into the creation of new commercial, military, and civil products and services that reflect the strength of its underlying scientific and technological capabilities for innovation.

The UK's national leadership has recently emphasized the importance of creating an environment that will stimulate and sustain innovation. The technology base for innovation is far-removed from that which existed at DARPA's founding more than six decades ago. The primary drivers of new military capabilities and civil sector innovation are global, not national, and are largely developed outside of the defense sector. Moreover, it cannot be readily ascertained how specific technologies will couple to specific military missions. Hence, DARPA's relies on its Program Managers to create military capabilities from advanced technologies rather than responding to a 'top-down' concentration on specific military missions to be served by the application of technology. DARPA's six offices are technology rather than mission centric.

DARPA's approach to technology development as one former DARPA Director has described it, "pushing the frontiers of basic science to solve a well-defined use-inspired need" have facilitated the creation of a remarkable array of technology applications. DARPA narrows the scope of its work to what it describes as "DARPA-hard" problems reflecting the diverse capabilities of the DoD R&D ecosystem to take-up other technical challenges. While these applications usually have a defense purpose, but often have far greater consequences for the civil sector and the national and global economy. Precision navigation and timing (GPS), microprocessors, the internet, and many others illustrate DARPA's contribution to innovation.

The commitment by the UK government to create a UK analog to ARPA/DARPA is a welcome one which has the potential to secure breakthroughs in the application of new commercial, military and civil innovations from its existing strong research base. The government should not, however, underestimate the difficulty of this venture: efforts to create DARPA analogs , both within the USG and in allied countries abroad are, thus far, 'unblemished by success'.

This compendium by Policy Exchange, if heeded, will increase the chance that the UK can create the transformational ARPA it desires. It brings together a group of specialists with international reputations in the application of science and technology to public policy needs. Their essays focus on some of the key institutional issues involved in the creation of a UK analog to the US DARPA that will be effective in the UK context. This approach is appropriate since institutional issues are likely to be the primary barriers to the creation of a UK "ARPA" and are likely to shape its degree of success.

William Schneider, Jr. (Senior Fellow, Hudson Institute and the US DoD Defense Science Board)

Executive Summary

The Government has committed in its manifesto to establish a new agency for high-risk, high-payoff research, at arm's length from government, modelled on the US Advanced Research Projects Agency (ARPA), with a budget over the years of the Parliament of £800m. Such an agency has the potential to make a significant contribution to the UK's leadership in scientific and technological innovation.

Our report summarises the history of the UK's science and innovation system and analyses the key features of the US system to consider how the lessons of ARPA/DARPA might be transferred to the UK. Seven experts in science and innovation, including former science ministers, vice-chancellors and leading academics then discuss aspects how an ARPA could be established in the UK.

- **William B. Bonvillian** summarises the key features of the 'DARPA model', analysing the factors that contributed to its phenomenal success.
- **Julia King** discusses how a dramatically different way of working could enable ARPA to help great scientific ideas escape from the laboratory by acting as an interpreter and matchmaker.
- **Richard Jones** sets out the centrality of empowered programme managers in driving research in support of the long term goals of the nation.
- **Jo Johnson** discusses the appropriate relationship between ARPA and UK Research and Innovation (UKRI).
- **Nancy Rothwell** and **Luke Georghiou** explore the concept of 'high innovation risk' and how ARPA must successfully navigate this to reap the rewards of its investment.
- **David Willetts** champions the role of ARPA in promoting the development and application of key technologies.
- **Tim Bradshaw** analyses the challenges of commercial pull through and the need for reform of public procurement if ARPA's innovations are to progress from the laboratory to the market.

Drawing upon these essays, we conclude that ARPA needs to focus on developing advanced technologies on a 10-15 year time horizon, rather than on theoretical basic research or near-to-market incremental product innovation. It must embrace risk – while we are hesitant to define the exact success ratio, we can say that if more than half of ARPA's projects succeed fully it will be being too cautious. The agency should be prepared to fail fast and fail often, with its success judged by the impact of its successes, which should be transformative.

A number of our essays discuss whether ARPA should be created within UKRI or as a separate body, a subject upon which our contributors have different position. Our own view is that if two distinguished former science ministers, amongst others, have reached different conclusions on this matter, there are clearly strong and credible arguments on both sides.

Wherever it is situated the government must tear up the rule book of research funding bureaucracy, allowing empowered and highly expert project mangers to drive forward projects and allocate funding to the best people and projects wherever it can be found. And to secure commercial pull-through, Government must take active steps to fill the gap created by the lack of a single intelligent customer (a role filled by the US Department of Defense[1] for DARPA) to ensure the technologies catalysed by ARPA are deployed for the lasting economic benefit of the UK.

ARPA has the potential to have a transformative impact on the UK's science and innovation landscape. The Government should move boldly to create it with it the mandate, freedom and risk appetite that will allow it to truly fulfil its potential.

1. A note on spelling. 'Defense' is used in relevant proper nouns, such as the US Department of Defense or Defense Advanced Research Projects Agency. Otherwise 'defence' is used.

Policy Exchange's Recommendations

1. **Government should move rapidly to establish a UK ARPA.** An effective ARPA pursuing high-risk, high-reward transformative research has the potential to make a significant contribution to the UK's scientific and economic performance.

2. **Government should clearly set out the role, objectives and mission of ARPA.** This should include clarifying what gap it is meant to fill, how its mandate differs from that of other UK funding bodies and its intended relationship with these bodies.

3. **The government should seek as far as possible to secure bipartisan support for ARPA.**

4. **ARPA should not carry out research itself or have its own research laboratories.** Instead it should fund the best research and individuals wherever they are found, in pursuit of its objectives.

5. **ARPA should focus on developing advanced technology on a 10-15 year horizon.** Unlocking transformative technologies, rather than basic research or incremental near-to-market innovation, is where ARPA's efforts should be centred.

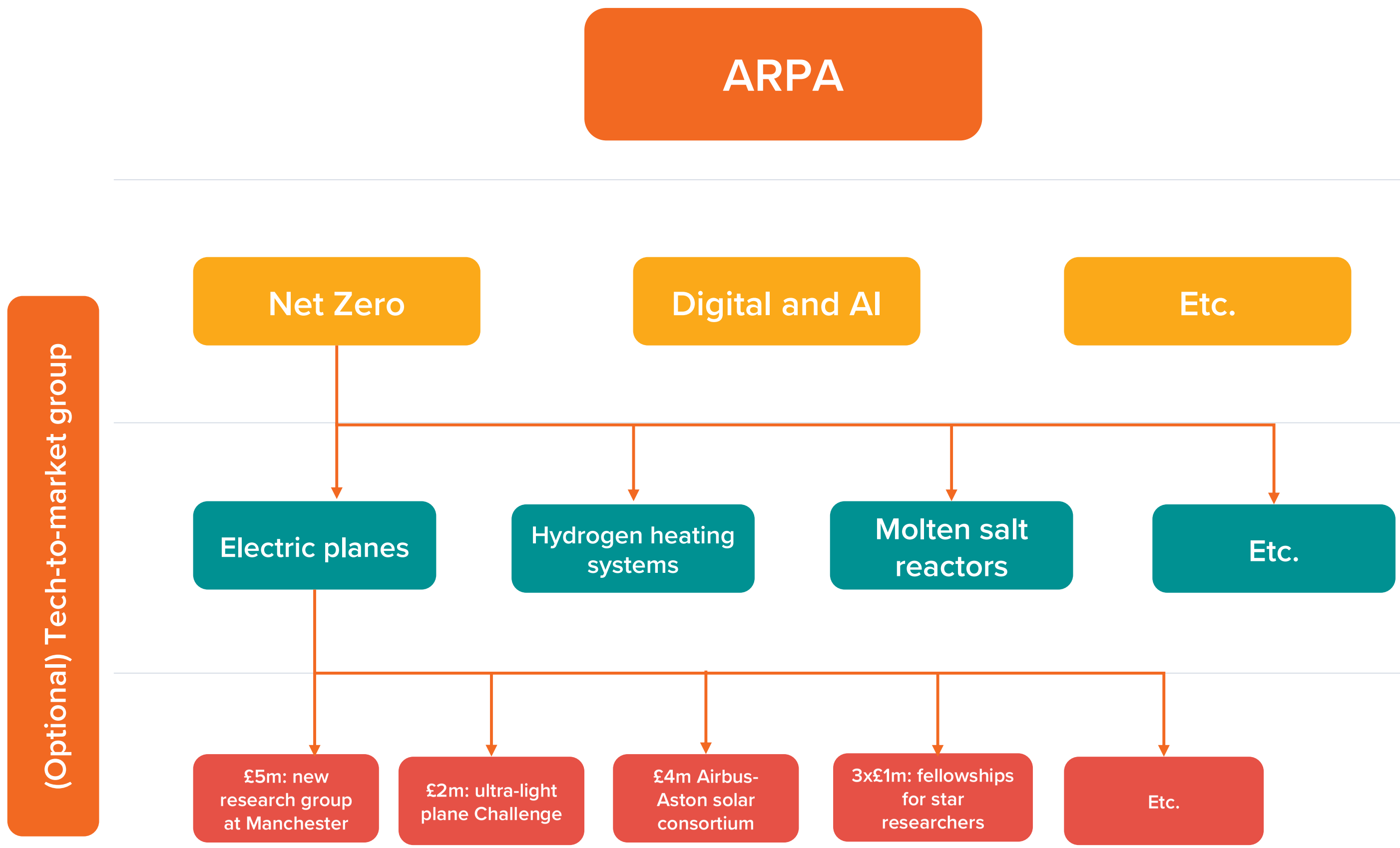
6. **ARPA must embrace failure.** ARPA's director, Ministers and the National Audit Office must recognise that most projects will not achieve their objectives – and that ARPA should be judged on the impact of its successes, not the proportion of its projects that fail. ARPA should be ruthless in cutting off funds for failing projects.

7. **ARPA should be given a small number of missions, each addressing a major societal challenge or scientific area.** These missions – ideally between two and four – should be determined by the Minister for Science and reviewed every five years. Each would correspond to an office within ARPA, and in turn would comprise a number of specific projects.

8. **Project managers must be highly capable, empowered and given genuine autonomy.** They should be highly talented individuals at the forefront of their field, typically brought in on three-year contracts with highly competitive salaries and considerable latitude to make decisions .

9. **Bureaucracy should be minimised.** Government must tear up the standard rulebook and allow money to be allocated to the best people and projects wherever they are found, in universities, research institutes or industry. Formal requirements for bidding rounds, peer review and evaluations should have no place within ARPA, with project managers needing to convince only two people – their Office Head and the ARPA Director – in order to allocate funding.

10. **Government must simultaneously develop the strong commercial pull-through to bring ARPA-developed technologies to the market.** This could take the form of a reform of public sector procurement, the creation of a single strategic customer for a particular area, the establishment of a tech-to-market group or other means – but is essential if ARPA is to be successful.



ARPA
Annual Budget: £250m - £300m
Headed by a Director..
Total employees <50
Either inside UKRI, independent agency, NDPB or charity

ARPA Offices (2 – 4)
Annual Budget: £50m - £100m
Determined by the Science Minister and reviewed every five years.
Each aligned to a grand challenge or major science area.
Headed by a Head of Office

Projects (5-10 per Office)
Annual Budget: £10m - £20m
Each focused on a specific, relatively narrow, project area.
Each headed by a highly skilled, specialist project manager (who may manage more than one project).

Grant Allocations
Budget: Typically £500k - £5m per grant, often over multiple years.
Allocated entirely at discretion of project manager, subject to Head of Office and ARPA Director approval.
May take atypical forms such as Challenge Prizes.

ARPA in Context

A Brief History of the UK Science and Innovation System

A central theme in UK science and innovation policy since the Second World War has been the need to ensure that the nation's investment in academic science is fully exploited for the benefit of the economy and society as a whole. This has often involved intervention by government to promote the transfer of technology from universities into industry, as well as support for science-based and high-technology industries. The extent of intervention, and the methods used, have varied from government to government, depending in part on the ideological stance of the ruling party.

That government should play an active role in funding research and promoting its exploitation was recognised as far back as the First World War. In 1916 the Department for Scientific and Industrial Research (DSIR) was created, charged with supporting scientific research in universities and other research institutes, and with encouraging industry to conduct more of its own research; the DSIR helped to fund several cooperative research associations – for example, in the scientific instrument industry – although these bodies did little to raise the level of industrial research in the UK.[2]

The inter-war period saw the establishment of the first research councils – the Medical Research Council in 1920, the Agricultural Research Council in 1931 – through which the government awarded grants to academic researchers for projects deemed to have high scientific merit. The government also created the University Grants Committee to advise on the disbursement of public funds to universities for staff salaries, buildings and research laboratories.

The creation of the DSIR was a response to the growing anxiety, following the outbreak of war, that Britain had fallen behind in several of the technologies that were essential to the war effort. The contribution of science to national security was even more important in the Second World War, when inventions made by British scientists, such as radar, made a major contribution to the Allied victory; there was also a big increase in industrial research during the war, much of it funded by government.

By 1945 the need for a high level of scientific research was seen across the political spectrum as essential, both for reasons of national defence and as a source of economic strength. There was also increasing

2. Sabine Clark, What can be learned from government industrial development and research policy in the United Kingdom, 1914-1965, British Academy, Lessons from the history of UK science policy, August 2019.

concern that, while British scientists had an impressive record in terms of inventions, the UK had been less successful in putting these inventions to commercial use. A well-known example was the "loss" of penicillin, which had been discovered in Britain but largely commercialised in the US. The Labour government which held office from 1945 to 1951 set up the National Research Development Corporation, charged with patenting and commercialising discoveries coming out of publicly funded research. Described by one newspaper as a way of "preventing foreigners from filching our ideas", the NRDC also provided grants and loans for firms operating in science-based industries; it intervened on a substantial scale in the emerging computer industry.[3]

Science continued to be given a high priority by the Conservative governments which held office between 1951 and 1964. In 1959 a Minister for Science was appointed, responsible for parts of the DSIR, the research councils and more generally for civil science policy; the Office for Science was later merged with education to form the Department of Education and Science. Academic research was funded through the dual support system: project-based funding from the research councils and non-specific funding from the University Grants Committee, later renamed the Higher Education Funding Council.[4] However, the bulk of the nation's research and development effort was in the hands, not of the DSIR and the research councils, but of the big spending departments, principally the Ministry of Supply (which handled the purchase of military equipment) and later the Ministry of Aviation. These departments had direct control of several research laboratories, such as the Royal Aircraft Establishment in Farnborough, which played a big part in the development of the Concorde supersonic airliner.

Concorde was a civil project, but under the earlier Labour government and under the Conservatives there was also heavy expenditure on advanced military technology. Harold Wilson, who led Labour to victory in the 1964 election, believed that the military had absorbed too large a proportion of the nation's scientific and technical resources. In his view British industry was in urgent need of modernisation, and this would require a stronger focus on exploiting non-military technologies.[5] The principal instrument was a new department, the Ministry of Technology, which was given a sponsorship role for several major industries, including computers, telecommunications and machine tools. Mintech, as the new department came to be called, took over control of the Atomic Energy Authority, the NRDC and parts of the DSIR, and later absorbed the Ministry of Aviation and the Ministry of Power. It became, in effect, a fully-fledged industry department, with wide responsibility for science and technology, including the principal government laboratories; the research councils remained with the Department of Education and Science.

The enlargement of Mintech came too late in Labour's term of office to bring about a major shift of resources away from defence, although some military projects were cancelled. It was an experiment in intervention which did not survive the change of government in 1970. The incoming

3. John Hendry, Innovating for failure: government policy and the early British computer industry, MIT Press 1989.
4. This was later renamed the Universities Funding Council and then replaced in 1992 by the Higher Education Funding Council for England.
5. David Edgerton, The 'White Heat' revisited: the British government and technology in the 1960s, Twentieth Century British History 7/1 (1996)

Conservative government, led by Edward Heath, merged Mintech with the Board of Trade to form the Department of Trade and Industry (DTI), and transferred some of its procurement functions to the Ministry of Defence.

The dismantling of Mintech marked a partial retreat from Labour's interventionist policies, although the Heath government's attachment to free markets and limited government was subsequently abandoned in response to a series of industrial crises, including the collapse of Rolls-Royce and severe problems in shipbuilding and other sectors. Through the Industry Act of 1972 the government gave itself extensive powers to provide selective assistance to companies in trouble.

On science policy, the Conservative government maintained the dual system for funding academic science, but made an important change in the way government departments organised their research. Following a report from Lord Rothschild, head of the Prime Minister's Central Policy Review Staff, the government adopted what became known as the customer/contractor principle, whereby each department set out its requirements and contracted with research laboratories to get the work done.[6] This involved the transfer of some research council funding to government departments, a move that was criticised by scientists as undermining the autonomy of the councils and giving more power over science funding to politicians and civil servants. The longer-term consequences of the Rothschild report, according to one historian of science, was to point the way towards the "marketisation" of science policy, which was to be taken much further by the Thatcher government in the 1980s.[7]

Meanwhile the Labour party remained committed to a strong role for government in promoting research and innovation. When Labour returned to office in 1974 it set up a new agency, the National Enterprise Board, one of whose functions was to support the creation and expansion of high-technology firms. Two of the firms created with NEB support were Inmos in semiconductors and Celltech in biotechnology. However, the NEB was also given the task of helping major industrial companies which were in financial difficulty, the extreme case being British Leyland, the car maker that had been created with government encouragement in 1968. The collapse of British Leyland and other "lame ducks" supported by the NEB destroyed the credibility of Labour's industrial policy.

For the Thatcher government which entered office in 1979, industrial policy, in the sense of direct government support for particular firms or industries, was seen as wasteful and unnecessary. Inmos was soon sold; although Mrs Thatcher was persuaded to provide limited support for Celltech, the biotechnology firm, this company was later sold to a Belgian pharmaceutical group. The NEB itself was merged with the NRDC to form British Technology Group. This new agency, which was later privatised, continued in its early years to have first refusal rights on discoveries coming out of publicly funded research, but its monopoly was removed in 1984. Mrs Thatcher believed that NRDC and the successor body had been insufficiently active in commercialising British inventions. A case in point was the NRDC's failure to patent monoclonal antibodies,

6. A framework for government research and development (the Rothschild report), HMSO Cmnd 4814, 1971.
7. Jon Agar, Science policy since the 1980s, British Academy, Lessons from the history of UK science policy, August 2019.

a technology invented in 1975 in the MRC's Laboratory of Molecular Biology in Cambridge; after further development it came to be widely used in the pharmaceutical industry, but most of the rewards went to companies outside Britain.

In the early years of the Thatcher government there was some support for advanced technology through the DTI, notably the Alvey programme in information technology which ran from 1983 to 1987, but there was no enthusiasm for schemes of this sort. Mrs Thatcher's approach to science policy, as it took shape later in her term of office, was to confine public support to basic research and to leave near-market research to the private sector; she also partially privatised several of the government research laboratories.[8]

The dual system for funding academic research was maintained (at a level which the science community regarded as far too low), but the government introduced a new system, known as the Research Assessment Exercise (later renamed the Research Excellence Framework), to ensure that public funds were directed to areas where the quality of the research, as judged by peer review, was outstanding. The aim was to ensure, at a time of tight budgetary restraint, that public investment in research was allocated efficiently, and in a way that produced benefits for the nation.

After Mrs Thatcher resigned in 1990, her stance on research was broadly maintained under John Major, who held office for the Conservatives until 1997. This later period saw a major review of science policy and organisation, the first such review since the Rothschild report of 1971.[9] It recommended some changes, including the creation of a Technology Foresight Programme, designed to bring academic researchers into a closer dialogue with industry. There was also some reshuffling of responsibilities among the research councils. But the main thrust of policy, building on what Mrs Thatcher had done, was to put more emphasis on wealth creation as a primary goal of science and innovation policy; this did not imply any significant departure from the Thatcherite insistence that the responsibility for exploiting technological innovations lay with the private sector.[10]

Throughout the long period of Conservative rule, from 1979 to 1997, interventionist industrial policy was largely off the political agenda; the role of the Department of Trade and Industry was to encourage the diffusion of new technology, but to do so on a "horizontal" basis, without discriminating in favour of particular firms or sectors. When Tony Blair's New Labour took office in 1997 there was no thought of returning to the failed policies of the 1960s and 1970s. What did change under the new administration was a greater willingness to increase public spending on scientific research, and a greater interest in promoting the commercialisation of academic discoveries. Ministers endorsed what they called a technology strategy, embracing, among other things, the provision of financial incentives to universities to strengthen their technology transfer arrangements. The government looked to the US for lessons to how to promote closer university/industry linkages, including the creation of spin-out firms; one initiative was the creation of the Cambridge-MIT

8. Jon Agar, Science policy under Thatcher, UCL Press.2019.
9. Cabinet Office, Realising our potential: a strategy for science, engineering and technology, Cmd 2250, HMSO, 1993.
10. Agar, Science policy since the 1980s.

Institute, designed to instil into Cambridge the entrepreneurial spirit of American universities.[11]

The importance of science and innovation was reflected in a reorganisation of government departments, with science and innovation first being transferred, together with higher education, into the short-lived Department for Innovation, Universities and Skills (DIUS) and then DIUS itself being reabsorbed into the Department for Business, Enterprise and Regulatory Reform (BERR) to create the Department for Business Innovation and Skills (BIS). The government also made several other institutional changes, including the creation of the Technology Strategy Board to manage and expand the DTI's industrial support schemes; the main focus was on funding collaborative R & D programmes between universities and industry. Towards the end of Labour's period in office the government commissioned a report from Hermann Hauser, a leading venture capitalist, which led to the creation of Technology and Innovation Centres (later called Catapult Centres), based in part on the Fraunhofer institutes in Germany.[12]

These changes did not amount to an industrial policy in the old sense, but the recession which followed the world financial crisis of 2008 prompted a shift to what Labour called "a new industrial activism". Public funds were used to support hard-hit industries and to stimulate investment in technologies which offered good prospects for UK-based firms. This approach was taken much further by the Conservative/ Liberal Democrat coalition which held office from 2010 to 2015.

Despite the urgent need to curb public spending, the coalition government protected state funding for science in cash terms (although it fell as a share of GDP) and stepped up state support for near-market research. The government sought to strengthen key sectors of industry which were seen as strategically important and which had a proven commitment to innovation. In the case of the motor industry, for example, the government provided funds for the Advanced Propulsion Centre, whose remit was to finance research on low-carbon emission powertrain technologies. The aerospace industry was also given support to set up the Aerospace Technology Institute.

All this marked a radical change from the hands-off policies associated with Margaret Thatcher. An articulate advocate for this new approach was David Willetts, Minister of State for Universities and Science. In a 2013 speech setting out what he described as "eight great technologies" (all of which, in his view, merited support from government), he highlighted what he saw as a gap in the approach that previous governments – by implication, the Thatcher government in particular - had taken to science and technology. "Strong science and flexible markets are a good combination", he said. "But, like patriotism, it is not enough. It misses out crucial stuff in the middle – real decisions on backing key technologies on their journey from lab to the marketplace. This is the missing pillar in any successful high-tech strategy".[13]

It followed that government should do much more than fund basic

11. For a review of Labour's innovation policy during the period, see Lord Sainsbury of Turville, The race to the top: a review of government's science and innovation policies, October 2007.
12. Department for Business, Innovation and Skills, The current and future role of Technology and Innovation Centres in the UK, A report by Dr Hermann Hauser (2010).
13. David Willetts, Eight great technologies, Policy Exchange 2013.

research. An example of what Willetts had in mind was the creation in 2015 of the Biomedical Catalyst, a new fund jointly sponsored by the Medical Research Council and the Technology Strategy Board. Its role was to identify promising projects in the life sciences sector, and to use grants and loans to help firms bring these projects closer to commercialisation. The Technology Strategy Board itself (which was renamed Innovate UK in 2014) was enlarged and the network of Catapult centres extended.

More controversial was the government's decision to put the research councils as well as Innovate UK into a new organisation, UK Research and Innovation (UKRI). This decision, following a review by Sir Paul Nurse, was criticised[14] on the grounds that it would reduce the autonomy and influence of Innovate UK and lead to an undue centralisation (and perhaps politicisation) of science and innovation policy. However, the government argued that the new organisation would deliver "a greater focus and capacity to deliver on cross-cutting issues that are outside the core remit of the current funding bodies, such as multi-and inter-disciplinary research." It would also create "a strengthened, unified voice for the UK's research and innovation funding system, facilitating dialogue with Government and partners on the global stage".[15]

After the 2015 election the newly elected Conservative government at first appeared to be less enthusiastic than its predecessor about industrial policy. However, when Theresa May took over as Prime Minister in 2016 after the EU referendum she quickly made it clear that what she called a modern industrial strategy would have a high priority in her administration. To mark this change of approach the DTI was given yet another new name, the Department for Business, Energy and Industrial Strategy (BEIS).

Launched in 2017, Mrs May's industrial strategy contained a wide range of initiatives, including the creation of the Industrial Strategy Challenge Fund, to be administered by UKRI. This fund would focus initially on "grand challenge" areas where, in the government's view, "the UK has a world leading research base and businesses ready to innovate, and there is a large or fast-growing sustainable global market".

In April 2017 Greg Clark, Business Secretary, announced that the fund would focus over the next four years on six key areas: healthcare and medicine; robotics and artificial intelligence; batteries for clean and flexible energy storage; self-driving vehicles; manufacturing and materials of the future; and satellites and space technology. This was followed by a series of decisions on the allocation of funds in these six areas. In the case of batteries, for example, the government made available a total of £246m, split between academic research in universities (to be coordinated by a new body, the Faraday Institution), innovation (to be handled by Innovate UK) and what was described as scale-up.[16] This third item was to fund a new battery development facility which would enable British and non-British suppliers of batteries and battery materials to test their products at a near-commercial scale. The chosen location for what was called the UK Battery Industry Industrialisation Centre (UKBIC), was Coventry, close

14. For example, by the House of Lords Science and Technology Select Committee
15. Department for Business Innovation and Skills, Case for the creation of UK Research and Innovation, June 2016.
16. Geoffrey Owen, Batteries for electric cars: A case study in industrial strategy, Policy Exchange, April 2018.

to Warwick University; it will come into full operation in the next few months.

Whether Mrs May's industrial strategy will be maintained under Boris Johnson's government, and if so in what form, is not yet clear. What is certain, as shown both in the Conservatives' 2019 election manifesto and in speeches from the new Prime Minister, is that the new government will have a strong commitment to science. This will involve, among other things, a major increase in science finding, and a new visa regime to encourage non-British scientists to come to the UK. In addition, the government intends to create a new funding agency for high-risk, high pay-off research loosely based on the example of DARPA in the US.

Lessons from the US Science and Innovation System

The US science and innovation system, as it took shape after the Second World War, acquired a number of distinctive features which other industrial countries have admired and envied, but have found difficult to replicate.

The starting-point in 1945 was the recognition that, just as science had played a crucial role in the war (for example, in the Manhattan project that led to the atomic bomb), so in peacetime scientific prowess would strengthen the economy and help to meet society's needs.[17] Among the agencies that were created or enlarged after the war were the National Science Foundation (NSF), which supported mostly basic research in universities and research institutes, and the National Institutes of Health (NIH), responsible for biomedical research. But the biggest spender in the early post-war years was the Department of Defence. As relations with the Soviet Union deteriorated and the Cold War intensified, the Department formed a close relationship with companies whose technology could be used in sophisticated weaponry and other military equipment. Much of this research was used by the companies concerned as the basis for the development of civil products; for example, military requirements in missile guidance and early-warning radar systems stimulated the growth of the computer industry.

The resources devoted to research have been far larger in the US than in other industrial countries. In 1969, when the combined R & D expenditures of the four largest foreign industrial economies (West Germany, France, the UK and Japan) were \$11.3bn, those for the US were \$25.6bn.[18] It was not until the late 1970s that the combined total for these four countries exceeded that of the US.

A second asset, closely linked to the first, is an array of universities committed to scientific research. Whereas American universities had been laggards in this area in the inter-war years, especially compared to Germany, the post-war period saw a great leap forward, especially but not only in disciplines related to defence and public health. Some of these institutions, notably the Massachusetts Institute of Technology, had close links with industry before the war, but others began to catch up in the 1950s and 1960. Technology transfer from academia into industry, in

17. The opportunities in civil research were set out by Vannevar Bush in an influential 1945 report, "Science, the endless frontier". Bush had headed the government's Office of Scientific Research and Development during the war.

18. David C. Mowery and Nathan Rosenberg, Technology and the pursuit of economic growth, Cambridge 1989 p125

the form of licensing academic discoveries and the creation of spin-out firms, was given a useful stimulus by the Bayh-Dole Act of 1980, which allowed universities to patent inventions resulting from government-funded research.

The porous boundaries between academia and industry in the US have constituted a major source of strength for science-based industries. As Nathan Rosenberg has written, "American success in high-technology sectors of the economy…..owes an enormous debt to the entrepreneurial activities of American universities".[19]

A third distinctive feature of the US innovation system is the role played by new firms in developing and commercialising new technologies. There has been a consistent determination, by the big spending departments such as the Department of Defence and by the antitrust agencies, to curb tendencies towards monopoly, and to widen the opportunities for new entrants. One example was the pressure put on IBM, at the end of the 1960s, to end the practice of tying the supply of software to the sale of its computers. The unbundling of IBM software gave a fillip to the growth of independent software vendors.

A more recent case is the commercialisation of the Internet, where, as Shane Greenstein has shown, competition policy had the effect of fostering more entrepreneurial entry and reducing the role for a dominant decision-maker in commercial markets. Government interventions, including the break-up of A T & T, "encouraged dispersed decision making, reduced the potential that a single prevailing view determined outcomes, and raised the potential for a variety of perspectives to shape the Internet".[20]

Fourthly, the US built a financial system which, to a much greater extent than in other industrial countries, facilitated the growth of start-up and early stage firms. The first non-family venture capital firm, American Research and Development, was founded in Boston in 1946. Its biggest success was the investment in Digital Equipment Corporation, funded by ex-MIT scientists, which became the leading manufacturer of mini-computers. Over the following decades the US venture capital industry supported scores of new entrants in semiconductors, computers and other branches of the electronics industry. Another example was the emergence of the US biotechnology sector in the 1970s and 1980s, when venture capitalists joined with academic scientists to exploit novel drug development techniques, based on advances in molecular biology.[21]

The venture capital firms themselves were financed largely by institutional investors. The inflow of funds from that source increased after 1979 when the rules governing pension funds were changed to allow them to invest in more risky businesses. An important complement to venture capital was the creation of a stock market, NASDAQ, whose rules and procedures were better suited to young, high-growth companies than the old-established New York and American stock exchanges. This exchange fostered a community of investors, private and institutional, who developed a deep understanding of high-technology industries and were willing to back early-stage firms.

19. Nathan Rosenberg, America's entrepreneurial universities, in David M. Hart (ed), The emergence of entrepreneurial policy,

20. Shane Greenstein, How the Internet became commercial, Princeton 2016.

21. Iain M. Cockburn and Scott Stern, Finding the endless frontier: lessons from the life sciences innovation system for technology policy, Capitalism and Society, 5/1, 2010

Finally, scientific research in the US has benefited from a diversity of funding sources. Funding decisions have been in the hands of a range of government agencies pursuing their particular missions, with little coordination between them; although there have been some interventions from the Federal government to strengthen particular sectors of industry, there has been no comprehensive technology strategy. Moreover, just as there is competition between universities and between firms, so there is competition among government agencies and government laboratories. "Competition exposes ineffectual bureaucracies, out-of-touch government laboratories, poor policy choices and project-level mistakes. It encourages diversity by opening alternatives for exploration by technology users and technology creators alike".[22]

The role of DARPA

One of these funding agencies which has attracted particular interest outside the US is the Advanced Research Projects Agency (ARPA), later renamed the Defence Advanced Research Projects Agency (DARPA), which was established within the Department of Defence at the end of the 1950s. It was a response to the launch of the Soviet satellite Sputnik, which had come as a great shock to the Eisenhower Administration, raising fears that the US might be losing ground to the Soviet Union in military-related technologies. DARPA's role was to anticipate and prevent technological surprises of this sort, and to ensure that the US stayed ahead in novel technologies that were far beyond existing scientific knowledge but might have military value.

DARPA was set up as a small, non-bureaucratic agency, separate from other parts of the Department of Defence. Programme managers, recruited on 3-5 year contracts from industry or academia, were given considerable freedom to fund, plan and execute their projects, relying on outside contractors in universities and in industry to carry out the research. Erica Fuchs, a US academic, has described DARPA's approach as "a new form of technology policy, in which embedded government agents re-architect social networks among researchers so as to identify and influence new technology directions in the US to achieve an organisational goal". These agents "do not give way to the invisible hand of markets, nor do they step in with top-down bureaucracy to pick technology winners. Instead, they are in constant contact with the research community, understanding emerging themes, matching these emerging themes to military needs".[23]

DARPA's fame, within the US and overseas, is partly based on its achievements in its early years, when visionary scientists were given the freedom and the funds to pursue ambitious projects. The most spectacular success was in computer networking, where DARPA-funded research paved the way for what eventually became, after contributions from many other actors, both public and private, the modern Internet.

When DARPA started work in this field, as Shane Greenstein has written, the creation of a general purpose technology for exchanging packets of data between many firms was risky. "It had no immediate obvious

22. John A. Alic, David C. Mowery and Edward S. Rubin, US technology and innovation policies: lessons for climate change, Pew Center on global climate change, November 2003.
23. Erica Fuchs, Rethinking the role of the state in technology development: DARPA and the case for embedded network governance, Research Policy, 39 (2010) 1133-1147.

commercial payoff. DARPA's program officers intended to fund radical technological progress that otherwise would not have been funded by private firms. They intended to develop research communities in those areas where almost none had existed".[24]

Since those early days there have been failures as well as successes, and there have been periods when DARPA has been criticised for putting too much stress on safer projects which would yield a short-term pay-off. But the DARPA model, described in detail by William Bonvillian later in this paper, is more or less intact some sixty years after the agency was created, and it remains an important ingredient in the US innovation system.

DARPA's appeal was strong enough for the Obama Administration to create a DARPA clone within the Department of Energy, to tackle what was seen as the pressing need to develop new energy technologies that were too risky or too speculative to interest the established funders or the private sector. The establishment of ARPA-E, following a report from the National Academies, was controversial, and remains so. Some critics argued that, whereas the original DARPA had a clear customer in the Department of Defence, the energy market was more fragmented and diffuse; commercialisation of new technologies was likely to prove more difficult. Others, notably officials in the Trump Administration, wanted to disband ARPA-E on the grounds that it was doing things that should be done by the private sector. However, although no major breakthroughs in energy research have been achieved, the progress of ARPA-E has been good enough so far to retain Congressional support.

A recent study of the ARPA model, based in part on the experience of ARPA-E, highlights a number of challenges that have to be met if the model is to be applied effectively.[25] One issue, with projects that may take many years to bear fruit, is the need for patience on the part of the agency's backers. "The mission of an ARPA-like agency often involves transformation of some industry or market to address a societal need. This transformation invariably occurs over the long term, and yet the ARPA model requires that individual projects be held to strict timelines; projects often only run for three years. In the case of ARPA-E, for example, a project that aims to create a new design for an energy device may be a tremendous success, and still the impact in the market and/or the environment will not be seen for decades. This limitation must be kept in mind during short-term efforts by Congress or the agency itself to measure the agency's progress toward its mission."

Another challenge is how to get the balance right between freedom and accountability. "As more freedom is given to both the Director and the program staff, the quality of the agency's activities is increasingly dependent on the talent of these individuals. Any research agency requires a Director with strong leadership ability and staff members with high technical acumen, and yet the organisational flexibility and program staff empowerment in the ARPA model raises the stakes on this requirement. The core elements of the ARPA model cannot exist under micromanagement by the Director or with under-qualified staff".

24. Shane Greenstein, Nurturing the accumulation of innovations: lessons from the Internet, NBER Working Paper 15905, April 2010

25. Pierre Azoulay, Erica Fuchs, Anna Goldstein and Michael Kearney, Funding breakthrough research: promises and challenges of the "ARPA model", NBER Working Paper 24674, June 2018

The authors' conclusion is that the ARPA model cannot solve all problems, but that it represents one set of practices geared toward mission-oriented research on nascent technologies. "It fits within a broader innovation landscape that includes support for early-stage blue sky research and later-stage incremental development. Importantly, ARPA-like organisations are not a substitute for other sources of R & D support but instead serve as a complementary piece of a diverse innovation system".

The Government's Proposals

What has been said?

It has become widely accepted within the research policy community that that the Government intends to establish a new agency modelled after the US ARPA. Yet despite the proposal appearing in the Conservative manifesto, details of what exactly this would entail have to date been relatively high-level. In considering the Government's intentions, it is worth therefore carefully examining the wording of the statements that have been made to date.

ARPA made its first formal appearance in the October 2019 Queen's Speech, which stated that[26]:

> *"My Government is committed to establishing the United Kingdom as a world-leader in scientific capability and space technology. Increased investment in science will be complemented by the development of a new funding agency, a more open visa system, and an ambitious national space strategy."*

The background briefing document went on to elaborate that this would involve[27]:

> *"Backing a new approach to funding emerging fields of research and technology, broadly modelled on the US Advanced Research Projects Agency. We will work with industry and academics to finalise this proposal."*

And that:

> *"A new approach to funding emerging fields of research and technology will provide long term funding to support visionary scientific, engineering, and technology missions, and will complement the UK's existing world class research system."*

ARPA was also featured during the General Election campaign. In the accompanying press release to a speech given by Boris Johnson in Coventry on 13 November 2019, the Conservatives committed that they would:

> *"Set up a British Advanced Research Projects Agency- investing £800 million over five years for a new research institution in the style of the US ARPA- to support blue skies, high-reward, research and investment in UK leadership in artificial intelligence and data."*

The Conservative manifesto subsequently provided slightly less detail, stating[28]:

26. https://www.gov.uk/government/speeches/queens-speech-2019
27. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/839370/Queen_s_Speech_Lobby_Pack_2019_.pdf
28. Conservative Manifesto (November 2019)

> *"We are committing to the fastest ever increase in domestic public R&D spending, including in basic science research to meet our target of 2.4 per cent of GDP being spent on R&D across the economy. Some of this new spending will go to a new agency for high-risk, high-payoff research, at arm's length from government."*

The December 2019 Queen's Speech, however, contained less detail, with the background document largely echoing the document from October 2019, albeit with a small tweak to emphasise the high-risk, high-pay off nature of the intended research:

> *"[We are] Backing a new approach to funding high-risk, high-payoff research in emerging fields of research and technology. The Government will work with industry and academics to finalise this proposal."*

And:

> *"Some of this new R&D spending will go towards a new approach to funding emerging fields of research and technology. It will provide long term funding to support visionary high-risk, high-pay off scientific, engineering, and technology ideas, and will complement the UK's existing world class research system."*

What has been said less formally?

In documents obtained by *New Scientist* under the Freedom of Information Act, officials have suggested that[29]:

> *"Our proposal is that a new body, offering academics longer term funding (spanning at least 10 years) to tackle significant societal challenges – problems or opportunities – could help do this and strengthen the UK's global reputation."*

It should be noted that the documents constituted working thoughts produced by the civil service and do not necessarily represent an agreed ministerial or government position – but they nevertheless provide some insight into the thinking that may be occurring, in particular the emphasis on tackling societal challenges.

The drive to establish a British ARPA is often suggested to have originated from Dominic Cummings, the Prime Minister's senior adviser, who wrote extensively in support of the idea before joining Government. Indeed, in a blogpost published during the General Election campaign on 27 November 2019, Cummings, emphasised his commitment to ARPA, while indicating that it might focus on challenges such as climate change and AI[30]:

> *"And for those of you who read this blog and are most concerned about climate change and AI, a new high-risk high-payoff research agency, modelled on ARPA and funded by an unprecedented DOUBLING of the basic science budget[31], is in the Conservative manifesto!"*

Cummings' previous thoughts on ARPA may be found in two pieces, *The unrecognised simplicities of effective action #3: lessons on 'capturing the heavens' from the ARPA/PARC project that created the internet & PC*[32] and *On the ARPA/PARC 'Dream Machine', science funding, high performance, and UK national strategy*[33]. The essays are

29. https://www.newscientist.com/article/2227122-revealed-details-of-dominic-cummings-plan-for-new-uk-research-agency/#ixzz6BCgYbonV
30. https://dominiccummings.com/2019/11/27/on-the-referendum-34-batsignal-dont-let-corbyn-sturgeon-cheat-a-second-referendum-with-millions-of-foreign-votes/
31. Emphasis in the original.
32. https://dominiccummings.com/2017/06/27/the-unrecognised-simplicities-of-effective-action-3-lessons-on-capturing-the-heavens-from-the-arpaparc-project-that-created-the-internet-pc/
33. https://dominiccummings.files.wordpress.com/2018/09/20180904-arpa-parc-paper1.pdf

extensive, but two quotations that give an insight into the thinking about how a UK ARPA might operate are:

> *"Its job (ARPA's?) was to fund high risk / high payoff technology development. In the 1960s and 1970s, a combination of unusual people and unusually wise funding from ARPA created a community that in turn invented the internet, or 'the intergalactic network' as Licklider originally called it, and the personal computer. One of the elements of this community was PARC, a research centre working for Xerox. As Bill Gates said, he and Steve Jobs essentially broke into PARC, stole their ideas, and created Microsoft and Apple. The ARPA/PARC project is an example of how if something is set up properly then a tiny number of people can do extraordinary things."*

And, quoting from Alan Kay, a central figure at PARC in this era:

> *"[I]t is no exaggeration to say that ARPA/PARC had "visions rather than goals" and "funded people, not projects". The vision was "interactive computing as a complementary intellectual partner for people pervasively networked world-wide". By not trying to derive specific goals from this at the funding side, ARPA/PARC was able to fund rather different and sometimes opposing points of view."*

As discussed above, ARPA/DARPA has been through a number of phases in its history; however, Overall, it suggests there may be a particular focus on the early stage of ARPA, where Licklider and others operated in a highly flexible manner to make transformative breakthroughs. It should, however, be emphasised that this may not be representative of the views of all others in government, nor are the essays, in any case, a direct 'manual' for how to create a UK ARPA, but rather an examination and presentation of how the lessons of ARPA/PARC can be applied in a number of fields, including broader public policy making.

What decisions must be made?

The Government's commitment to a UK ARPA is unambiguous and the high-level budget - £800m over the course of the Parliament – has been determined. The limited public statements made so far, however, demonstrate that much remains to be determined about the nature, role and means of operation of the proposed agency. In particular, important questions include:

- What should be the structure and governance of ARPA and how should it be accountable to Ministers and Parliament?
- What should the relationship be between ARPA and the rest of the UK's research base, including UKRI, universities, research institutes and the private sector?
- Where should ARPA focus its efforts on the spectrum between pure science and near-to-market innovation?
- Should ARPA have one or more overarching 'challenges' or 'missions'?

- Will ARPA conduct any research itself, or act purely as a funder?
- How will ARPA choose what to fund?
- How to ensure ARPA is able to fund high-risk research and be able to tolerate failure?
- How to create the necessary commercial pull through, in the absence of the single dedicated customer that DARPA enjoys in the US Department of Defense?

The following essays explore these questions and, collectively, provide a wealth of information from leading experts for the Government to consider as it takes forward this important project.

A Summary of the Darpa Model

William B. Bonvillian

DARPA has a breakthrough research model once described as "one hundred geniuses connected by a travel agent." But how does it actually work?

The Advanced Research Projects Agency arose from America's Sputnik crisis in 1958. President Eisenhower saw that the separate, stove-piped space programs run by the military services had led to the Sputnik technology failure and wanted a more unified defence research and development effort. ARPA became a unique entity, directed first to avoid then to also create 'technology surprise,' and became famous for playing a critical role in the information technology (IT) revolution. With "Defense" later added to its name, ARPA became DARPA and played a critical role in such technology advances as the internet, microprocessor advances, personal computing, supercomputing, wireless transmission advances, GPS, microelectromechanical systems, robotics, the 'revolution in military affairs' (precision strike, stealth, and drones), synthetic biology, computer simulations and gaming for training, and the driverless car challenge.

What is the DARPA model?

The DARPA model for organizing innovation is distinct from other U.S. research and development agencies in its rejection of 'pipeline' and technology 'hand-off' approaches used by most agencies. As an innovation organization, DARPA takes responsibility not simply for research but to bring about technological breakthroughs and nurture them toward final products.

In the post-World War II period, Presidential Science Advisor Vannevar Bush formed the dominant 'pipeline model' for the organization of U.S. R&D agencies.[34] It was a 'technology push' or 'technology supply' model, with government support for initial research but with only a very limited role for government in moving resulting advances (particularly radical or breakthrough innovation) through the innovation pipeline toward the marketplace. Development and the later stages of innovation were left to private industry. American critics subsequently attacked the Bush pipeline model as inherently disconnected, separating the government supported research actors from the industry development actors with few means for technology handoffs between them.[35]

American innovation policy theorists in recent decades have analysed

34. Bush, V. (1945). Science: The Endless Frontier. Government Printing Office: Washington, D.C., http://www.nsf.gov/od/lpa/nsf50/vbush1945.htm

35. Stokes, D. (1997), Pasteur's Quadrant, Basic Science and Technological Innovation. Brookings Institution Press: Washington, D.C.

the gap known as the "Valley of Death" between the 'front end' of the innovation system—the research side, typically supported by government R&D funding for university research—and the 'back end,' the late-stage development through implementation phases, typically a private sector domain. To solve this structural problem, numerous bridging mechanisms have evolved, often with government support. This requires technology diffusion approaches, and a wide range of institutional intermediaries.[36] DARPA has been the most successful American intermediary.

DARPA is not simply a basic research agency, it is a public sector intermediary as well. It works to nurture new technologies from breakthrough stages through applied research and initial development, then to pass off the technologies to entities that will move them into implementation. Such entities intermediate between finding the breakthrough and moving it into technology implementation. As intermediaries, they also operate as change agents. But DARPA must play its intermediary role in a defence sector that is often profoundly conservative about technology advances. The challenge of innovation for intermediaries is already difficult; the difficulty is multiplied when the technology must be stood up in a complex, established legacy sector.[37]

DARPA, in effect, rejected the prevailing, research-only pipeline model in favor of *connected science and technology*, linking science research to industry and implementation stages. It has also pursued a *challenge* model, fostering research to meet specific mission technology challenges. DARPA built a deeply collaborative, flat, close-knit, talented, participatory, flexible system, oriented to breakthrough and radical innovation. Its challenge model for R&D, moved from fundamental research, back and forth with applied, creating connected science and technology that linked research, development, and prototyping, with access to initial production. In other words, it followed an innovation path not simply a discovery or invention path.

The Basic DARPA Ruleset

At the heart of the DARPA ruleset is what one analyst has termed a *technology visioning* process.[38] It uses a *right-left research model* – its program managers contemplate the technology breakthroughs they seek to have emerge from the right end of the innovation pipeline, then go back to the left side of the pipeline to look for proposals for the breakthrough research that will get them there. As noted, it uses a *challenge-based* research model – seeking research advances that will meet significant technology challenges. It looks for *revolutionary breakthroughs* that could be transformative of a technology sector. All of these elements go into a process where agency program managers develop a vision of a technology advance that could be transformative, then work back to understand the sequence of R&D advances required to get there. If these appear in range of accomplishment, DARPA's administrative processes allow very rapid project approval by the agency's director and a prompt start.

This technology visioning process is very different from how other

36. Shapria, P and J. Youtie (2016) Presentation on the Next Production Revolution: Institutions for Technology Diffusion, Conference on Smart Industry, OECD and Sweden Ministry of Enterprise and Innovation, Stockholm, September 18, 20.

37. Bonvillian, W. and C. Weiss (2015), Technological Innovation in Legacy Sectors. Oxford Univ. Press: New York, NY.

38. Carleton, T. (2010), The Value of Vision in Technological Innovation, dissertation. Stanford University: Palo Alto, CA, http://purl.stanford.edu/mk388mb2729

federally-funded R&D organizations work; these place the emphasis on research for the sake of research not on carrying out a technology vision. While research selection at traditional agencies is controlled by an often inherently conservative peer review process, DARPA empowers program managers to take risks and select research awardees. The technology visioning process is also very different from the way industry undertakes step-by-step down-selection of technology options known as the 'stage gate' process. There, budgets and potential market gain are factors applied in a series of milestones to weed out which incremental advances to pursue.

Other DARPA characteristics enhance its ability to operate at both the institutional and personal innovation organization levels. The following list is largely drawn from DARPA's own descriptions of its organizing elements[39]:

- *Small and flexible* - DARPA consists of only 100 program managers and office directors and has been non-bureaucratic, cohesive and face-to-face.
- *Flat* - a flat, non-hierarchical organization, with empowered program managers who have significant independence and authority in developing a research program, selecting R&D awardees and supervising their ongoing performance. Program managers are the critical organizational level at DARPA.
- *Entrepreneurial* - emphasis on selecting highly talented, entrepreneurial program managers, often with both academic and industry R&D experience, who want to press their best ideas toward implementation. They serve for limited (3 to 5 year) terms, which creates a continuing flow of new talent and ideas into the agency and sets the timeframe for DARPA projects.
- *No laboratories* - research is performed entirely by outside performers, with no internal research laboratory. DARPA's program managers commission and oversee research they don't perform it.
- *Focus on impact not risk* - projects are selected and evaluated on what impact they could make on achieving a demanding capability or challenge, which must be 'DARPA hard.' High risk is accepted in return for the potential of high reward.
- *Seed and Scale* – provides initial short-term funding for seed efforts that can scale to significant funding for promising concepts, but with clear willingness to terminate non-performing projects at all stages.
- *Autonomy and freedom from bureaucratic impediments* - DARPA operates outside of the civil-service hiring process and standard government contracting rules, which gives it unusual access to talent, plus speed and flexibility in contracting for R&D efforts.
- *Hybrid model* – DARPA often puts small, innovative firms and university researchers together on the same projects so firms have access to breakthrough science and researchers see pathways to

39. DARPA (2005), 'DARPA - Bridging the Gap, Powered by Ideas,' DARPA: Arlington, Va. ;

DARPA (2003), 'DARPA Over the Years,' DARPA: Arlington, Va., implementation.

- *Teams and networks* - at its best, DARPA creates and sustains highly talented teams of researchers, that are highly collaborative and networked to be 'great groups,' around the challenge model.
- *Acceptance of failure* - DARPA pursues a high-risk model for breakthrough opportunities, and is quite tolerant of failure where the payoff from potential success is high.
- *Orientation to revolutionary breakthroughs in a connected approach*: DARPA is focused not on incremental but breakthrough/radical innovation. Its high-risk investments move from fundamental technological advances to prototyping, and then work to hand off the production stage to the armed services or the commercial sector.

The above rules have never been formally written down by DARPA; they are part of an established DARPA culture transmitted by oral tradition between generations of office and program managers. The rules have made DARPA a critical innovation-oriented, as opposed to a research-oriented, institution.

Other DARPA Practices

Catalyse the Formation of Great Groups: If R&D is not being conducted at an adequate scale by talented researcher teams, innovations will not emerge. But talent alone is not enough – talent must also operate within institutional mechanisms capable of moving technology advances from idea to innovation. Innovation institutions occupy the space where research and talent combine, where the meeting between science and technology is best organized. Arguably, there are science and technology institutions that can introduce not simply inventions and applications, but significant elements of entire innovation systems.[40] This is where DARPA takes center stage, with its history of attracting outstanding research talent and of spurring remarkable technology advances.[41]

However, innovation requires not only a process of creating connected science and challenges at the *institutional level*, it also must operate at the *personal level*. People are the innovators, not simply the overall institutions where talent and R&D come together. Warren Bennis and Patricia Beiderman have argued that innovation, because it requires more linkages than the earlier stages of discovery and invention, requires *great groups* not simply individuals.[42] Unlike other federal R&D agencies, DARPA has attempted to operate at *both* the institutional and personal levels. DARPA became a bridge organization connecting these two institutional and personal organizational elements.[43]

Apply the Island/Bridge Model: Bennis and Biederman have also argued that innovation requires placing the innovation entity on an 'island,' protecting it from 'the suits,' the bureaucratic pressures in larger firms or agencies that too frequently repress and unglue the innovation process.[44] But they note that there must also be a 'bridge' - the innovation group must also be strongly connected to supportive top decision-makers who can press the

40. Bonvillian, W. (2009), 'The Connected Science Model for Innovation: The DARPA Role,' in National Research Council, *21st Century Innovation Systems for Japan and the U.S.* National Academies Press: Wash., DC.
41. Van Atta, R. (2008), 'Fifty Years of Innovation and Discovery,' in *DARPA, 50 Years of Bridging the Gap* (DARPA: Arlington, VA).
42. Bennis, W. and P. Beiderman (1997), *Organizing Genius.* Basic Books: New York, NY.
43. Bonvillian, W. and R. Van Atta (2011), 'ARPA-E and DARPA, Applying the DARPA Model to Energy Innovation,' *Journal of Technology Transfer*, 36(5), Oct., 469
44. Ibid

innovation forward, providing the needed resources. Some argue this is a foundational innovation element.[45]

Island/Bridge from the beginning has been a key to DARPA's success, and other innovative organizations use it as well. Lockheed's Skunkworks,[46] Xerox's PARC (Palo Alto Research Center)[47] and IBM's PC project[48] have exemplified Island/Bridge at the industry level, isolating innovation teams from interference from the business/bureaucratic side. While the Skunkworks and IBM PC groups also had strong bridges back to 'mainland' decision makers, PARC famously did not and exemplifies the need for the bridge. PARC created a remarkable early personal computer with a graphical user interface, the mouse, text editing, and bitmap graphics. However, Xerox's senior management, focused on copiers, never understood PARC's creation and failed to commercialize it. The bridge failed, and it took Steve Jobs' Mac to bring these features to the public. DARPA exemplifies a workable Island/Bridge model at the federal R&D agency level.[49] It has initiated innovation in frontier sectors, particularly IT, as noted, where it operated largely outside the Pentagon's legacy systems, working with and helping to build emerging technology private sector firms. It has also worked within the defence legacy system. It has operated as an island there but also used strong links with the Secretary of Defense and other senior defence leaders as the bridge; these Defense decision makers helped bridge technology advances from DARPA researchers to the implementing military services.

Build a Thinking Community. A prerequisite for ongoing success of the Island/Bridge is building a community of thought. In science, it is well understood that each contributor stands on the shoulders of others, building new concepts on the foundations of prior concepts. This applies to technology development as well. Building a sizable 'thinking community' has been key to DARPA's success, as a source of contributing ideas but also for talent and political support.[50]

Composed of multiple generations of DARPA program managers, as well as researchers DARPA has supported working in particular fields, at its best this community becomes a group of change agents and technology advocates. For example, J.C.R. Licklider, a tech visionary of the first magnitude, in his two stints at DARPA brought in a succession of office directors and program managers and built supporting university research teams that initiated a series of multi-generational technology breakthroughs that over time led to personal computing and the internet.[51] Building a thinking community around a problem takes time to evolve, but reaches a density and mass where ideas start to accelerate.

Link Technologists to Operators: Another key organizational feature of successful innovation organizations involves connecting the technologists to the operators. DARPA's work on major defence technology advances, like drones, exemplifies an effort to link technologists with operators, to transform operations. Its work on personal computing and the internet, which shattered the arm's length relationships in mainframe computing between technologists and operators/users, also exhibits the same drive

45. Sen, A. (2014), *Transformative Innovation*, dissertation. George Washington University: Washington, DC.
46. Rich, B. (1996), *Skunkworks*. Little Brown/Back Bay Books: Boston, MA.
47. Hiltzik, M. (1999), *Dealers of Lightening: Xerox PARC and the Dawn of the Computer Age.*

Harper Collins New York, NY.

48. Chposky, J. and T. Leonsis (1986), *Blue Magic: The People, Power and Politics Behind the IBM Personal Computer.* Facts on File: New York.
49. Bonvillian, W. and R. Van Atta (2011), 'ARPA-E and DARPA, Applying the DARPA

Model to Energy Innovation,' *Journal of Technology Transfer*, 36(5), Oct., 469

50. Bonvillian, W. and R. Van Atta (2011), 'ARPA-E and DARPA, Applying the DARPA

Model to Energy Innovation,' *Journal of Technology Transfer*, 36(5), Oct., 469

51. Waldrop, M. (2001), *The Dream Machine, J.C.R. Licklider and the Revolution that Made Computing Personal.* Viking: New York, NY

to produce technologies that connect with operators. DARPA's Tactical Technologies Office (TTO) is specifically designed to bring technologies into military tactical systems, using rapid prototyping to transition to air, ground and naval operators. Maintaining ties between innovators and operators/users during the innovation process is a key means of assuring relevant and workable innovation.

Transitioning Technology: DARPA has a major advantage over other innovation-oriented agencies in the U.S.: it can take advantage of defence procurement and acquisition programs. In other words, if DARPA develops a new technology, the military services may well be willing to buy it, creating the crucial initial market to transition the technology into implementation. However, when DARPA drove the creation of large elements of the IT revolution,[52] these landed largely in a civilian market not in a defence market. These DARPA IT advances in turn spurred creation of much of the U.S. venture capital system. While venture has worked well for sectors such as software, IT and biotech, it is not working for "hard tech" advances that require major manufacturing or for technologies than must launch into legacy economic sectors that resist them, like energy.[53] These sectors generally require longer-term investments and higher risks than venture capital can manage.

Unlike the Defense Department, the U.S. Energy Department does not have a significant procurement budget. When a DARPA-clone, the Advanced Research Projects Agency-Energy (ARPA-E), was formed in 2009 as an independent agency within that department reporting to the Secretary, it therefore had to focus on the technology transition problem.[54] ARPA-E created not only a strong group of program managers but a 'tech-to-market' group with experience in scaling up start-up firms. Every ARPA-E award-winner has to have not only a technology development approach but a technology scale-up plan, which the tech transition team helps them to fashion and implement. Since venture capital funding has been difficult to obtain for energy projects, creative approaches to scale-up have been developed, including alliances with established companies and follow-on R&D funding from applied agencies. As an innovation organization without access to a procurement budget and with a mission where there is only limited venture capital interest, this tech transition effort has been key to ARPA-E. The tech-to-market team approach has been so successful at ARPA-E that DARPA, facing its own transition challenges, has copied it and created its own such group.

Can DARPA be Copied?

As explored above, DARPA is a multi-faceted innovation organization organized around a strong innovation culture and traditions. Could it be copied? There have been two successful attempts to clone DARPA in the U.S., ARPA-E and IARPA.[55] These agencies are little more than a decade old, which is a limited time period for significant technology transitions, and they have their critics. But ARPA-E has carefully evaluated its positive technology contributions in a series of studies,[56] and a detailed

52. Fong, G. (2001), 'DARPA Does Windows, The Defense Underpinnings of the PC Revolution,' *Business and Politics*, 3(3), 213-237.
53. Bonvillian, W. and P. Singer (2018), *Advanced Manufacturing – The New American Innovation Policies*. MIT Press: Cambridge, MA.
54. Bonvillian, W. and R. Van Atta (2011), 'ARPA-E and DARPA, Applying the DARPA Model to Energy Innovation,' *Journal of Technology Transfer*, 36(5), Oct., 469
55. Bonvillian, W. (2018), 'DARPA and its ARPA-E and IARPA clones: a unique innovation organization model,' *Industrial and Corporate Change*, 27(5), October.
56. ARPA-E (2016), *ARPA-E: The First Seven Years, A Sampling of Project Outcomes*, August 23, v.1; ARPA-E (2017), *ARPA-E Impacts: A Sample of Project Outcomes*, Feb. 27, v.2; ARPA-E (2018), *ARPA-E Impacts: A Sample of Project Impacts*, May 7, v. 3.

National Academies technical evaluation has found that it has made significant progress toward its mandate of fostering breakthrough energy technologies.[57] IARPA, which focuses not on commercialization but on working with its intelligence agency customers, has had over 70% of its projects that are past their development midpoint achieve at least one transition to an intelligence agency.[58]

Each agency is different from DARPA in significant ways, oriented to innovation needs in their energy and intelligence sectors. Each, however, had early leadership from technologists fluent with the DARPA ruleset, who systematically adopted it then added additional rules that fit with nature of their sectors. As noted above, ARPA-E had to develop a technology transition capability because it lacked the access DARPA enjoyed to a large military procurement budget and to technologies venture capital firms were willing to back. IARPA had to find additional ways to connect with intelligence users and operators to implement the technologies it was nurturing. Like DARPA, both agencies were able to hire outstanding program managers, which is the critical creative level for a DARPA-like entity. But these agencies also benefited from having able leaders from the outset who understood that the initial culture and ruleset within any agency tends to lock-in quickly and control its future. They saw that getting that initial culture right so that their new organizations could release creative energies in the way DARPA has long been able to, was their central task.

DARPA has been an important model for a different kind of research agency. It is not based on curiosity-driven science research, it seeks technology outcomes. It is not organized around peer-reviewed, committee evaluations, it is driven by strong program managers who are given substantial freedom to push for new technologies. It is not organized around incremental advances but around achieving breakthrough outcomes. It uses a "hybrid" approach, engaging with both academic researchers and industry, always keeping technology implementation in mind. It has been freed from bureaucratic impediments in contracting and hiring, so it can move quickly once it identifies a project to pursue. It has the advantage of working in a military procurement context that can follow-up on its technology advances, but it has also been successful in bringing advances to market in the private sector, notably its IT breakthroughs. Its unique ruleset has been successfully applied by two other agencies in very different technology contexts. It should be explored as a different kind of innovation model.

57. National Academies of Sciences, Boards on Science Technology and Economic Policy and on Energy and Environmental Systems, (2017), *An Evaluation of ARPA-E*. National Academies Press; Wash., D.C., 125-132.

58. Bonvillian (2018), DARPA and its ARPA-E and IARPA Clones, 20.

ARPA: A Critical Addition to our Innovation Landscape

Julia King, The Baroness Brown of Cambridge DBE FREng FRS

ARPA should focus on helping great scientific ideas escape from the laboratory by acting as an interpreter and matchmaker.

Why do we need an ARPA? The gap I see in our research and innovation landscape is 'science push': helping great scientific ideas escape from the laboratory into applications which enable a step change in the way current technologies or processes work, or into applications no one has yet thought of.

Our universities perform outstanding basic research. Near-to-market 'technology-pull' is also well-addressed. Innovate UK has run a range of successful programmes (although several of these are now in dire need of additional funding) which support companies to find solutions to technical problems or develop new technologies for specific markets. The network of Catapults works with industry – from spinouts and start-ups through SMEs to large companies such as GSK and Siemens at the top of the supply chain – to accelerate innovation. The Engineering and Physical Sciences Research Council has co-funded programmes with industry where academics address real-world problems with companies like Rolls-Royce and BP. These are well established 'technology pull' approaches with some very positive results.

But there is a lot of outstanding research in our universities that industry isn't yet picking up for a range of reasons, including:

- the demise of in-house company research centres over the last 25 years means that industry has less engagement with science and tends to focus on higher technology readiness levels. Researchers in industry are now less likely than before to be reading papers in Nature and Physical Review Letters;
- many outstanding academics are not motivated by, or indeed rewarded for, driving the application of their ideas, and don't have access to a wide view of where they might make a difference;
- people who have the ability and the broad experience to think imaginatively about where research might make a difference – seeing how ideas might transform applications and solutions - are rare and don't fit well into the structures and reward systems of our academic and industrial environments;

- the 'valley of death' is still with us. It is very hard to find funding for accelerating development of new ideas where there is a high risk that they may not be successful, especially where there are significant capital costs associated with early scale up and demonstration – so it tends to be easier in the area of 'tech' than it is for physical processes;
- in some areas like materials, we lack the UK supply chain to pull through the ideas from an early stage;
- some of the ideas just don't have a market yet – hydrogen as part of the Net Zero economy being one of these.

The first three of these bullets are about communication and how we value and reward particular activities and capabilities in different environments. The second group are inhibitors in terms of risk (and of course funding), customers and our industrial landscape. There are plenty of reasons why great science can get 'stuck in the lab'.

I chair the Henry Royce Institute, the UK's national institute for advanced materials, an Institute open to academia and industry, with a hub at the University of Manchester and key centres at universities and national laboratories across the UK. The UK has world-class academic capability in materials, but many of the points above apply: developing new materials for demanding applications involves expensive and capital-intensive scale-up and demonstration. Whilst we have companies wanting advanced materials to address their technical challenges, such as Rolls-Royce and BP, and an important end-customer in developing fusion reactors, we don't have a strong indigenous materials supply chain, so much of the excellent work being done will not be exploited directly in the UK. One of our big challenges in Royce is how we support this 'science push' to drive economic growth in this environment.

An ARPA scheme that addresses my six bullets: improving communication by acting as interpreter and matchmaker between new ideas and needs; risk taking - the ability to test, quickly, which ideas have real potential; acting as a customer where no market yet exists; and providing diverse and relevant packages of funding to accelerate development through high risk stages; would be an impactful addition to our innovation landscape.

What an ARPA scheme does not need to do is stimulate cutting-edge science in our universities. With increased funding this is something our research councils can already do very well. In my view fellowship schemes at both early career and senior levels, to allow people with great potential and ideas, to take significant periods of time away from the academic hamster wheel of continuous grant applications and focus on exciting research, are a great way of doing this, it would be good to see them doing more. ARPA would also not be a replacement for Innovate UK, which needs to be strengthened to continue its business-focussed support. The research councils and Innovate UK would both be key partners for ARPA, with their knowledge of what is going on in our universities and the needs of UK business.

What an ARPA does need to be able to do is pick winners and take risks. To identify early stage high potential research and have the freedom and flexibility to do what it takes to accelerate it towards an application or customer need – whether this means investment in more intensive research, facilities and demonstration, the formation of a company, manufacture of prototype devices, etc. Whilst it needs to be able to start things quickly it also needs to be able to stop them just as effectively and move the focus and funding elsewhere. What we are missing is the ability to follow the high risk, potential high reward paths. Not all of these will lead to success – by definition, if they do, the risk levels weren't high enough. The ability to stop programmes as soon as it is clear they will not deliver will require changes in the way core funding in our universities and research institutes is used.

What will an ARPA need to enable it to do this?

- *Outstanding programme managers* – the interpreters and matchmakers. Well networked in industry and academic sectors, with an excellent understanding of the science and technology and strong lateral thinking skills. Risk takers but not gamblers, people who know when to stop and move on. They will need to be tough – stopping programmes won't be comfortable. They will be hard to find, and there may not be that many of them – finding the right people to decide on the investments and run the programmes could be the main constraint on how much of this we can do.
- *A system free of constraints* – the programme managers need to be given the freedom to fund and invest significant sums of government money in whatever (legal) way they judge will accelerate the project. This will need a culture change. My experience of the Higher Education and Research Bill in the Lords was that we were trying to reduce the controls on what UKRI could do with its funding – for example the Bill initially prevented UKRI from making investments without getting permission from the Treasury, which would have significantly constrained the way Innovate UK would be able to work with small companies. So, the natural tendency is for control – can our system really give programme managers the freedoms they need to take risk and fail (hopefully fast)? I hope it can.
- *A different attitude to risk with public money*. ARPA will need to be able to spend public money and fail – if everything it supports succeeds we won't have created something that adds to the landscape we already have, apart from some more bureaucracy and some (welcome) extra funding. We need a Public Accounts Committee (PAC) that recognises that innovation requires risk taking and it will sometimes fail. The right question is sometimes 'if everything you did worked, how do you know what you have missed?'
- *The concept of a 'customer'*. DARPA was a success in the US because

the DOD was the customer for new military capability and could and would use technologies that weren't yet 'commercial'. A UK ARPA will need a 'customer' with a requirement of some sort to accelerate science through to early application – a real use, but potentially before there is a commercially exploitable demand. The Programme Managers may be able to find actual customers, in the form of organisations and businesses, but other forms of customer requirement might work too – the need to deliver Net Zero in the transport sector for example. I don't see the concept working so well with a technology rather than a customer need focus, although individual programmes might be about focussing that technology on a customer need.

- *Changes in universities.* Universities, and other research institutions, will play a key role in this. But we aren't used to potentially large tranches of funding that start quickly and can suddenly stop. The implications for recruiting research staff and then potentially terminating their contracts would be a real inhibitor. Universities will need core funding that covers flexible research staff who can be moved from one project to another when funds come and go to be able to cope with this, most universities don 't resources in this way at the moment.

Finally, some thoughts about where an ARPA- type approach might be effective. In my experience at the Royce, there is plenty of great science, where this type of support could be transformational. For example graphene, photonic materials, photon multiplying materials could potentially address needs in the energy transition, availability of clean water, sensing and monitoring applications. Similarly, delivering Net Zero and the energy transition could be made much cheaper and more effective if we could accelerate some of the research on ultra-low energy electronics, new routes to hydrogen, and new technologies with the potential to revolutionise solar, out of the lab, not to mention developing crown-shaped molecules to sieve CO_2 out of the air!

The suggestion of a UK ARPA scheme is exciting, I hope we recognise and implement the dramatically different ways of working that will be needed for it to succeed.

UK ARPA: An experiment in science policy?

Professor Richard A.L. Jones

A UK ARPA could form the experimental branch of UK science policy, empowering visionary leaders of research in support of the long-term goals of the nation.

The UK's research and innovation funding agency – UKRI - currently spends £7 billion a year supporting R&D in universities, public sector research establishments and private industry.[59] The Queen's Speech in December set out an intention to increase substantially public funding for R&D, with the goal of raising the R&D intensity of the UK economy – including public and private spending - from its current level of 1.7% of GDP to a target of 2.4%. It's in this context that we should judge the Government's intention to introduce a new approach, providing "*long term funding to support visionary high-risk, high-pay off scientific, engineering, and technology ideas*". What might this new approach – inevitably described as a British version of the legendary US funding agency DARPA – look like?

If we want to support visionary research, whose applications may be 10-20 years away, we should be prepared to be innovative – even experimental - in the way we *fund* research. And just as we need to be prepared for research not to work out as planned, we should be prepared to take some risks in the way we support it, especially if the result is less bureaucracy. There are some lessons to take from the long (and, it needs to be stressed, not always successful) history of ARPA/DARPA. To start with its operating philosophy, an agency inspired by ARPA should be built around the vision of the programme managers. But the operating philosophy needs to be underpinned by as enduring mission and clarity about who the primary beneficiaries of the research should be. And finally, there needs to be a deep understanding of how the agency fits into a wider innovation landscape.

Most funding for science – in the UK and elsewhere – is based on one of two philosophies. The most common is based on competitive funding for *projects*. A researcher or group of researchers put in a research proposal outlining a project of work for a few years (somewhere between 2 and 5, typically), and this is judged by other scientists, in competition with other proposals. The topic may be completely open, or focused on some priority area. Most research council funding takes this form.

59. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/731507/research-innovation-funding-allocation-2017-2021.pdf

The other approach focuses on funding *people* - individual scientists. A judgement is made on the quality of a scientist applying for funding based on their track record of previous discoveries, and on this basis funding is awarded – usually for a relatively long time, and with a relatively open programme, with the expectation that the scientist will explore whatever avenues turn out to be interesting and productive. This is largely the approach used by the European Research Council, which has gained a very high reputation in its 12-year history, with the quality of applicants driven up by continent-wide competition. The longer-established Royal Society Research Chairs – whose previous holders include Sir Andrew Wiles, a mathematician notable for proving Fermat's last theorem, and Sir Konstantin Novoselov, Nobel Laureate and co-discoverer of graphene – operate on similar principles.

The US research agency ARPA – whether by accident or design – hit on a third philosophy. J.C.R. Licklider ran the information technology programme at ARPA between 1962 and 1964, when the research he funded laid down most of the foundations for modern computing, including networking that led to the internet, and the principles of human/computer interaction that were further developed at the XEROX PARC laboratory to give us mice and graphic interfaces.

This third philosophy, then, focuses on the *programme manager*, or perhaps better, a *programme leader*. These are individuals who come with a vision of the future of some field of science of engineering, they develop and elaborate that vision – in collaboration with others - into a research programme, and then they create and support a research community to realise the vision.

But even before we define an operating philosophy, we should understand what the fundamental purpose of any new agency is, and who or what it should serve.

Part of ARPA's success is complete clarity on both fronts. Its purpose was, and is, to ensure the technological superiority of the US armed forces. The people it serves – its customers or beneficiaries, if you will – are soldiers, sailors and airmen of those forces, as they carry out their task of projecting the military power of the USA. Others may well benefit from its investments – defence contractors, industry more widely, the whole economy, and ultimately everyone in the world who has benefitted from the internet, but these weren't ARPA's primary purpose.

So who should the primary customers of a UK version of ARPA be? It's easiest to start by listing who should not be those primary customers. It shouldn't be academia; this should not be about maintaining the health of the conventional disciplines. This is not to say that it isn't important to maintain the continuing progress of scientific fields and the training of researchers in those fields – this is crucially important as the foundation for all scientific and technological progress. But this is the role of the research councils and funding agencies in partnership with the universities. The academic scientists and technologists who will generate the ideas and carrying out much of the research for our UK ARPA will emerge from this foundation.

Neither should industry be thought of as a primary beneficiary. Expertise from the private sector will be needed, and ultimately the ideas should create significant new commercial value – but this should be for tomorrow's industries and tomorrow's companies, rather than for the near term benefit of the current incumbents. Once again, there is a place for the state to support the nearer-term R&D of industry, but this should be carried out directly through innovation grants, and indirectly through R&D tax credits – together with much smarter use of government procurement to drive innovation.

This still leads us in search of the fundamental purpose of the UK ARPA – the equivalent of ARPA's mission to ensure the technological supremacy of the US armed forces. This example suggests that to have longevity and political staying power, the purpose needs to be closely coupled to the strategic goals of the nation.

The cold war provided an existential threat to the US nation; the environment from which ARPA emerged was the shock that Sputnik posed to the USA's technological self-confidence. The cold war is over, but the world remains a dangerous place and the future is even more uncertain than ever.

Direct threats to security from hostile state and non-state actors remain important. Moreover, new threats will emerge; we live at a time when the world is more connected than ever, so events in distant parts of the world could have direct, yet difficult to predict, consequences for the UK. Rapid changes in our natural environment, together with a paradoxical blend of economic stagnation and rapid technological change could combine with uncertain consequences.

The global physical environment is changing fast; anthropogenic climate change will certainly result in significant warming, while tail-risks from more extreme scenarios need to be taken seriously. How, for example, would the UK react to a powerful state in another part of the world unilaterally implementing geo-engineering measures that mitigate the effects of climate change there, but impact deleteriously on the UK's own climate?

The UK has committed to reducing its own net greenhouse gas emissions to zero by 2050. This is the right thing to do, but there's not a wide enough understanding of how demanding this target is for an advanced economy like the UK, whose economy still depends on fossil fuels for about 80% of its essential energy needs. And even if the UK did reach this target, what good would that do if major emerging economies insist on prioritising widening access to energy over decarbonising the sources of that energy? The solution to this dilemma can only come from innovation to drive down the cost and increase the scale of low carbon energy sources, and increase the efficiency with which it is used.

There are socio-economic threats too. We have seen a decade of stagnation in productivity growth unprecedented in the UK for more than a century, yet we have no consensus on how to end that. We have no intuition as to how the economy and society of the UK might respond to a no-growth world (we may need to look at the experiences of countries like Argentina to understand the threats that emerge in the scenario of continuing stagnation). There are specific technological issues that need to be faced. The unpredictable effects of rapid technological change in some areas – machine learning and ubiquitous computing – are widely discussed, but equally or even more important will be the consequences of the apparent slow-down of technological progress in some areas – the end of half a century of exponential growth in computing power, the dramatic slow-down in the rate of creation of new medicines[60].

An effective government needs to sponsor serious long-term thinking about the changing world and the UK's place in it. There will be no better time to do this now, as the UK leaves the EU. Such a long-term look ahead would provide a framework for identifying the areas of greatest need for technological innovation, and joining up this kind of thinking should be a priority for this new government. The enduring goal of UK ARPA should emerge from this analysis.

But we can't wait for this kind of thorough strategic forward-look at the threats the UK faces, necessary though it is. What practical steps do we need to do to get our UK version of ARPA up and running within a year or so, and what relationship should it have to the existing umbrella organisation for science and innovation funding, UK Research and Innovation?

There's no compelling reason why the UK ARPA shouldn't be set up within UKRI, and some good reasons why it should, particularly in the first instance. Most importantly, it can be done without delay – under the Higher Education and Research Act the Secretary of State has the power to instruct UKRI and provide new funds conditional on these instructions. Moreover, UKRI already has the necessary governance and administrative infrastructure to issue grants, and there's no point rebuilding that. The existing processes can, with imagination and will, be easily be streamlined to reduce bureaucracy.

After being established in UKRI, should the UK ARPA subsequently be spun-out as an entity separate from UKRI? I would turn the question round - UKRI is a young organisation which itself needs to evolve further. Whether UKRI can comfortably accommodate an experimental and risk-tolerant organisation like UK ARPA will be a good test of its own evolving responsiveness and flexibility.

But the approach of a UK ARPA can and should be quite different to existing funding mechanisms within UKRI, especially the classic project-based funding used by the research councils. It is possible that, notwithstanding the already significant powers of the Secretary of State to change the structures of UKRI by regulation, further legislation will be needed to allow UK ARPA to adopt such mechanisms within the overall framework of UKRI, and if so the government should not hesitate to introduce this.

The priority should be to recruit programme leaders in a few areas.

60. See e.g. Bloom N., Jones, C.I., van Reenen, J., Webb M., *Are ideas getting harder to find?*

https://web.stanford.edu/~chadj/IdeaPF.pdf,

Jones R.A.L., and Wilsdon, J., *The Biomedical*

Bubble: Why UK research and innovation needs a greater diversity of priorities, politics, places and people, NESTA 2018, https://media.nesta.org.uk/documents/The_Biomedical_Bubble_v6.pdf, These leaders will need to have deep technical expertise, a vision for their research area, and the personal skills to build a wider research community around this vision. It should be obvious that such individuals will be rare and at a very high level – these are people who will probably be very accomplished academic scientists or technology industry leaders. The main task of the new director of the UK ARPA will be to design the conditions that will make these positions an attractive career move for such exceptional individuals.

The programmes that each of these individuals lead will probably be at the scale that would provide support for perhaps half a dozen research groups, with that support at a level that their leaders will be able to devote most of their time to the problem. The level of support should be sufficient to attract the most talented researchers from overseas, and this internationalism should of course be welcomed and facilitated. Over 5 years, each programme might have a budget of order £20-30 million if it is focused on laboratory science, rather more if it involves any technology demonstrators.

Setting up these programmes should be accompanied by considerable rigour and scrutiny, but once established the programme leaders should have very considerable discretion in assigning and redirecting the funding without further bureaucratic overheads. There will be risks in this approach that need to be foreseen and guarded against – programme leaders might have conflicts of interest or they might not look widely enough to build their research communities, relying too much on existing networks.

Finally we need to think about the place of UK ARPA within the UK's wider innovation landscape. That landscape needs to change, to achieve the widely shared goal of making the UK a significantly more R&D intensive economy.

It's important to remember that the UK ARPA will always be a relatively small part of a much bigger system, just as DARPA itself is only a small part of a much bigger US innovation system. DARPA's 2015 budget was $2.9 billion[61] out of a total R&D expenditure by the US Federal Government of $121 billion[62]. In round numbers, UKRI needs to have something like a £10 billion budget if the UK is to meet its 2.4% R&D intensity target, so a £200 million budget for UK ARPA would make it occupy a comparable niche in the UK system.

DARPA, like any funding agency, relies on other people and organisations to actually do the work that its success depends on. In the US, this involves a rich system, including university researchers, government laboratories, but also a strong degree of private sector involvement, including big companies like the defence contractors which in the US carry out so much directly federally funded R&D. But there is also an important tier of what are essentially research SMEs – private, sometimes not-for-profit, contract R&D laboratories like SRI International (formerly the Stanford Research Institute). These have no direct UK counterpart, though the R&D consultancies and design houses like Cambridge Consultants are perhaps the closest analogues[63].

61. 2015 enacted budget from https://www.darpa.mil/attachments/(2G1)%20Global%20Nav%20-%20About%20Us%20-%20Budget%20-%20Budget%20Entries%20-%20FY2016%20(Approved).pdf

62. National Science Board, *2018 Science and Technology Indicators*, https://www.nsf.gov/statistics/2018/nsb20181/report

63. See e.g. Connell, D. and Probert, J. (2010), *Exploding the Myths of UK Innovation Policy: How 'Soft Companies' and R&D Contracts for Customers Drive the Growth of the Hi-Tech Economy*, CBR, University of Cambridge.

https://www.cbr.cam.ac.uk/fileadmin/user_upload/centre-for-business-research/downloads/special-reports/specialreport-explodingthemyths.pdf

The UK's innovation system needs to change, to reflect some wider shortcomings of the existing landscape – in particular a relative neglect of translational research, and an unhealthy degree of geographical concentration that contributes significantly to the UK's regional economic imbalances[64]. But as we change the landscape, those changes can be shaped to make the UK ARPA more effective.

A well-designed UK ARPA could be an important part of the wider innovation system, part of a necessary process of being more experimental in the way the UK government supports science and technology. We should learn from the best of the US experience, focusing on visionary programme leaders given the freedom to create and support research communities to develop those visions. The agency should have a strong and enduring clarity of purpose, set within a long-term view of the strategic threats and opportunities facing the nation. The development of the new agency should also be set into a context of a wider reshaping of the UK's innovation system, with more emphasis on translational research and less geographical concentration.

64. See Jones R.A.L., *A Resurgence of the Regions: rebuilding innovation capacity across the whole UK.* Available at: http://www.softmachines.org/wordpress/wp-content/uploads/2019/05/ResurgenceRegionsRALJv22_5_19.pdf

ARPA's place in the UK's Public Research Landscape

Jo Johnson

For maximum impact, ARPA should be created within UKRI.

The Conservative manifesto has committed to the creation of a "new agency for high-risk, high-payoff research, at arm's length from government". In doing so, it the Government should take care not to forget why George Osborne, as Chancellor, commissioned Sir Paul Nurse to review the UK's Research Councils back in 2014, ensured that we committed to implement Nurse in the 2015 manifesto and then supported legislation to create UK Research & Innovation via the Higher Education and Research Act (2017) (HERA).

UKRI is a (relatively) new agency, it is committed to funding world class discovery and applied research, and it has numerous protections from Ministerial interference, including for the first time the incorporation of the Haldane Principle into domestic law. In principle, it should be capable of delivering the objectives that the Government wishes to obtain from an ARPA.

Government bureaucracies and policy units may not have much by way of institutional memory, but it is less than four years since Sir Paul Nurse observed that the UK's public research system was fragmented, inefficient and lacking in strategic oversight, coherence and weight in Whitehall.

That is the gap UKRI is meant to fill and it is fulfilling the duties Parliament has given it. Sir John Kingman and Sir Mark Walport were appointed its first chairman and chief executive with the remit to create a single, ambitious organisation and provide the UK with a world class funding system that would keep it at the forefront of global research and innovation. Building on the strengths of the seven UK Research Councils, Innovate UK and Research England, they have led the crucial first phase of UKRI's transformation programme, established a single operational organisation and secured a significant increase in public funding. The Government must listen carefully to them as it considers how to proceed.

Sir Mark, who has announced that he will retire at some point in 2020 once a suitable successor has been identified, has laid great foundations upon which a successor must be able to build with confidence. A strong voice in Whitehall, UKRI is delivering for the scientific and innovation communities it represents in a way that is measurable, not least in the form of a strong cross-party consensus in support of record increases in the funding it disburses. Most importantly, it has made the research councils add up to more than the sum of the parts, a critical shortcoming for the Treasury, which had long been frustrated by the lack of a single-point of accountability to Government for science spending.

A New Agency?

If the Government is serious about creating a new agency, it must first establish a clear purpose for it that is distinct from what UKRI is already doing or able to do within the scope of the powers set out in the HERA 2017 and earlier legislation, including the Science and Technology Act 1965. Above all, the Government must ensure it does not recreate many of the structural problems with how we fund research and innovation that the creation of UKRI was intended to solve:

- by depriving UKRI of its raison d'etre as a single-point of accountability to Government for science spending;
- by preventing UKRI from operating as a funder with strategic oversight of the UK's research system;
- by re-creating the silos that prevent the efficient funding of inter-disciplinary and mult-disciplinary research;
- by denying UKRI the additional resources needed to sustain and enhance public funding for the research and innovation;
- by creating unhelpful, confusing and duplicatory overlap with Innovate UK and UKRI's challenge funds.

If the Government feels it necessary to have a new body dedicated to supporting emerging technologies, it has a duty to think through how it will relate to UKRI, and how it will differentiate itself in particular from Innovate UK and the Industrial Strategy Challenge Fund. There is a real risk of duplication of effort that we cannot afford, even in an environment of increased public spending on R&D. In particular, the legislation that will be required to create the new ARPA must ensure that ARPA has the power – and, where appropriate, the duty – to cooperate and share information with UKRI to ensure that the two bodies work together most effectively. This could be modelled after Section 112 of HERA which establishes similar powers and duties of cooperation between UKRI and the Office for Students.

Establishing ARPA within UKRI

Although it would be possible to establish ARPA as an independent agency, creating it within UKRI (using powers under the 1965 Science & Technology Act/Higher Education and Research Act 2017 as appropriate) would be much less disruptive than legislating to create a new standalone quango. The risk is that a pet quango, if created outside of UKRI, fractures confidence in an entity that is central to the successful funding of our national research and innovation endeavour, at a critical stage in its development.

The purpose of creating ARPA is to pursue high-risk, high-reward scientific opportunities and to support emerging technologies with the potential to have a transformative effect. There is considerable latitude for Government to steer UKRI in a way which will ensure that it delivers these objectives, through a combination of guidance to the organisation's chair and the appointment of a new chief executive later this year.

If this is not sufficient, an amendment could be made to HERA to explicitly create ARPA as a new body within UKRI, in a similar way to which Innovate UK and Research England are given direct mention within the Act. In this way ARPA could be given a distinct remit, with its own unique functions and powers that would cause it to operate very differently from the other Research Councils. Although this would require primary legislation, it would be much simpler than creating a whole new body, as ARPA could make use of the general functions and legislative arrangements that any new body requires but that are already in place for UKRI. In a similar way, there would be the opportunity for enhanced efficiency by sharing back office functions.

Another principal advantage of creating ARPA within UKRI is speed: as UKRI is a body that is already established and with grant-giving abilities, establishing ARPA within it would allow the new organisation to become rapidly operational and begin disbursing money. There are also longer term benefits. Based on the budget proposed for ARPA in the manifesto, the agency will be spending approximately £250m a year, or about 2% of the UK's total publicly funded R&D. If ARPA is to be effective, it must therefore operate in a manner which has a catalytic impact on wider research spending, stimulating investment to 'pull through' advances in the areas in which it invests. This form of catalytic relationship is more likely to occur effectively if ARPA is part of UKRI.

ARPA has the potential to make a valuable contribution to science and innovation in the UK. In order to achieve its objectives and have the maximum positive impact, both individually and on the system as a whole, it should be establishes as a body within UKRI.

Navigating high scientific risk and high innovation risk to reap the rewards of ARPA funding

Nancy Rothwell and Luke Georghiou

For ARPA to be successful, Government must address the full pathway from high-risk research to technological pull-through via commercialisation and procurement.

Why is 'ARPA-like' funding needed?

Andre Geim is rather fond of what he calls 'Friday evening experiments'. They are not necessarily always undertaken on a Friday evening, but they are outside normal projects, they are usually not formally funded and test 'out-of-the box thinking and high risk experiments.'

'Friday evening experiments' have served Andre well. In 2000 he won the Ig Nobel Prize[65] with Mike Berry for levitating frogs with a magnet, then in 2010 he won the Nobel Prize in Physics with Kostya Novoselov for ground breaking experiments regarding the two-dimensional material graphene.

Not all scientists are likely to benefit from such high-risk approaches to research as Andre has done, but many have ideas that don't easily fit into current funding models, or have a sense of urgency or simply not be able to find the time to take such risks.

Creating an agile, flexible and speedy funding system for high risk and potentially high reward projects seems to be behind the government's suggestion to create an 'ARPA-like' funding scheme based on the US Defense Advanced Research Projects Agency.

It is certainly true that UK researchers find the normal processes of securing funding lengthy, extremely time consuming and, with relatively low success rates, often quite inefficient, requiring significant amounts of preliminary data and highly credible plans for success. Funding bodies (I have served on many) rarely want to take undue risk, except perhaps with the most successful, leading researchers with a strong track record (see below).

QR (Quality Related) research funding, awarded to universities based on their success in the Research Excellence Framework, and securing grants from charities and funding for PhD students is intended to provide core funding including for research that might be too early or too risky to secure grants through standard pathways. But QR funding (and the increase in indirect costs on government grants) have been eroded over

65. A satiric prize awarded annually, with the stated aim to "honor achievements that first make people laugh, and then make them think."

time so that for most research intensive universities government funded research is subsidised by the order of at least 25%.

Hence an ARPA-like funding scheme would be attractive to many researchers, though clarity over its aims, core activities and management are essential if it is succeed. The Prime Minister's Council for Science and Technology recommended the establishment of such a body in 2016 and reiterated this again more recently. However, there is a risk that ARPA-like funding is seen to serve many different purpose by different players.

How would ARPA need to be adapted for UK civilian benefit and how would it differ from current UK funding?

The original purpose of DARPA and its more recent, but to date rather less successful, civilian establishment ARPA-E (addressing energy research) was to provide rapid and agile funding for high risk, but potentially high pay back research projects. DARPA has a very flat structure, with a relatively small number of highly qualified staff, many with an industry background and with a fixed tenure. DARPA has a significant degree of autonomy with the ability to hire quickly and at significantly higher salaries than other government employees. There is no 'peer review' and very limited requirements for capture and ownership of intellectual property.

All of this contrasts quite markedly with current UK government funding through UKRI (UK Research and Innovation, encompassing the Research Councils, Research England and Innovate UK), – though Research England does operate somewhat differently in allocating QR income to universities to spend as they choose and Innovate is very business facing. This might argue for a new structure to be developed, though the costs and time required to establish a wholly new funding agency would need to be balanced against the benefits.

The key feature of DARPA has been its approach to risk, of which there are two distinct aspects-high scientific risk and high innovation risk. The former would be less costly and easier to establish-indeed several of the UK's current major funders have run 'high risk' schemes. The latter is much more challenging since it depends on commercialisation 'pull-through'. Notably ARPA-E, without the military links, has been much less successful in links to industry and commercialisation.

ARPA funding can be of longer duration (to allow radical ideas the time to reach a level of maturity without being stifled by premature scepticism), which is already increasingly deployed by UK funding agencies, though this is in tension with the concept of 'fail fast and terminate early'.

ARPA funding is also often focussed around 'missions' which has been a feature of the UK's Industrial Strategy and Grand Challenges approaches to research funding. These might be most appropriate in the areas identified in the most recent strategy: clean growth, artificial intelligence, healthy ageing, future mobility.

What are the potential pitfalls, problems and benefits?

There are strong arguments supporting a portion of the UK government's research funding to be faster, leaner and favouring high risk projects, though this would need a very different approach to that used presently. Where companies have been involved in joint bidding, even the larger and better resourced firms find the current funding schemes too slow and cumbersome when time to market is critical for them.

Given the more modest funding required for 'high scientific risk' research, this might be funded through an uplift in QR funding. This would dramatically reduce the bureaucratic processes required for national competitions but would rely on universities investing the funds into new research and may require a new funding allocation for QR income.

It is notoriously difficult to select high risk projects for funding, especially so when these are submitted by early career researchers who have yet to establish a strong track record, but who might have particularly innovative ideas especially if they don't feel the need to 'play safe'. Peer review depends as much on track record as on the nature of the projects. Thus funding could be skewed towards those who are already highly successful. This might be overcome by a separate, perhaps more modest fund for early career researchers, though in both cases, absence of peer review by international experts in itself carries risk.

ARPA would therefore be free to focus on areas of 'high innovation risk'.

Commercialisation and technological pull-through

The grand challenges identified above each demands multiple, cross-disciplinary approaches, so pre-defining areas of focus may be unhelpful. There should also be some scope in a high-risk funding scheme for proposals that do not fit with current missions but test completely new and as yet not thought of areas.

There will be a tendency to focus on science, engineering and technology, but we should not ignore the innovations that can be brought to service and creative industries and human behaviours.

An international dimension to the funding would be helpful. DARPA does fund scientists outside the UK, including Andre Geim for his ongoing research on new two dimensional materials, and some of the most significant research breakthroughs come from international partnerships.

The most challenging aspect of ARPA-like funding is commercialisation, where UK markets are much smaller than the US, and application of new discoveries could be improved significantly. Hence engagement of the commercial sector, including small and medium sized companies as well as the larger, research and development focused organisations will be important.

The challenge is how to establish a clear pathway from fundamental technological advances to prototyping and production stages. Normally this cannot be achieved without an engaged customer to provide feedback (and in the case of an innovative SME, also credibility). The DARPA model has worked in sectors where public procurement (notably in defence) provides that pathway, albeit that the technologies and products subsequently diffuse to civilian applications. The UK lacks the large and technologically adventurous defence sector needed to take advantage of this approach.

Looking more widely at opportunities for demand-pull, the UK's pre-commercial procurement schemes (notably SBRI) have generally failed to be followed up with actual purchases, largely because of the reluctance of public procurement budget holders/commissioners to take risks. A new agency would need to have a changed relationship with central government departments. Several key opportunities could be boosted by early commitment from public budgets. An example would be the health data sector given that the UK has, via the NHS, one of the highest shares of publicly funded healthcare (79%) among OECD countries.

An obvious additional requirement is the engagement of firms with the investment capability (from internal resources or by attracting venture capital) to scale up the innovation.

Several of the opportunities that a mission-oriented ARPA-style approach opens could be manifested at a regional level. Local government spends around £100bn p.a. on procurement. Cities are key investors in infrastructure and can potentially provide a greater degree of cross-functional integration than large central government departments. A further advantage is that clusters of capability can be built around regional strengths and deliver benefits directly to their localities.

Manchester for example is heavily engaged in building an innovation ecosystem around graphene and other 2-D materials, partnering with key infrastructure providers such as the Highways Agency (to produce roads resistant to potholes!) and companies in the construction, water and energy sectors. The trail goes right back to the breakthroughs of those Friday evening experiments!

Designing a British DARPA

David Willetts

A British DARPA is a good opportunity to plug gaps in the UK innovation system and strengthen our ability to develop and apply key technologies.

America's DARPA is part of a much wider science and innovation ecosystem – getting $3 billion out of $150 billion of US Federal spend on R&D. It draws on enormous research capacity which is funded separately by classic public funding agencies. From these it then creates distinctive teams for its projects. Our public spend on R&D as a proportion of GDP is about half that of the US. And our GDP is about a fifth of theirs. So we end up spending about a tenth of what the Americans do. An equivalent British DARPA would therefore have a budget of about a tenth of America's or £250m if the ratios were maintained. This is broadly in line with what the Government has proposed.

Comparing the world's major research systems shows that by and large you get what you pay for - more funding buys more output of world class highly cited research. One conspicuous exception is the UK which gets far more world class research relative to its spend than any other major country. Indeed, using field-weighted citation impact as a proxy for research quality and with a global baseline of 1 UK achieves 1.61 overall, and 2.23 for UKRI-supported grants - the highest in the world.

Given its exceptional performance our basic research does not require further structural change (though there are some interesting, deep questions about the creativity of the modern scientific enterprise globally). Instead the priority in this area should be to increase our core research budget, reversing the real cuts of the past decade and going further to position the UK's research base as a magnet for talent and investment from around the world. There was widespread relief when the Government in which I served protected the science budget with flat cash in the 2010 spending round as much worse options were on the table but, ten years on, flat cash has become a tight squeeze doing real damage to our core capacities. The one big increase in spending when UKRI was created was all attached to Theresa May's Industrial Strategy with no increase in the core responsive-mode budgets of the Research councils. That means that the success rate of British based academics bidding for funding for curiosity driven research has fallen to very low levels. We can and should do more for them.

The problem a British DARPA can help solve

There are weaknesses in British R&D which need to be tackled – but the problem is with the D not the R. The cliché is right - we are indeed much better at pure research than at successfully commercialising and applying it. This is not the result of some deep-seated cultural problem: it is the result of particular institutional arrangements and incentives which can be changed. The biggest problem is early specialisation in our secondary schools. Many sophisticated people in senior positions in finance, industry, and indeed politics and the civil service stopped studying maths and science at the age of sixteen to specialise in just three subjects for A level. (I'm a victim myself.) No other Western country does this. It explains the peculiar assumptions of the English elite about people in white lab coats - that what they do is incomprehensible because science and technology are uniquely difficult; and that advances in science and technology come from unpredictable, extraordinary flashes of solitary genius. It might even be the key to the persistent concerns about the quality of the civil service most recently expressed by Dominic Cummings. Tackling early specialisation is the real education reform which we are still waiting for.

Meanwhile there are other things which can be done to tackle the British innovation challenge – and it is here that a British DARPA could be a real game-changer. It should be a boost to our investment in technology and commercialisation which is where we are weak. A British DARPA backing key technologies and applying them would match the Prime Minister's own rhetoric which frequently refers to technologies where Britain is strong – synthetic biology, small satellites, nuclear fusion, and batteries.

That happens to be the real role of America's DARPA. ARPA was created by President Eisenhower in 1958 after the Soviet Union's successful launch of Sputnik caught America by surprise and shook its post War complacency. ARPA's mission was to prevent technology surprises for the US and instead to create them for others. A shorter version, which applies to this day, is to prevent and create technological surprise.

DARPA's role could be called Industrial Strategy – but perhaps it is safer to pretend it isn't. Their team of programme managers are clearly and deliberately intervening so as to boost America's technological and industrial capabilities. DARPA functions free from the inhibitions and agonising about what role there is for Government to support the development of technologies, a phenomenon that in the UK has repeatedly led to ideologically driven retreats just when things are starting to work.

This focus on technology is crucial as the principal gap in the British model is support for innovative general purpose technologies. There is no British strategic technology fund and there should be. There used to be a Technology Strategy Board which we rebranded as Innovate UK – a decision of mine which was probably a mistake as it hid the real purpose of the organisation.

We think somehow that American entrepreneurs are bolder risk-takers than us when actually public agencies there are willing to bear far more risk than here and do more to lead the way for commercial development of a technology. Even basic British schemes to help start-ups with funding for proof of market and proof of concept have been cut back on the entirely false belief that this is something governments cannot or should not do – when in reality they do it everywhere else. Hence the absurd experience of British researchers and technologists of being approached by public agencies from other countries who can see the value of what they do when there is no public funding for them here. The latest absurdity is innovators being told that they can't sell it to other countries for security reasons (because we know how valuable it is, say the security people) while simultaneously being told that we will not fund it ourselves (because we could not possibly know if it is valuable, say the sceptics).

How DARPA works

It is not just that DARPA backs technological innovation. It does it in way which inspires excitement and enthusiasm like few other public agencies in the world. How it works is part of its message. It has certainly been willing to go for wild and wacky ideas which can sometimes have a touch of genius – rather like the spirit of British innovation during World War II still captured in James Bond's "Q".

The absence of academic peer review means that DARPA can pursue odd-ball projects. One estimate is that 85% of their projects don't work. But that does not matter. Forgiveness of failure is crucial – a quality which has largely gone from the British public debate and leads to over-regulation and excessive caution. This way of working is why it is sometimes thought of as a funder of blue skies research. But in reality DARPA, however free-booting, has always served America's core long-term security strategy of having a dominant position in key technologies. Its biggest innovations come from tackling technological challenges – the internet originated with the need to link the computers managing missiles in silos across America.

DARPA's competitions for driverless cars and for humanoid robots have caught the imagination – and made DARPA a YouTube phenomenon. We have promoted NESTA as our centre of expertise on prizes and competitions and it could be used across Whitehall to do more of them. However DARPA have make it clear that their prize competitions are only possible because of underlying capabilities funded in other ways. Larry Jackel who ran the DARPA Grand Challenges race for autonomous vehicles said of the Challenge "It's not self-sustaining… You can do it based on something that already exists, but if all we did was have challenges, then at some point we'd just stagnate." The best competitions and challenges derive from a deep understanding of the state of technology. Kennedy's moon shot was not a random ambition; it was based on prior DARPA investment in rocket technologies. By contrast some British missions and challenges seem to emerge from groups of amateurs randomly thinking of things it would be nice to have – and others are really technology investments disguised as missions in order to get funding.

DARPA has an unusually high tolerance of risk and failure. It operates at pace. It is highly autonomous with a head who is trusted to get on with the job and in turn gives lots of autonomy to programme managers. The expert and confident programme manager is a key feature of DARPA's success over the years. They have a deep understanding of how a technology is developing. DARPA has the convening power to pull together different experts and get them to share their ideas. This is increasingly important as vertically integrated technology companies are becoming rare, leading to more distinct commercial players which find it harder to link up. Moreover, within the academic community competition between institutions and researchers is intensifying. So a safe space where they can co-operate becomes increasingly important. Government agencies do have this convening power – usually driven by the over-riding prerogative of national security which licenses DARPA today just as it licensed British technological innovation in the days of what David Edgerton neatly calls the Warfare State. We gave that up in the late 1960s – indeed, some of DARPA's commercial interventions would probably be contrary to EU state aid rules and our own competition regulations. America, however, still thinks and acts in this way. And it is possible that the emergence of American/ Chinese technological competition is bringing this way of thinking back to Whitehall.

Where does Innovate UK fit in?

One tricky organisational issue is how this new British DARPA would relate to Innovate UK. Innovate UK was supposed to be – and indeed for a while functioned – as the home of strategic horizon scanning on new technologies emerging from the UK research base. Its work, alongside the Research Councils and the office of the Government's Chief Scientist, contributed to my identification of the eight great technologies in an earlier Policy Exchange pamphlet[66].

In 2015, Innovate UK was heavily cut in the Spending Round: its core responsive mode grants cut by a third, or £165m p.a. Since 2018, Innovate UK has become the business-facing part of UKRI. This has helped to position UKRI as the body which can span fundamental research to business-led innovation, and make the case for the £7bn uplift to R&D that was a central part of the Industrial Strategy.

There are various ways that a technology-focused British DARPA could work alongside Innovate UK and UKRI. One would be to evolve the Industrial Strategy Challenge Fund to be as free and ambitious as the DARPA model (as was part of the original vision for the ISCF): it already focuses on employing Challenge Directors, but there would need to be a bold move towards pay and financial freedoms to liberate it truly and enable it to take decisions and risks with the agility of the DARPA model. Indeed many of the freedoms envisaged for DARPA could and should be extended to UKRI. In its early years it has had heavy-handed and intrusive supervision, making it hard to manage its budget efficiently when it comes in so many specific jam-jars of allocated funding.

One option would be for DARPA to incorporate Innovate UK, but this would risk undermining UKRI just as it is gathering momentum and

66. This has recently been reprinted and seven years later its analysis broadly stands up – disproving those claims that we cannot forecast how technology will develop.

delivering several billion pounds of new flagship programmes. It would also reduce the connectivity between research programmes and the industrial needs of the UK. And it would be disruptive to take UKRI apart now. Another option therefore would be for DARPA and UKRI to keep distinct identities but to work closely together. Innovate UK could have a strengthened better funded broad technological capability to complement DARPA just as American public agencies such as the National Institute for Health and the National Science Foundation do with their DARPA. These are the sort of questions which can pre-occupy Whitehall's finest minds for many months – but on balance, the latter appears better

Conclusion

Britain's problem is that we need to do better at turning science into innovation. If there is one agency in the world which is the master of innovation it is America's DARPA. We can learn from it. But to do that we need to be clear about what exactly is the problem we are trying to solve. And I think that is the challenge of promoting the development and application of key technologies.

When failure is the key to success

Dr. Tim Bradshaw

A UK ARPA must encourage failure as a positive outcome and turn the Government into an intelligent customer for innovation.

Failure is good

A few years ago, I visited the UK base of a well-known Japanese company on the outskirts of Cambridge. The Technology Director was rather glum. They'd just been reviewing the success rate of that year's innovation projects: 70% of them had been successful. However, his demeanour was not because of the 30% failure rate, but because the success rate had been too high. It meant his teams had played too safe – delivering some good incremental improvements, yes, but missing the opportunity for more radical innovation that could transform the company over the following 5-10 years. The Tech Director, and the company, had an admirably high tolerance for failure (the right kind of failure anyway), accepting that sometimes taking higher risks is essential to making real progress.

Imbuing this sort of failure tolerance will be one of the biggest on-going challenges likely to face the UK's new ARPA if it is to deliver on the promise of 'high-risk, high-reward' for the UK economy and society.

The challenge is systemic, but three areas provide a useful illustration.

The first – and really this should be the easiest to solve, although the candidate pool is likely to be slim – will be finding a cadre of mission champions and programme leaders able to commission and then drive forward projects at pace. This is no sinecure. This is hands on. They'll need to be ambitious and probably have a CV involving industrial CTO-level success, science and tech entrepreneurship and the choreography skills to keep multiple (and disparate) partners all pulling in the same direction. We may need to import some of these people and pay them well. They will also need to be ruthless in stopping projects that aren't going to be successful: failing fast means valuable resources can be redeployed (time being the biggest enemy). However, if we really want to get ahead, then the ruthlessness needs to go even further: stopping projects that *are* delivering, but just not fast enough or only offering incremental gains.

For those on the receiving end, this is going to feel brutal if (and when) ARPA is operating effectively.

In turn then, this requires a fundamental mindset shift for those doing the research. They'll need to recognise success is not about delivering the next iteration of an established market product or about producing papers that will improve your REF score (at least not as a primary aim). Instead, this is all about the mission. Winning an ARPA grant may give you substantial resources and freedom to innovate over a longer period of time, but you will also need to be accountable throughout the project, not just at the end. Researchers should expect to face a series of 'go/no go' milestones and accept that 'no go' will always be a highly likely outcome. If you have put everything into your project and it still fails early then see that as a success, both for the mission and for your own future research.

One key compensation for research teams should be that ARPA funding comes with all costs covered. Universities already face a looming sustainability crisis in research (which needs to be addressed separately) so ARPA has to take a very different approach if it is to encourage top researchers to embark upon projects that are, by their nature, likely to fail.

A third, and perhaps the hardest part of the failure challenge to crack, sits with the Government itself. Just how patient will it be for ARPA to deliver and how much failure (even of the 'right type') will it really accept?

Experience from DARPA in the US (current budget around $3.5 billion/year[67]) is that this type of approach to advancing technology does not come cheap. With taxpayers ultimately footing the bill, the pressure to deliver outcomes will inevitably create tension between ARPA and the Treasury. ARPA on its own cannot be the answer to revitalising the UK's productivity growth, but failure to deliver substantial progress in five years risks an early end to the experiment, or of ARPA morphing into another version of Innovate UK just to keep the auditors happy.

Success requires intelligent customers

For the UK ARPA to be a success, and to differentiate itself from UKRI (NB: I see them as two very separate entities), I've taken for granted that it will be an entirely mission-oriented agency. Even with the £800 million funding proposed – and, hopefully, that's just an initial sum for the start-up phase as remember the announcement was for this amount over 5 years, not per year – it won't be able to do very much without spreading its resources too thinly. This means it will need to focus its efforts on a small handful of high profile, high impact, missions at a time – and, again, will need to be ruthless in their selection. Themes around zero carbon (or, better still, negative carbon), infrastructure systems and everyday use of AI in healthcare come to mind as early missions where the UK can and should take a global lead.

Already then, a few critical design elements of the UK ARPA are emerging: focus, long-term political backing, high tolerance of failure, substantial funding (sufficient to make a real difference), and researchers and mission teams driven to succeed. But that is just the first part. However radical ARPA is, its outputs need to find real world application: an innovation isn't really an innovation if it isn't being used.

Back to my business example. The Japanese company was motivated

67. https://www.darpa.mil/about-us/budget

to create lasting value for its shareholders and it could only do this by selling new technology to its customers. They knew potential customers could go elsewhere for 'standard kit', but a close relationship with a few key customers to really understand their needs gave the company an opportunity to be more radical. Instead of just pushing technology out to compete in the market, the company and end customers were actively working together to pull through innovative ideas for mutual benefit.

And that is the other defining challenge for ARPA: how to establish and build an equivalent 'innovation pull' dynamic, but do it at a national scale. In the US, DARPA does this through its intimate links with the military – setting challenges that may require entirely new technologies or left-field adaptations of existing tech to solve, and then developing successful solutions to the point where commercial delivery has been significantly de-risked. Having a clear and engaged customer with a real need also helps to keep projects focused. For the UK, the MOD could be a customer for some of ARPA's work (even if defence is unlikely to be a key focus) but on its own it lacks scale: £22 billion of procurement spend in 2017/18 compared to the US Department of Defense budget of $147 billion for procurement in the same year[68]. We need to think bigger.

The UK ARPA should seek to engage customers across the public sector, and beyond where possible. According to the Institute for Government, total UK public sector procurement spend in 2017/18 was around £284 billion[69]. Imagine the transformative power for the UK economy if it could be mandated that 5% of this must be spent on truly innovative solutions. That would give us around £14 billion a year of innovation pull potential from central Government funding – a spark that could trigger more widespread and transformative change. Better regulatory signalling and mobilisation of patient capital alongside this should also be prioritised to ensure great ideas from ARPA generate high value jobs in the UK. Add to this the doubling of public R&D investment to £18 billion a year outlined in the General Election run up and that will make the UK a very attractive place for those at the cutting edge of research and innovation.

The catch is we probably need a fundamental shift at the operational level of public procurement to realise this opportunity. At the very least ensuring procurement teams are engaged with ARPA mission leads right from the start and that they are empowered to think beyond the parameters of existing solutions and performance measures. If it is to go beyond central government to involve the NHS, local government and other major spenders, it may require new nationwide guidance or legislation to ensure that innovation is actively considered as a factor in procurement across the wider public sector. Procurement partners will also need support to trial and implement new systems: for example, in the NHS supporting individual Trusts to demonstrate new advances at scale to help build a wider culture of receptiveness to change in technology.

The bigger catch is that this was recognised over a decade ago: by the DTI in 2003[70], by the Office for Government Commerce in 2004[71], and by Sir George Cox in his review for the Chancellor in 2005[72]. A report I wrote

68. https://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2020/FY20_Green_Book.pdf
69. https://www.instituteforgovernment.org.uk/sites/default/files/publications/IfG_procurement_WEB_4.pdf
70. *Competing in the global economy: the innovation challenge*; DTI innovation report, December 2003
71. *Capturing innovation: nurturing suppliers' ideas in the public sector*; Office of Government Commerce, summer 2004
72. *Cox Review of Creativity in Business: building on the UK's strengths*; November 2005

with QinetiQ for the CBI in 2006[73], which looked at public procurement as a driver of innovation, also still feels highly relevant. We concluded that an ARPA-like body was needed and that Government Departments and Agencies should be challenged to become early adopters of new ideas to catalyse innovation activity across the economy. But to achieve this, the Government would need to "*invest in significant business transformation for public procurement, bringing in new skills, training procurers at all levels, placing outcome-based and whole-life value approaches at the heart of operational activity and devising targets and incentive structures to reinforce this change of culture.*"

The challenge for the 2020s is that we now need to make this happen. Indeed, beyond the development of any individual technologies, ARPA's underlying mission should be to create a genuine intelligent customer relationship for public procurement in the UK, and then build on this as one of the fundamentals of an enhanced innovation economy.

73. *Innovation and public procurement: a new approach to stimulating innovation*; CBI, October 2006 (https://nzrise.org.nz/wp-content/uploads/2015/12/innovation-brief-1006.pdf)

Conclusion

The seven essays in this collection provide a rainbow of different perspectives upon the creation of a UK ARPA. Written from a diverse set of perspectives – that of science ministers, administrators and practicing academics – they illuminate the challenges and opportunities that are involved in such an undertaking.

Our contributors do not agree on everything – for example, there are differences of opinion as to whether ARPA should be created within UKRI or as an independent agency (our view is that there are credible arguments in support of both cases). But what is perhaps startling is how much they do agree.

Though it is phrased in different ways, a consistent message is that ARPA should not be focusing on theoretical, basic research, but nor should it be carrying out near-to-market innovation to deliver incremental improvements in existing products. Instead the focus should be on advanced technologies, bringing great ideas from the laboratory to the prototype stage, where they can be brought to market through commercial pull-through. This, it should be emphasised, involves R&D across a range of technology readiness, but it provides a clear focus on tangible, describable technologies, likely 10-15 years away from full commercial deployment.

Integral to success in the views of several contributors was the need for one or more clear strategic goals or objectives. In the US DARPA focuses on advanced technologies for national defence, ARPA-E on advanced technologies for energy. In the UK this could take the form of one of more grand challenges, or technology areas, such as Net Zero, Health Care or Digital and AI. How these goals are determined, how they relate to the industrial strategy and the degree to which they should prioritise societal goods such as tackling climate change as opposed to UK economic opportunity and competitiveness are all important matters that must be resolved.

Below the level of these challenges, however, will sit project managers. These are an essential element of ARPA/DARPA's success in the US and will be pivotal to whether or not ARPA succeeds in the UK. ARPA must be able to bring in highly talented, specialist individuals operating at the frontier of their field on short-term, typically three-year contracts, pay the necessary sums to attract such talent and give them broad discretion to fund the best research as they see fit. Our contributors agree that ARPA must embrace risk. By some measures, up to 85% of DARPA projects fail to fully achieve their objectives and building in and maintaining that risk appetite is a challenge that must be solved. This does not imply that projects should not be closely monitored, with regular milestones to ensure that progress is being made - if progress is inadequate, the project should be terminated.

A common theme as to one of the biggest challenges in creating a UK ARPA is the lack of a committed customer to help determine projects and provide the necessary commercial pull-through. In the US, DARPA has the Department of Defense as its primary customer, and every project has a clear end-use application which the programme manager is targeting and is directly relevant to military needs. In the UK, particularly in an agency focused on civilian objectives, there will be no equivalent customer. There are a range of options available to address this, including major reform of public procurement, the establishment of a tech-to-market group in the style of ARPA-E or – for some sectors – close working with major spenders: for example, in healthcare, the NHS could potentially take on the role of the Department of Defense. Each of these has its challenges; however, it is essential that the UK finds a way to emulate this aspect of DARPA if the new body is to have the impact hoped for.

ARPA's relationship with the other funding bodies and schemes in the UK, in particular UKRI, will be important to determine early and a clear and distinctive remit for ARPA explicitly set out. If, in addition to creating ARPA, the Government intends to make changes in UKRI or in the Industrial Strategy Challenge Fund, the nature of these changes should be spelt out at the time of the ARPA announcement. ARPA will, of course, operate in similar fields as other funders – it cannot be the only body working in an area such as energy or life sciences. ARPA's role, however, must to be to identify and fund the transformative and often higher-risk projects that would otherwise not be funded by more conventional funding agencies.

One of the strengths of DARPA in the US is that, because of its link to national security (and partly also because of its early successes), it has been largely insulated from short-term party political pressures. It is important to ensure as far as possible that the UK ARPA is not yet another short-lived initiative in what has been, throughout the post-war period, a somewhat erratic government approach to science and innovation policy. Given that the benefits of UK ARPA will only show through over the long term, bipartisan support for the new agency is all the more essential.

The recommendations below, and the schematic that follows, are those of Policy Exchange, guided and informed by the essays of our seven contributors. While they do not address every question, we believe they form a clear blueprint upon which a successful UK ARPA can be developed.

Policy Exchange's Recommendations

1. **Government should move rapidly to establish a UK ARPA.** An effective ARPA pursuing high-risk, high-reward transformative research has the potential to make a significant contribution to the UK's scientific and economic performance.

2. **Government should clearly set out the role, objectives and mission of ARPA.** This should include clarifying what gap it is meant to fill, how its mandate differs from that of other UK funding bodies and its intended relationship with these bodies.

3. **The government should seek as far as possible to secure bipartisan support for ARPA.**

4. **ARPA should not carry out research itself or have its own research laboratories.** Instead it should fund the best research and individuals wherever they are found, in pursuit of its objectives.

5. **ARPA should focus on developing advanced technology on a 10-15 year horizon.** Unlocking transformative technologies, rather than basic research or incremental near-to-market innovation, is where ARPA's efforts should be centred.

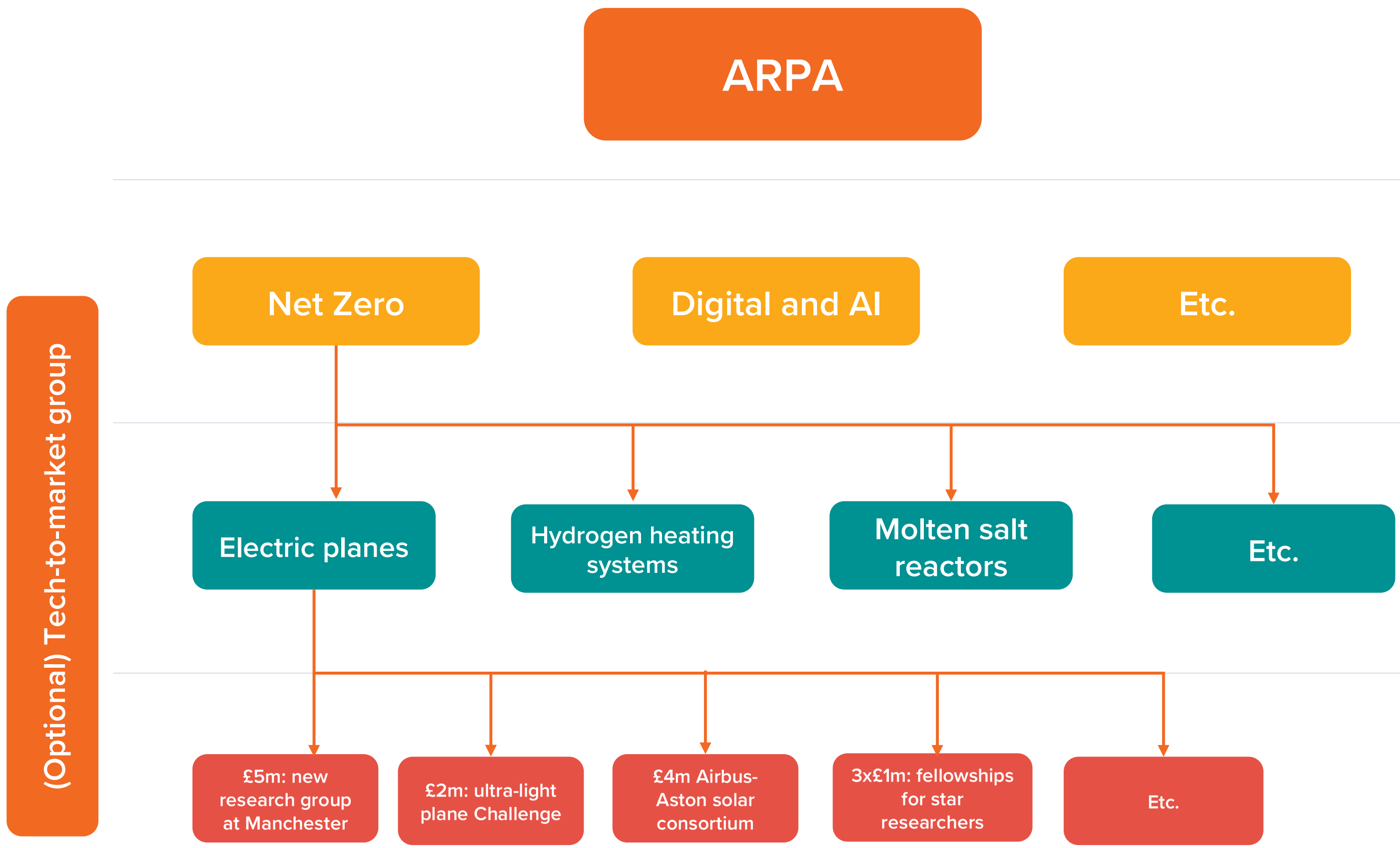
6. **ARPA must embrace failure.** ARPA's director, Ministers and the National Audit Office must recognise that most projects will not achieve their objectives – and that ARPA should be judged on the impact of its successes, not the proportion of its projects that fail. ARPA should be ruthless in cutting off funds for failing projects.

7. **ARPA should be given a small number of missions, each addressing a major societal challenge or scientific area.** These missions – ideally between two and four – should be determined by the Minister for Science and reviewed every five years. Each would correspond to an office within ARPA, and in turn would comprise a number of specific projects.

8. **Project managers must be highly capable, empowered and given genuine autonomy.** They should be highly talented individuals at the forefront of their field, typically brought in on three-year contracts with highly competitive salaries and considerable latitude to make decisions .

9. **Bureaucracy should be minimised.** Government must tear up the standard rulebook and allow money to be allocated to the best people and projects wherever they are found, in universities, research institutes or industry. Formal requirements for bidding rounds, peer review and evaluations should have no place within ARPA, with project managers needing to convince only two people – their Office Head and the ARPA Director – in order to allocate funding.

10. **Government must simultaneously develop the strong commercial pull-through to bring ARPA-developed technologies to the market.** This could take the form of a reform of public sector procurement, the creation of a single strategic customer for a particular area, the establishment of a tech-to-market group or other means – but is essential if ARPA is to be successful.



ARPA
Annual Budget: £250m - £300m
Headed by a Director..
Total employees <50
Either inside UKRI, independent agency, NDPB or charity

ARPA Offices (2 – 4)
Annual Budget: £50m - £100m
Determined by the Science Minister and reviewed every five years.
Each aligned to a grand challenge or major science area.
Headed by a Head of Office

Projects (5-10 per Office)
Annual Budget: £10m - £20m
Each focused on a specific, relatively narrow, project area.
Each headed by a highly skilled, specialist project manager (who may manage more than one project).

Grant Allocations
Budget: Typically £500k - £5m per grant, often over multiple years.
Allocated entirely at discretion of project manager, subject to Head of Office and ARPA Director approval.
May take atypical forms such as Challenge Prizes.

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