Submission of Evidence to The Cabinet Office Enquiry on The Biological Security Strategy

Prepared by Tom Hobson, Lalitha S. Sundaram, David Aldridge, Alec Christie, Brett Edwards, Malcolm Dando, Silviu Petrovan, Lijun Shang, William Sutherland, Seán Ó hÉigeartaigh, Rebecca Smith[1]

March 2022

1. Introduction and summary

The authors are academic researchers in the field of biosecurity, bioethics, biodiversity, technology governance and policy. We have a long-standing interest in policy and practice of biological security in the UK and globally. In this submission we draw upon our collected expertise in technology and innovation governance, horizon scanning, expert elicitation, foresight methods and biosecurity education, in addition to our knowledge of present and historical challenges and opportunities of biosecurity.

This is a joint submission from researchers at the Centre for the Study of Existential Risk[i] and BioRISC - Biosecurity Research Initiative at St Catharine's[ii] , alongside collaborators

[1] Tom Hobson (tch46@cam.ac.uk) led the submission, all other authors contributed equally (order randomized). Tom Hobson and Lalitha S. Sundaram are Research Associates at the Centre for the Study of Existential Risk, Seán Ó hÉigeartaigh is the acting Director of this institution. Brett Edwards is a Senior Lecturer in Security and Public Policy at the University of Bath. Malcolm Dando is an Emeritus Professor of International Security at the University of Bradford. Lijun Shang is a Professor of Biomedical Science at London Metropolitan University. Alec Christie is Henslow Research Fellow at Downing College, University of Cambridge, and an Associate of the BioRISC Initiative. Silviu Petrovan is a Research Associate in the Department of Zoology, University of Cambridge, and a member of the BioRISC Initiative. Rebecca Smith is a Senior Research Associate in the Department of Zoology, University of Cambridge, and a member of the BioRISC Initiative. David Aldridge is a Professor of Zoology at the University of Cambridge and a member of the BioRISC Initiative. William Sutherland is the Miriam Rothschild Professor of Conservation Biology at the University of Cambridge and Director of the BioRISC Initiative.

from the University of Bath, the University of Bradford and the Biological Security Research Centre at London Metropolitan University.

We argue here that there are a number of cross-cutting lessons to be learned from extant approaches to biosecurity, but that UK biological security — and the role of the UK as a soft-power leader in biosecurity globally — would be greatly enriched by the following:

- Work to enhance the capacity and policy participation of civil society and academic actors in developing and implementing the UK's biological security strategy on an ongoing basis
- Work to further enhance biosecurity and bioethics education across both practice and policy communities
- Further developing an approach that sees biological security as intrinsically connected to a number of other intersecting concerns, most notably, environmental degradation and climate change.
- Establishing a national coordinating institution to act as a focal point for the UK's national biological security strategy.

To this end, we highlight the need to consolidate domestic expertise in order to ensure that the UK biological security strategy is fit for purpose and is, by design, prepared for and resilient towards future developments in the biological sciences and adaptable towards shifts in intersecting fields. Additionally, **we also propose that there would be significant value in undertaking a further thoroughgoing assessment of progress made on the present Biological Security Strategy (2018) conducted by a consortium of interested parties from civil society and academia.**

In this submission we:

1. Argue that there **is a need for a new focal point for a UK biological security** strategy. **(Section 3.1)**

We highlight **the need for a coordinating body that** could play a pivotal role in linking up capacities domestically in the area of biological security assessment, strategy and governance. This body could: **a) systematically track developments of relevance to UK biological security**; **b) support the development and evolution of a robust civil society network to shape policy and best practice while; c) fostering collective oversight of**

both policy and practice; and d) develop consolidated policy on the issue of biosecurity, while acting as a coordinating institution for implementation.

This is the right time to discuss such a proposal, considering the UK's emerging foreign policy priorities as well as the recent establishment of the National Science and Technology Council and Office for Science and Technology Strategy. It would help build upon existing and emerging domestic capacities — and provide a new transmission-belt between civil society and government, as well as domestic and international work in this area.

2. **Suggest an organisational blue-print for such a body, outline the type of issues such a body could address** and propose some of the mechanisms it could implement. **(Section 3.2)**

Finally, we also discuss how such a body would potentially help build upon past and current UK successes in international institution building — by increasing domestic capacity to lead on international initiatives and foster closer collaboration with industry and other states in this area.

Such a body would put the UK in a better position to understand and respond to ongoing global transformations which are both mediated and driven by scientific advance and technological change.

3. Introduce a number of **approaches to fostering and maintaining strong biological security, centring on those approaches that emphasise civil society and academic engagement, reciprocal education, horizon-scanning and ongoing, early-stage assessment**. **(Section 4)**

We argue that it would serve the UK's current and longer-term biological security to: a) foster a robust engagement with relevant academic and civil society actors; b) more systematically monitor developments in science and technology, as well as evolving norms and practices in biotechnology governance globally, in an ongoing manner; c) advocate for biological security education that is forward-looking and engaged with pragmatic realities; d) utilise a broader range of horizon scanning tools, and; e) ensure that biological security is assessed as a complex and multifaceted risk that interacts with other risk and policy fields such as climate change.

2. Context

In 2018, the UK government produced the 'UK Biological Security Strategy' which was intended to bring together and set out in one place for the first time, the wide range of activity that is carried out across Government to do this. The strategy focused on the goals of Understanding, Preventing, Detecting and Responding to the wide range of biological hazards the UK faces. The document also set out a series of commitments related to its domestic and international facing policy.

Since this time, the emergence of COVID-19, and the broader impacts of the pandemic on a wide range of policy areas, has had a profound effect on this area of policy. In December 2020, Joint Committee on the National Security Strategy Biosecurity and National Security Enquiry made a series of recommendations — to which the UK government responded in March 2021.[iii] It is clear that there will be significant developments in this area of UK policy in coming years. Further to this, a recent academic study, has pointed to an even broader range of issues facing policy makers in this area.[iv]

The UK will continue to innovate both its domestic and international policy in this area in response to longer-standing interests, as well as those raised by the global pandemic. **Such work will likely benefit from additional means of co-operation and communication**. In addition, the emphasis placed on both innovation and the shaping of global norms seems to suggest that the UK will be expected to play an even more prominent role in the assessment of technological innovation as well as the norms that shape it globally.

This points to the value of supporting the ongoing development and review of policies specific to this issue area — but also to develop cross-cutting insights, practices and policies in the wide range of areas in which biological technology assessment and norms are becoming increasingly pertinent.

The UK has played a leading role historically in promoting biological security practices. This includes strong diplomatic leadership on matters related to the prohibition and non-proliferation regime directed at biological weapons.

The UK has held a prominent role in the negotiation and continued evolution of the Biological and Toxin Weapon Convention treaty regime — reflected most recently for

example in its participation in preparations for the Ninth Review Conference. This is in addition to the areas of export control harmonisation, global public health, global laboratory safety and security as well as the UK's long-term support for disarmament education for practising life-scientists.

In this area, the UK has an opportunity to both build upon this legacy of international leadership and to capitalise on the unique circumstances presented by the convergence of a post-Brexit and post-COVID19 world in the coming years.

According to the (now withdrawn) Bioeconomy Strategy, the UK bioeconomy is worth £220 billion GVA, and contributes over 5 million UK jobs.[v] The same report cites the prestige and influence of UK academic research in the biological sciences. **While the UK is a world player in life sciences research, and has historically led diplomatic efforts towards non-proliferation, there is presently no national coordinating institution to lead on policy and implementation of biological security.**

Any efforts to refocus the biological security strategy must centre on meaningful engagement with relevant civil society, academic and practitioner communities – a static rulebook will quickly become redundant. Instead, efforts should be made to draw upon, and further develop, strong independent expertise in biological research, bioethics and biosecurity within the UK, whilst also fostering enhanced and better integrated biological security education among policy and practitioner communities.

3. Establishing a UK Biosecurity Coordinating Body

3.1 Need for and Nature of National Co-ordination

A number of existing policy proposals have advocated for the creation of a national centre for biosecurity. The Joint Committee on National Security Strategy published its report on Biosecurity and National Security, where it advanced that:

> *The Government should establish a dedicated national centre for biosecurity, a new cross-government body to serve as a centre of expertise on the full spectrum of interlocked biological risks facing the UK.*[vi]

While the recommendation was not accepted in the government's response, it represents a good starting point for considering the blueprint and remit for such a national body. The recommendation in the JCNC focused on biosafety standards, contribution to the National Security Risk Assessment and disease surveillance.

Building on this, the Centre for Long Term Resilience further advocated for a National Centre for Biosecurity in its 2021 Future Proof report. The report noted:[vii]

> *The new National Centre for Biosecurity would be tasked with prevention of, and preparedness for, future large-scale and high-priority biological threats faced by the UK, regardless of their origin.*

In this submission, we similarly endorse the creation of a central coordinating organisation, however, we place greater emphasis on **the need for engagement with, and coordination of, a broad range of stakeholders from both within and outside government and developing mechanisms for ongoing biological technology assessment** as policy priorities. While the integration of biological security concerns into National Security Risk Assessments is doubtless important, we argue that **biosecurity education and mechanisms to better understand the opportunities and hazards of current and future biological technologies is an equally urgent task** for such a national coordinating body.[viii]

The UK should thus seek to establish a co-ordinating body, initially tasked with:

1. **Developing policy and encouraging best practice for biological security assessment of research projects throughout their lifecycle, in collaboration with relevant experts and stakeholders**
2. **Broadening and deepening engagement with relevant academic and civil society institutions, inclusive of learning relevant lessons from and maintaining pathways for policy input and oversight**
3. **Developing and rolling out enhanced biological security education**

The body should have a broad inclusive participation from across government, political parties, and wider civil society.

3.2. Proposed Organisational Structure

The organisational structure, and institutional affiliation of the co-ordinating body could take many forms, but in-order for our proposal to stimulate discussion, **we suggest it could have a five-part structure:**

Steering Committee: A leadership panel tasked with establishing standing and open-ended ad hoc working groups on key priority areas of technology and/or foreign policy objectives.

Administration and Reporting Body: Tasked with producing and disseminating report materials produced in collaboration with working groups, as well as the day-to-day administration of the functioning of the body.

UK Biological Security Assessment Strategy Working Group: This group will include senior representation for key stakeholders — as well as expert groups members. Initially it should be tasked with the development of policy options. Later tasks might include strategy implementation monitoring and review.

Emerging Technology Working Groups: These working groups are designed and populated by the steering committee. It is likely that there would need to be standing committees, arranged around important foreign policy agenda areas — or else specific areas emerging biological technology. The working groups would consist of relevant

technical experts and stakeholder representatives — nominated by the steering committee.

Industry and Research Outreach and Engagement Office: This group would be tasked with overseeing education activities and fostering meaningful participation and collaboration with academic, civil society and industrial stakeholders.

We recommend that the development of this coordinating body should be based, in part, on a thorough-going review of intuitional capacities and on existing developments in UK biological security governance since the strategy was announced in 2018.

Further to this, we advise that the authors will undertake such a review during 2022 and would welcome further discussion on this matter with the Committee.

4. Relevant approaches to fostering a resilient and adaptable biological security strategy

In this section we provide an overview of a number of relevant approaches and strategies that should underpin the development of a UK biological security strategy, and that should guide the formation of any coordinating institution.

4.1. Developments in science and technology

Biological technology capabilities are expanding rapidly and international regimes governing biological research date back several decades. **The convergent and frenetic nature of biotechnology advances raise significant proliferation concerns — and presents incremental as well as more fundamental challenges to the existing global biological weapon control regime**.[ix]

Currently, discussion and assessment of biological weapon proliferation risks take place in a wide range of contexts.[x] There is then always a substantial stream of both primary data on scientific trends, as well as expert discussion of the potential proliferation hazards of technology to keep track of the open literature.

The timely analysis of such work can provide an evidence base about the impacts of such advances in the area of non-proliferation and help support the UK in anticipating and shaping discussions of such developments at the global level.

Biological research and technology assessments should be an ongoing and central component of the UK biological security strategy. It should explicitly link international governance with the daily practices of biologists and practitioners, as advocated in the handbook "Preventing Biological Threats: What You Can Do" (see particularly Chapter 18: Future Governance of Biotechnology).[xi] The handbook states:

> ***Developments in science and technology could clearly have implications for the operation of the Conventions****, and processes have*

been developed for regular review of relevant scientific and technological advances. (Emphasis added).

While also noting that:

*Concerns have been raised that these processes are neither frequent nor comprehensive enough to adequately inform States Parties about relevant advances and possible forms of response**. As possible revisions to the processes are discussed, there is a clear role for advice from scientists on e.g. how frequently such reviews should take place, what sort of evidence they should be based on, and what the future role of scientists within such processes should be**. (Emphasis added).*

A UK national coordinating organisation could play a major role in promoting the participation of relevant expertise and meaningfully engaging with scientists and other experts in developing policy and practice.

Efforts to prevent the development and proliferation of biological weapons are multi-faceted and multi-layered. Frameworks to protect biodiversity and human and environmental health are similarly complex and numerous. Both require robust international agreement and national coordination of assessment, foresight and policy implementation. **Scientific and technological change has profound impacts upon these regimes.**

This is reflected in the attempts by numerous states and civil-society groups to engage technology assessment exercises in this area. It is also reflected in attempts to strengthen the S&T review mechanism of the BTWC[xii].

In order to develop a strong national biosecurity strategy, there is a need for the UK to support and track work that seeks to better understand the challenges involved in foresight of emerging biotechnologies.[xiiixiv]

There is also a need for the UK to track and explore the possibilities created by emerging and experimental frameworks for collaborative governance of biological research. This should include approaches that address rapid **c**hanges in technical, social, and political environments, coupled with the emergence of natural diseases such as COVID-19, that are testing existing governance processes.[xv]

This will allow the UK to develop and advocate good practice in the area. This includes advancing the evidence and methods developed and utilised by UK science advice and technology assessment institutions. It will also allow the UK to show-case and adopt methods developed within academia, civil society, and the private sector. We discuss many such approaches in further detail in section 4.2, below.

We wish to emphasise the importance of the following key practices for a robust and adaptable biosecurity strategy:

1. **Integration of *risk assessment* into the *earliest stages*** of developing and procuring novel technologies, especially for safety-critical or defence-related systems.[xvi]
2. **Ensuring *throughout-lifetime accountability*** for high-technology systems, particularly those used by the military.[xviixviii]
3. **Investing in regulation, auditing, and support for academic research to build an ecosystem** that is able to hold developers of emerging technologies accountable.[xix]
4. **scenario exercises and futures exploration** as tools to raise the profile of biosecurity, and to better understand the possible trajectories of scientific and policy development in the field.[xx]

4.1.1. Existing Models of Emerging (Biological) Technology Assessment

At both the national and the international level, there is a long history of attempts to monitor, assess and manage the broader economic, social and political impacts of technological change. Initially, technology assessment focused primarily upon providing an early warning for government planners of potential hazards associated with emerging technologies, based on expert advice. Over time however, technology assessment has come to include a much broader range of aims, institutions and activities.

The function of TA bodies has also extended beyond a more traditional science advice model — coming to incorporate approaches centred on:

i. **the provision of expert advice**
ii. **the facilitation of public discussion, and**
iii. **the integration of social and economic considerations to the stewardship and practice of innovation.**

A number of example cross-cutting technology assessment initiatives are outlined in Appendix I of this document.

4.2. Methods for emerging biotechnology assessment, foresight, and accountability

Consultation and evidence gathering for policy making in the realm of technology and science governance can often tend to be reactive to events rather than be anticipatory and as a result policy-making is less timely, effective and efficient. In order to address this, researchers at the BioRISC Initiative and at CSER have created a set of processes that we believe substantially improve risk assessment and planning. To date, these have been used for work on biosecurity and more broadly.

4.2.1. Horizon- and Solution-Scanning

We highlight a number of streams of work below, suggesting that they could inform biological research assessment practices or efforts to improve horizon scanning, foresight and models of expert engagement and elicitation.

1. **In order to understand how biological research and innovation may interact with or impact extreme risks or critical ecosystems**, researchers have pioneered the application of a range of *horizon scanning methods* based on the *investigate, discuss, estimate, aggregate* (IDEA) protocol.[xxixxiixxiii]
2. **To help direct research activities towards the most pressing topics**, they have utilised a *modified expert elicitation* to identify specific questions that are of sufficient breadth and importance to gain an understanding of priority research agendas within the life sciences globally, and that are of significance for the UK.[xxiv] Led by William Sutherland, the BioRISC Initiative is completing an open access edited book on improving decision making, that describes detailed methods such as expert elicitation.
3. **In the exploration of near-term developments in (biological) technology** they have advocated the use of regular *expert elicitation exercises* which emphasise a diversity of experts, and which may incorporate a "red team" approach to increase the range and creativity of scenarios considered.[xxvxxvi]
4. **To assist in the exploration of longer-term (biological) technological developments** we recommend the use of *theoretical analysis and survey work* to identify key themes and milestones that can structure future foresight exercises.[xxviixxviii]

We have run horizon scans on a wide range of subjects (26 so far), which can be broad — such as our horizon scans on conservation[xxix] or bioengineering[xxx] — or narrow — such as invasive species[xxxi]

We recommend that regular horizon scanning activities, engaging with relevant academic, industry and civil society stakeholders, should form a core element of the activities convened by a national biosecurity coordinating body.

We have similarly developed a number of approaches to solution scanning. We recommend that solution scanning may provide a valuable tool for a UK national biosecurity coordinating body. We suggest the process of solution scanning as an initial resource for the development of policy and practice in collaboration with relevant stakeholders.

4.2.2. Improving evidence-based decision-making:

Maintaining a current and thorough evidence base is an ongoing challenge for good policy and practice for biosecurity. BioRISC researchers have effectively conducted subject-wide evidence synthesis in relation to wetland and farmland management for conservation.

We believe it would be useful to collate all the evidence on biosecurity topics (where possible, and in conjunction with ongoing assessments), including laboratory safety or human behaviour change relating to biosecurity threats and hazards.

4.3. Improving biological security and bioethics education

It is widely accepted that biological security will require effective biorisk management at the international, regional, national, professional and institutional levels in what has become known as the web of prevention.[xxxii]

Yet the World Health Organisation's draft *Global guidance framework for the responsible use of the life sciences*[xxxiii] recently put out for consultation, states in its Executive Summary that:

> *…governance and oversight frameworks to manage the risks posed by science and technologies lag behind developments and innovation in the life sciences. There are several reasons for this situation, including the rapid development and diffusion of biotechnology capabilities; the lack of biorisk governance structures in many countries and the increasing convergence of the life sciences with other scientific fields (e.g., chemistry, artificial intelligence, nanotechnology and neurosciences**). In addition, there is an important lack of awareness of these biorisks and a lack of incentives among practising scientists, technologists and other managers and funders of scientific research and technology development to identify and mitigate such risks.** (Emphasis added)*

The draft then elaborated this point in its Introduction to the context of the report as follows:[xxxiv]

> *A chronic and fundamental challenge is that practising scientists, technologists, and other managers and funders of scientific research and technology development lack a basic awareness that their work – which is predominantly undertaken to advance knowledge and tools to improve health, economies and societies – could be conducted or misused in ways that result in health and security risks to the public. There is also a lack of incentives for these groups to identify and mitigate such risks.*

Although this view lacks support from any large-scale systematic surveys, it is supported by many smaller scale projects that have reported since the States Parties to the Chemical Weapons Convention (CWC) and the Biological and Toxin Weapons Convention (BTWC)

began to take a serious interest in codes of conduct for scientists to support these international agreements in 2005.

Moreover, **there is a well-supported view that in order to engage scientists effectively in support of these Conventions imaginative active learning processes will be required.**[xxxv]

The World Health Organisation's draft framework is also quite clear that **biological security education can be one of the tools and mechanisms that can be effectively used to improve biological security**, stating that:[xxxvi]

> ***Introducing responsible science concepts, including biosafety, biosecurity and dual-use****. Integrating concepts pertinent to conducting responsible research into scientific and medical curricula can enhance awareness of risks to health, safety and security with basic and applied life sciences. Academic and scientific institutions can help by including these concepts in their courses and educational activities. (Original Emphasis)*

The UK Government is well aware of this problem and, together with the Canadian Government, has financed the development of teaching resources on biological security education and translation of these resources into multiple languages for use overseas.[xxxvii]

UK Universities have also developed innovative ways of using active learning strategies in teaching biological security to scientists,[xxxviii] but correcting the current deficiencies in security education for the many thousands life scientists in the UK will require the long-term application of major resources well beyond anything that has been envisaged to date. **However, biological security will require enhanced biological security education worldwide.**

With the aim of supporting biological security here in the UK and elsewhere, **London Metropolitan University has set up a Biological Security Research Centre with one of its dedicated aims of setting up a biological security education hub to develop curriculum and training facilities.**[xxxix] However, collaborating internationally in biosecurity education with other countries would also benefit from requesting government support to find useful ways to implement the Tianjin Guidelines for Codes of Conduct that hopefully will be endorsed at BWC 9th Review Conference.[xl]

4.4. Deepening engagement with civil society and academia

Effective biosecurity policy is likely to be much more effective if it is broader in scope and intention, involving ongoing, multilateral, trust-based engagements between civil society (including scientists from academic, industry or other settings) and government.

Education certainly is an important part of this puzzle, as we have pointed out in **4.1** but there is also a need to work with a broader consortium of partners. Below we draw attention to a number of approaches that could be taken to build these partnerships:

4.4.1. Leveraging existing coalitions

The Royal Society for Biology (RSB) has played a pivotal role in the InterAcademy Partnership Biosecurity Working Group[xli] which was established to promote responsible research and to strengthen links to the BTWC.

The RSB co-convened a roundtable on a Scientific Advisory Process ahead of the BTWC's 8th Review Conference, and we argue that similar engagement ahead of the Review Conference in 2022 should be encouraged and supported. **Their report, *Assessing the implications of advances in science and technology for the Biological and Toxin Weapons Convention (BTWC)*[xlii], is a clear demonstration of how bodies like the RSB and its counterparts around the world can support biosecurity**, in activities that we suggest in other parts of this submission.

Involvement of organisations like these can also help ensure that a broader range of scientists (not just those working areas of biology already presumed, rightly or wrongly, to be 'risky' such as Gain-of-Function virology) are involved in biosecurity discussions:

4.4.2. Commercial and industry coalitions

Built with Biology (formerly SynbioBeta) is the leading global networking organisation for companies wishing to "use biology to make the planet a better place".[xliii] Prominent members include Twist Bioscience and Ginkgo BioWorks, US-based companies that both have some focus on biosecurity. Though biosecurity is not Built with Biology's mission,

it does address the issue in its internal publications, noting for example that "Biosecurity is Economic Security[xliv] ".

There is much to be gained from engaging with industry organisations, especially when much of cutting-edge biotechnology (such as DNA synthesis and organism design), and thus biosecurity points of interest, is facilitated by commercial entities that provide essential services (often remotely), like DNA synthesis or organism design.

They are thus **an important locus for oversight, regulation and legislation, at domestic and national levels. The UK's Industrial Biotechnology Innovation Centre (IBioIC)[xlv] could provide a similar complementary role here in sensitising industry members to issues of biosecurity** (including export controls) and providing them with a platform to participate in national conversations.

4.4.3. Responsible Research and Innovation expertise and advocates

A core element of effective biosecurity is a matter of governance and practice. These issues have been developed in academic and policy spheres as '**Responsible Research and Innovation**'. Some of the leading scholars in the field are based in UK institutions (see for instance work by Jack Stilgoe and Richard Owen[xlvi]).

Synthetic Biology in particular has been closely associated with this movement, with synbio initiatives often incorporating RRI streams within projects. In academia, this is notable in how RRI has been embraced by funding organisations like the BBSRC, EPSRC and the EC's Horizon 2020. This has also translated to industry interest: IBioIC recently held a conference on Responsible Research and Innovation.[xlvii] **However, the biosecurity element within RRI is rarely overt and therefore, we argue that there is a need to strengthen these existing programmes' connection to the Government's biosecurity mission.**

4.4.4. Distributed actors and the "DIY Bio" community

In non-traditional settings, the example of DIY-biology (loosely defined as biological practice that occurs outside traditional academic or industrial settings) is an instructive one in many dimensions.[xlviii] While the DIY-bio community is often assumed to be an

inherently bio-*in*secure one, **this is a space where much innovative thinking about norms and practice occurs**.

Currently in the UK, registration with the Health and Safety Executive appears to be the only formal interaction with policy that DIY-bio groups in the UK have; other efforts are entirely self-motivated. A prominent group of DIY-bio community-members recently published a wide-ranging biosafety and biosecurity manual, for example, an effort that should be applauded within biosecurity circles.[xlix]

We recommend that the UK biosecurity coordinating body should emphasise the meaningful involvement of scientists, civil society, industry and academic researchers in developing and implementing all of the approaches we have thus described. Practitioners are often well placed to understand the current and future potentialities of their research and, encouraging these communities to think 'beyond the lab bench' is also an important part of inculcating responsibility and biosecurity in practice.

5. Appendix I

The Global Technology Assessment Initiative	The Global Technology Assessment is a network of non-profit institutions from around the world working together in the area of science and technology, promoting responsible and sustainable research and innovation to tackle global grand challenges. Initiative membership includes a number of government technology review, advisory and assessment bodies from around the world.
The European Parliament Technology Assessment Network	The currently 23 members of EPTA give advice to their parliaments on topical issues such as nanotechnology, brain research, mobility pricing or future energy systems. Their projects use various methods and draw on insights from citizen panels, stakeholders, workshops as well as the foremost experts in the relevant fields.
UNIDIR Security and Technology Programme	Contemporary developments in science and technology present new opportunities as well as challenges to international security and disarmament. UNIDIR's Security and Technology Programme (SecTec) seeks to build knowledge and awareness on the international security implications and risks of specific technological innovations and convenes stakeholders to explore ideas and develop new thinking on ways to address them.
The International Academies Partnership	The InterAcademy Partnership (IAP) empowers academies and regional academy networks to provide independent, authoritative advice on global, regional, and national issues through synthesis reports, consensus statements, foresight

	studies, critiquing public policy processes and outputs, and convening key stakeholders.
Technology Facilitation Mechanism (TFM) Department of Economic and Social Affairs	The goal of the Technology Facilitation Mechanism is to support the implementation of the Sustainable Development Goals (SDGs). Its goal is to facilitate multi-stakeholder collaboration and partnerships through the sharing of information, experiences, best practices and policy advice among Member States, civil society, the private sector, the scientific community, United Nations entities and other stakeholders.

[i] The Centre for the Study of Existential Risk (https://www.cser.ac.uk/) is an interdisciplinary research centre within the University of Cambridge dedicated to the study and mitigation of risks that could lead to human extinction or civilisational collapse. 16 Mill Lane, Cambridge, CB2 1SB.

[ii] The BioRISC Initiative was established in 2019 thanks to the generosity of The David and Claudia Harding Foundation, with the objective of exploring ways of linking science and policy, especially in biosecurity. They work closely with The Conservation Evidence Team in the Department of Zoology, University of Cambridge and The Invasive Species Group in the Department of Zoology, University of Cambridge.

[iii] https://committees.parliament.uk/work/316/biosecurity-and-national-security/publications/

[iv] Kemp, L., Aldridge, D. C., Booy, O., Bower, H., Browne, D., Burgmann, M., ... & Sutherland, W. J. (2021). 80 questions for UK biological security. Plos one, 16(1), e0241190. https://www.cser.ac.uk/resources/80-questions-uk-biological-security/

[v] Department for Business, Energy and Industrial Strategy's Science and Innovation, https://www.gov.uk/government/publications/bioeconomy-strategy-2018-to-2030/growing-the-bioeconomy-a-national-bioeconomy-strategy-to-2030

[vi] Joint Committee for National Security https://committees.parliament.uk/publications/4035/documents/40449/default/

[vii] Future Proof. https://www.longtermresilience.org/futureproof

[viii] Whitby, S.et al (2015) Preventing Biological Threats: What you can do. https://www.bradford.ac.uk/media-v8/site/news/archive/Preventing-Biological-Threats-What-You-Can-Do-(PDF,-10.6mb).pdf

[ix] Wintle, Bonnie C et al., 2017. A transatlantic perspective on 20 emerging issues in biological engineering. *eLife*, 6, eLife, 2017–11-14, Vol.6. https://pubmed.ncbi.nlm.nih.gov/29132504/ Luke et al., 2020. Bioengineering horizon scan 2020. eLife, 9, pp.eLife, 2020–05-29, Vol.9. https://elifesciences.org/articles/54489

[x] Revill, A. Anand and G. Persi Paoli. (2021) Exploring Science and Technology Review Mechanisms Under the Biological Weapons Convention, Geneva, Switzerland: UNIDIR, https://doi.org/10.37559/SECTEC/2021/SandTreviews/01

[xi] Whitby, S.et al (2015) Preventing Biological Threats: What you can do. https://www.bradford.ac.uk/media-v8/site/news/archive/Preventing-Biological-Threats-What-You-Can-Do-(PDF,-10.6mb).pdf

[xii] Revill, A. Anand and G. Persi Paoli. (2021) Exploring Science and Technology Review Mechanisms Under the Biological Weapons Convention, Geneva, Switzerland: UNIDIR, https://doi.org/10.37559/SECTEC/2021/SandTreviews/01

[xiii] Beard, S., Rowe, T., & Fox, J. (2020). An analysis and evaluation of methods currently used to quantify the likelihood of existential hazards. Futures, 115, 102469. https://www.cser.ac.uk/resources/analysis-evaluation-methods/

[xiv] Currie, A. (2019). Existential risk, creativity & well-adapted science. Studies in History and Philosophy of Science Part A, 76, 39-48. https://www.cser.ac.uk/resources/xrisk-creativity/

[xv] Centre for the Study of Existential Risk. (2019). Managing global catastrophic risks Part 1: Understand. https://www.cser.ac.uk/resources/policy-series-managing-global-catastrophic-risks-part-1-understand/

[xvi] Beard, S., Rowe, T., & Fox, J. (2020). An analysis and evaluation of methods currently used to quantify the likelihood of existential hazards. Futures, 115, 102469. https://www.cser.ac.uk/resources/analysis-evaluation-methods/

[xvii] Rhodes, C. (2020). Scientific freedom and responsibility in a biosecurity context. In The freedom of scientific research. Manchester University Press. https://www.cser.ac.uk/resources/scientific-freedom-and-responsibility-biosecurity-context/

[xviii] Kemp, L., & Rhodes, C. (2020). The Cartography of Global Catastrophic Governance. https://www.cser.ac.uk/resource_s/cartography-global-catastrophic-governance/

[xix] Hanea, A. M., McBride, M. F., Burgman, M. A., Wintle, B. C., Fidler, F., Flander, L., ... & Mascaro, S. (2017). Investigate Discuss Estimate Aggregate for structured expert judgement. International Journal of Forecasting, 33(1), 267-279. https://www.cser.ac.uk/resources/investigate-discuss-estimate-aggregate-structured-expert-judgement/

[xx] Hemming, V., Burgman, M. A., Hanea, A. M., McBride, M. F., & Wintle, B. C. (2018). A practical guide to structured expert elicitation using the IDEA protocol. Methods in Ecology and Evolution, 9(1), 169-180. https://www.cser.ac.uk/resources/practical-guide-structured-expert-elicitation-using-idea-protocol/

[xxi] Jucker, T., Wintle, B., Shackelford, G., Bocquillon, P., Geffert, J. L., Kasoar, T., ... & Mukherjee, N. (2018). Ten-year assessment of the 100 priority questions for global biodiversity conservation. Conservation Biology, 32(6), 1457-1463. https://www.cser.ac.uk/resources/tenyear-assessment-questions-conservation/

[xxii] Kemp, L., Aldridge, D. C., Booy, O., Bower, H., Browne, D., Burgmann, M., ... & Sutherland, W. J. (2021). 80 questions for UK biological security. Plos one, 16(1), e0241190. https://www.cser.ac.uk/resources/80-questions-uk-biological-security/

[xxiii] Wintle, B. C., Boehm, C. R., Rhodes, C., Molloy, J. C., Millett, P., Adam, L., ... & Sutherland, W. J. (2017). Point of View: A transatlantic perspective on 20 emerging issues in biological engineering. Elife, 6, e30247. https://www.cser.ac.uk/resources/point-view-transatlantic-perspective-20-emerging-issues-biological-engineering/

[xxiv] Kemp, L., Adam, L., Boehm, C. R., Breitling, R., Casagrande, R., Dando, M., ... & Sutherland, W. J. (2020). Point of View: Bioengineering horizon scan 2020. Elife, 9, e54489. https://www.cser.ac.uk/resources/bioengineering-horizon-scan-2020/

[xxv] Martınez-Plumed, F., Loe, B. S., Flach, P., O hEigeartaigh, S., Vold, K., & Hernández-Orallo, J. (2018). The facets of artificial intelligence: a framework to track the evolution of AI. In International Joint Conferences on Artificial Intelligence (pp. 5180-5187). https://www.cser.ac.uk/resources/facets-AI/

[xxvi] Cremer, C. Z., & Whittlestone, J. (2020). Canaries in Technology Mines: Warning Signs of Transformative Progress in AI. https://www.cser.ac.uk/resources/canaries-technology-mines/
[xxvii] Jayanti, A., & Avin, S. (2020). It Takes a Village: The Shared Responsibility of 'Raising' an Autonomous Weapon. Submitted to and Presented at RSIS Military Transformations Programme Workshop. https://www.cser.ac.uk/resources/it-takes-village/
[xxviii] Shackelford, G. E., Kemp, L., Rhodes, C., Sundaram, L., ÓhÉigeartaigh, S. S., Beard, S., ... & Sutherland, W. J. (2020). Accumulating evidence using crowdsourcing and machine learning: A living bibliography about existential risk and global catastrophic risk. Futures, 116, 102508. https://www.cser.ac.uk/resources/accumulating-evidence-using-crowdsourcing-and-machine-learning-living-bibliography-about-existential-risk-and-global-catastrophic-risk/
[xxix] Sutherland et al (2022).A horizon scan of global biological conservation issues for 2022. Trends in ecology & evolution
[xxx] Kemp, L., Aldridge, D. C., Booy, O., Bower, H., Browne, D., Burgmann, M., ... & Sutherland, W. J. (2021). 80 questions for UK biological security. Plos one, 16(1), e0241190.

[xxxii] Novossiolova, T. A., Whitby, S., Dando, M. R. and Pearson G. S. (2021) *One Health Outlook*, **3**, 17. Hjttps://doi.org/10.1186/s42522-021-00049-4.
[xxxiii] World Health Organisation (2022) *Global guidance framework for the responsible use of the life sciences.* WHO, Geneva, 22 February, p.12.
[xxxiv] WHO (2022) *op. cit.* p .17.
[xxxv] Novossiolva, T. A., Dando, M. R. and Martinelli, M. (2021) Enhancing the Utility of Codes of Conduct for Chemical and Biological Security through Active Learning. *ACS Chemical Health and Safety*, Special issue "Safety Policy, and Codes from Around the World", https://doi/10.1021/acs.chas.1c00047.
[xxxvi] WHO (2022) *op. cit.* p 53
[xxxvii] Whitby, S., Novossiolova, T., Walther, G. and Dando, M. R. (2015) *Preventing Biological Threats: What You Can Do*. University of Bradford, Bradford, December.
[xxxviii] Novossiolova, T., Shang, L. and Dando, M. R. (2021) Biological Security Education, Awareness, and Outreach as Essential Elements of Strengthening the Review of Science and Technology under the BTWC. *Journal of Chemical and Biological Weapons*, **Winter**, 36 – 40.
[xxxix] London Metropolitan Biological Security Research Centre: https://www.londonmet.ac.uk/research/centres-groups-and-units/biological-security-research-centre/
[xl] Yang X, Shang L, Zhang W. (2021) Building a Multiple-level System of Ethical Code for Biological Scientists under the Biological and Toxin Weapons Convention (BTWC) of the United Nations with Effective Implementation. *Journal of Biosafety and Biosecurity*, **3**: 108-119
[xli] https://www.interacademies.org/project/iap-biosecurity-working-group
[xlii] https://royalsociety.org/topics-policy/projects/biological-toxin-weapons-convention/
[xliii] https://www.sgr.org.uk/projects/science-oath-climate
[xliv] https://www.builtwithbiology.com/
[xlv] https://www.ibioic.com/
[xlvi] Stilgoe, R., Owen, R., and Macnaghten, P. (2013) Developing a framework for responsible innovation. *Research Policy*, **42**: 1568-1580
[xlvii]https://carbonrecycling.net/event/responsible-innovation-industrial-biotechnology-and-engineering-biology/
[xlviii]. Sundaram, L. S. (2021) Biosafety in DIY-bio laboratories: from hype to policy. *EMBO Reports*, **22**: e52506.
[xlix] https://www.genspace.org/community-biology-biosafety-handbook