Chapter 12

Foresight in Synthetic Biology and Biotechnology Threats

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Abstract Rapid developments in the fields of synthetic biology and biotechnology have caused shifts in the biological risk landscape and are key drivers of future threats. From a security perspective, extending our understanding beyond current risks to include emerging threats in these and related fields can play a vital role in informing risk mitigation activities. Insights that are generated can be combined with other efforts to identify vulnerabilities and prevent undesirable outcomes. Emerging risks that may occur at some point in the future are inherently difficult to assess, requiring a systematic approach to examining potential threats. Foresight is a process to consider possible future scenarios. Comprising a range of methods and

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techniques, foresight processes can offer novel insights into emerging synthetic biology and biotechnology threats.

This chapter offers an introduction to foresight, including definitions of key terms that could support a shared lexicon across NATO partners. An overview of different foresight methodologies, their potential applications, and different strengths and limitations are presented. As a key first step, an approach to selecting appropriate questions to guide foresight activities is suggested. Example questions for synthetic biology and biotechnology are highlighted. At the end of the chapter, the authors offer recommendations for the design of a foresight process, with the intention of providing a useable resource for NATO partners investigating emerging synthetic biology and biotechnology threats.

12.1 Introduction

The study of the future dates back to antiquity. Understanding what could lie ahead was of strategic importance to rulers and military leaders and was of great general interest to ancient societies and religions. While cultures developed different ways of thinking about the future that evolved over time, a historically common point of view was that there was one single predetermined future (Cuhls et al. 2012). The systematic study of different possible futures, and how these could be shaped by present actions, emerged as a new field of inquiry in the mid-twentieth century, in part due to pioneering work conducted by the Research and Development (RAND) corporation in Santa Monica, California (Kaplan et al. 1950; Helmer 1967). Since its emergence, the field of futures studies has undergone rapid expansion with the refinement of its conceptual underpinnings and development of different methodologies.

Today, futures work is undertaken by governments, militaries and scientific institutions, and other interested groups, with the aim of gaining actionable insight into possible emerging futures. In fields like synthetic biology and biotechnology that are undergoing rapid and continuous change, the ability to gain strategic insight from possible futures is highly relevant to policy development, risk assessment and threat analysis. It is particularly important to be able to identify the underlying drivers, range of uncertainty, points of convergence, and potential opportunities and challenges in these developing fields, and how these might be affected by particular policy interventions. For all of these, foresight – a process of conducting futures work – can offer strategic insight.

Foresight has been defined in multiple ways. In this chapter, we use an understanding commonly found in the literature, which highlights that it is first and foremost a process that involves “systematically attempting to look into the longer-term future of science, technology, the economy and society” through which “one comes to a fuller understanding of the forces shaping the long-term future” (Martin 1995; Miles 2010). Foresight, therefore, differs from forecasting, in that it does not aim to

predict the future. Although the two terms are sometimes used interchangeably, forecasting is concerned with making “a probabilistic statement, on a relatively high confidence level, about the future” (Martin 2010).

Foresight can also be contrasted with hindsight, which is a systematic examination of the past. While the past offers useful information that can inform a foresight process, hindsight has access to outcome information that foresight does not. Care should be taken when combining these processes in order to avoid “observation selection effects” or biasing thinking towards historical occurrences (Fischhoff 1975).

Many additional terms specific to futures studies have been introduced and refined in the literature, with some confusion arising given shared and contradictory wording used in colloquial contexts (Trump et al. 2019). In order to use clear terminology in describing futures research, with the aim of developing a consistent lexicon across NATO partners, a definitions list is provided below. This is followed by examples of foresight research conducted on the topics of emerging synthetic biology and biotechnology.

The two subsequent sections provide an overview of different foresight methodologies and present an approach to foresight question choice, highlighting some specific questions for synthetic biology and biotechnology. Finally, recommendations for the design of a foresight process are offered, with the intention of providing a useable resource for NATO partners investigating emerging synthetic biology and biotechnology threats.

12.1.1 Foresight Terminology

Audience The individuals or organisations that are the intended recipient or end-user of the foresight process output. This might include, for example, government, business, military, civil society or broader public groups.

Backcasting Starting from a point in the future, analysing backwards in time the steps required for that future to occur.

Brainstorming A process in conversations or workshops used to develop a list of issues, drivers or ideas on a topic.

Cross-Impact Analysis An exploratory method to investigate the positive and negative effects between different interacting outcomes. It assumes that future events do not occur independently from each other, but rather the development of one influences the development of another.

Delphi Method A structured method used to gather and systematically prioritise expert views on the future.

Driver A key force or trend that is likely to have an impact in a relevant area.

Fifth Scenario A method to add a new scenario to an already existing set of scenarios to improve the understanding of the impact of the factors and drivers.

Futures Studies Structured approaches used to explore possible futures.

Forecasting A process used to make predictions about the future, commonly involving the use of past data and analysis of trends.

Foresight A process which systematically attempts to examine possible futures and determine the drivers shaping the longer-term future.

Horizon Scanning A specific foresight technique used during investigation which serves as a basis for analysis.

Participants The people taking part in a foresight exercise.

Roadmapping A method to showcase how a range of inputs, such as certain technology trends or policy changes, may combine in future development of the area of interest.

Red Teaming A process by which an external and independent group challenges an organization by assuming an adversarial role, with the aim of identifying weaknesses and gaps that can be addressed.

Scenario Analysis A process by which a range of identified possible future events are examined by considering alternative possible outcomes.

Scenario Creation Building scenarios for the purpose of a foresight exercise. It can be subdivided into four or more phases, including: *Investigation* (e.g. Horizon Scanning), *Analysis* (e.g. Driver identification; Uncertainty Analysis; Cross Impact Analysis), *Projection* (e.g. Scenario Writing), *Implications* (e.g. Backcasting; SWOT analysis), *Communication* (e.g. Trend reporting) and *Monitoring* (e.g. Trend monitoring).

Scenario Construction A generic term that summarizes various methods for scenario creation, with the end result being generation of generic scenarios which are transferred into narrative format for ease of communication.

Scenario Writing A method to create coherent scenario storylines in order to communicate them clearly to an audience.

SWOT Analysis A method of identifying the Strengths, Weaknesses, Opportunities and Threats (SWOT) in an area of interest.

Trend A general course, prevailing tendency or emerging pattern that suggests a change or particular trajectory.

Trend Analysis A process by which past data is examined and a pattern discerned.

Uncertainty Analysis A method used to identify key factors through analysis of possible impacts and their probability.

Wild Card An event that has a very low probability of occurring, but would have very high consequences.

12.1.2 Examples of Foresight for Biological Threats

While futures research is relevant to many fields, this chapter will focus on its applications to emerging synthetic biology and biotechnology threats. Conducting foresight in these domains is highly relevant to governments, military institutions, and a range of industry, academic and civil society groups given the rapid speed at which developments are taking place. There are a growing number of ways in which synthetic biology and biotechnology may pave the way to novel and high consequence risks while simultaneously offering new opportunities to address them (Hauptman and Sharan 2013). Foresight processes can help to avoid technological surprise and unexpected societal impacts, in part through identifying possible security threats before they emerge. When done well, insights from foresight exercises in synthetic biology and biotechnology can be used to inform action to avoid undesirable futures.

Foresight research for emerging synthetic biology and biotechnology issues has already taken place in a variety of settings. The following section highlights some recent published examples.

Using a scenario analysis ‘causes and consequences’ method, a 2013 study investigated reasons why an international Genetically Engineered Machine (iGEM) competition might hypothetically be closed down (Frow and Calvert 2013). The group quickly identified biosecurity and biosafety concerns, including synthetic biology competitors engineering pathogens with pandemic potential, as a possible reason. In another horizon scanning study looking at environmental threats to the UK, emerging biotechnology methods to genetically engineer pathogens were found to pose a ‘high’ risk of unintended consequences for biodiversity if released (Sutherland et al. 2008).

In one 2013 foresight study on emerging technologies, new gene transfer technologies and synthetically engineered biological agents ranked amongst the top ten risks, when prioritised by threat intensity and potential for misuse (Hauptman and Sharan 2013). The authors highlighted that security policy can be informed by adopting a long-range perspective where awareness would enable mitigation of threats that might otherwise be unaddressed.

A 2015 Delphi study asked 63 experts from government, academia, industry and non-governmental organisations how they perceive the bioweapons threat (Boddie et al. 2015). It found a wide diversity of opinion, including on the likelihood of an attack in the next 10 years with significant difference between biological scientists and other participants. Use of biological weapons by nonstate actors, especially religious extremists, or covert use of biological weapons by a state, were seen as much more likely than overt use by state actors. However, in this study, the diversity of participant views led the authors to conclude that assessing risks that research would be misused will be challenging: “a red line for what is allowable and what is forbidden in the name of security may not be clearly defined, and the way forward will be nuanced and complicated, possibly requiring a case-by-case evaluation with guidelines agreed upon by the scientific and policy communities” (Boddie et al. 2015).

In a 2017 report, scenario development was used to assess the changing security landscape in light of new genome editing technologies (Kirkpatrick et al. 2018). In this study, plausible future scenarios were developed through a series of workshops involving subject matter experts and published research. Using this approach, the authors were able to examine the current vulnerabilities and risks and couple each scenario with policy options to address governance gaps identified.

A 2017 study used a modified Delphi technique to examine emerging issues in biological engineering (Wintle et al. 2017). Twenty-seven experts from a diverse range of backgrounds participated in a horizon scanning exercise and identified 70 potential issues. Through voting and a workshop to systematically discuss the short-list, 20 top-scoring issues emerged. These included issues highly relevant to synthetic biology and biotechnology threats, including synthetic gene drive developments, accelerated defence agency research in biological engineering, including the Defense Advanced Research Projects Agency (DARPA) Insect Allies Program, and the emergence of robotic ‘cloud labs.’

In 2018, a consensus study report by the National Academy of Sciences in the US proposed a framework for assessing concern associated with a new technology in the field of synthetic biology (National Academies of Sciences, Engineering, and Medicine 2018). The framework was comprised of four main components: the technology’s usability, the potential for use as a weapon, the requirements of actors and the potential for mitigation. Combined, this allowed for the ranking of synthetic biology-enabled capabilities by level of relative concern, with the highest being: recreation of known pathogenic viruses, biochemical production via *in situ* synthesis, and modifying bacteria to be more transmissible and/or lethal.

The above research highlights the role that foresight studies can serve in identifying novel threats in synthetic biology and biotechnology. The value in conducting formal, structured exercises comes from collating ideas and perspectives from a range of participants. Bringing together experts from diverse fields and backgrounds for a foresight study can enable identification of convergence points of technologies, which is highly relevant to synthetic biology and biotechnology threats. The following section will discuss in more detail different foresight methods, and highlight their strengths and limitations.

12.2 Foresight Methods

Since foresight emerged as an approach to futures studies, multiple techniques have been developed. Broadly, these can be divided into qualitative and quantitative methods (Fig. 12.1). It should be noted that often multiple methods are combined to examine a foresight research question. A general approach to foresight is presented below, followed by a non-exhaustive examination of common foresight methodologies, outlining their intended use, how they are applied, and their inherent strengths and limitations.

12.2.1 General Approach

While foresight methods vary widely, the majority share a common approach involving taking a range of inputs – such as historical data, published literature, technological trends or expert opinion – and conducting a structured exercise involving analysis, interpretation and prospection (Voros 2003). The type of foresight process selected will inform the tools that can be employed at this stage, which can include trend analysis, driver identification, and envisioning possible future scenarios. The output of a foresight exercise can be tangible or intangible, and might include identification of the range of next-step options, or general changes in thinking about the topic under scrutiny. Foresight processes should be set up so that the outputs can support action, for example by being able to directly inform planning, policy and strategy.

Fig. 12.1 Overview of some common forecasting methods

12.2.2 *Delphi Method*

One of the first foresight techniques developed, the Delphi Method is still widely used today.¹ This method employs a structured group communication process to allow future scenarios to be constructed. Using a multi-step approach, the Delphi Method allows for individual expert contributions and feedback with the aim of reaching participant consensus on all posted responses (Linstone and Turoff 1975). Carrying out a Delphi exercise requires planning and preparation, with the whole process taking weeks to months. The phases are outlined below.

Phase A: Participant Selection

The first phase consists of selecting and inviting individuals to participate in the foresight study. This phase is important because the outcome of the Delphi exercise will depend upon the knowledge and range of expertise of the participants. It is recommended to aim for between 15-35 specialist participants (Renzi and Freitas 2015). Invitations should be sent to experts from a range of backgrounds, which might include technologists and representatives from civil society, the natural and social sciences, humanities, and the defence, intelligence and security services. Achieving diverse participation should bring the relevant expertise without biasing the outcome to a narrow perspective from one domain. Participant selection should be guided by the foresight research question and consideration should be given to ensuring cultural and demographic diversity.

Phase B: Questionnaire

After participants have accepted the invitation to take part in the Delphi exercise, a strategically formulated questionnaire should be sent to each individual. Questions should be clearly phrased and their objective transparent, but they should not be leading. Answers should be collated anonymously into a single document which is sent to all participants for review and comment, with the aim of reaching a consensus on its contents.

Phase C: Future Scenarios

Following *Phase B*, the combined document is then used by the study organisers to construct future scenarios. Each scenario should be based upon the foresight exercise theme, and the total number generated should be agreed with the expert participants. The scenarios should be built from the convergence of material submitted and be expanded upon in an iterative fashion with expert input. This phase can be conducted remotely, or completed in a workshop format.

¹ The Delphi Method was named after the Greek Oracle of Delphi, the high priestess of the Temple of Apollo who was said to be able to prophesize the future, although this foresight method's reliance on collated expert opinion and group consensus to deliver multiple possible scenarios makes the analogy imperfect.

Phase D: Result Analysis

The resulting scenarios should be analysed to understand their implications. In particular, actions that can be taken to steer towards desirable future scenarios or away from identified risks should be summarised explicitly. The results of scenario exercises can be condensed into a report with the intended target audience in mind.

12.2.2.1 Strengths

The Delphi Method has a variety of strengths depending on how the exercise is prepared. Bringing together a range of subject matter experts from diverse but relevant fields allows for the generation of multiple ideas that cover different perspectives. Because participant opinions are initially solicited individually, groupthink can mostly be avoided. A consensus can be reached rapidly, and the ideas generated can be refined by experts in the later phases. Some of these viewpoints would be difficult to extract from the literature or other sources, and therefore this method is useful to generate ideas in an area where data is lacking. The Delphi Method is also attractive because it is relatively low cost to administer, especially when conducted remotely via email.

12.2.2.2 Limitations

This foresight technique is ultimately bound by how it is initially constructed. Poor selection of participants, questionnaire content, or route to later expert input, can limit the usefulness of its results. Because consensus is required in Phases B and C, the Delphi Method struggles when there is a wide range of differing opinions or conflicting views. The method is also prone to various biases, being constrained by the knowledge and opinions of the participants, and carrying the risk that the facilitator's viewpoints and interpretation can dominate the analysis in the final report. The Delphi Method can also be quite time consuming, both for those leading it – with each phase lasting several weeks to allow expert input to be gathered – and for participants whose active involvement is needed throughout the process.

12.2.3 Horizon Scanning

There is ambiguity around the meaning of the term “horizon scanning” as it is often used interchangeably with “foresight” and “futures.” However, although some variation exists, amongst practitioners in the field horizon scanning is generally a well-defined foresight method. A standardized approach to horizon scanning is outlined below.

The UK Government Office for Science Futures Toolkit presents a ‘Three Horizon Model’ in which Horizon 1 issues fall within current policy and strategy, Horizon 2 issues are those that increase in importance in the medium term, and

Horizon 3 (H3) issues are new challenges and opportunities that have not yet begun to emerge, and whose drivers are difficult to spot (Government Office for Science 2017). Horizon scanning activities are generally aimed at H3: There is no commonly accepted timeframe for this horizon; in some contexts horizon scanning work may look 5 years ahead and in others a 20 year gap may be considered.

The aim of horizon scanning is to identify and understand so-called “weak signals”. These are events, trends and developments taking place today that could shape H3. In most cases, it will not yet be clear what their impact will be on H3, which are the more and less important signals, and how they may evolve or converge in the future.

Horizon scanning involves a group of participants who collect information and opinions, usually over the course of at least several weeks. Some horizon scanning exercises ask participants to perform “scans” at regular intervals (e.g. once a week). These scans are brief, often no more than one-page reports on possible signals to be considered. In a very open-ended exercise, participants are given the freedom to report on any signal they feel is relevant, based on any source of information. In a more constrained horizon scanning exercise, individual participants may be asked to consider particular issues, or monitor a specific source of information (e.g. a particular academic journal).

At the end of the exercise, all scans from every participant are compiled into a single document which synthesizes their findings and highlights recurring themes. Other approaches are possible; some horizon scanning activities adopt a phased structure, involving individual submissions first, and later collective refinement and prioritising of issues. In many organizations, the results of horizon scanning are used to inform further futures work, such as scenario exercises or a Delphi Method activity (see above).

12.2.3.1 Strengths

Horizon scanning exercises are relatively easy to organise, and can be performed without a physical meeting taking place between participants. They also enable a diverse group of stakeholders to be engaged in considering the future. Participants may range across disciplines and backgrounds, bringing together a variety of perspectives.

Another strength of horizon scanning is its emphasis on external stakeholders and sources; the technique is not reliant on in-house expertise or knowledge. Rather, the aim is to filter through a large volume of data, leveraging many stakeholders to distill a list of weak signals or identified issues that could influence H3. Horizon scanning is inherently inclusive; its aim is not to narrow down this list, so a large number of signals are usually considered and included. Subsequent phases may include work to prioritise or rank signals or issues.

12.2.3.2 Limitations

Although offering many advantages, the very wide net thrown by horizon scanning exercises is an important limitation to consider. Horizon scanning usually produces a large list of weak signals, but many of the signals identified may be irrelevant or unimportant. This can be mitigated by using a phased approach, or subsequently trimming the list with other futures techniques, e.g. to produce a set of scenarios for further expert elicitation.

Horizon scanning also relies to some degree on human intuition. In many cases, even for signals which will ultimately prove critical, there is little evidence available to assess their importance. It is important that those taking part in a horizon scanning exercise, and those who will be using its output, understand and accept this limitation. It is inherent in the long-term focus of horizon scanning that many of its results will not be robustly evidence-based.

12.2.4 Scenario Analysis

Scenario Analysis is a useful method to identify the multiple ways situations in the future might evolve. This technique can help decision makers develop plans to exploit opportunities, reduce uncertainties and manage risks the future may hold. Additionally, the monitoring of indicators embedded in various scenarios can create early warning signals of likely future trajectories. Scenario analysis is recommended when a situation is complex or single predictions are too uncertain to trust.

If used in the initial stages of national policy formulation or long-term corporate strategies, scenario analysis can have a strong impact on decision making. This method provides a set of plausible and possible futures for which decision makers may need to consider. It is also useful as a tool for strategic planning processes that brings together decision makers or stakeholders with analytical experts to work on alternative futures for which they must plan. Engaging stakeholders and decision makers in the scenario analysis process can generate commitment for the projects, save time and produces more useable results.

Scenario creation, which surrounds the process of scenario analysis, can be subdivided into different phases, including: *Investigation* (e.g. Horizon Scanning), *Analysis* (e.g. Driver identification; Uncertainty Analysis; Cross Impact Analysis), *Projection* (e.g. Scenario Writing), *Implications* (e.g. Backcasting; SWOT analysis), *Communication* (e.g. Trend reporting) and *Monitoring* (e.g. Trend monitoring). In order to create scenarios including implications at least the first four phases are required.

There are different techniques for generating scenarios, e.g.: *Simple Scenarios*, *Cone of Plausibility*, *Alternative Future Scenarios*, *Explorative Scenario Construction* with or without quantitative analysis. These methods have been referred to by various names in the literature.

12.2.4.1 Strengths

The use of scenarios offers the possibility to describe many different possible and plausible futures. Comparing multiple scenarios in the analysis makes it easy to identify factors or drivers that are essential for future developments, whether desired or not. In addition, scenario analysis can be used to test assumptions about the future or even find and warn against critical developments.

A very important advantage of scenario analysis is the possible involvement of decision-makers and stakeholders in the scenario process. This promotes a high level of understanding for the various possible future developments and achieves a high commitment to the actual work.

12.2.4.2 Limitations

The results of a scenario analysis exercise can be misleading if the group of participants are too homogeneous with limited diversity, falling prey to groupthink. For the method to be successful, it is necessary to have creative thinking and prospection far into the future about a variety of plausible possibilities. If the participants in the scenario analysis do not fully engage with this step, this will severely affect the quality of the results. In addition, it is important that the analyst for the exercise is an expert in the analytic techniques and also has a deep understanding of the subject matter. This is critical to ensuring appropriate analysis of the quality of the key driving factors and the assumptions that are present throughout the exercise.

12.3 Foresight Questions

The formulation and selection of question(s) are very important components of the foresight process. Compared to approaching a topic broadly, well-constructed questions enable a tailored exercise. Not only should the question encapsulate the subject matter to be examined, but it should also lead towards actionable content in the final output. The following section covers an approach to question choice and lists specific questions that could be considered for emerging synthetic biology and biotechnology threats.

12.3.1 Approach to Choosing Questions

For any given area of interest, there could be a range of questions that a group would like to answer about possible futures. Framing the question(s) carefully at the beginning of the foresight process will help define the study's aim and scope, and have an

important impact on the quality of the process. Questions should be designed such that they are:

- Framed in broad, rather than specific, terms
- Open and not too narrowly focused
- Stimulating discussion and thinking instead of leading to a particular endpoint
- Within a specific timeframe (e.g. in the next 15 years)

Participants in a foresight exercise should be made aware of the overarching question as early as possible in the process. The question itself need not overly constrain the final report or its conclusions; unanticipated areas of interest might arise during the process, for example. At the same time, questions should be formulated so that they avoid out-of-scope deviations that might hinder the topic of interest being fully addressed.

12.3.2 Questions for Synthetic Biology Threats

Concern about potential emerging threats associated with synthetic biology and biotechnology and related fields can lead to a range of future-focused questions of strategic interest to national governments, military leaders, and a range of other groups. The focus of these questions could, for example, range from future risks associated with a particular form of biotechnology or a new synthetic biology development, advancements more broadly in these fields, or on convergence of two or more trends within these and related fields.

Often it will not only be emerging threats which are of interest when seeking to apply foresight to synthetic biology and biotechnology. There is also great interest in more positive aspects of the transformative potential of these technologies and the ways in which developments might also help to address security threats. While some questions and the associated processes may focus only on one aspect, there will also be value to foresight processes which combine these. In addition to this, it is not only technological developments that will influence the future security impacts of synthetic biology and biotechnology, but also developments in economic, social and political contexts, and changes to the policy and regulatory environments. Questions can be designed that will incorporate some of these developments as well.

Some example questions in this area, formulated during the workshop, that may be of strategic interest include:

- Over a 15 year timeframe, what are the potential impacts of synthetic biology developments converging with other disruptive technologies?
- In the next 10 years, what regulatory and legislative gaps will be prominent if developments in gene-editing technology converge with a widespread availability of low-cost desktop DNA synthesizers, enabling the capability of practically any lab to design, engineer and print pathogen genomes?

- If, in the next 5 years, a do-it-yourself synthetic biologist were to accidentally or deliberately release a contagious human pathogen, what impact would this have on the research community as a whole and Code of Conduct creation?
- Will current information controls, such as embargoes on publication of dual-use synthetic biology research, be suitable in 20 years?
- In the next 10 years, how will emerging DNA synthesis technology impact screening for potential synthetic biology threats?
- How will developments in delivery mechanisms of biological agents affect synthetic biology threats over the next 5 years?

12.4 Recommendations

The use of foresight techniques to generate insightful and actionable information about emerging synthetic biology and biotechnology threats has great potential. To increase the effectiveness of foresight, careful consideration should go into process design, including the choice of methodological approach, questions and participants. Potential constraints on the resources and capacities of the organisers and participants should be taken into account at this stage as well.

The intended audiences and users should be aware of the limitations and inherent uncertainties of foresight in general, as well as the particular process used. In general, the further out in time a foresight process is being used for, the more speculative the results will be, with less resolution and a greater chance of unanticipated and wildcard events in the interim. It is particularly important for users to remain cognizant of the difference between foresight and forecasting; foresight does not aim to predict the future. Below, some recommendations on the foresight process design are provided, followed by specific considerations for emerging synthetic biology and biotechnology threats.

12.4.1 *Foresight Process Design*

Careful consideration should go into the preparation and design of a foresight process. A deliberately constructed exercise will be more likely to deliver a relevant and actionable outcome for the intended end-users. The process should be designed keeping in mind the available resources and necessary timeframe. The target audience should be a key consideration and the foresight methodology should be made transparent to them with the limitations explicitly acknowledged.

Answering the following five questions will help in the foresight process design, and a worked example based on a synthetic biology foresight question, which was examined during the Lausanne workshop, is provided for illustration.

1. For what specific purpose is foresight being done?

2. What are the objectives?
3. Who is the audience?
4. What are their expectations?
5. What process is required?

Example Foresight Question Over a 15 year timeframe, what are the potential impacts of synthetic biology developments converging with other disruptive technologies?

1. *For what specific purpose is foresight being done?*
 - (a) In order to avoid technological and societal surprise.
2. *What are the objectives?*
 - (a) To engage and inform key stakeholders;
 - (b) To enable the development of appropriate governance mechanisms, for example through informed regulatory export control;
 - (c) To gain insight into adversarial capability;
 - (d) To drive the creation of new capabilities and realize emerging opportunities;
 - (e) To identify key trends and early warning signals;
 - (f) To understand and identify threats;
 - (g) To avoid technological surprise;
 - (h) To create conceptual connections to inform strategic action.
3. *Who is the audience?*
 - (a) Civilian population
 - (b) Military leaders and Defense Department
 - (c) Policymakers
 - (d) Funders
 - (e) First responders
 - (f) Non-Governmental Organizations
 - (g) Intergovernmental Organizations (UN, WHO, OIE)
 - (h) Academic researchers
 - (i) Intelligence and security services
4. *What are their expectations?*
 - (a) To generate specific, actionable recommendations;
 - (b) To reduce uncertainty while also assessing and indicating the degree of uncertainty;
 - (c) Raise awareness and engagement with possible futures;
 - (d) Identify key possible future events, including their associated forks, nodes and branch points;
 - (e) Identify possible interventions;
 - (f) Encourage dialogue between stakeholders;

- (g) Note: expectations may need to be managed, for example, explicit communication about foresight not being a tool to generate accurate predictions about the future.

5. *What process is required?*

- (a) Delphi Method with horizon scanning component;
- (b) Identification of the key drivers and scenario analysis;
- (c) SWOT analysis;
- (d) Sharing of findings with the target audience.

12.4.2 Synthetic Biology Considerations

When designing a foresight exercise specifically for emerging synthetic biology and biotechnology threats, due consideration should be given to a number of factors. The participants involved in the exercise should be chosen for their expertise, but not limited to a certain discipline: the value in a foresight process is achieved through harnessing opinions from across domains, and even for technology-specific foresight questions, fields such as the social sciences and humanities and the security community have important perspectives to add. In addition, the inclusion, from the design phase onwards, of foresight expertise will have great value for the proper execution of the process.

Emerging synthetic biology and biotechnology inherently have sensitivities that require consideration. For example, certain developments may be occurring within confidential industrial contexts, and concerns about dual-use applications may prevent certain scientific findings from being openly discussed. In addition, security concerns and evolving threats are likely to be confidential in nature. All of these may skew the inputs going into a foresight exercise. However, this need not undermine the value of a well-designed process, that does not breach security concerns, for strategic insight. Foresight exercises at different confidentiality levels could be considered in the military context and combined for use by decision-makers.

For many fields, but for synthetic biology in particular, emerging threats are likely to arise at the convergence points of new developments. This highlights the importance of ensuring foresight exercises are designed to allow for broad thinking on how scientific knowledge and technology can enable threats and reduce the risk threshold level.

Foresight can have a significant impact on strategic decision-making and direct work within a wide range of military contexts and government institutions, but it is important to acknowledge that evaluation of a foresight exercise's utility is inherently difficult. Iterative processes that allow for the systematic re-examination of the outputs of a foresight exercise, both at regular intervals and as significant or unpredicted wildcard events take place, will increase the likelihood of foresight offering substantial benefits.

12.5 Conclusion

The ability to consider future scenarios in a systematic fashion is highly relevant to examining emerging synthetic biology and biotechnology threats. From both a governmental and military perspective, extending understanding beyond current risks and being able to take proactive steps in addressing vulnerabilities. Mitigating emerging threats is preferable to being surprised by and reactive to technological developments. Insights gained also have value for a range of other groups and stakeholders. Foresight offers a process by which to consider and explore possible future scenarios, and while any examination of the future has inherent limitations, if designed correctly, foresight exercises can provide strategically useful information for action.

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