CNS OCCASIONAL PAPER NO. 21

Biotechnology E-commerce: A Disruptive Challenge to Biological Arms Control

by
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Funding support to realize the project that generated this occasional paper has been provided by the British Foreign and Commonwealth Office.

Biotechnology E-commerce: A Disruptive Challenge to Biological Arms Control
978-0-9908622-6-0
Imprint: Pixels Graphic Design

Cover image: Ms. Beatrix Zilinskas

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Acknowledgements

From the beginning of the project reported here, we planned to request persons who possess bioscientific and arms control expertise to review critically the project's draft report in terms of data collection methodology, quality of assessment, and reasonableness of policy recommendations. We were fortunate to receive assistance for this purpose from an extremely knowledgeable group of persons:

Mr. Michael Carson, Global Policy and Regulatory Management, eBay Inc., United States
Dr. W. Seth Carus, National Defense University, United States
Dr. Malcolm R. Dando, University of Bradford, United Kingdom
Dr. John Hart, Stockholm International Peace Research Institute, Sweden
Dr. Astrid Lewis, United States Department of State
Dr. Richard Pilch, Raytheon Technical Services, United States
Dr. David Relman, Stanford University, United States
Mr. Tim Trevan, International Council for the Life Sciences, United States
Dr. Simon Wain-Hobson, Institut Pasteur, France

We thank them all for the valuable commentaries and suggestions they made that helped us immensely when writing the final project report. In addition to experts outside CNS, we benefit from having in-house expertise that we can approach on a continuous basis. Thus, we thank the following persons for their help and suggestions that were given throughout the project: Stephanie Lieggi and Robert Shaw, as well as graduate research assistant Zachary Kallenborn. However, we must make clear that we are responsible for the final product and its contents, including errors if any.

Finally, this project could not have been undertaken without the financial support we received from the British Foreign and Commonwealth Office. We thank the Office for its support and convey our special appreciation to two of its staff members at the United Kingdom Embassy in Washington, D.C., namely Mr. Christopher Wright and Ms. Katarina O'Regan, for their enthusiasm and assistance.

A note on the online version of this report

In preparing the online version of this report, we attempted to balance the desire for transparent and reproducible findings with the need to publish responsibly. Care was taken not to exceed the level of information provided in the Australia Group's *Volume II: Biological Weapons-Related Common Control Lists Handbook* concerning distinguishing Australia Group listed biotechnology equipment. In most cases, the research necessary to find sensitive items did not draw upon specialized knowledge or detailed cross-referencing. We therefore followed precedent in the literature and published the full item listing as part of our endnotes.[1] In select instances, a small amount of specialized information has been removed. When it was deemed necessary to do so, the omission is flagged and the missing information is summarized in general terms.

The positive worldwide growth of civilian biopharmacy and bioindustry depends on a lively trade in dual-use biotechnology products. This trade is increasingly conducted online, and ensuring that this trade is not exploited to support biological weapons development is a global responsibility. We emphasize throughout that we do not allege that the vendors whose products are cited in this report are involved in wrongdoing. Moreover, these vendors do not form a representative sample of the overall international trade in dual-use biotechnology products. To avoid any possible misunderstandings on these points, we have de-emphasized vendor names in the text of the report.

Executive summary:
The Internet has had disruptive effects on how scientific research is conducted, how education is delivered and knowledge transmitted, how health services are provided, and how individuals and organizations communicate and do business. We postulate that the emergence of the Internet, and in particular the rise of commercial transactions conducted over the Internet (e-commerce), is having a major disruptive effect on biological arms control. The project we conducted, as reported in this paper, aims to support our supposition.

The current approach to prevent the proliferation of biological weapons development relies heavily on the existence of effective export controls for equipment particularly suitable for use in the production or dissemination of biological agents. The Australia Group (AG), an informal forum that brings together 41 countries and the European Union, seeks to harmonize national export controls on such equipment. We state our concern that the rise in biotechnology e-commerce will significantly disrupt the effectiveness of current efforts undertaken by AG participants.

As we make clear in this paper, we are concerned with the emergence of e-commerce in dual-use equipment; i.e., equipment that is useable for the production, processing, and dissemination of biological agents. Our primary focus is on equipment listed on the AG's Dual-use Biological Equipment and Related Technology and Software list (AG Biological List for short), which are referred hereafter as AG-grade items. We investigated the extent to which AG-grade items from eight equipment categories are available from Internet vendors. These categories are:

Fermenters;
Centrifugal separators;
Cross (tangential) flow filtration equipment;
Freeze-drying equipment;
Spray-drying equipment;
Protective and containment equipment;
Aerosol inhalation chambers; and
Spraying or fogging systems and components therefor.

Our research depended largely on tracking down vendors of AG-grade items on the Internet and investigating their wares and business tactics. We focused on vendors headquartered in non-AG participating countries, such as China, India, and Russia. Our searches found AG-grade equipment from at least seven out of these nine categories offered for sale online.

Our analysis of the information provided by vendors on their websites found that a significant proportion of them were particularly vulnerable to proliferator exploitation. These typically were small firms with limited resources, facing significant competition, and offering transactions of single units (for example, a single fermenter, or a single Class III biosafety cabinet, etc.). We found no indication that the vendors in question are cognizant that they are offering to sell AG-grade equipment; i.e., that their offered

product has the potential to be misused for BW applications. At the same time, we emphasize that we do not allege that any of the vendors we name in this paper are involved in illicit activities.

Since vendors did not disclose information about their export policies on their websites, we attempted to contact several AG-grade equipment vendors with questions about their export policies. We had no success; i.e., none replied to our queries.

All AG-grade items are inherently dual-use, with both legitimate and illicit end uses. A biotechnology equipment order intended for a biological warfare (BW) program can therefore appear identical to an order going to a legitimate end user. Transactions serving BW programs can be carried out openly, in effect hiding in plain sight amongst lawful transactions. Compounding these issues, we found that online vendors routinely offered payment options that could be utilized by unscrupulous buyers to hide their identities and to launder funds.

In the course of the project, we found that a host of new biotechnology innovations had emerged in the last ten or more years that potentially have BW-related applications and are being offered for sale by vendors on the Internet. Of the newly emerged technologies, we are particularly concerned about the dual-use applications of algae photobioreactors, freeze-dryer gas sterilization upgrade kits, hand-held aerosol generators, DNA kits, synthetic biology kits, and 3D bioprinters. These technologies are not listed by the AG, although we believe that they should be to some degree. We have included a brief overview of these technologies and documented their online availability to facilitate discussion on this issue.

Thanks to the Internet, we found it relatively easy to gather large amounts of information about vendors that was useful for comparing the many offerings of dual-use items. We assume that would-be proliferators would be similarly able to conduct Internet searches that would allow them to rapidly discover and instantaneously contact large numbers of AG-grade item vendors. We fear that the availability of these items, as well as the characteristics of the AG-grade equipment vendors, poses a significant challenge to all states attempting to preempt, identify, or interdict purchases by would-be proliferators.

To highlight the combined disruptive impact of the new trends in international business, we compare how Iraq's BW procurement network operated in the 1970s and 1980s with how a modern-day proliferator could use the Internet to acquire the equipment necessary for instituting a modern BW program.

Finally, we offer a number of recommendations for participating AG states. These include: suggested outreach efforts to online sales companies; suggested ways of ensuring e-commerce industry input is heard; means to improve the monitoring of online biotechnology equipment offers and sales; and a new process for updating the AG biotechnology list. These suggestions have the potential to alleviate, albeit not solve, the problems raised in this paper.

> We are in the midst of a Gutenberg-scale change in how information is generated, stored, shared, protected and turned into products and services. We are seeing individuals become superempowered to challenge governments and corporations.
> Thomas L. Friedman[2]

Introduction

The Internet and the World Wide Web have revolutionized how business is conducted throughout the world.[3] Illicit businesses, such as bioweapons-related procurement networks, are not exempt from changes brought about by the Internet.

The business-world conceptual framework of disruptive innovations helps explain both the tremendous developments that have taken place, and why our current arms control efforts have been slow at catching up. The term "disruptive technologies" was coined by Clayton M. Christensen and Joseph Bower in an article aimed at business executives, published in 1995.[4] Fourteen years later, Christensen published *The Innovator's Dilemma*, in which he proposed that there were two types of technologies that affected business – sustaining technologies and disruptive technologies.[5] Sustaining technologies were those that made marginal improvements to enterprises and required their managers to institute only gradual changes to how they did business. Conversely, disruptive technologies were based on unanticipated scientific and technical breakthroughs whose adoption by enterprises required their managers to rethink all their methods of conducting business.

In *The Innovator's Dilemma*, Christensen came to replace the term "disruptive technology" with "disruptive innovation" because he concluded that few technologies were intrinsically disruptive or sustaining in character; rather, it was the business model that the technology generated that created the disruptive impact.[6] Managers have observed that when first introduced to a new technology, both customers and investors show little interest in it. This causes managers to pay scant interest in the new technology, especially since business-as-usual continues at a satisfactory pace. However, the new technology is adopted by newfound businesses that are established by a generation of investors and managers who are not beholden to the past, and their business methods lead to developments that within surprisingly short times completely overturn existing products, markets, and ways of doing business. Examples include the mobile phone (which displaced fixed-line operators), digital photography (which displaced photographic film and caused Kodak to change its business model), and Internet retailing (which wiped out many traditional retailers). In general, innovations can be considered disruptive to businesses if their implementation requires:

- totally new infrastructure comprised of
    - new suppliers
    - unique facilities
    - new maintenance procedures
    - specialized training for those who will operate and maintain the facilities

- totally new logistics and supply chains where
    - existing networks have to be redesigned or replaced
    - consumers will be in a position to rate suppliers, with ratings shared among those participating in the marketplace
    - suppliers will similarly be in a position to rate consumers

The Internet has not only had disruptive effects on business networks, but also on how scientific research is conducted, the providing of education, the sharing of information and knowledge, how health services are provided, and how individuals and organizations communicate. We infer that an important aspect of how the international community seeks to prevent the proliferation of biological weapons, which is denying or preventing would-be proliferators from acquiring vital equipment, has been significantly disrupted by the emergence of the Internet. In effect, the arms control community – operating under the aegis of the Biological and Toxin Weapons Convention (BWC), Chemical Weapons Convention (CWC), United Nations Security Council Resolution (UNSCR) 1540, and the Australia Group (AG) – appears to be behaving like a traditional business faced with a disruptive innovation. In other words, this community has so far lagged in responding to how the growth of Internet and e-commerce has affected international biological non-proliferation efforts and instead conducts biological arms control negotiations as was done in the pre-Internet era.

The development of the Internet has made a host of new suppliers of dual-use equipment available to would-be proliferators. It has also enabled proliferators to tap into new supply chains and allowed them to use unique methods for secretly transferring funds. The current situation is certain to become even more complicated and troubling if left unaddressed. The number of persons connected to the Internet is predicted to grow from an approximate 2.5 billion users in 2013 to 4 billion users by 2018, with almost all of this growth occurring outside of the U.S. and the E.U.[7] Similarly, online commerce will continue to develop, expand, and innovate at an ever-increasing pace.[8] Our recommendations for what might be done to improve biological arms control in this new environment are spelled out in Section 10.

Biological arms control seeks to prevent would-be proliferants from acquiring pathogens and toxins, dual-use equipment and supplies of concern, and scientific/technical knowledge and know-how. Practical limitations require us to narrow this project's scope to consider only eight categories of AG-grade equipment that are listed in the AG's "Control List of Dual-use Biological Equipment and Related Technology and Software" (hereafter referred to as the "AG Biological List;" see Annex 2).[9] Specifically, we infer that there is a large, uncontrolled supply of items of concern that can be acquired through the Internet in a manner defying current efforts to control the trade in these sensitive commodities.

To test and validate our inference, the paper is comprised of ten parts. First, we describe in general terms how Internet-enabled purchases pose new and unique challenges to the traditional export control regimes related to dual-use biological equipment of concern. Second, the new business environment populated by creations peculiar to the Internet era,

namely websites set up to enable business-to-business e-commerce (B2BEC), are described and discussed.[10] Third, the dual-use biological equipment listed by the AG of primary interest to this report is described. Fourth, our search of B2B businesses that market dual-use biological equipment is described and its findings are reported. Fifth, we report our assessment of the ease or difficulty with which the dual-use items in question could be obtained through B2B websites. Sixth, our impact assessment is presented through a hypothetical case study: we summarize how Iraq's BW equipment acquisition network functioned, and show how such a network could operate efficiently today. In the seventh section, we discuss six technologies that have recently emerged and thus are currently not found in the AG Biological List but that we are convinced already have, or will in the not too distant future have, implications for biological arms control. They are: photobioreactors, freeze-dryer gas sterilization upgrade kits, hand-held aerosol generators of micron-size particles, DNA kits, synthetic biology kits, and 3D bioprinters. The validation of our hypothesis, which depends on project findings, is explained in the eighth section. The ninth section summarizes project limitations. In the tenth section, we present recommendations that the AG participating states, and BWC states parties in general, might consider when developing an Internet-directed biological arms control strategy.

The paper also has six annexes. The first is a case study of eBay's policy on transactions involving items that are subject to export controls. Annexes 2, 3, 4, and 5 serve as *aide memoires*, providing brief overviews of the AG, BWC, CWC, and UNSCR 1540. The sixth is a short list of the B2B web sites we accessed and investigated.

1. Internet Purchases of Dual-use Biotechnology Items of Concern

There has been a growing online trade in illegal products, from counterfeit drugs, to illicit Botox, to automatic weapons.[11] Buyer-vendor networks that specialize in the trade of illicit products pose new challenges for law enforcement agencies that attempt to shut them down.

Internet-enabled purchases pose an even more difficult challenge to nonproliferation-related export control regimes, such as those deployed by AG participating states. Owing to the dual-use nature of numerous proliferation-sensitive commodities, where products have civilian as well as military applications, the Internet-enabled buyer-vendor networks typically are legal. The equipment needed by biotechnology industry in particular is almost entirely dual-use. Buyers representing nations or groups intent on acquiring biological weapons can exploit such purchasing networks to buy dual-use equipment of concern from manufacturers in countries with weak trade controls. For instance, experts have written about the possibility of placing orders through the Internet for de-novo synthesized genes with oligo synthesis services in countries where such services are unregulated in order to obtain the DNA building blocks of pathogens on the AG's Biological List, thus circumventing traditional BW agent export controls.[12] More generally, the unprecedented access today by would-be proliferators to products offered by thousands of biotechnology companies willing to ship internationally raises the possibility that proliferators could purchase every item listed on the AG Biological List through online purchases.

Strategic trade control specialists in fields other than biology have recently brought up concerns that online procurement networks could be used to source proliferation sensitive equipment in the chemical, missile, and nuclear fields. For instance, a 2014 U.S. National Academy of Sciences (NAS) report raised the alarm concerning chemical warfare (CW)-related equipment sold through B2B websites, calling the phenomenon "a new challenge to non-proliferation activities."[13] King's College London's Project Alpha has also repeatedly highlighted that B2B websites could be exploited to enable missile and nuclear proliferation. It publicized the fact that a sanctioned missile-related entity was at the time listed as a vendor on no less than 15 Internet trading platforms, and that five sanctioned Iranian companies were advertising on one of the largest B2B websites in the world, Alibaba.[14] In the nuclear sphere, Project Alpha conducted a search of B2B website listings, and noted with alarm the presence of "metals suitable for centrifuge manufacturing, gauges and pumps for centrifuge cascades for uranium enrichment, metallurgical casting equipment suitable for making nuclear weapon ``pits,'' […] high-speed cameras suitable for use in nuclear weapon diagnostic tests" and even "an ad for the sale of the rare metal gallium, which the vendor trumpeted could be used to stabilize plutonium."[15] Project Alpha took a direct approach to demonstrate the seriousness of the problem by successfully purchasing a controlled MKS pressure transducer from a Chinese firm through eBay, and publicized the fact that the Chinese firm had not sought end user information, and hence may also have failed to seek an export license.[16] These findings demonstrated "the need to rethink how Internet trading platforms ensure that they are not used as platforms that enable proliferation."[17]

These concerns are set to grow. The sale of industrial-use technical equipment over the Internet, typically categorized as B2BEC, is a significant and expanding market. Senior analyst Andy Hoar at Forrester Research Inc. estimated that the e-commerce market in the United States in 2013 was $559 billion and that "the market is growing rapidly."[18] Making the reasonable assumption that biotechnology-related B2BEC also has followed these market trends, with both new and used dual-use laboratory equipment and supplies being traded online, we believe that this scoping study is needed as a first step to determine whether biotechnology-related B2BECs have rendered the traditional export control regime in its current form inadequate for effective biological nonproliferation.

2. The New Business Environment Created by the Internet

Numerous industries that possess B2B websites have extensive biotechnology equipment catalogs. Annex 6 contains a list of the B2B websites we investigated for this project, as well as their host countries and B2B types. Owners of B2B websites are a highly heterogeneous population, but can be divided into two categories: those that employ e-catalogs and those who offer e-marketplaces.

i. *E-catalogs:* An e-catalog displays a specific company's offerings, replacing printed catalogs. The most straightforward sites in this category are those maintained by equipment manufacturers themselves. However, there is also an enormous market for companies that trade in used and surplus equipment. The companies that publish e-catalogs range in size from small (fewer than 10 employees) to firms that employ

thousands of workers. A sale (legal or otherwise) through an e-catalog B2B website typically has two actors: the website owner and the would-be buyer. The company that owns the website also sells the product, which means that the vendor remains the same across transactions.

ii. *E-marketplaces:* An e-marketplace serves as a facilitation platform where vendors can advertise their products or services, and where buyers can often also place product or service requests. Basic item and company information is typically available to viewers browsing without having an account on the particular e-marketplace, while the ability to interact with companies through the B2B platform is often restricted to those who have registered an account and are logged in. This latter model is used by eBay and Alibaba. In some particularly open sites, we have even found highly skilled individuals, not just companies, who wish to leverage their technical know-how by listing refurbished equipment for sale. The level of information required to create an account varies. Some, like Alibaba, essentially work on the honor system. Others, such as the Russian b2b-center and affiliated websites, require proof in the form of a Taxpayer Identification Number. A sale (legal or otherwise) through an e-marketplace B2B website involves at least three actors: the B2B website owner acting as a facilitator, the vendor, and the buyer. Since there are numerous vendors operating through an e-marketplace, transactions occurring through the site can be expected to have different vendors and buyers.

Of these two categories, e-marketplaces appear particularly likely to challenge the AG export control regime. The rationale behind this assertion it that vendors that depend on e-catalog sales do not depart from typical company import-export trading. E-marketplaces, on the other hand, create a niche by providing visibility and a degree of legitimacy for small and specialized vendors to sell products abroad. That is, e-marketplaces are a particular element of the e-commerce disruptive innovation that has created a new supplier base. The existence of e-marketplaces has reduced the necessary marketing team size, start-up costs, and dependence on brand recognition required to sell internationally, leading to a plethora of low-volume mini-company vendors, termed “low-profile actors.” In the past, companies wishing to enter foreign markets would have to send out expensive trade delegations to demonstrate their products in person. The harnessing of the Internet for commerce, notably through e-marketplaces, has reduced the necessity of doing so.

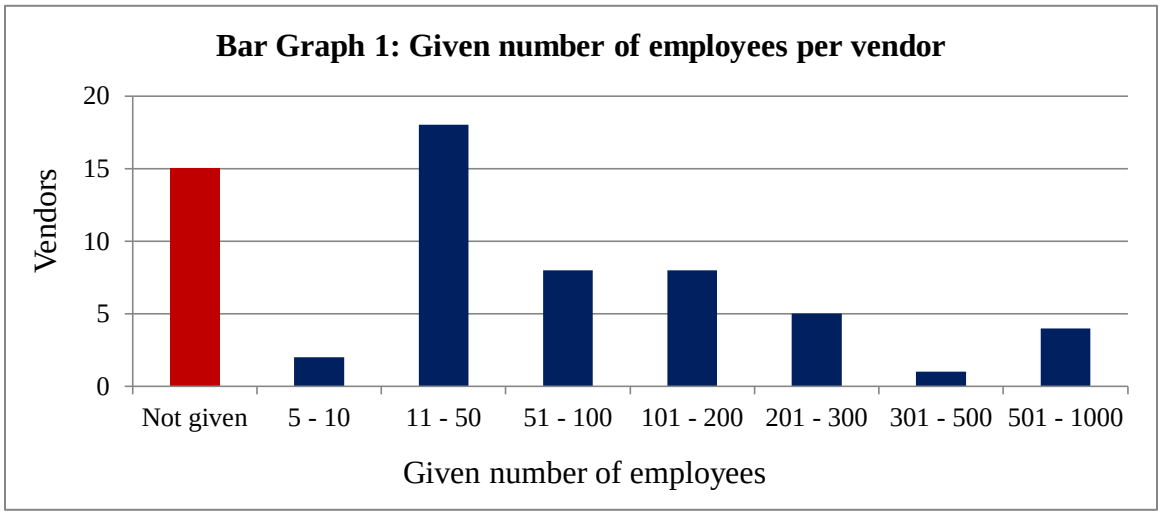
The rise in export control cases involving these spaces raise concerns that e-marketplaces permit would-be proliferators “to find suppliers who will not ask so many questions.”[19] Importantly, these low-profile actors are able to sell second-hand products through e-marketplace websites. Unfortunately, second-hand sales are particularly vulnerable to diversion given lower vendor awareness of the product. A vendor of second-hand items will have difficulty matching the knowledge of the initial manufacturer with regards to the item’s parameters, as well as its available upgrades and options.

The AG lists generally include items that are easily modified to meet AG specifications. For instance, a spray dryer that does not generate an average product particle size of at

most 10 microns (μm),[20] but that can be engineered to do so through minor nozzle modification, is classed as an AG-item. Hence, the availability of upgrades and options can create dangerous situations. For instance, a vendor who is trying to sell an obsolete cross-flow filtration system with variable disposable filters may not know that the system had been designed also to fit a larger filter cartridge whose size is equal to, or larger, than the size placing it under AG control. We encountered this problem when trying to determine whether a used system being offered online was an AG-item. In order to do so, we had to contact the original manufacturer to find out whether the system could fit a larger cartridge than the one that came with the used system. A used equipment vendor would have to do the same unless they happened to know this information through experience. Similarly, a vendor of second-hand spray dryers may not know the exact average particle size that the devices they have on hand generate; indeed, we found that this information is often not mentioned in vendor listings. Even armed with this knowledge, they may still fail to know the performance of other spray nozzles manufactured for their used spray dryer, which may produce sprays of smaller particle size. In both the cross-flow filtration system and spray dryer examples, the item would fall under AG control requirements without the vendor's knowledge. Even more vulnerable are vendors specializing in the liquidation of equipment seized from bankrupt companies. Such a vendor may very well have no expertise about the laboratory equipment they are offering, and lack the knowledge needed to differentiate between a typical and a spurious declared end use. Overall, we anticipate the following trends:

- An increase in the number of transactions carried out by low-profile actors;
- An associated increase in small transactions involving single items (i.e., a buyer purchases one fermenter, one freeze dryer, and so on);
- Greater difficulty in tracing the resultant financial transactions due to the minor amounts of money involved;
- An increase in the number of used equipment transactions carried out by low-profile actors;
- A faster rate of completion of transactions due to increased competition, ease of money transfers, and access to new international courier services;
- Greater potential for anonymizing financial transactions as low-profile actors probably have a greater willingness and flexibility for the use of alternative, less secure, methods of payment—this may even include the future use of new Internet-enabled anonymizing currencies such as Darkcoin;
- Shorter timeframes for innovative products to advance from the development stage to global markets;
- Moreover, far greater access to vendors operating in countries with weak national export control laws.

The data presented in Bar Graph 1, which was aggregated from the market search detailed in section 4 below, provides some evidence for the above claims. We collected published information about 61 vendors of likely AG-items (60 of which are outside of the U.S. and the European Union).[21] Most of the vendors reported employing between 11 and 50 employees. A small number of vendors reported having only between 5 and 10 employees. These data indicate that a substantial number of small companies exist that are selling AG-grade items.

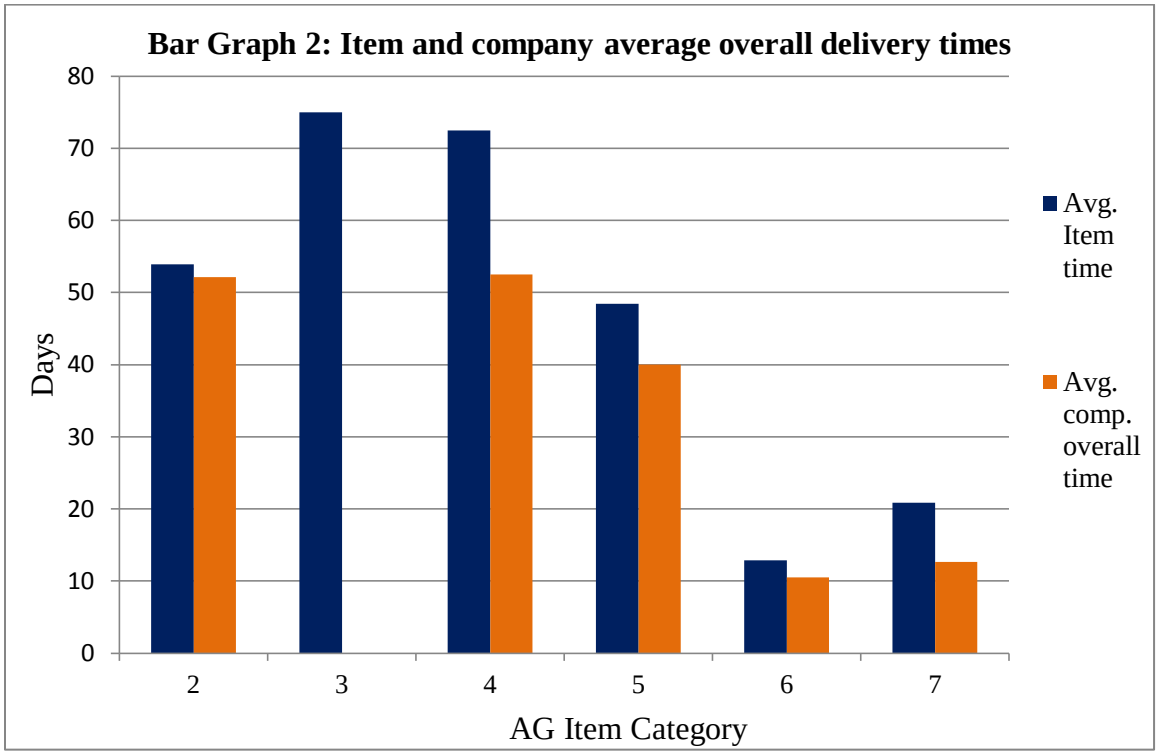


The average length of time required by companies to complete a transaction for a particular item type– that is, the average length of time between a customer paying the vendor for an item and receiving it– is a key metric. We refer to this metric as the "average item delivery time." The shorter the average item delivery time, the more pressure there is on individual vendors to ship quickly, and the less time there is for custom and law enforcement officials to interdict a sale. For instance, a 20 ton fermenter may take six months to manufacture to the customer's specifications and to dispatch. In contrast, Class III biosafety cabinets tend to be relatively small items that are standardized, and hence the vendor may take only two weeks to supply one or a few to a customer. We report values for a second metric, the "average company delivery time," that is more useful for items that have great variability in design. Most companies surveyed sell several versions of an item type. For instance, a company may sell AG-grade fermenters ranging from 20L to 20 tons, but the former will be significantly faster to ship than the latter. When we compute the average item delivery time, we use the delivery time given for the version of the item we documented—for instance, a 20L fermenter. However, a would-be proliferator purchasing a larger fermenter could expect that its delivery would take much longer to accomplish.

The values presented in Bar Graph 2 are rough estimates. Companies reported times differently, using differing units (days, weeks, months) and sometimes by using intervals rather than total values. We averaged intervals and converted all values to number of days, with months set to 30 days, but the level of uncertainty for delivery times varied from company to company. There is also significant uncertainty added by the fact that most companies did not clarify the following: whether they were referring to total days or business days; whether they were referring to days after payment was received, or days after an engagement to purchase was given; and whether they were referring to the maximum time delay or the average delay. As noted above, there are also significant differences between items even within some of the item categories; for example, packing and shipping a 20 ton fermenter is an entirely different process than for a 25L fermenter. Finally, for some item categories, such as cross-flow filtration systems, we found only a few transactions, so delivery times in these situations could not be accurately averaged.

The data we present in the Bar Graph 2 therefore reflects what we learned from out online research.

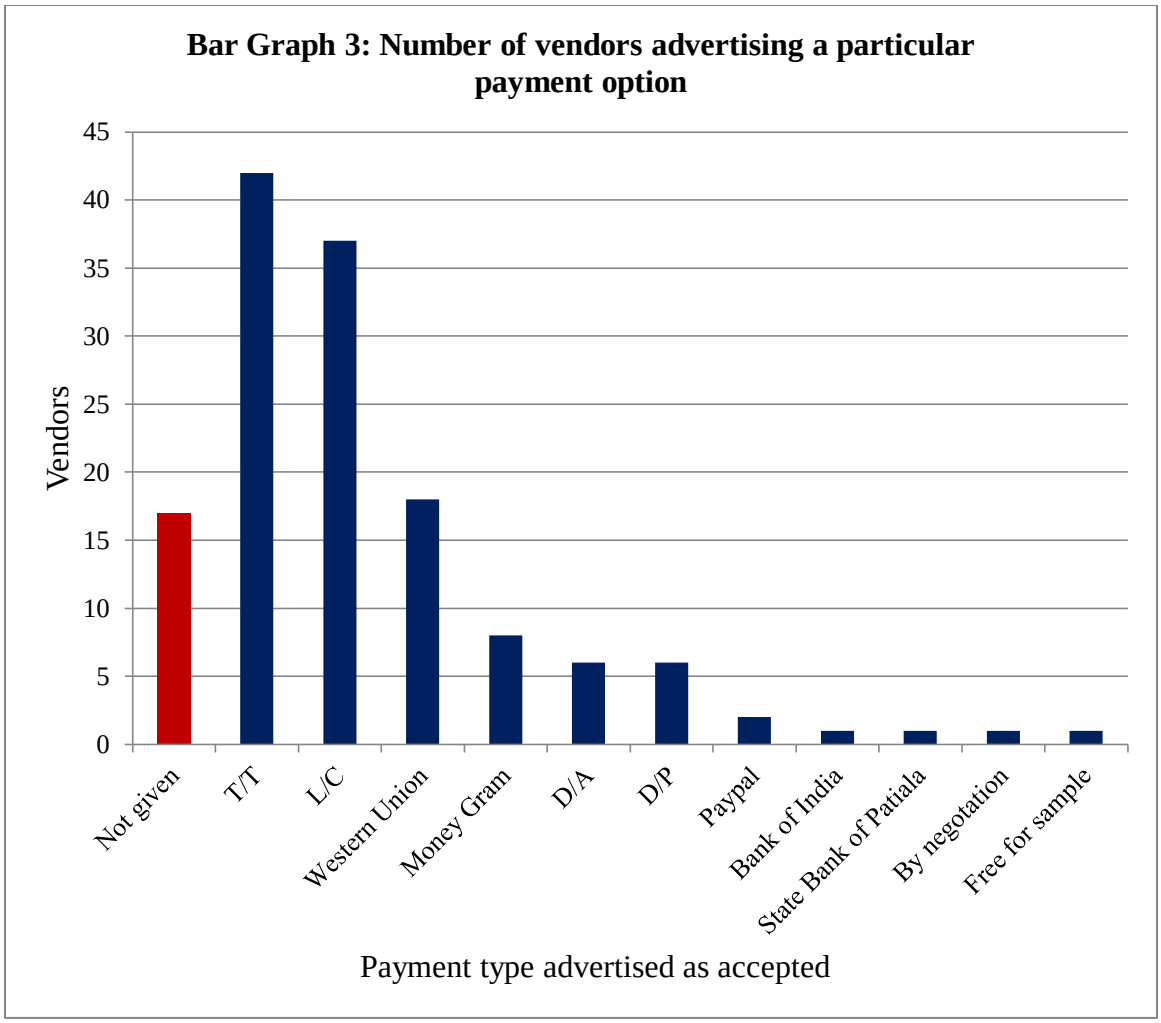
Vendors are separated by item type; the item categories are detailed in section 3 and the vendors are documented in section 4. We report two values: the average item delivery time, and the average company delivery time.



Section 4 of this report, Market Study Results, contains similar bar graphs that summarize individual vendor data within a particular AG item category when the item category has more than 10 vendors documented in the report (Bar graphs 4, 5, 6, and 7, providing information on vendors of fermenters, freeze-dryers, spray dryers, and Class III biosafety cabinets).

Although we do not have baseline data of average times for offline sales to compare our numbers to, the reported times for the surveyed companies appear to be relatively fast for international transfers of equipment.

Finally, payment types were quite diverse and flexible, as Bar Graph 3 demonstrates. T/T stands for telegraphic payment, a service that Alibaba facilitates;[22] L/C stands for letter of credit; D/A stands for Documents Against Acceptance; and D/P stands for Documents Against Payment.[23]



We emphasize that we do not allege that any particular vendor, such as those documented in the market search section, is involved in illicit activities. Indeed, there is a huge biotechnology industry that has legitimate uses for AG-items. However, we cannot ignore that the overall market segment characteristics of B2BEC trading of AG-items also provides opportunities for would-be proliferants to purchase equipment they need and for this purpose, low-profile vendors are easy prey.

3. Australia Group Biotechnology Items of Concern

The items searched for on these B2B websites were taken from the AG Biological List. The developers of the AG Biological List recognized that the development and manufacture of a type classified biological weapon is a long process that requires equipment to produce, stabilize, and disseminate a BW agent.[24] AG guidelines seek to keep as many parts of the necessary supply chain, from pathogen inoculums to delivery systems, as possible out of the hands of proliferators.[25]

AG participant states are committed to “Catch-All” measures, whereby national legislation makes clear to exporters within their jurisdictions that if they are aware, or are made aware, that the items they are attempting to export “may be intended, in their

entirety or part, for use in connection with chemical or biological weapons activities" they then are obligated to inform and seek an export authorization from the national authorities.[26]

Particularly sensitive equipment is directly controlled through the AG Biological List, which is composed of the following item categories:

1. Complete containment facilities at P3 [BSL-3] or P4 [BSL-4] containment level;
2. Fermenters;
3. Centrifugal separators;
4. Cross (tangential) flow filtration equipment;
5. Freeze-drying equipment;
6. Spray-drying equipment;
7. Protective and containment equipment;
8. Aerosol inhalation chambers;
9. Spraying or fogging systems and components therefore.

AG items 2-9 were selected for this market search. A description of these items, as well as the AG control parameters for each, can be found in the market search result section below.

We recognize that would-be proliferants possess various levels of biotechnological capability. For our purposes, three levels may be defined. The lowest level is exemplified by the Rajneesh's Sect that in 1984 decided to sicken persons who lived in an Oregon county for political purposes.[27] Under the direction of a nurse, its operatives propagated *Salmonella enterica* Typhimurium on simple agar plates and then transferred colonies to a saline solution. Operatives then sprayed aliquots of the contaminated saline solution over the contents of unguarded salad bars using simple plastic sprayers. Approximately 750 persons who ingested these contents soon manifested symptoms of gastrointestinal illness, although none died. We note that none of the equipment the Rajneesh used was AG-listed. The most difficult aspect of this endeavor was for the Rajneesh to procure a culture of *Salmonella enterica* Typhimurium. We estimate that this problem will continue to be a barrier for low level capability programs. Conversely, future attacks of this type cannot be prevented or affected by whatever the AG does.

A medium level of biotechnological capability is exemplified by that possessed by Iraq's government in the 1980s. By the time that Saddam Hussein's government surrendered to the Coalition forces in 1991, its scientists had been able to acquire a substantial biotechnological capability that was applied to propagate *Bacillus anthracis* (the cause of anthrax) and *Clostridium botulinum* (which naturally produces botulinum neurotoxin). Sufficient quantities of *Bacillus anthracis* spores and botulinum neurotoxin were produced as payloads for SCUD missiles and aerial bombs. As is described in Section 6, before the AG was established the Iraqis were able to purchase with ease what now are considered items of concern, such as fermenters, live cultures, dryers and other items, from mostly European countries.[28] After the AG became operational, it became much

more difficult for Iraq to affect purchase of items of concern, which forced it to set up a secret procurement network.

The Soviet Union's BW program exemplifies a high-level biotechnological capability. The modern Soviet BW program commenced in the early 1970s and its objective was to utilize genetic engineering for the purpose of weaponizing both bacterial and viral pathogens.[29] This program continued at least until the USSR was dissolved in late 1991. The AG faces two problems when dealing with any future BW program similar to the one operated by the Soviets. First, the Soviets were successful in keeping this program so secret that other nations, including AG participants, did not know about it. Thus, the Soviet Union was able to purchase dual use equipment and items because it was not initially considered a proliferant threat. (It is not known to what extent the Soviet Union did so.) Second, the Soviet Union had an advanced industrial and scientific infrastructure, allowing it to develop and manufacture most items on the AG Biological List. Were countries with advanced infrastructures intent on acquiring a BW program, it is doubtful whether AG operations would be able to hinder them. Further, as is made clear in this report, these countries would be able to circumvent the AG by purchasing the few specialized items they might need from Internet vendors based in non-AG countries.

This three-tier ranking system can be applied at any level of program scale, down to so-called "lone operators." A lone operator is a person who seeks to acquire a BW capability for any of a number of reasons to, for example, avenge a wrong done by former or present employers, colleagues, or lovers; sicken rivals; express hatred against a detested person, group, or populations; blackmail a business; perpetrate product tampering to harm a business; or gain perverse pleasure from overcoming technical challenges or proving scientific and technical superiority. A low-level operator could be, for example, an undergraduate student with some biology training that acquires used equipment in person or from Internet vendors. On the high-level side, an experienced bioscientist employed in a well-equipped research laboratory may decide for any of the reasons stated above to weaponize a pathogen or toxin after normal working time, using all the resources of their work place. The point we make is that a lone operator, regardless of their capability level, can purchase equipment from Internet vendors.

4. Market Study Results

Dual-use equipment from AG control categories 2-9 can be found listed on B2B websites, albeit in varying quantities. We found that when we limited our preliminary search to AG-grade items explicitly advertised for shipment internationally, this finding did not change. The search results are summarized in Table 1.

It should be noted that, apart from fermenters, Class III biosafety cabinets, and freeze-dryers, company-advertised parameters were insufficient to determine whether an item was AG-grade or not. Additional cross-referencing was required to make such a judgment. As such, establishing whether equipment is AG-grade and thus meets control requirements is a nontrivial task, even for companies with good awareness of their national export control laws.

Table 1: AG Item Search Results		
AG Item 1	Complete containment facilities at P3 or P4 containment level	Not selected for analysis
AG Item 2	Fermenters	Plentiful
AG Item 3	Centrifugal separators	Rare
AG Item 4	Cross or tangential flow filtration systems	Rare
AG Item 5	Freeze dryers	Plentiful
AG Item 6	Spray dryers	Common
AG Item 7	Protective and containment equipment	Class III biosafety cabinets plentiful
AG Item 8	Aerosol inhalation chambers	Rare, domestically-oriented sales
AG Item 9	Spraying or fogging systems and components	Not found apart from entire crop-sprayer airplanes

As noted above, a substantial number of vendors found to be offering AG-grade equipment online were small companies with 50 or fewer employees. Export compliance for such small firms is likely a significant resource constraint; particularly so given that determining whether the second-hand equipment they are selling is controlled for export requires knowledge of parameters apparently not specified when drawing up contracts.

Some of the items falling under the AG Awareness Raising Guidelines categories were easily available online, including "Fermenters of less than 20 litre capacity with special emphasis on aggregate orders or designs for use in combined systems" and "Conventional or turbulent air-flow clean-air rooms and self-contained fan-HEPA filter units that may be used for P3 or P4 (BL3, BL4, L3, L4) containment facilities."[30] Dedicated "equipment and technology (not specified elsewhere in the control list of Dual-use Biological Equipment and Related Technology and Software) for the encapsulation of live pathogenic micro-organisms, viruses and toxins, with a typical mean product particle size of 10 μm or less" was harder to come by.[31]

We found that many companies selling AG-grade equipment offered more than only installation and equipment debugging services; typically they offered to send company engineers to a site specified by the purchaser. This means that some aspects of the trade of AG-grade equipment are of intangible value; i.e., an outsider investigating a trade will find it very difficult to determine how much a buyer paid for an item and how much for optional technical services provided by the vendor to install the item. Further, buyers who exercise an option for expert assistance could greatly reduce the number of technical personnel and level of know-how necessary to set up a generic production line; for example, one that could be used to propagate many species of aerobic bacteria. A terrorist group content with acquiring a low-grade BW capability, such as was done by the Rajneesh, probably would be content with tweaking such a generic setup for the purpose of propagating a *Salmonella* or *Shigella* species. Even if a would-be proliferator in need of technical services did not feel confident enough in their cover story to risk physically bring in outside help, installation assistance through B2B chat services, direct emails, or

telephone conversations with the vendor's experts might be sufficient to commence the production process.

i. **AG item #2: Fermenters**

Fermenter systems consist of vessels for growing microorganisms, and typically come equipped with a cultivation chamber where the microorganism and the necessary growth media are placed, and basic equipment for monitoring and controlling certain growth parameters (such as temperature and pH).[32] Once the microorganism is given time to grow and reproduce, the vessel can be emptied and cleaned. In a BW program, fermenters are used to propagate desired quantities of a bacterial species, such as *Bacillus anthracis*, from an initial sample (inoculum). Fermenters can also be used to propagate bacteria or fungi that produce extracellular metabolites such as toxins. When this is done, the product of interest is usually released into the substrate.

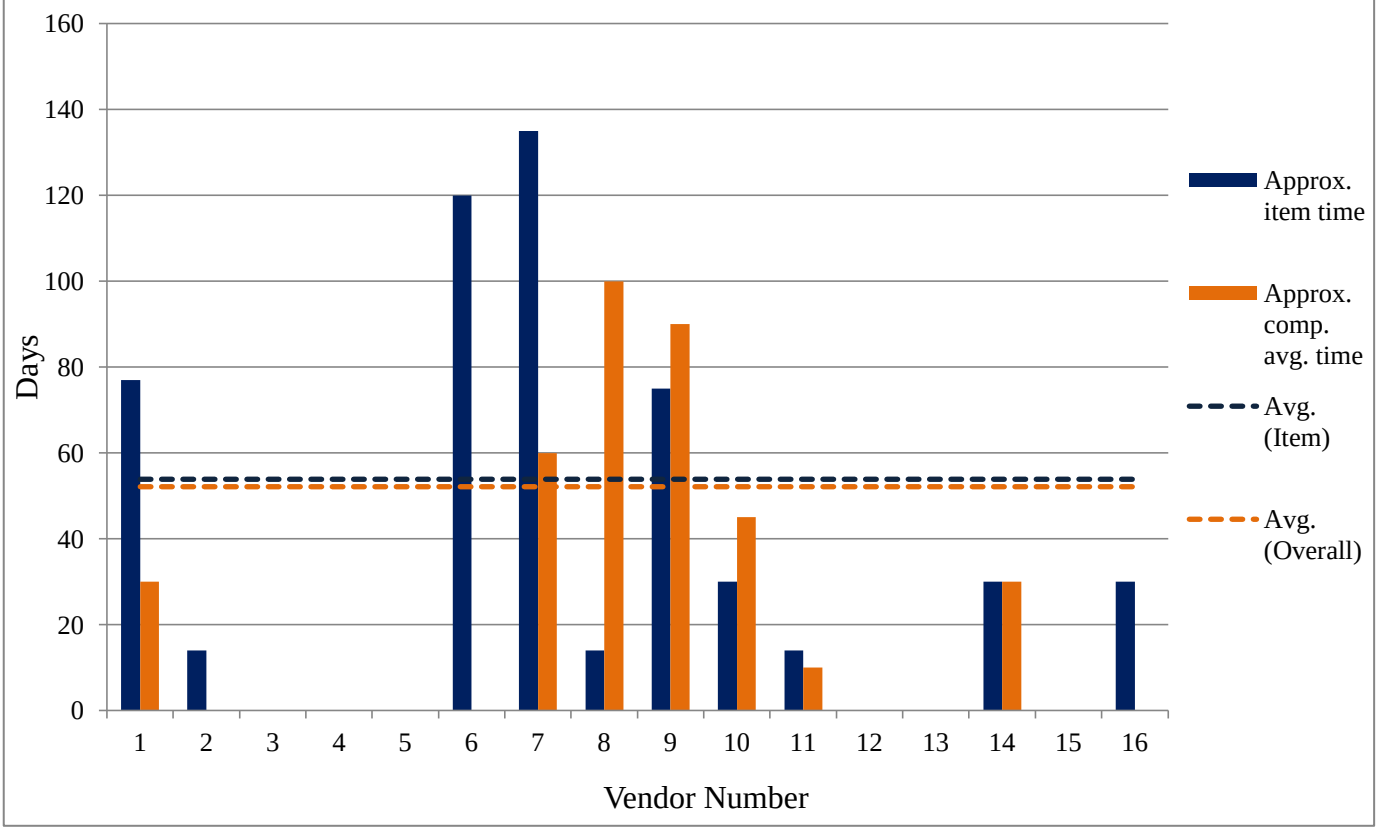
There are numerous peaceful applications of fermenters, ranging from the laboratory growth of microorganisms for research purposes, to the industrial production of medication, to the production of certain foods such as yogurt and beverages such as beer.[33]

The AG Biological List restricts the sale of complete fermenters with the following characteristics:
a) cultivation of pathogenic microorganisms or of live cells for the production of pathogenic viruses or toxins;
b) without the propagation of aerosols;
c) with a capacity of at least 20L.

This project targeted complete fermenters that have clean in place (CIP) and sterilization in place (SIP), or were disposable (single-use) bioreactors[34]*. Since many complete models were found, the likely trade in AG-controlled fermenter parts was not investigated, although such parts are also restricted under the current AG list.*

The online trade in AG-grade fermenters is large, with numerous manufacturers throughout the world selling them. The documented vendors (16 in the search dataset) are a tiny proportion of the vendors offering AG-grade fermenters online. Graph 4 shows the approximate advertised item and company average overall delivery times for the items.

Bar Graph 4: Advertised item and company average overall delivery times, fermenters



Vendor 1: offers to sell, through Alibaba.com, a wide range of SIP-capable fermenters with capacities ranging from 20L to 30,000L.[35]

Vendor 2: offers to sell, through Alibaba.com, auto-sterilizable 150-5000L fermenters, and 1000-40,000L glass-lined fermenters with optional SIP capabilities.[36]

Vendor 3: offers to sell, through the English-language global e-marketplace site TradeKorea, a laboratory size steam-sterilizable 350-500L fermenter.[37]

Vendor 4: offers to sell, through Alibaba.com, 50-100L fermenters with SIP capabilities.[38]

Vendor 5: offers to sell, through Alibaba.com, fermenters with 21 to 700L capacity and SIP capabilities.[39]

Vendor 6: offers to sell, through Alibaba.com, a 1000L fermenter with optional automatic sterilization procedure.[40]

Vendor 7: offers to sell, through Alibaba, a large number of fermenters that meet AG-grade parameters. For instance, the firm advertises “virus culture” jacketed bioreactors between 30L and 50,000L, with SIP capabilities, to be delivered in 2-3 months.[41] They also sell a 50L fermenter, advertised for bacteria, with SIP capabilities.[42] All of these

items are advertised for export. The delivery time required for the 50L bacteria fermenter is given as 3-4 months.

Vendor 8: used to offer to sell, through Alibaba.com, 500-10,000L fermenters with SIP capabilities.[43] The company took down its advertisement while the current report was written.

Vendor 9: offers to sell, through Alibaba.com, a range of 20L-100L fermenters explicitly designed for bacteria and fungi growth and possesses automated sterilization capabilities.[44] The company explicitly advertises "fast delivery" as a company advantage; the listed delivery time for the item is given as 2 weeks, and the company's average lead time is listed as 10 days.

Vendor 10: offers to sell, through its soctrade.com website, a disposable bioreactor made by Solaris Biotechnology (Italy) with working volume up to 25L.[45] The company's main export market is in the CIS countries.[46]

Vendor 11: offers to sell, through Alibaba.com, a 100L fermenter with SIP and clean-in-place (CIP) capabilities.[47]

Vendor 12: offers to sell, through Alibaba.com, in-situ sterilizable fermenters, including 20L to 1000L models.[48]

Vendor 13: offers to sell, through Alibaba.com, 30L disposable bioreactors.[49]

Vendor 14: offers to sell, through Alibaba.com, a line of fermenters, including SIP-capable models with capacities ranging from 20L to 20,000L.[50]

Vendor 15: offers to sell, through Alibaba.com, 30-5000L fermenters with CIP and apparently SIP, with advertised uses including bacteria growth.[51]

Vendor 16: offers to sell, through Alibaba.com, 50-50,000L single-use bioreactors.[52]

ii. **AG item #3: Centrifugal separators**

After fermentation has reached a stationary or steady state phase in a fermenter, the culture is removed from the fermenter and transferred to a centrifugal separator. Specifically, the culture is inserted into a chamber ("bowl"), which then is rotated at high speeds to generate centrifugal forces that separate the biomass from substrate.[53] The desired product can then be removed and be further processed for use as the payload in a biological weapon.

Civilian applications of centrifugal separators include the separation of biomass that can be used in agriculture as pesticides, biomass useful as probiotics, metabolites recovered from substrate such as toxins, purification (clarification) of liquids such as wastewater, skimming of milk; and mineral processing.[54]

The Australia Group Control List restricts the sale of complete centrifugal separators with the following characteristics:
a) continuous separation of pathogenic microorganisms;
b) without the propagation of aerosols;
c) at least one sealing joint within the steam containment area;
d) a flow rate of at least 100L/h;
e) components of polished stainless steel or titanium;
f) capable of in-situ steam sterilization in a closed state.

Vendor 1: offers to sell, through Alibaba.com, a centrifugal separator unit.[55] The item is advertised as having been designed for shear-sensitive microorganisms, has parts made of stainless steel (which, from the process pictures, appear to be polished before being installed), and is listed as steam-sterilizable SIP and has CIP functionality, and is hermetically sealed through the use of lip seals.[56] It appears the company can make products with a flow rate capability of 500 liter/hour (L/h).[57] As such, this company is probably a supplier of AG-grade centrifugal separators. The company claims to have done business throughout the world, including with American, Syrian, and Iranian firms.[58]

iii. **AG item #4: Cross (tangential) flow filtration equipment**

An alternative technology to centrifugal separation is cross (tangential) flow filtration. In this case, the culture removed from a fermenter is passed tangentially across a membrane filter.[59] The filter pore size is selected depending on the size of the material to be isolated. Thus the bacteria or toxin is separated from substrate. For BW purposes, the filtered bacteria or toxin can be further processed and then used as the payload in a biological weapon.

Peaceful applications of cross (tangential) flow filtration equipment include: purification and separation of proteins, peptides, and viruses for laboratory or industrial uses; the reduction of microbial content in fermented products; the separation of fuel oil; and the recovery of catalysts used to speed up industrial chemical processes.[60]

The AG Biological List restricts the sale of cross (tangential) flow filtration equipment with the following characteristics:
a) separation of pathogenic microorganisms, viruses, toxins, or cell cultures;
b) a total filtration area at least $1m^2$;
c) capable of being sterilized or disinfected in-situ, or using disposable/single-use filtration components;

The AG list also restricts the sale of some types of parts suitable for use in AG-grade cross (tangential) flow filtration systems. Only full systems have been investigated in this report.

Since cross (tangential) flow filtration systems come in many different setups, and that reverse osmosis systems employ tangential flow methods, it is difficult to differentiate between AG-controlled and non-AG controlled filtration equipment.[61] This problem

complicates the task of both would-be proliferants and custom and law enforcement officials.

Vendor 1: offers to sell, through Alibaba.com, an SIP-capable cross-flow filtration system having 92m^2 of nano/micro membrane.[62] This is the only item included in the current dataset from a European country (Italy). The listed delivery time required for this particular item is 30-60 days, and the average lead time required in general by the company is listed as 90 days.

Vendor 2: offers to sell, through Alibaba.com, a cross-flow filtration system advertised for (amongst other applications) bacteria and virus filtration.[63] The system uses filter cartridges, which are also sold separately by the company, and as such can likely be classed as disposable. The cartridges have membrane areas well in excess of 1m^2.[64]

Vendor 3: this vendor offers to sell an obsolete cross-flow filtration system. As this system is now quite rare, the original item manufacturer was contacted to obtain information on its parameters; the system accepts filter cartridges with membrane area significantly over 1m^2, which can then be disposed of after use. The system is therefore AG-grade. The listed delivery time is very short (less than a week). We anonymize this entry in the current public version of the report so as not to provide sensitive item information otherwise unavailable online.

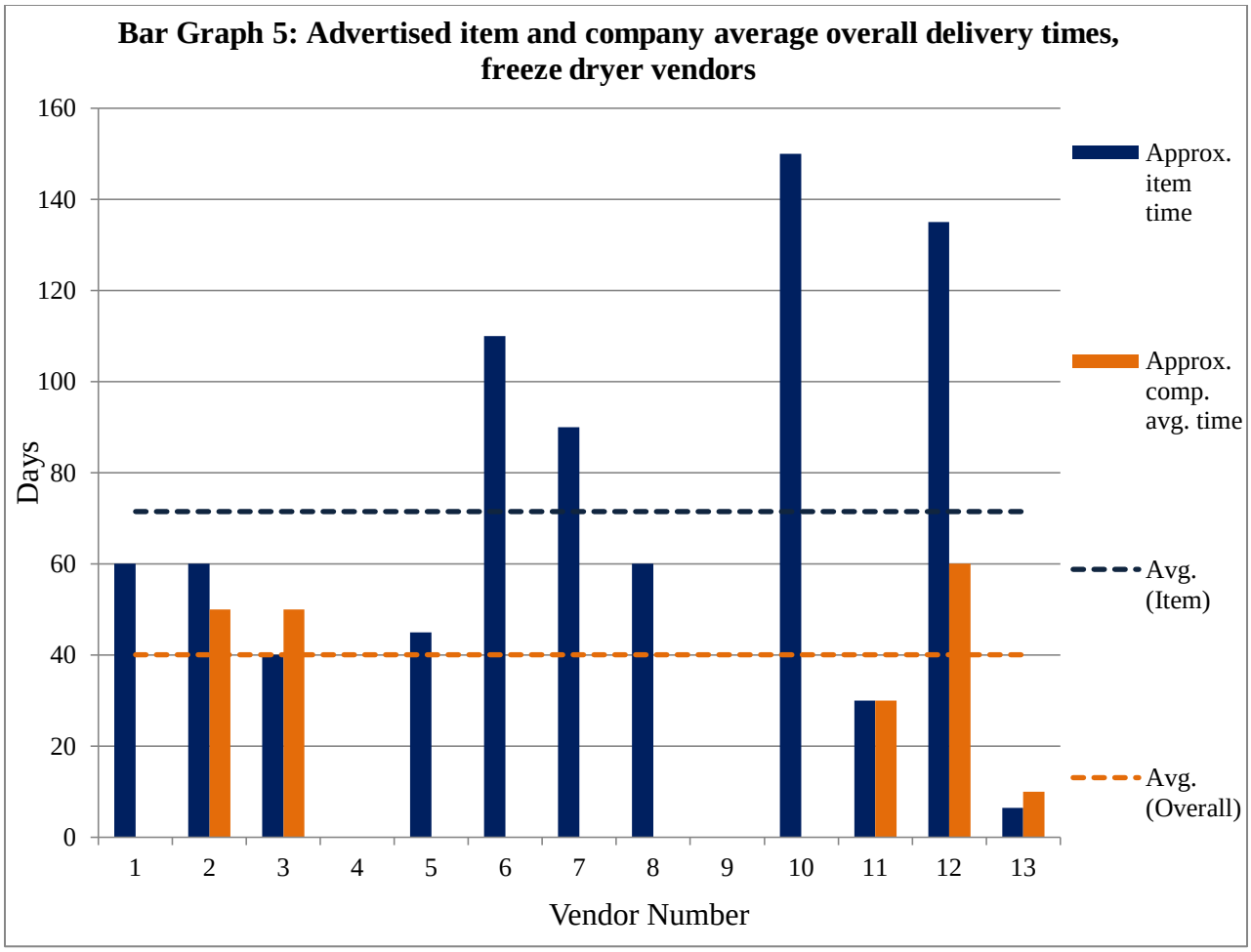
iv. **AG item #5: Freeze-drying equipment**

Freeze-drying dehydrates perishable materials at below the freezing point. In a BW program, freeze-drying is used to dehydrate bacterial cultures, allowing for long-term storage (over 30 years).[65]

Peaceful applications include: conserving pharmaceutical and medical products such as blood plasma and vaccines; the production of dried fruits and meats; the preservation of coffee, flowers, and animal skins (taxidermy); and the salvage of water-damaged books and documents.[66]

The AG Biological List restricts the sale of freeze-drying equipment with the following characteristics: a) steam sterilizable; b) a condenser capacity of 10 kilograms (kg) ice/24h or greater BUT below 1000kg ice/24h

There appears to be a lively e-trade in AG-grade freeze dryers, with numerous manufacturers throughout the world selling such items. The following graph shows the approximate advertised item and company average overall delivery times for the items.



Vendor 1: offers to sell, through Alibaba.com, a freeze-dryer with optional SIP capability.[67]

Vendor 2: offers to sell, through Alibaba.com, freeze-dryers with optional steam sterilization.[68]

Vendor 3: offers to sell, through Alibaba.com, a vacuum freeze-dryer unit.[69] It can be sold with steam-sterilization (or chemical sterilization) and has a 30-36kg ice/24h capacity.

Vendor 4: offers to sell, through ec21.com, freeze-dryers.[70] These have optional steam-sterilization. The company has also made clear they carry the 20 square meter (m^2) productive drying area version (amongst other models), and according to other vendors this particular model has a 200-300kg ice/24h capacity.[71] This company claims to have exported unspecified items to Syria, amongst other countries.[72]

Vendor 5: offers to sell, through Alibaba.com, 15-90kg/24h ice capacity freeze dryers with optional steam sterilization.[73]

Vendor 6: offers to sell, through Alibaba.com, a series of SHPM-LYO freeze dryers with steam sterilization.[74] While their capacities are not given, it is most likely that the models are either analogous or identical to the LYO series models sold by Vendor 12 below.

Vendor 7: offers to sell, through Alibaba.com, a vacuum freeze-dryer unit.[75] It has advertised SIP and CIP capabilities through steam sterilization and a 75kg ice/batch.

Vendor 8: offers to sell, through Alibaba.com, a range of vacuum freeze-dryer units.[76] These have advertised SIP and CIP capabilities and use steam sterilization. Models 0.5 to 50 all have between 10kg ice/24h and 1000kg ice/24h, inclusive.

Vendor 9: offers to sell, through Alibaba.com, a range of freeze-dryers.[77] These have steam-sterilization and range from 20kg/24h to 1000kg/24h ice capacity models.

Vendor 10: offers to sell, through Alibaba.com, a range of freeze-dryers.[78] These have optional steam-sterilization SIP systems, and have condenser capacities ranging from 20kg ice/24h to 200kg ice/24h, inclusive.

Vendor 11: offers to sell, through Alibaba.com, freeze-dryers with steam sterilization.[79] The particular model in question has a 20kg ice/24h capacity.[80]

Vendor 12: offers to sell, through Alibaba.com, LYO series vacuum freeze-dryer units with SIP capabilities.[81] The systems use steam sterilization as their SIP method and some of the models sold have capacities ranging from 200 to 400kg ice/24h. This company has a near identical name to Vendor 11's, but has a different company page on Alibaba, employs a different team as their Alibaba contact point, and presents different company information; as such, Vendor 11 and Vendor 12 are most certainly two distinct companies.

Vendor 13: offers to sell, through Alibaba.com, a freeze-dryer model with optional SIP.[82]

v. **AG item #6: Spray-drying equipment**

Spray-drying equipment is a dehydrating technique used to produce fine powders. Its main advantage over freeze-drying for BW production is that it also reduces the material to a particular particle size, removing the necessity to mill frozen products.[83] A spray dryer works by having the feed product streamed through a nozzle that generates controlled size drops, which are then deposited on the sides of an enclosed chamber. As the deposited material is thoroughly dry, it is free-flowing, and is easily conveyed into an appropriate container. For BW-related purposes, the spray dryer system must be equipped with a nozzle that generates drop particles with a mean product size of at most 10 μm.

Spray-drying equipment is widely used in industries that require the production of particular powders, ranging from the preparation of powders for traditional Chinese medicine, to the preparation of coffee and milk powders, to the production of ceramic and

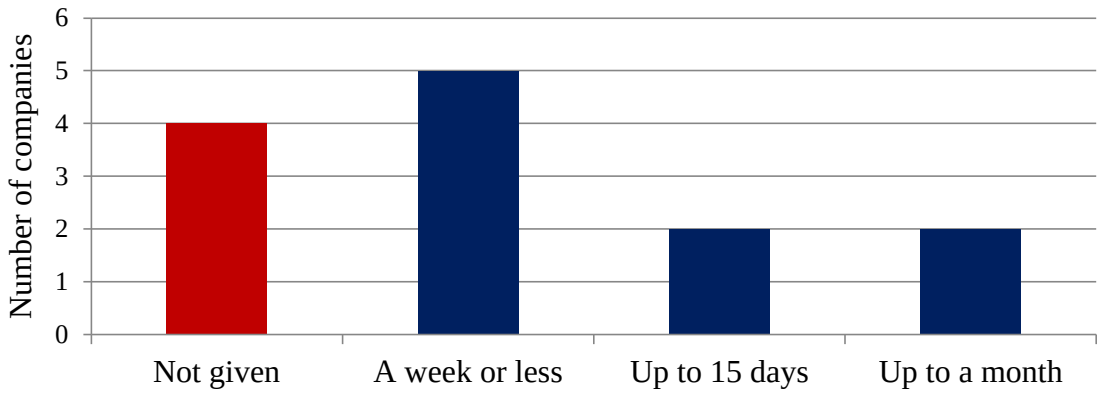
metal powders.[84] For most industrial purposes, such as dried milk powder, the particle sizes will be in the 100-200 µm range.

The AG Biological List restricts the sale of spray-drying equipment with the following characteristics: a) capable of drying toxins or pathogenic microorganisms; b) water evaporation capacity between 0.4kg/h and 400kg/h, inclusive; c) typical mean product particle size of at most 10 µm either as is or with minor nozzle modification; d) capable of in-situ sterilization or disinfection.

We documented 13 vendors of potentially AG-grade spray dryers. Making the distinction between a non-AG-grade and an AG-grade system, however, was not a trivial undertaking. Doing so required compiling and comparing information from various sources on multiple offered systems, and comparing these to known AG-grade spray dryers. No company model explicitly advertised system SIP or CIP capabilities. As judging whether the system would be "capable of in-situ sterilization or disinfection" required some additional publicly available information that went beyond what is available in the Australia Group's *Volume II: Biological Weapons-Related Common Control Lists Handbook*, we omit this discussion in the public version of the present report. We emphasize that the items offered were only probable AG-grade equipment.

We provide an anonymized graph below that shows the approximate advertised item delivery times. The average advertised item delivery time was 13 days. The company average overall delivery time was about 11 days. Several vendors advertised item delivery times under one week, and several vendors also advertised company average delivery times under one week. These values strike us as short timeframes.

Bar Graph 6: Anonymized advertised item delivery times, spray dryer vendors

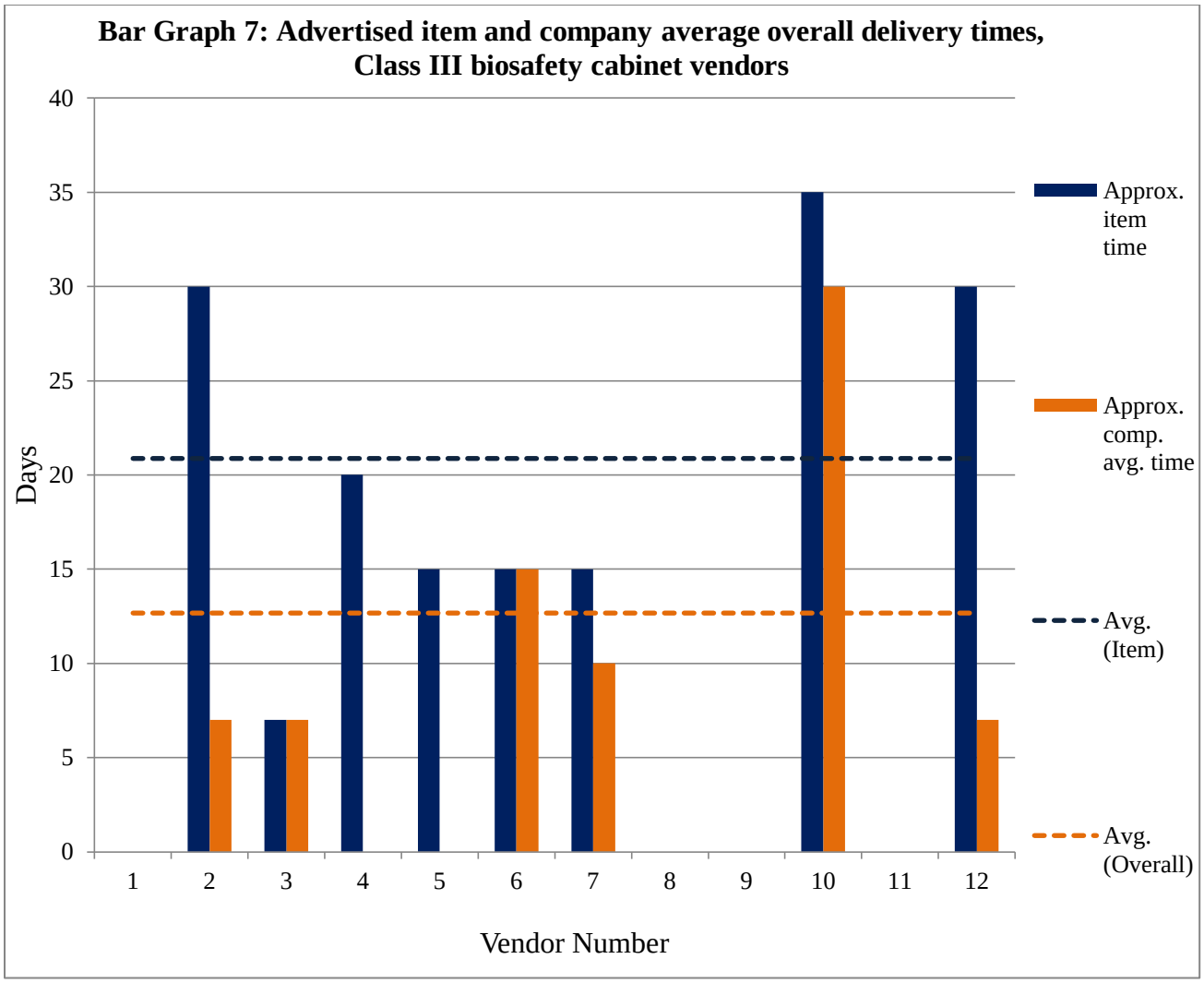


vi. **AG item #7: Protective and containment equipment**

Facilities who employ persons to work with dangerous pathogens typically provide them with protective and containment equipment. As such, the AG Biological List covers high-end protective and containment equipment. However, protection metrics are not uniform throughout the world; nations differ greatly as to the regulations or laws they have adopted to ensure adequate levels of protection for those of their subjects who work with dangerous pathogens. For example, in the 1980s, Iraq's BW program provided its workers with a low level of protection. When UN inspectors investigated for the first time the Al Hakam microbiology production plant, they noted the absence of personal protection equipment, which seemed to validate Iraq's claim that only nonpathogens were produced at this plant. However, the inspectors later learned that when workers were propagating *B. anthracis* in the plant, they simply donned gas masks. The Iraqi managers had deemed this rudimentary procedure as sufficient to protect workers from bacterial cells. This account taught us that we should not assume that criteria common to industrialized countries are also adopted by developing countries or terrorist groups.[85] Nevertheless, a country intent on acquiring a high technology level BW program in most instances can be expected to acquire personal and facility protective equipment.

The AG Biological List restricts the sale of the following protective and containment equipment: 1- Protective full or half suits, or hoods dependent upon a tethered external air supply and operating under positive pressure; 2- Class III biological safety cabinets (or isolators meeting similar performance standards, such as laminar flow hoods closed with vertical flow)

A large number of models of Class III biological safety cabinets are available online. The following graph shows the approximate advertised item and company average overall delivery times for the twelve vendors of Class III biosafety cabinets documented below.



Vendor 1: offers to sell, through Alibaba.com, Class III biological safety cabinets.[86]

Vendor 2: offers to sell, through Alibaba.com, a Class III biological safety cabinet.[87] The item is advertised for export. The item delivery is offered "within one month," with the average lead time given as 7 days.

Vendor 3: offers to sell, through Alibaba.com, a Class III biological safety cabinet.[88] The item is advertised for export. The item delivery is listed as 7 days, with the average company lead time given as 7 days.

Vendor 4: offers to sell, through Alibaba.com, Class III biological safety cabinets.[89]

Vendor 5: offers to sell, through Alibaba.com, a Class III biological safety cabinet.[90] The item is advertised for export abroad. The listed delivery time required for this particular item is 10-20 days.

Vendor 6: offers to sell, through Alibaba.com, a Class III biological safety cabinet.[91] The item is advertised for export. The item delivery is listed as 15 days, with the average company lead time given as 15 days.

Vendor 7: offers to sell, through Alibaba.com, a Class III biological safety cabinet.[92] The item is advertised for export. The item delivery is listed as 15 days, with the average company lead time given as 10 days.

Vendor 8: offers to sell, through Alibaba.com, Class III biological safety cabinets.[93]

Vendor 9: offers to sell, through Alibaba.com, Class III biological safety cabinets.[94]

Vendor 10: offers to sell, through Alibaba.com, a Class III biological safety cabinet.[95]

Vendor 11: offers to sell, through Alibaba.com, a Class III biological safety cabinet.[96]

Vendor 12: offers to sell, through Alibaba.com, Class III biological safety cabinets.[97]

vii. **AG item # 8: Aerosol inhalation chambers**

Aerosol inhalation chambers consist of enclosed chambers wherein animals are exposed to aerosols constituted by various bacteria, viruses, or toxins. Inhalation chambers are used in a BW program to discover the Infectious Dose 50 (ID_{50}) of a BW agent on animals that range in size from mice to apes.[98] Scientists who operate inhalation chambers can obtain good data on the infectivity of BW agents by varying the concentration of the test agent in repeated trials. Further, after having tested several animal models, it is possible to estimate the ID_{50} of each pathogen for humans.

The AG Biological List restricts the sale of aerosol inhalation chambers with the following characteristics: a) designed for aerosol challenge testing with bacteria, viruses, or toxins; b) of at least 1 m^3 capacity.

Vendor 1: offers to sell, through bio-launching.com, 1.28m^3 whole body exposure systems for infectious research.[99] It is unknown whether the company exports its wares out of China.

Vendor 2: offers to sell, through bio-equip.com and through bioon.com.cn, an aerosol testing chamber with 1m^3 explicitly advertised for military medicine and biological weapons protection capacity (in some configurations).[100] It is unknown whether the company exports its wares out of China.

Vendor 3: offers to sell, through its hope-med.com website, shaped aerosol exposure chambers of up to 10m^3 in capacity for toxicology testing.[101] It is unknown whether the company exports its wares out of China.

viii. **AG item # 9: Spraying, atomizer, and fogging systems**

In the civilian realm, these systems tend to be used for pest control, notably the elimination of flying insects and ground-level agricultural pests.[102] BW programs would use these systems to disseminate aerosols containing pathogens from an airborne platform over a target population or to contaminate an area to deny the enemy access to it.

The AG Biological List restricts the sale of the following spraying or fogging systems:
a) Complete spraying or fogging systems, specially designed or modified for fitting to aircraft, lighter than air vehicles (LAVs) or ultralight air vehicles (UAVs), capable of delivering, from a liquid suspension, an initial droplet volumetric mean diameter (VMD) of less than 50 microns at a flow rate of greater than two litres per minute.
b) Spray booms or arrays of aerosol generating units, specially designed or modified for fitting to aircraft, lighter than air vehicles or UAVs, capable of delivering, from a liquid suspension, an initial droplet VMD of less than 50 microns at a flow rate of greater than two litres per minute.
c) Aerosol generating units specially designed for fitting to systems that fulfil all the criteria specified in paragraphs a and b.

We found that numerous mini-helicopters and UAVs for spraying and fogging were available from Internet vendors, but no entry was found that advertised systems capable of dispersing particles of less than 50 μm in size and having a flow rate greater than 2L/min. One pesticide-spraying UAV with a flow rate of exactly 2L/min, but of unknown particle size, was listed for sale on Alibaba.[103] A very small UAV multi-rotor system (12.5kg take-off weight) had a flow rate in the 0.3-0.65L/min range with a 50-200m particle size range.[104] The flow rate for a small UAV multi-rotor system (18kg take-off weight) appeared to be in the 0.2-0.4L/min range with a 50-100μm particle size range.[105] A somewhat heavier multi-rotor model of similar design had an identical flow rate with an 80-120μm particle size range.[106] A larger mini-helicopter model (30kg take-off weight) has a reported flow rate in the 0.8-1.2L/s range but with an unreported particle size.[107]

We were surprised to have found crop sprayer/agriculture systems based on the Soviet-designed Antonov An-2 airplanes listed for sale.[108] The An-2 is a highly versatile and high capacity airplane with a 1350L or 1600kg payload. Although no details on the spraying system were provided, it most likely would be able to carry a fully functional AG-grade sprayer system.[109] No prices were publicly available and potential buyers had to contact the vendors directly in order to be quoted prices.

Another surprise that once again demonstrates that the purchase of almost anything can be arranged over the Internet concerns the sale and the rent of submersibles and semi-submersibles (which are not listed by the AG). The sophistication of underwater vehicles offered varies widely. At the upper end of the spectrum, one finds products from a United Kingdom-based firm which asserts that it is the largest purveyor of used submarine in the world. It advertises on its website that it has “a wide range of submarines, tourist submarines, T-subs, small manned submersibles, one-man subs, wet subs, and ROVs

[remotely operated underwater vehicles] available for sale and charter."[110] One of these submarines is a highly-capable Russian Projektu-613 class submarine, NATO code named "Whiskey". It was built in the 1956-1957 period as a Soviet Navy hunter/killer. When in service, the sub had a crew of 56. The vessel can stay submerged for three days. Possibly more threatening as carriers of biological dispersal equipment are small submarines that can be manned by two or three persons. A few such submersibles can already be found advertised through B2B websites. A not too fanciful scenario is that a mother ship camouflaged as a fishing boat could carry a small submarine near to the targeted coastal city and then launch it during the night. The submarine, which would be very difficult to detect, would surface upwind from the targeted city and then disperse an aerosol constituted by pathogens using one of the modern ground-based aerosol generating devices available on the Internet. After finishing the dispersal, the submarine would submerge and return to the mother ship, be loaded onto the mother ship, which would sail far away from the target by the time the first victim of the bioattack presented to a doctor or emergency ward. Open air tests carried out by the U.S. Navy in 1950 off San Francisco proved that an approach such as presented here could be frighteningly effective.[111]

The sheer size and highly specialized nature of large products like the An-2 airplanes and the submarines does, however, make is difficult to imagine a company selling or renting these without first conducting know-your-customer due diligence.

5. Acquiring Australia Group Listed Items Through B2BEC Platforms

Out of all of the domestic and international vendors of dual-use items of concern investigated by this project, only one vendor explicitly noted that its wares would only be "sold to pharmaceutical or chemical manufacturers" once proper authorization had been obtained.[112] This vendor is based in the U.S. and therefore is not included in the list of vendors in part 4.

Despite searches on all of the B2B sites listed in Annex 4, the majority of items documented in this report were listed on just one major B2B website, which was Alibaba.com. The Alibaba website does list the Chinese regulations relevant to biotechnology export controls.[113] Yet, in one documented case occurring through this website's buyer-vendor platform, numerous ostensibly Chinese companies responded to an ostensibly European individual's request to purchase a 50-60L fermenter, despite the purchaser making clear that the fermenter was meant for personal use. Some of these company responses offered larger fermenters, with one company apparently willing to sell 30,000L fermenters to the prospective buyer.[114]

The second phase of this project involved reaching out to some companies listed as vendors in section 4, Market Study Results, for the purpose of finding out about their export control procedures. As has been emphasized above, our goal was to identify best practices currently in place. We were unsuccessful at obtaining direct responses from companies regarding their export procedures, but were able to glean some additional information from our interactions with these vendors. The method we used was to message suppliers through the Alibaba Message Center, although it is important to

emphasize that buyers do not have to do so since venders typically list a contact phone number, an email address, and/or a physical address. We took this approach because the Alibaba system rates suppliers on their responsiveness to queries, a system that would encourage responses to our messages. Moreover, unlike email services, the system displays whether a message has been opened by a recipient, which provides useful information in case of non-response; opened but ignored messages let us know when we should change our messaging strategy. None of the messages sent were duplicitous regarding our identity and since we did not intend to purchase units, our messages contained no end-user information.

The first batch of messages sent simply asked for details on the paperwork necessary to affect a purchase. We noted that several of the recipients had opened the message, but we received no answers. Given these results, we decided to focus instead on obtaining more detailed information on the particular unit manufacturing processes, in part to see how the companies themselves had acquired or manufactured the units. Our second batch of messages therefore asked the company for the current unit price of an item and for additional documentation on the item of interest. This approach was immediately successful, with responses from vendors arriving in less than a day. The additional documentation acquired through these messages showed that even if the item of interest was assembled by the supplier, in many cases components of the item were sourced abroad. For example, one freeze dryer unit assembled in China used 36 parts that were manufactured by American, German, Swiss, Swedish, South Korean, and Italian companies. It was apparently expedient for this company to source these small components on the open market. This might have been done to drive down manufacturing costs, or because the assembler lacked certain technical or manufacturing capabilities, or perhaps to impress foreign buyers about the quality of the item by emphasizing familiar brands. This finding indicates that important subcomponents of items of dual-use concern are available from a host of sub-manufacturers. Determined proliferators could purchase components that they could assemble to acquire key equipment required for a BW program, or that they could use to refurbish or mend obsolete or broken items. The implication of this finding for proliferation is discussed in the next section.

6. Implications of Internet Purchased for Illicit BW-related Procurement Networks

The market search findings raise the possibility that a BW-related procurement network could be successfully operated today. Such a hypothetical network would take advantage of the existence of the lively trade in AG-grade equipment detected above, both for ease of procurement and concealment. In this section, we describe Iraq's pre-Internet era procurement network for BW-related items and then describe how a current proliferator could harness the Internet to establish an efficient illicit procurement network.

When Iraq began procuring BW-relevant equipment abroad in the mid-1970s, there were few export controls related to biologicals in place.[115] A similar situation existed in the chemical field. The structure of the Iraqi procurement network for both biologicals and chemicals at that time was simple: the money for the transaction was held in Iraqi and foreign banks, there was direct contact between the solicitor and the potential supplier throughout the entire deal-making process, and the supplier was usually responsible for

shipping the purchased item.[116] In the mid-1980s, leaders of industrialized nations recognized that Iraq had been able to acquire a significant CW program by having purchased the required equipment, chemical precursors, and protective gear from indigenous industries. To prevent other countries from acquiring chemical weapons and to hinder further CW-related progress in Iraq, industrial countries decided in 1985 to establish the AG, and by the late 1980s had implemented additional measures to hamper BW-related equipment procurement. Iraq's weapons of mass destruction (WMD) acquisition programs were significantly disrupted as a result.[117] In particular, its attempts in 1988 to purchase large-scale fermentation equipment and AG-grade spray dryers for the Al Hakam biological production facility failed, as would-be suppliers could not secure appropriate export licenses from their governments and did not chance selling their wares illegally.[118] Likewise, Iraq could not obtain "special dryers" (likely freeze dryers), which inhibited its military scientists from developing a dried formulation for *B. anthracis* spores.[119] Iraqi BW specialists had to shift previously-acquired equipment from other civilian laboratories to Al Hakam, and convert two previously-acquired facilities (Al Dawrah and Al Fudaliyah) in order to meet the military's large-scale BW production requirements.[120] Iraq, and sanctioned proliferators since then, established ever more complex acquisition networks to bypass export controls. In the case of Iraq, this involved: using legitimate commercial organizations as well as government ministries and trading agencies as fronts; employing middlemen in third countries to hide from potential vendors the actual end country; employing transshipments at various destinations to obscure the real destination; and using ostensibly-civilian Iraqi governmental agencies and their officials abroad to move and disburse money out-of-country.[121] While these methods worked to some extent, the procurement process became much slower and very expensive after the AG became operational.

Our analysis suggests that the rapid expansion of the biotechnology industry and the emergence of Internet-enabled biotechnology equipment purchases have set the stage for something akin to the simplistic "1970s-style" BW proliferation procurement. A bare-bones model of covert illicit acquisition is as follows: the proliferator secures funds; they then set up a front that has the appearance of a legitimate business and which then can act as a customer; the solicitor searches for suppliers of the needed items; a supplier of new or used AG-grade equipment, whether in an AG or in a non-AG country, is found and targeted; and the item is purchased by the solicitor who pays in a hard to track fashion. After the supplier has received the funds, the item is shipped to the front company. In order to demonstrate how Internet trading has made each of these steps easier than before, we refer to the aforementioned example of Iraq's inability to acquire a suitable freeze dryer and disclose how such an item could be obtained today.

As a consequence of the enormous growth in the biotechnology industry worldwide, there are now numerous small firms engaged in the trade of AG-grade items, including through B2B websites. The large number of such vendors implies the existence of numerous companies that utilize AG-grade equipment for commercial purposes. A modern proliferator can therefore set up, without great expense, an end-user that appears to have a legitimate reason for possessing the items it is attempting to procure. This company could even be in-country, depending on the level of suspicions or sanctions the

country is under, removing the need to arrange a final international shipment to the proliferating country. That is, a proliferator can set up a small company that for all intents and purposes does require the AG-grade item in question to conduct its operation. Doing so could be as simple as establishing a re-sale and trade company; for example, specialized in the distribution of AG-grade freeze-dryers in its part of the world. In this regard, 29 out of the 61 firms documented in the present report used the terms “trading company,” “agent,” “distributor,” or “wholesaler” to describe their commercial activities in part or in whole. The ability for a proliferator to set up an actual company is particularly worrisome, as many WMD-related illicit trafficking cases have to resort to fictional end users. For instance, there are reports that an individual allegedly seeking valves ultimately destined for Iranian centrifuges introduced himself to German industrialists as a “refinery manager,” but it would be out of the question for a proliferator actually to establish a refinery to increase their odds of securing the shipment.[122] Not so for biotechnology, where setting up a company with a reasonable excuse for purchasing AG-grade equipment is relatively cheap– as evidenced by the plethora of small vendors documented in the present paper.

A proliferator unsatisfied with such a cover can easily develop another by noting what online vendors are advertising and how their goods may be applied. For instance, nearly all of the surveyed freeze-dryer vendors emphasize their product’s application to the production of dry fruits. It is worth emphasizing that this type of information was not commonly available knowledge in the past. The level of technical competence necessary to establish a convincing cover story has dramatically decreased, and the speed at which cover-story relevant information can be obtained has greatly increased. For example, the Iraqis made numerous blunders when it came to cover stories, describing supposed civilian applications at odds with the parameters of the equipment in question. As we have documented in this report, today any individual with an Internet connection can rapidly develop a list containing information about dozens of freeze dryer vendors, determine which commercial applications are advertised for particular AG-grade items, and use this information when justifying their purchase offer.

In either case, the proliferator is now shielded by a cover story. They can exploit the ease and speed of communication enabled by the Internet to rapidly message a great number of suppliers found using the plethora of B2BEC websites currently active. As this study demonstrated, it is possible to identify purveyors of AG-grade equipment sold online using only open-source information. A proliferator could therefore message dozens of AG-grade freeze-dryer vendors with offers to purchase their wares and continue doing so until a deal with one of them has been worked out.

At this stage, there is an element crucial to both the proliferator’s cover and to the legitimate entity’s bottom line, namely the payment. Here, the proliferator and the potential vendor have diverging interests. For the vendor, a large payment made in a transparent manner by the buyer with as much documentation as possible is best. For the proliferator, large payments, greater transparency of the financial transaction, and exchange of documentation increase the chance of being detected by law enforcement or foreign intelligence agencies. It was for this reason that whenever possible the Iraqi

program relied on cash payments being made from controlled government accounts with minimal paperwork.[123] Returning to the modes of payment options summarized in part 2 of this report, a significant portion of companies selling AG-grade items accept modes of payment that can be misused to reduce the visibility of the purchaser. This issue is compounded by the relatively small sums involved; some vendor-listed items, such as a number of spray dryers and Class III biosafety cabinets, were advertised as costing less than $10,000 apiece. A state actor would have little difficulty in financing and concealing a series of modest payments of this sort. Since companies were found to advertise openly the payment types they accept, the proliferator would not have to inquire into alternate payment modes and risk raising a red flag. To return to the example of the illicit freeze-dryer procurement, based on the offers documented in this report, the advertised available methods of payment, and our interactions with suppliers, an AG-grade unit can be obtained for less than $115,000 (without shipping) and paid for in a hard-to-trace fashion, for instance by exploiting Western Union's services.[124]

The last stage is shipping the item. Our study specifically focused on companies willing to sell their wares to foreign entities. In these transactions, shipping costs are typically paid by the buyer, while the shipment process details appear to be organized by the vendor. This being the case, the proliferator does not need to organize the shipment, but instead relies on the vendor's network. As summarized in section 2 of the present report, some of the smaller items (spray dryers, Class III biosafety cabinets) have relatively fast transaction times; there would be little time for custom and law enforcement to interdict illicit shipments of this nature. If the proliferator is lucky, he may find a vendor who is unconcerned by export license requirements and simply ships the item to its destination. Indeed, if they procure the item from a vendor in a non-AG-participating country, the vendor may have no awareness of the item's dual-use nature. However, even if the potential vendor undertook to check out the customer, it would be extremely difficult for them to determine whether the buyer was a legitimate firm or a component of an illicit procurement network. As noted above, small biotechnology start-ups and unknown low-volume re-shippers are now common throughout the world. Hence, typical red flag guidance, even if applied, is unlikely to be effective. Unfortunately, we were unable to obtain responses from vendors with regards to the paperwork necessary before one could effectuate a shipment, and are hence unable to evaluate current customer investigation best practices.

Finally, the ability to source replacement parts for obtained items is an important element to a proliferation network. First, it impacts a proliferator's ability to maintain a unit in working condition. This challenge may not be of concern for a terrorist group attempting to produce a sufficient quantity of pathogens to mount a one-time attack, but would be quite serious for a proliferating state attempting to develop a substantial production line for manufacturing large quantities of pathogens. Second, it opens proliferation possibilities by enabling proliferators to rely on used, obsolete, or damaged units being sold in the second-hand market. In this regard, the apparent lively trade in subcomponents for some AG items suggests that sourcing spares for biotechnology equipment, unlike for some other WMD-relevant technologies, is a relatively easy task. Such subsystems, apart from the select few critical components already identified on the

AG list, can hardly be controlled given their ubiquity. It is already difficult to prevent high-technology components from ending up in the wrong hands, as Project Alpha's MKS pressure transducer experiment vividly demonstrated. It then appears impossible to interdict the acquisition of simple items, such as the DANFOSS (Denmark) oil pressure differential controller used in a particular AG-grade freeze dryer unit. While we focus on whole AG-grade systems, it appears that the rise in B2BEC has also improved access to spare parts. For instance, if a proliferator had broken the controller in his freeze-dryer, he could attempt to source a spare through a vendor listed on Alibaba, where several DANFOSS controllers are listed for sale.[125]

7. Technologies not Listed by the Australia Group but with Implications for Biological Arms Control

The rise in e-commerce is significantly speeding up the rate at which innovative biotechnology products become globally available. With regards to assessing the need for interdiction of new technologies that are likely to have applications in BW programs, we fear the AG Biological List is failing to keep up with recent advances in biotechnology and bioindustry. To demonstrate this problem, we showcase six emerging technologies that are available on the Internet and, we believe, have potential biological and chemical warfare applications. They are: algae photobioreactors; freeze-dryer gas sterilization upgrade kits; hand-held aerosol generators; DNA kits; synthetic biology kits; and 3D bioprinters. We are particularly concerned about kits, as the underlying technology is rapidly advancing, complicating efforts to predict their potential negative impact. As far as we are aware, the AG has not dealt with possible arms control issues generated by kits. Certainly, there are no kits listed on either the AG's chemical and biological control lists. As with other dual-use items discussed above, kits are easily purchased by anyone with access to a computer and possessing a credit card acceptable by vendors.

i. **Algae growing systems (photobioreactors)**

Several vendors offer algae growing systems, commonly called photobioreactors,[126] of varying capacities. These algae growing systems have legitimate use in the biofuel industry, and are also used by small producers of proprietary cosmetic creams and oils.[127] However, algae growth equipment could potentially be used to propagate pathogens or species of algae that produce toxins. The stated commercial applications of these systems are new, and the industries that propagate algae to produce their products were not operational when the AG Biological List was developed. As such, the AG Biological List does not provide guidance as to whether or when algae bioreactors should be classed as fermenter/bioreactor systems, and fails to regulate other types of algae growth equipment. The following four photobioreactor vendors demonstrate the online accessibility of the technology:

Vendor 1: offers to sell, through Alibaba.com, a step-wise, horizontal bioreactor system that promotes fast-growing algal bloom and that any algal type can be produced."[128] The system advertised has a minimum 3000m^3 capacity.

Vendor 2: offers to sell, through Alibaba.com, an equipment set using photobioreactors to support algae growth.[129] They advertise their closed-loop system's self-cleaning

mechanism.

Vendor 3: offers to sell, through Alibaba.com, a closed-loop, continuous photobioreactor array for algae growth.[130]

Vendor 4: offers to sell, through Alibaba.com, an entire algae biodiesel production plant with a production capacity in the 1 to 500 ton range.[131]

ii. **Freeze-dryer gas sterilization upgrade kits**

Currently, the AG Biological List contains only freeze-dryers employing steam sterilization. However, new gas sterilization technology retrofit kits for freeze-dryers are now available online. A producer of gas sterilization kits claims that a freeze-dryer equipped with their device possesses equivalent sterilization performance to that of a freeze-dryer equipped with a traditional steam-sterilization system.[132] Moreover, traditional steam-sterilization requires a robust and specially designed freeze dryer, while gas sterilization systems have been advertised as a gentler, more flexible alternative.[133] The availability of these upgrade kits thus reveals a loophole in AG controls since they are unlisted. An example of a gas sterilization vendor is as follows:

Vendor 1: advertises a system through the B2B website *IndiaMart*.[134] The company claims to be the "only manufacturer that offers this technology."

iii. **Hand-held aerosol generators**

The AG Biological List includes only aerosol generators that are easily fitted on airborne platforms. There is now a significant offering of ground-based aerosol generating systems on the Internet, including systems that are advertised as capable of dispersing 1-10 micron size particles. These systems have legitimate uses as fog generators, pesticide spray systems, hospital sanitization devices, and to administer aerosolized vaccines. Several such systems might be capable of spraying biological agents without destroying them.[135] Some of these systems are hand-held devices that could be easily concealed in, for example, a backpack or valise.

As part of this report, we documented three example companies that offered ground-based aerosol generators that were capable of generating particles below 10 microns, that could be hand-carried or mounted on small vehicles, and that had other essential characteristics. We deem it judicious not to reproduce the vendor listings in the current online report.

iv. **Recombinant DNA Kits**

In the context of this report, a "kit" is a package that contains premeasured and pre-prepared chemicals and complete instructions for accomplishing a specific genetic engineering project. These kits usually are relatively inexpensive to purchase. For example, a *Bacillus subtilis* expression system suitable for industrial-scale protein production can be purchased for $578.[136]

In order to undertake a genetic engineering project without a kit, the scientist needs to develop a protocol for the project he proposes to conduct, purchase and take delivery of all reagents required for the project, measure and formulate the reagents as needed, and proceed with applying the methodology specified in the protocol. The process of developing an effective protocol is unpredictable in the likelihood of success, and in the time and other costs that might be required. Some seemingly straightforward procedures in molecular biology can take a year or longer to develop and then optimize. Conversely, a scientist may simplify his research by purchasing a kit that contains all the ingredients required for his research, including well-validated protocols and premeasured reagents. Readily available modern-day biotechnology kits make it possible for a scientist or technician to access and use high technologies that they otherwise would be unable to acquire and master, as well as making it possible for students and interested biological hobbyists with limited lab experience to exploit successfully genetic engineering for whatever their purposes. Examples of the many types of molecular biology kits available on the Internet are presented in Table 2. PCR machines and necessary reagents for the automated extraction and amplification of DNA/RNA are also widely available online.[137]

The implication of the availability of genetic engineering biology kits is the lowered threshold of technical capability required to perform genetic engineering work for many purposes. A committee established in 2011 by the National Research Council to assess trends in the life sciences relevant to the BWC noted in its conference proceedings that: "increasing access to sophisticated reagents such as standardized DNA "parts" and easy-to-use commercial kits and services has placed some hitherto advanced technologies within the reach of less highly trained practitioners, and has expanded the global spread of life sciences research and its industrial applications."[138] As a result of this de-skilling trend, a proliferator could draw upon a larger pool of persons who are sufficiently technically competent to participate in the development of new or improved biological and toxin weapon agents than was the case when kits were unavailable or primitive. Kits could simplify the conduct of gain-of-function research and development that aim to, for example, produce bacteria that are resistant to multiple antibiotics, that possess virulence factors not present in nature and thus are highly pathogenic, and/or that have altered antigenic structures that allow them to defeat currently available vaccines. Kits do so by enabling their operators to simplify and standardize some of the preparatory steps in these complex experiments.

Table 2: Genetic Engineering Sub-Categories and Number of Kits Available in Each from Just One Commercial Vendor[139]
• BAC Plasmid Purification (37) • Bacterial Plasmid Purification (42) • DNA Amplification Products and Kits (7) • DNA Labeling Kits (16) • Fluorescence Immunoassay (28) • Mutagenesis (24) • PCR Cloning (37) • Protein Detection Kits (147) • RNA Amplification Products and Kits (10) • Transcription Kits (19) • Transfection Kits (152)

v. **Synthetic biology kits**

Similar to our discussion in the above section dedicated to DNA kits, it is possible for any member of the public to purchase synbio kits. We provide a detailed description of one readily available synbio kit to demonstrate the product's capabilities. It is far from the only available kit (a Google search using the term "synthetic biology kits" generated more than 240,000 hits).

Vendor 1: offers to sell, through its website, a kit called Genomikon Rainbow Factory for $595.[140] The information about this kit is as follows:

> Genomikon Rainbow Factory is a learn-by-doing synthetic biology kit that enables teachers, researchers, and citizen scientists to practice genetic engineering in a few hours, spread over two or three days. This experience requires minimal equipment. Genomikon makes building DNA molecules almost as simple as putting together Lego blocks, and Synbiota software helps you to design DNA ahead of time, to aid in the conceptualization of the DNA circuit. To demonstrate, below we will explain how to engineer *E. coli* to be colorful by designing and building a DNA circuit made up of color producing genes that appear red, yellow, and blue. The colors are produced by the red fluorescent protein, green fluorescent protein, and blue chromoprotein.[141]

On its website, the manufacturer repeatedly emphasizes the kit's de-skilling nature. As can be seen from the product description that follows, it is designed to enable individuals with only a "basic" grasp of biology to carry out complex procedures:

"1. Product Details

- This project enables 15 people/groups to design, build, and transform DNA circuits. These kits come with freeze dried DNA ligase (you just add water), LB agar, LB media, chloramphenicol, 8 magnets.
- You need to purchase microcentrifuge tubes to do your reactions in, 6 cm plastic Petri dishes so you can grow your bacteria, tips/pipets, gloves, and a 37°C incubator.

2. Needed basic Complexity Level:
- basic knowledge of DNA structure (http://en.wikipedia.org/wiki/DNA).
- basic knowledge of the central dogma of molecular biology (http://en.wikipedia.org/wiki/Central_dogma_of_molecular_biology).
- basic knowledge of bacteria (http://en.wikipedia.org/wiki/Bacteria).

3. Methodology
- Design the DNA you are going to build using Synbiota software.
- Based on your designs, build real DNA using the Genomikon Kit.
- Boot up your organism, take pictures of your bacteria and log/share your data in your lab book."[142]

While kits like this one provide novices with the means to create genetic constructions with quite limited functional capabilities, the pace of technology advancement in this area of science suggests that within 10 years novices will be afforded many more opportunities for creating recombinant organisms with far more diverse capabilities.[143]

vi. **3D bioprinters**

A survey of 3D printing technology has been published in *Nature Technology*.[144] 3D bioprinters are related to the common ink jet printer. Instead of spraying different colored ink though a set of nozzles onto paper, 3D bioprinters spray different kinds of cells onto a scaffold. The sprays can be designed to produce layers of different cells, which can lead to the construction of tissues. Recent advances that utilized 3D bioprinters include "…the printing and growing of an ear that can be used for reconstructive surgery on children born with malformed ears and to produce a splint to treat the trachea and bronchus of a child suffering from traecheobronchomalacia."[145] The technology is currently in the early development and commercialization phase.[146] It seems already possible, as allegedly done by a (DIY bio) group dedicated to the subject, to piece together a rudimentary 3D bioprinter from commercially available components.[147]

One dual-use application of this technology is the printing of tissues upon which to test compounds of possible use in medicine for toxicity.[148] This technique, for example, can be used to rule out toxic compounds discovered while searching for novel pharmaceutical compounds.[149] Conversely, the technique could also be used for the development of chemical weapons, with printed tissues used to evaluate the toxic effects of CW compounds. Specifically, tissue testing could be misused to speed up the discovery of novel CW agents and to improve the toxicity models used to predict CW effects on humans.

We think it is noteworthy that a new term has appeared, namely 4D printing. This is defined by including "time" as the fourth dimension. In other words, tissues are conditioned and matured post-3D printing to allow for additional development and differentiation within the tissue construct. Conceivably this might add greater specificity and accuracy to the evaluations mentioned in the preceding paragraph.

Vendor 1: is a U.S.-based start-up currently designing a 3D bioprinter. It offers a developmental version for a trial period to customers willing to pay $5,000.[150]

Vendor 2: is offering for sale on Alibaba a 3D bioprinter for $24,500.[151] The company emphasizes that its bioprinter uses living cells to construct tissues.[152]

8. Conclusion

Current BW interdiction efforts devote significant resources to maintaining effective export controls for equipment particularly suitable for use in the production or dissemination of biological agents. Efforts to secure such equipment are coordinated through the AG forum. We believe that the Internet, in particular the advent of e-commerce, is having a major disruptive effect on BW-relevant export controls. This effect, in turn, negatively impacts current biological arms control measures.

The project reported in the paper sought to test this inference. We say "test," because due to inherent project limitations we could not hope to accomplish more than a scoping study of the availability on the Internet of a limited set of dual-use biotechnology and related equipment as listed on the AG Biological List. We searched for online vendors of eight of the nine items on this list to determine in general terms the degree of availability of each item, the specifications of items sold, and the degree of vendor vulnerability to exploitation by would-be proliferators. The eight categories and the broad estimate of vendors for each was as follows:

- Fermenters – plentiful
- Centrifugal separators – rare
- Cross (tangential) flow filtration equipment – rare
- Freeze-drying equipment – plentiful
- Spray-drying equipment – common
- Protective and containment equipment- Class III biosafety cabinets – plentiful
- Aerosol inhalation chambers – rare, domestically-oriented sales
- Spraying and fogging systems mounted on aircraft per AG specifications – not found as specified apart from offers to sell entire crop-spraying airplanes

The detailed data in the survey supports our contention that there are many vendors of dual-use equipment of concern that sell their goods over the Internet. Importantly, we found a great many vendors in non-AG participant states, such as China, India, and Russia. We do however caution that it was often difficult to establish whether equipment had the characteristics sufficient to be included on the AG Biological List.

We noted that the selling companies were often small and hence probably lacked the resources to conduct extensive know-your-customer checks as part of an export control due diligence process. Moreover, we did not discern any indicators that these companies knew they were selling dual-use items. We highlighted that these companies advertised payment options known to be exploitable to anonymize buyers. In sum, these vendors are a particular market segment that appears quite vulnerable to targeting by would-be proliferators. It is incumbent on arms controllers to recognize that products of concern are now being sold by Internet vendors who, unlike large and well-established companies, might "not ask so many questions."[153]

We made three further observations. First, some companies offered installation assistance up to and including full installation of the purchased equipment, and this raised the question of the transfer of intangible knowledge. Second, our findings showed that a large number of sub-manufacturers exist that manufacture and sell important subcomponents of items of dual-use concern, which opens up the possibility of key equipment being assembled by a proliferator from diverse sources. Third, we noted the online availability of a number of emerging technologies with potential BW applications that were not listed on the AG Biological List.

We conclude that would-be proliferants, in particular aggressive governments, would not find it difficult to set up a BW-related procurement network that could operate efficiently today. Plausible methods by which such a network might be able to operate undetected are discussed in section 6 of this paper.

Vendors are ultimately responsible for ensuring that they comply with all export laws and regulations. We offer a number of recommendations in section 10 below to help online vendors rise to this challenge. We urge all concerned national authorities, in particular those of AG participants, to engage with the e-commerce sector to ensure that national laws and regulations are well-publicized.

These efforts will only be meaningful, however, if national legislation is enforced and kept up-to-date. All United Nations member states are obliged to follow the strictures of UNSCR 1540, whose Article 3 states:[154]

"…that all States shall take and enforce effective measures to establish domestic controls to prevent the proliferation of nuclear, chemical, or biological weapons and their means of delivery, including by establishing appropriate controls over related materials and to this end shall:

[…]

> (d) Establish, develop, review and maintain appropriate effective national export and trans-shipment controls over such items, including appropriate laws and regulations to control export, transit, trans-shipment and re-export and controls on providing funds and services related to such export and trans-shipment such as financing, and transporting that would contribute to proliferation, as well as establishing end-user controls; and establishing and enforcing appropriate criminal or civil penalties for violations of such export control laws and regulations."

In practice, the AG Biological List serves as an international standard for what the mandated BW-relevant export controls should cover, and remains highly relevant today. Indeed, some non-AG participants adapt recommended AG export measures for their own purposes. It is therefore critical that the AG acts to make sure that its Biological List keeps pace with rapid technological progress in biotechnology and bioindustry.

We conclude with a sobering case that presents several of the concerns this paper brings up. The Pakistani industrial microbiologist Abdur Rauf Ahmed worked for Al Qaeda in Afghanistan for some length of time before 2000. When American forces captured his notebooks in 2001, one of his letters read as follows:

> "…successed [sic] in obtaining some of the important internet connections and tried to solve technical problems of our work […] the complete unit of fermenter along with accessories was in its final stages of its completion […] I finalised all the accessories required for the smooth running of our bioreacter [sic]…I am sending you a final price list of items to be shipped"[155]

We do not know from whence Abdur Rauf Ahmed was attempting to source the bioreactor and its accessories, nor what was meant by the mention of "Internet connections." We can pose, however, a believable scenario. The equipment could have been ordered online using a fake laboratory as cover, and then transported to Adbur's real location in Afghanistan. If this were what occurred, it would have been very difficult for an outsider to find out that all items ended up at one site. We fear that if nothing is done to adapt current BW-related interdiction efforts to the Internet age, we may well see the next proliferator confirm this scenario's viability.

9. Project Limitations

This section explains four study design choices and restrictions, and the resultant study limitations.

i. **Inability to test offers**

We were not in a position to conduct "sting" purchases of items, nor could we initiate transactions by posing as legitimate buyers. While we report what types of AG-grade equipment was found offered online, we cannot provide evidence that some companies would actually sell these items without conducting due diligence.

ii. **A focus on vendors from outside the AG participating states**

With few exceptions, we do not document AG-grade equipment sold out of the U.S. or the E.U., or sold through B2B websites hosted in these countries. We explicitly searched for companies operating outside of the U.S. and the E.U., and outside of the AG overall, to demonstrate that AG-grade equipment is now sold by or through non-AG participating states. Since we could not test offers (limitation i.), we felt it necessary to restrict our findings to countries where AG export controls would not necessarily apply, i.e. where the items might be sold without customer screening taking place. We see little reason why a proliferator would risk approaching vendors of dual-use items in AG participating

states when the same equipment can be obtained elsewhere where controls are comparatively weaker.

iii. **Documenting what is readily available**

We designed the study to analyze the online availability of AG-grade equipment, and further restricted ourselves to non-AG-based vendors (see limitation ii.). As a result, the vendors selected do not form a truly random subset of the entire AG-grade equipment vendor population. The metrics reported, such as average delivery times or proposed payment options, are not meant as overall market averages. Rather, they reveal the types of services found to be readily available.

iv. **Evaluating market changes: "What is the Delta?"**

Finally, only qualitative changes in the worldwide biotechnology market detectable to us are reported. We lack baseline data on conventional, non-Internet, vendors of biotechnology equipment. We also lack historical data on worldwide biotechnology equipment trading. We therefore refrained from making quantitative claims regarding the evolution of biotechnology equipment trading.

10. Recommendations for AG Participants and other concerned states

Urgently pursue strengthened national export control laws on BW-related items

As demonstrated by our findings expressed in this report, there are now numerous vendors of AG-grade equipment in non-AG participating states, where export control regulations can be expected to be comparatively lax. This adds urgency to efforts to help other nations strengthen export control laws regarding BW-related items. These laws are the first step in interdicting illicit exports of AG-grade equipment. They provide the necessary rules, regulations, and guidelines that national companies must obey, and ensure that directors of companies that transgress them are dealt appropriate punishment.

There is an international legal framework that underpins such efforts to strengthen and harmonize export controls. All 173 states parties to the BWC are legally bound by its provisions, especially those found in Article III and Article IV (see Annex 3). Article III forbids state parties to "transfer, or in any way assist, encourage or induce anyone else to acquire or retain biological weapons." Article IV enjoins states to "take any necessary measures to prohibit and prevent the development, production, stockpiling, acquisition or retention of the agents, toxins, weapons, equipment and means of delivery specified in Article I [...]"[156] Moreover, all UN member states are legally bound by UNSCR 1540 (see Annex 5).[157] The resolution requires all UN member states to put in place and support measures to interdict chemical, biological, and nuclear weapons proliferation.

One specific area of concern is the apparent gap in the Chinese Export Control List regarding AG-grade spray dryers. This is worrisome, as we documented in this report numerous vendors in China that appear to offer AG-grade spray-dryer models. While having specific entries in its export control list for the rest of the items on the AG

biotechnology list, the Chinese do not mention, as far as we can observe, AG-grade spray dryers directly. The relevant law is the Regulations of the People's Republic of China on Export Control of Dual-Use Biological Agents and Related Equipment and Technologies, and its "Dual-Use Biological Agents and Related Equipment and Technologies Export Control List" Annex.[158] The law became effective in December 2002, and the Ministry of Commerce followed up on this action in 2006 by publicizing the "Biological Agents and Related Equipment and Technologies Export Control List."[159] Under Article 16 of the aforementioned regulations document, China maintains a catch-all clause that would still be applicable for sales of spray dryers: "where any unit or individual knows or should know that the dual-use biological agents and related equipment and technologies to be exported will be used by the receiving party directly for the purpose of biological weapons, it shall not export such dual-use biological agents and related equipment and technologies, whether included in the Control List or not."[160] However, it would be highly beneficial for spray dryers to be directly listed in the Export Control List.

Consider having an approved government group attempt to purchase an AG-controlled item online without presenting end-user information

By mirroring what Project Alpha did with the MKS pressure transducer discussed above, such an operation would verify whether a buyer can easily purchase items on the AG Biological List and have them delivered to a site designated by the buyer. To avoid legal issues and the risk of diplomatic embarrassment should procurement fail, the purchase could be coordinated with the vendor's home country.

Our recommendation is that the first attempt should be to purchase an AG-grade spray dryer. These units are relatively cheap and small, which should keep shipment and customs costs down; the market search results placed the average cost of a spray dryer between $3100 and $8300 depending on options, and the characteristics summarized in Annex 5 indicate that items tend to weigh less than 130kg and take up significantly less than $1m^3$ of space.

If, as we fear, such a transaction is easy to carry out successfully, significant information on the entire transaction process will be obtained. Moreover, specific sensitive parameters of the spray dryer unit, such as its ability to withstand clean-in-place routines, the particle sizes generated, and its longevity under heavy use could be measured. This would provide a snapshot of the aerosol capability that is currently available to a would-be proliferator.

Persuade B2B e-marketplace owners to educate their users

Perhaps the easiest way to reach out to companies selling biotechnology equipment through B2B e-marketplaces is to have the B2B e-marketplace owners themselves educate vendors before allowing them to post items for sale on their websites.

At the very least, B2B e-marketplace owners should make sure that vendors attempting to post items for sale are first shown a list of relevant laws and regulations

with appropriate links and contact information, and are made aware that they must follow any applicable regulations as part of their terms of use of the B2B service.

Going beyond such a minimalist approach, it is possible to deploy a system like eBay's where messages are tailored to the particular item being posted and the regions involved. This approach is in line with recommendations made by Project Alpha in the context of the e-commerce of items controlled for sale by international export control regimes and UN sanctions.[161] The eBay approach serves as a positive case study and is summarized in the box below.

B2B e-marketplace owners could also consider providing vendors attempting to export their wares with short training videos on export compliance. National agencies could provide these training videos to B2B e-marketplaces operating within their jurisdiction. For the purposes of marketing dual-use items, the trainees would need to be made aware of their legal liability to carry out due diligence of vendors, become knowledgeable about appropriate laws and export control lists for the types of products they sell, be introduced to national agencies who deal with export controls and find out who to report suspicious cases to, and become knowledgeable about standard export transaction "red flags."[162] In an ideal world, the training would be mandatory, but commercial pressures and the ease of setting up a B2B website is very likely to undermine any such efforts.

Convincing B2B e-marketplaces that it is in their interest to educate their users about export controls can be done by emphasizing publicity and reputational impacts, as well as (where applicable) potential legal consequences of acting as a "facilitator" to an illicit deal. Outreach activities by national export control authorities should be attempted to facilitate this process.

In some countries, B2B e-marketplaces hosting goods intended for export are already strongly incentivized to register with a local governmental agency. For instance, some Chinese provincial industrial-commercial authorities have put in place an online business website identity check that e-commerce companies register with, and which is designed to prevent copycat websites from perpetrating scams, false advertising, and unfair competition.[163] For countries that have such systems already in place, this initial identity system provides a good basis for educational outreach and for the provision of assistance in setting up such a system.

Nearly all of the companies that we have surveyed made an effort to highlight their commercial trustworthiness. In practice, this was done by displaying production licenses, posting pictures of their factories and videos of their team, and by highlighting facilities they had helped set up for customers. Rewarding export control compliance in a tangible fashion, for instance by having relevant government agencies present certificates to company employees with some measure of export control training who registered with local law enforcement, would provide these companies with another way to demonstrate their commercial legitimacy.

Persuade B2B e-marketplace owners to monitor for "red flag" activities
B2B e-marketplaces should screen for abnormal activities. We know from experience that some e-marketplaces (notably Alibaba) already track messages sent about particular items for commercial reasons, in order to recommend similar items sold by other companies. Since such a tracking system is already in place, widely abnormal behavior regarding sensitive items should be detectable if these logged queries are compared to a list of keywords compiled from national export control lists. For instance, a user that sends out hundreds of price check requests a day for numerous and unrelated sensitive items should cause alarms to ring. Similarly, a user simply searching for numerous unrelated equipment categories should be flagged as potentially suspicious.

Since user information can be falsified, since search functionality is typically available to users without them being logged in, and since the real IP address of a user is easily concealed, logging suspicious searchers is unlikely to reveal their identities. However, knowing what items suspicious searchers are targeting, and what companies they have been focused on, would provide valuable information for law enforcement. National export control and law enforcement officials should actively assist B2B companies in setting up such systems, in particular by providing the keyword lists they want the companies to use. This last recommendation is in line with comments made by Michael Carson, Senior Manager for Global Regulatory and Policy Management at eBay (see Annex 1).[164]

Screen companies against a list of sanctioned entities provided by the authorities
When a seller or buyer attempts to create a profile, list an item for sale, or post an item request on a B2B website, the B2B website owner should first automatically screen the company name against a list of sanctioned entities.[165] The appropriate list should be provided by national authorities.

Recognize that item filter systems that screen and delete entries will not help prevent illicit sales of AG biotechnology items
One popular recommendation for strengthening export controls on Internet trading is to have B2B companies implement keyword filter systems to find and remove illegal entries.[166] Such deletion filter systems work when well defined items are banned for export, for instance, sales of military weaponry or night-vision goggles. However, they are likely to be ineffective at preventing illicit sales of biotechnology equipment because such products are inherently dual-use. Unlike the hypothetical sale of not-for-export night-vision goggles, sales of AG-grade biotechnology items can be perfectly legal. Controlling biotechnology sales online will therefore require other measures, such as the two recommended above.

A keyword filter system would only be effective in case the particular B2B e-marketplace simply blanket-bans biotechnology products, or more specifically AG-grade biotechnology items. One should not rely on such enforcement options, however, given the large number of specialized B2B websites that focus on the sale of such equipment.

Enable B2B user reporting of red flags, while recognizing that it will only work in the most egregious cases

Most B2B websites, including eBay and Alibaba, have reporting functions that can be used by any user to flag a problematic vendor. One of our recommendations is to enable and encourage B2B website vendors to use this reporting function to flag abnormal cases where the potential for export control violations appears high. This requires user education in common export control red flags, and it also requires responsiveness by the B2B website owner that has to process these flags. Since biotechnology goods are entirely dual use, user-flagging systems will only work against vendor entries that are in blatant violation of export control laws, such as vendors that are on a sanctioned entities list. However, since there have been such cases (see Part 1), this recommendation still has merit.

Consider setting up a monitoring unit focused on AG-grade biotechnology e-commerce at the national level

This unit would monitor biotechnology goods sold online to track the evolution of available equipment capabilities, and provide subject matter expertise for the aforementioned outreach efforts to B2B e-marketplace companies. This should cover AG-grade items, but also include related and emerging technologies, such as ground-based aerosol generators and algae production equipment, so as to provide expert advice when considering potential additions to the AG list. Additional monitoring efforts would be particularly beneficial with regards to AG category 9 “spraying or fogging systems.” We were unable to find individual AG-grade spray systems for sale online. However, we expect that the market for cheap and increasingly capable UAVs will grow greatly in the next few years, so there will be increased possibilities for ill-willed persons to combine these UAVs with high-rate, micron-particle size spraying or fogging platforms (not necessarily designed for aircraft use) being sold online.

Perhaps one of the most threatening developments in this regard is the increased availability of drones that can be purchased by members of the general public and be freely operated by them. We believe that persons who are able to purchase kits that enable them to build drones at home would have no problems fitting a light weight spray system on a drone. By adding a GPS system, such a drone could be accurately piloted to a target area.

The increased availability of UAVs and drones in the near future that can act as platforms for high capability dispersal devices could drastically affect nations’ counter-terrorism efforts, as they would add an extra dimension to developing plans to defend sites and populations. As such, we recommend that governments increase their efforts to monitor the sales of these aircraft, much like the sales of dangerous weapons are restricted and monitored. Further, national laws ought to be promulgated that control and document the fitting of high-capacity spray systems on aircraft.

Ensure that communication channels exist between the e-commerce industry and government advisory committees on nonproliferation export control
E-commerce businesses are ideally placed to detect and flag emerging security-relevant trends. Establishing a partnership between national e-commerce companies and national governments should be a priority effort, as emphasized in the previously mentioned recommendations.

One way to do so at the national level is to set up an industry-government advisory committee on e-commerce and nonproliferation export control. We suggest the establishment of a group or subgroup at the national level focused on e-commerce export controls with representation from members of the e-commerce industry. The U.S. Technical Advisory Committee is an example of a committee serving such a bridging function between governmental nonproliferation export control experts and industry, although it is not specific to e-commerce.[167]

Increase the rate of review of the AG Biological List
As pointed out above, we believe there are a number of emerging technologies whose utility have implications for BW programs be they at the lowest or highest technological level. The technologies we have discussed, and their products, are all available for purchase online, but none has as yet been added to any AG list.

Generally speaking, the length of time between innovation and world-wide commercialization has significantly decreased since society entered the Internet era. Like businesses that are faced with entirely new products and altered marketing techniques, the AG is left with less time than ever to evaluate or re-evaluate novel technologies for possible inclusion into one of the AG lists. For this reason, increasing the rate at which the AG lists are reviewed appears necessary. To do so, a small review committee should be established for each list topic. For the AG Biological list, the biological review committee should be composed mostly of invited bioindustrial experts and bioscientists with experience working with the technologies to be discussed. The AG biological review committee could be organized in a similar fashion to the Scientific Advisory Board of the Chemical Weapons Convention and its operations might involve one annual meeting and continuous interactions via the Internet.[168] If our previous recommendation is followed and a monitoring unit focused on AG-grade biotechnology e-commerce emerges at the national level, this committee should flag emerging technologies in the process of commercialization and provide baseline data for evaluation by AG participants.

Annex 1: eBay's Efforts to Prevent Illicit Exports Through its Services as a Case Study

eBay has taken significant steps to seek to ensure that its services are not exploited by proliferators in close cooperation with U.S. and international authorities, and as such offers a positive industry role model for online marketplaces. A description of eBay's export control measures was provided by Michael Carson, Senior Manager for Global Regulatory and Policy Management at eBay, during a 2014 U.S. National Academy of Sciences (NAS) workshop.[169] We interviewed Carson as part of this project.

Vendors who wish to use eBay's services must first agree to eBay's terms and conditions that include a clause on respecting export and import regulations. Enforcing this policy is a challenge given the volume of trade occurring through eBay's services. The commercial traffic handled by eBay's services is extremely large: 155 million active users and 800 million live listings as of the end of 2014.[170] To police such a large amount of content, eBay has implemented a rules based keyword filter system to screen entries and tailor informational messages. The automated system is supplemented by continual monitoring conducted by customer service agents.

In essence, the eBay system has four item categories: items banned from being offered for sale, items that eBay precludes from being exported, items potentially allowed for export, and fully allowed items.

Examples of banned items are illegal narcotics and endangered animal species. Items banned from export are those covered by the International Traffic in Arms Regulations (ITAR) from being listed for international sale.[171] The company employs a keyword-matching algorithm to spot and block offending entries.[172]

The items of highest interest to this project are those that are potentially allowed for export. These include AG-grade items, which are Export Administration Regulation (EAR) controlled items listed in the Commerce Control List's "Category 2- Materials Processing" entries.[173] If a would-be vendor attempts to list such an item for sale, eBay's detection algorithm cues in on it by matching keywords, and an informational message is displayed to the vendor.[174] This message provides the vendor with links to the relevant regulations, warning him that the item is potentially controlled.[175] Similarly, a buyer trying to purchase the item through eBay would also receive an informational message.[176]

The company works closely with U.S. law enforcement agencies, in particular by adding suggested keywords into eBay's filter system list. Further, the company regularly interacts with various governmental agencies to consider additional avenues for cooperation."[177] As eBay conducts business throughout the world, the company also interacts with non-U.S. national regulators on a regular basis.[178]

Annex 2: Overview of the Australia Group (AG)

In 1984, reacting to the use of chemical weapons in the Iran-Iraq war, several industrialized countries began informal consultations with the aim of discouraging and impeding chemical weapons proliferation by harmonizing national export controls on chemical warfare (CW) materials.[179] In June 1985, they formed an informal organization that was chaired by the Australian ambassador to France and thus became known as the Australia Group (AG). In the early 1990s, the AG's scope of concerns was widened; in addition to its objective to stop or impede the proliferation of chemical weapons, its added objective was to stop or impede the proliferation of biological weapons.[180] Accordingly, the AG currently has five export control lists:[181]

- Chemical Weapons Precursors;
- Dual-use Chemical Manufacturing Facilities and Equipment and Related Technology and Software;
- Dual-use Biological Equipment and Related Technology and Software;
- Human and Animal Pathogens and Toxins;
- Plant Pathogens.

This report's scope was limited to the Dual-use Biological Equipment and Related Technology and Software list. As noted in the main text, the nine categories of biotechnological equipment found on this AG list are as follows:[182]

1. Complete containment facilities at P3 [BSL-3] or P4 [BSL-4] containment level;
2. Fermenters;
3. Centrifugal separators;
4. Cross (tangential) flow filtration equipment
5. Freeze-drying equipment;
6. Spray-drying equipment;
7. Protective and containment equipment;
8. Aerosol inhalation chambers;
9. Spraying or fogging systems and components therefore.

The AG currently has 41 participating countries plus the European Union.[183] Mexico was the last country to join the group, on August 12, 2013.[184] The official objective of the group's participants is:

> "… to use licensing measures to ensure that exports of certain chemicals, biological agents, and dual-use chemical and biological manufacturing facilities and equipment, do not contribute to the spread of chemical and biological weapons. The Group achieves this by harmonising participating countries' national export licensing measures. The Group's activities are especially important given that the international chemical and biotechnology industries are a target for proliferators as a source of materials for CBW programs."[185]

Annex 3: Overview of the Biological Weapons Convention (BWC)

The Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on their Destruction, commonly known as the Biological Weapons Convention (BWC), is an international treaty that bans biological and toxin weapons.[186] It opened for signature in 1972, entered into force in 1975, and today has 173 States Parties and 9 signatories.[187] Only 14 states have neither signed nor ratified the BWC.[188] Four BWC articles, Article I, III, IV, and X, are of particular importance for this project.

Article I:
“Each State Party to this Convention undertakes never in any circumstances to develop, produce, stockpile or otherwise acquire or retain:
(1) microbial or other biological agents, or toxins whatever their origin or method of production, of types and in quantities that have no justification for prophylactic, protective or other peaceful purposes;
(2) weapons, equipment or means of delivery designed to use such agents or toxins for hostile purposes or in armed conflicts.”

Article III:
Each State Party to this Convention undertakes not to transfer to any recipient whatsoever, directly or indirectly, and not in any way to assist, encourage, or induce any State, group of States or international organisations to manufacture or otherwise acquire any of the agents, toxins, weapons, equipment or means of delivery specified in Article I of the Convention.

Article IV:
"Each State Party to this Convention shall, in accordance with its constitutional processes, take any necessary measures to prohibit and prevent the development, production, stockpiling, acquisition, or retention of the agents, toxins, weapons, equipment and means of delivery specified in Article I of the Convention, within the territory of such State, under its jurisdiction or under its control anywhere."

Article X:
"(1) The States Parties to this Convention undertake to facilitate, and have the right to participate in, the fullest possible exchange of equipment, materials and scientific and technological information for the use of bacteriological (biological) agents and toxins for peaceful purposes. Parties to the Convention in a position to do so shall also cooperate in contributing individually or together with other States or international organizations to the further development and application of scientific discoveries in the field of bacteriology (biology) for prevention of disease, or for other peaceful purposes.
(2) This Convention shall be implemented in a manner designed to avoid hampering the economic or technological development of States Parties to the Convention or international cooperation in the field of peaceful bacteriological (biological) activities, including the international exchange of bacteriological (biological) and toxins and equipment for the processing, use or production of bacteriological (biological) agents and toxins for peaceful purposes in accordance with the provisions of the Convention."

Annex 4: Overview of the Chemical Weapons Convention (CWC)

Though this report addresses biological arms control and nonproliferation, we also consider toxins – chemicals of biological origin – since they are part of the BWC. The parts of the CWC of relevance are as follows.

CWC Article 1 states:[189]

"Each party to the CWC undertakes never under any circumstances:
(a) To develop, produce, otherwise acquire, stockpile or retain chemical weapons, or transfer, directly or indirectly, chemical weapons to anyone;
(b) To use chemical weapons;
(c) To engage in any military preparations to use chemical weapons;
(d) To assist, encourage or induce, in any way, anyone to engage in any activity prohibited to a State Party under this Convention."

The CWC contains an Annex on Chemicals with three "Schedules" of toxic chemicals and their precursors based on the threat they pose to the purpose and objectives of the CWC and the extent of their commercial use.[190] Schedule 1 chemicals are known chemical warfare agents and final stage precursors with few, if any, commercial uses. Schedule 2 includes chemicals with potential as chemical warfare agents and precursors used in moderate amounts for commercial purposes. Finally, toxic chemicals and precursors used in large quantities for commercial purpose make up Schedule 3. None of these chemicals can be transferred to any other party if they are to be used for the production of chemical weapons. The Verification Annex describes restrictions on transfers of scheduled chemicals in detail (References in the Verification Annex are provided in parentheses below).[191]

Schedule I (Part VI, A and B):[192] The CWC states that a "...State Party may transfer Schedule 1 chemicals outside its territory only to another State Party and only for research, medical, pharmaceutical or protective purposes in accordance with paragraph 2." Paragraph 2 contains other restrictions on transfer including "…The types and quantities of chemicals are strictly limited to those which can be justified for such purposes…" and "…the aggregate amount of such chemicals at any given time for such purposes is equal to or less than 1 tonne."

Schedule 2 (Part VII, C):[193] Schedule 2 chemicals can be transferred to other States Parties to the CWC. During a three year interim period after the CWC enters into force, States Parties can transfer Schedule 2 chemicals to countries not party to the CWC. An end-use certificate must be accomplished that requires an agreement of restrictions on the use of the chemicals. Once the interim period elapses, transfer will not be permitted to States outside the Convention.

Schedule 3 (Part VIII, C):[194] An end-use certificate is required for transfer of Schedule 3 chemicals to States outside the Convention. Consideration will be given to further measures five years after the CWC enters into force.

Annex 5: Overview of UNSCR 1540

The United Nations Security Council adopted United Nations Security Council Resolution (UNSCR) 1540 in April 2004.[195] UNSCR 1540 decisions taken under Chapter VII of the Charter of the United Nations are legally binding on all UN Member States, as per Articles 48 and 49 of the UN Charter.[196] The resolution requires all UN Member States to put in place and support measures to interdict chemical, biological, and nuclear weapons proliferation:

> With regards to "nuclear, chemical, or biological weapons and their means of delivery," UNSCR 1540 calls in part upon all states to:
>
> "[…] Develop and maintain appropriate effective border controls and law enforcement efforts to detect, deter, prevent and combat, including through international cooperation when necessary, the illicit trafficking and brokering in such items in accordance with their national legal authorities and legislation and consistent with international law;"[197]
>
> And to:
>
> "[…] Establish, develop, review and maintain appropriate effective national export and trans-shipment controls over such items, including appropriate laws and regulations to control export, transit, trans-shipment and re-export and controls on providing funds and services related to such export and trans-shipment such as financing, and transporting that would contribute to proliferation, as well as establishing end-user controls; and establishing and enforcing appropriate criminal or civil penalties for violations of such export control laws and regulations;"[198]

The Resolution also "calls upon all Member States, when necessary, to pursue at the earliest opportunity the development of [effective national control] lists."[199]

The obligations imposed by the Resolution are meant to be complementary to, and do not conflict with, the obligations States Parties to the Chemical Weapons Convention and the Biological and Toxin Weapons Convention have undertaken.[200]

The 1540 Committee was created for the purpose of supporting the Resolution. It maintains working groups in order to facilitate monitoring and national implementation, the provision of assistance, cooperation with international organizations, and transparency and outreach efforts in support of the Resolution.[201] In addition, the creation of a small Expert Group has been authorized by the UN Security Council.[202]

Annex 6: List of Non-U.S., Non-EU B2B Websites Reviewed by Project Personnel

B2B service provider	Host country	B2B type
TD "Neftehimmash" KO	Russia	e-catalog
Zirbus Technology	Russia	e-catalog
SocTrade	Russia	e-catalog; vendor of second-hand items
Biochimmash	Russia	e-catalog
MTH-Sistema.RU	Russia	e-marketplace; Company directory
All-Biz Ltd.	Russia	e-marketplace
agroru.com	Russia	e-marketplace
medprom.ru	Russia	e-marketplace
B2B-Center	Russia	e-marketplace; bidding system
MedWOW Global	Russia	Company directory[203]
GlobalMarket Group	China	e-marketplaces[204]
Biomate India	India	e-catalog[205]
Infocom Network Ltd.	India	e-marketplace[206]
IndiaMART InterMESH Ltd.	India	e-marketplace[207]
Vajra BioMetrix Pvt. Ltd.	India	e-catalog[208]
Alibaba Group	China	e-marketplaces[209]
Focus Technology Co. Ltd.	China	e-marketplace[210]
Hangzhou Weiku Information Technology Co. Ltd.	China	e-marketplace[211]
Yi Xun Network	China	e-marketplace[212]
LABQUIP	Malaysia	e-catalog[213]
Solution Bioforce SDN BHD	Malaysia	e-catalog[214]
TradeSoon.com	China	e-marketplace
Focus Technology Co. Ltd.	China	e-marketplace[215]
Bossgoo Co. Ltd.	China	e-marketplace[216]
BIOONGROUP	China	e-marketplace[217]
China Bio-equip	China	e-marketplace[218]
Beijing Biolaunching Technologies Co. Ltd.	China	e-catalog[219]
Tianjin Hope Co. Ltd.	China	e-catalog[220]
Hangzhou Weiku Information Technology Co. Ltd.	China	e-marketplace[221]
gongchang.com	China	e-marketplace[222]
EC21 Inc.	South Korea	e-marketplace[223]

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[2] Thomas L. Friedman, "Time for a Pause," *New York Times*, January 7, 2015, <http://nyti.ms/1xCQUul>.
[3] Technically, the World Wide Web (WWW) and the Internet are different. The Internet is an infrastructure that connects the various global networks. The WWW is one application that uses the Internet to share information. In accord with popular usage, the two terms Internet and World Wide Web are in this report referred to as, simply, "the Internet." For an authoritative discussion of the Internet and WWW see: S.N. Dorogovtsev and J.F.F. Mendes, *Evolution of Networks: From Biological Nets to the Internet and WWW* (Oxford: Oxford University Press, 2013), pp. 34-35.
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