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A Vision for Global Health: How Demand Forecasting, Supply Planning and Market Shaping Can Deliver *a New Model for Global Vaccine Manufacturing*

with a Foreword by Dr Ahmed Ogwell Ouma and Dr John-Arne Røttingen

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The One Shot Vision

ONE SHOT: TO MAKE PREVENTABLE DISEASE HISTORY

The response to Covid-19 saw dramatic advancements in the development of life-saving vaccines. These changes have created an opportunity to make preventable disease history. Now is the time to transform the global-health infrastructure, making it more equitable and also ensuring the world is prepared for the next pandemic. This means harnessing the potential of and demand for next-generation vaccines and preventative injectables. The potential rewards are huge, with at least 10 million deaths a year attributable to preventable diseases that have adult vaccinations either already approved or in clinical trials.

The Global Health Security Consortium's One Shot campaign sets out a roadmap to combat preventable diseases worldwide that draws on innovations in vaccines and preventative injectables and builds on progress made in response to Covid-19. This vision for a disease-prevention programme that is "always on" would save millions of lives and billions of dollars, addressing health inequalities and leading to more prosperous, healthy and resilient societies.

One Shot focuses on global adult vaccination as a necessary component of a life-course approach to vaccination that addresses people's health needs and specific risks they may face across different life phases, including maternal, newborn, child and adolescent health, and healthy adulthood and ageing.[1,2]

ALSO IN THE ONE SHOT SERIES:

A New Vision for Global Health

Identifying the Most Promising Adult Vaccines and Injectables

The Digital Toolbox Needed to Deliver One Shot

ABOUT THE GLOBAL HEALTH SECURITY CONSORTIUM

The Global Health Security Consortium (GHSC) provides insight, analysis and support for leaders around the world to help them prepare for the health-security challenges of tomorrow. It is a joint initiative of the Tony Blair Institute for Global Change, the Ellison Institute for Transformative Medicine and a team of scientists at the University of Oxford.

FOUNDING PARTNERS

The Tony Blair Institute for Global Change, under the leadership of Tony Blair, brings a global perspective on health security and an understanding of how to deliver change at a national and international level.

The Ellison Institute for Transformative Medicine, under the leadership of Dr David Agus, brings deep technical expertise in tech-driven medical science, research and the intersection with health policy in the United States and abroad.

A network of researchers at the **University of Oxford** provides academic rigour and scientific evidence to the work of the Global Health Security Consortium (GHSC), under the leadership of Professor Sir John Bell.

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Foreword

In the aftermath of the acute phase of the Covid-19 pandemic, there is significant momentum for investing in regional vaccine-manufacturing capacity. Leading global and regional health organisations, including the World Health Organisation (WHO), Coalition for Epidemic Preparedness Innovations (CEPI), Gavi – the Vaccine Alliance – and the Africa Centres for Disease Control and Prevention (Africa CDC) Partnership for African Vaccine Manufacturing (PAVM), as well as national governments and pharmaceutical companies, have begun to undertake critical investments to expand vaccine-manufacturing capacity, especially in the Global South. To identify common needs and leading practices that facilitate the establishment of regional manufacturing efforts, the World Economic Forum has launched the Regionalised Vaccine Manufacturing Collaborative (RVMC) together with CEPI and the US National Academy of Medicine. Under the leadership of India's G20 presidency, the G20 is currently considering plans for a global network of vaccine, therapeutic and diagnostic (VTD) R&D and manufacturing hubs. All of these are important initiatives to promote self-reliance of Global South countries, economic development, life-sciences industries, and global public health and health security.

However, the complexity of these endeavours and the speed at which investments are progressing present a risk that the global community may misallocate its resources. Investments need to be balanced and coordinated to meet forthcoming demand for both routine and emergency vaccines. We note that all investors – including governments, pharmaceutical manufacturers, development banks and philanthropists – have the right to make their own investment and risk decisions. However, the global health community has an obligation to shape the market for these investments to increase the likelihood that future regionally distributed manufacturing capacity is financially sustainable and has the capability to make the quality vaccines needed for public health. Success will best be realised through a coordinated global effort.

The global health community has a strong track record of market-shaping for specific products. For example, Gavi, UNICEF and others have successfully negotiated lower prices and diversified the supplier base for many individual vaccines. Similar achievements have improved the availability and affordability of other commodities, such as antiretrovirals, antimalarials, bed-nets and medicines for tuberculosis. We now need to use innovative market-shaping approaches not just for individual commodities and not just for scale efficiencies, but also to achieve a resilient, geographically distributed, technologically diversified and financially sustainable network of vaccine-manufacturing facilities.

As this paper argues, to successfully shape this market, the global community should start with a clear picture of what routine and emergency vaccines a geographically distributed manufacturing network could produce in the future. This should include current and future adult vaccinations, which could contribute to a reduction in 10 million preventable adult deaths per year, as well as childhood vaccines that prevent between 2 and 3 million deaths per year.[3] While well-meaning efforts to invest in manufacturing capacity and a patchwork of demand-forecasting efforts are already under way, the global community still lacks dynamic, scenario-based global-demand forecasts for a broad portfolio of vaccines, including pipeline assets, which could be manufactured in these and other planned facilities.

Therefore, we welcome the One Shot initiative's call to action for the global health community to fund scenario-based demand forecasts for all vaccines that include pipeline assets and that span all regions, and a coordination mechanism that more directly links forecast demand to investments in supply. We are aware that future procurement of vaccines will vary based on many factors, including evolving epidemiological patterns, fiscal space for public-health programmes, and new vaccines that will receive regulatory approval. Documenting these assumptions in different scenarios will make demand forecasts more valuable to investors.

Demand forecasts should be updated regularly, at least once per year, to account for evolving information, and should be shared openly as a global public good. They should include not just the vaccines procured by a specific funder, programme or country, but the full portfolio of child and

life-course immunisations that should be manufactured on a geographically distributed, technologically diversified, and financially sustainable network of vaccine-manufacturing facilities. These demand forecasts should also include vaccines that are still in the R&D pipeline. And, critically, they should forecast not only the demand for doses of individual antigens, but also work backwards to estimate the demand for capacity along the manufacturing value chain (for example, capacity for drug-substance and drug-product manufacturing using different platform technologies, fill/finish capacity, other commodities along the supply chain) to guide investment decisions in manufacturing facilities.

Only with clarity on what products the world needs to manufacture can we hope to build manufacturing facilities that meet this demand in a sustainable way.

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01

Executive Summary

The Covid-19 pandemic spurred major advancements in our ability to develop, manufacture and distribute vaccines. To deliver the biggest adult-vaccination campaign in history, manufacturing plants dramatically scaled up production, and there was significant investment in new technology and the training of a skilled biomanufacturing workforce. These efforts ultimately prevented an estimated 20 million deaths in one year.[4]

The scientific developments that were accelerated by Covid-19 have led to a robust pipeline of game-changing life-course vaccines and preventative injectables.[5] However, the Covid-19 vaccine rollout also exposed inequities in the geographical distribution of vaccines. Most of the early Covid-19 doses went to countries and regions with existing manufacturing capacity; those without sufficient vaccine infrastructure were forced to wait, and accusations of vaccine hoarding on the part of countries with manufacturing capacity abounded.[6] To use life-course vaccines on a global scale both for routine preventative health and as a strategy for pandemic prevention, preparedness and response (PPR), it is now incumbent on the key players – governments, industry, funders, international norm-setting agencies, civil society and multilateral platforms such as the G20 and G7 – to drive a global effort to harness and deploy these products to significantly reduce mortality and morbidity.

A new model for global vaccine manufacturing is needed. This will require an urgent transition to regionally coordinated manufacturing capabilities, with special consideration given to the Global South and how to develop the viability of manufacturing hubs in these parts of the world. There also needs to be an optimisation of supply and distribution networks to support a programme that can facilitate demand for life-saving vaccines beyond pandemics while remaining resilient enough to ramp up in response to serious pathogen threats.

Governments, industry and global health bodies must act now to ensure strong population health and PPR. Capitalising on the potential of these new products will require a strategic expansion of global manufacturing

capacity and diversification of technology, aligned with demand across each region. To establish the right global network of manufacturing capacity, governments, global health organisations and the private sector need to know what types of manufacturing capacity to invest in. These decisions should be informed by robust information about the demand for vaccines, guided by existing and forecasted manufacturing capacity, and supported by clear market signals and assurances whenever possible. We believe that the global community is making significant progress on mapping existing and forecasted manufacturing capacity but still has a major gap in long-term demand forecasting, especially for pipeline assets (products that have not yet launched), to guide manufacturing-investment decisions. The Resource List we have compiled below demonstrates some of the most promising efforts towards global mapping of vaccine supply and demand.

The Global Health Security Consortium's (GHSC) One Shot campaign – an initiative that sets out a roadmap for the development of a permanent and preventative global public-health programme that promotes adult vaccination as a vital part of life-course immunisation and the use of prophylactic injectables – is a response to the current barriers to vaccination and the opportunity to improve global health through universal, equitable access to these life-saving products.[7] The analysis in this paper represents a first attempt to provide a unified picture of the existing and forthcoming vaccines categorised by manufacturing technology and to map current demand for doses against manufacturing technology. The Technical Deep Dive at the end of this paper presents a summary of current global procurement of vaccines as a step towards forecasting supply and demand efforts.

HOW DO WE TAKE ACTION?

A geographically distributed, technologically diversified global manufacturing network starts with a better understanding of demand and supply. This supply and demand information will allow global health actors to design the right incentives and policies to achieve a geographically distributed and technologically diversified manufacturing network for future vaccine needs. It will also help governments and the private sector decide how and where to invest their capital in new manufacturing technology.

A manufacturing network that can support robust life-course vaccination will need to be geographically distributed such that each region has a reliable and accessible supply of vaccines, and a key focus is Africa. Prior to Covid-19, Europe, India, China and the United States dominated vaccine production.[8]

For a commercially viable, geographically distributed manufacturing network to be established that meets the demand for vaccines and preventative injectables both between and during outbreaks, the global health community, including national governments, regional organisations, multilateral institutions, regulators, industry, funders and civil society, must:

1. Increase market information through strategic demand forecasting for products.

2. Facilitate transparent documentation of existing and forecasted manufacturing capacity.

3. Use this market information to translate demand for products into upstream demand for manufacturing capacity and to identify potential gaps in manufacturing capacity. This information can act as a common point of reference to inform government and industry investments as they create a geographically distributed and viable manufacturing footprint.[9]

DEMAND FORECASTING

Clear demand and supply forecasts are a prerequisite for estimating the manufacturing capacity, technologies and investments required in a given region. Centralised, scenario-based demand forecasting for the quantities and types of products needed for a region must be the driver of the manufacturing supply required to fulfil routine demand and surge needs during a pandemic; this centralised forecasting should build on the work of organisations including: Gavi, the Vaccine Alliance;[10] the United Nations Children's Fund (UNICEF);[11] the Coalition for Epidemic Preparedness Innovations (CEPI) and the Developing Countries Vaccine Manufacturers Network (DCVMN);[12] the Africa Centres for Disease Control

and Prevention's (Africa CDC) Partnerships for African Vaccine Manufacturing (PAVM) Framework for Action;[13] the Global Vaccine Market Model (GVMM);[14] and Market Information for Access to Vaccines (MI4A).[15] This transparent forecasting will be critical for building manufacturing capacity in the right technologies and ensuring that product supply chains are better coordinated, especially during a public-health emergency.

Long-term demand forecasts can also support efforts to create an investment case for donors and governments to support broader life-course vaccination programmes. By forecasting potential demand, donors and governments can begin to estimate the budgets needed for expanded vaccination programmes, and their potential economic and population-health benefits.

SUPPLY PLANNING

Equally important for informing manufacturing-investment decisions is an understanding of the existing and forecasted manufacturing capacity. As with demand forecasting, individual companies already undertake global forecasting for supply. While some individual global health organisations such as CEPI, DCVMN and MI4A have begun publishing their own mapping and forecasting exercises, greater collaboration to forecast supply is required. This collaboration should be facilitated by a neutral broker of information, such as an independent global health organisation, so that companies are not asked to share confidential information with each other.

Global health organisations such as the World Health Organisation (WHO), Gavi, CEPI or a consortium of regional organisations such as the Africa CDC, the Pan American Health Organisation (PAHO) and the Association of Southeast Asian Nations (ASEAN) are among the candidates who could act as a neutral broker with governments, industry and industry associations to facilitate the sharing of an agreed-upon set of supply information from pharmaceutical manufacturers in a manner that does not violate anti-trust rules.

These same global health and regional organisations could conduct global, long-term demand forecasts and integrate demand and supply information to inform the planning of a geographically distributed,

technologically diversified and financially sustainable vaccine-manufacturing network. Industry, industry associations and global health organisations should leverage their data, information and existing demand-forecasting expertise to guide investments in manufacturing capacity.

USING DEMAND FORECASTS AND SUPPLY PLANS TO SHAPE MARKETS

Increased market information is necessary but not sufficient to create financially sustainable manufacturing capacity for vaccines and injectables. Market-shaping activities to guarantee demand for manufacturing capacity will be a key driver for additional investment. Such forecasting can increase the market information available to governments, global health actors and industry in their pursuit of reducing commercial risks and shaping a viable manufacturing network at the regional and global levels. This is especially important for adult vaccines, many of which are not publicly funded in many low- and middle-income countries (LMICs) and are often sold in relatively small private markets. Approaches to develop, aggregate, consolidate and finance the demand based on these forecasts include:

1. Creating a mechanism to review and ensure inclusion of products in essential-medicines lists (EML) and other guidelines.

2. Harmonising registration systems and strengthening quality-assurance systems that will allow for exports of quality-assured products across borders.

3. Providing advance market commitments (AMCs) and volume guarantees for manufacturing capacity or specific products, potentially at specific prices.

4. Investing in resilience payments to subsidise or offset the costs of manufacturing in countries with more nascent capabilities.

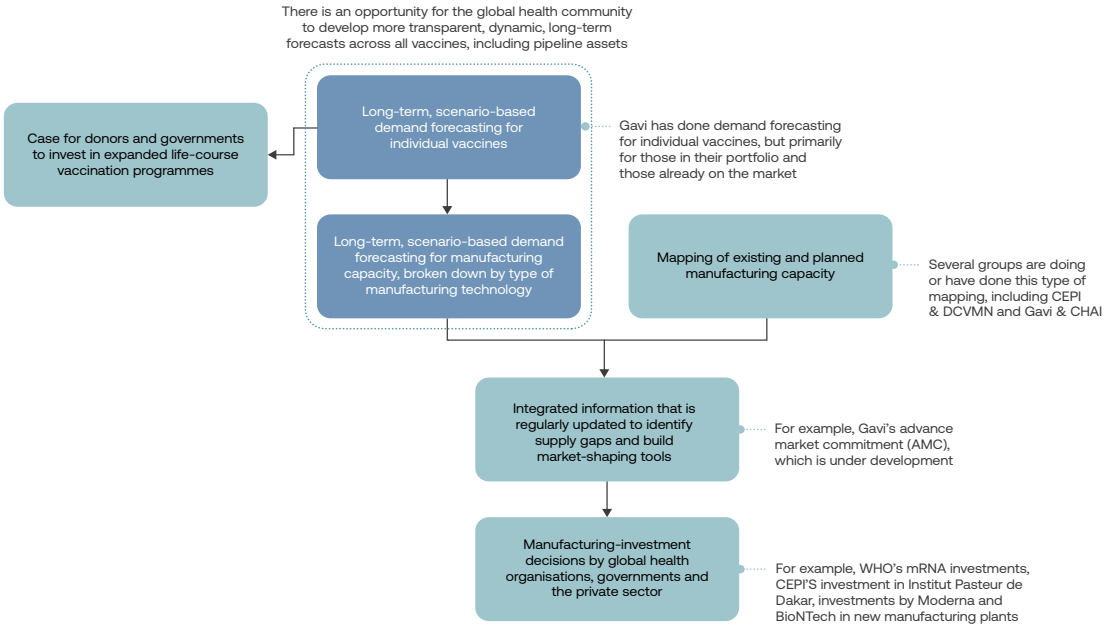
5. Setting up or leveraging an existing pooled procurement mechanism for these products.

6. Investing in demand-creation programmes for vaccines and preventative injectables, including use of clinical data to demonstrate the impact of new and established technologies as the portfolio of vaccines and target pathogens is broadened.

Implementing some or all of these interventions will help to futureproof investments and create a geographically distributed manufacturing network that is better aligned to the new pipeline of vaccines and injectables and promotes diversification and commercial self-sufficiency so that the network is agile.

FIGURE 1

Global demand forecasting and supply planning are needed to build a geographically distributed vaccine-manufacturing network



Resource List

Several organisations have started to undertake the type of demand forecasting and supply planning that will be needed to deliver One Shot. These efforts can provide guidance and a template for the globally coordinated tracking that will allow global health organisations, governments and industry to shape markets. As indicated in the Executive Summary, there are more organisations engaging in supply planning than demand forecasting – a gap that will need to be filled if we are to implement a strong, global, life-course vaccination programme.

DEMAND FORECASTING

- Gavi, the Vaccine Alliance, produces two types of forecasts for Gavi-eligible countries, covering 12 vaccines – primarily childhood vaccines and a handful of adolescent vaccines. The forecasts are strategic demand scenarios (SDS), which are vaccine-specific and intended to inform medium- and long-term decisions in the market context relevant to each vaccine, and a base demand forecast (BDF), which is undertaken annually and covers all Gavi-funded vaccines across the countries that were eligible for Gavi support as of 2011. These tools ensure clarity and understanding of the market for stakeholders including manufacturers and governments.

- Gavi and the Clinton Health Access Initiative (CHAI) have also published high-level demand forecasts through to 2040 for select vaccines across Africa.

- The World Health Organisation's (WHO) Market Information for Access to Vaccines (MI4A) maintains a vaccine-purchase database based on reporting from more than 150 countries. The database for all vaccines is updated annually and a separate Covid-19 vaccine-purchase database is updated monthly.

- Linksbridge develops the Global Vaccine Market Model (GVMM), which aggregates information on vaccine demand for multiple sources.

- The Africa Centres for Disease Control and Prevention's (Africa CDC) Partnerships for African Vaccine Manufacturing (PAVM) has produced Framework for Action to make it possible for the continent to manufacture 60 per cent of its vaccine needs locally by 2040.

SUPPLY PLANNING

- The United Nations Children's Fund's (UNICEF) COVID-19 Vaccine Market Dashboard is an interactive tool that tracks Covid-19 vaccine approvals, manufacturing capacity and COVAX vaccine deliveries, among other metrics, so that partners, manufacturers and countries have up-to-date information on the Covid-19 vaccine and therapeutics market. This is a strong model that a tracker of the wider vaccine-manufacturing field could be based on.

- In addition to the vaccine-purchase database, the WHO's MI4A produces vaccine-specific market studies that contain information on both demand and supply prospects for individual vaccines with the goal of mitigating risks to sustainable vaccine supply.

- The Coalition for Epidemic Preparedness Innovations (CEPI) has produced several examples of what transparency in manufacturing could look like, including their analysis with the Developing Countries Vaccine Manufacturers Network (DCVMN) of the technical capabilities and manufacturing capacities in developing countries, the CEPI 2021 Vaccine Manufacturing Landscape of Africa, Latin America-Caribbean, South East Asia-Western Pacific, and the Middle East and the CEPI Covid-19 Manufacturing Survey Results Analysis.

OTHER

- United States Agency for International Development (USAID) explains the importance of market shaping as well as the steps to achieving it in the pre-Covid era in the paper "*Healthy Markets for Global Health: A Market Shaping Primer*".

- Gavi is engaged in efforts to integrate Covid-19 vaccinations with routine immunisations to strengthen overall vaccine coverage.

- CEPI's 100 Days Mission lays out important steps we can take now to prepare to meet the next pandemic, including the importance of virus surveillance and appropriate vaccine-manufacturing infrastructure.

- The WHO Global Observatory's "Health products in the pipeline from discovery to market launch for all diseases" is a regularly updated reference tool that summarises the AdisInsight database from the academic publisher Springer Nature.

02

A New Model for Global Vaccine Manufacturing

In order to achieve the One Shot goal of making preventable disease history, we need a geographically distributed, technologically diversified and financially sustainable network of vaccine-manufacturing facilities.

The disparity in access to adult vaccines between high-income countries and low- and middle-income countries (LMICs) has been striking: adult vaccines account for more than 64 per cent of vaccine doses used in high-income countries, but less than 10 per cent in lower-income countries.[16] Countries and regions with existing manufacturing capacity received most of the early Covid-19 vaccine doses, while those without were forced to wait, with access stymied by export bans from countries with significant vaccine-production capabilities, leading to accusations of vaccine hoarding.[17]

Moreover, while Covid-19 vaccine production improved the scale of global vaccine-manufacturing capacity, there are many important vaccines that cannot be manufactured using the same technology as the Covid vaccines. In order to ensure adequate global manufacturing capacity for life-course vaccination programmes, further investment and coordination are needed.

GEOGRAPHICALLY DISTRIBUTED MANUFACTURING

The vaccine-manufacturing capacity developed since the beginning of Covid-19 has increased the number of vaccines that can be distributed in absolute terms – 15 billion doses of Covid-19 vaccines were distributed by late 2022.[18] Yet disparities in the distribution of and access to vaccines, especially adult vaccines, could continue if manufacturing capacity remains concentrated in specific regions due to inadequate understanding of future regional-capacity needs or insufficient strengthening of cross-border supply chains.

Ensuring that manufacturing infrastructure is distributed evenly around the globe has multiple benefits: it supports vaccine-supply security and resilience, the associated investments contribute to industrial and economic development, and it allows vaccines to reach all populations equally.

These issues are not new. The same bottlenecks in supply were seen during the global response to the swine-flu pandemic in 2009.[19] Prior to 2020, there were approximately 16 developing countries with end-to-end vaccine-manufacturing capabilities, of which only three were African.[20, 21] The concentration of vaccine-manufacturing capacity in certain LMICs is also highlighted by the fact that 65 per cent of children worldwide have received at least one vaccine manufactured by the Serum Institute of India (SII), which is also a major producer of Covid-19 vaccines.[22]

Governments and regional organisations are determined to achieve geographically distributed manufacturing in the long term: the Africa Centres for Disease Control and Prevention's (Africa CDC) objective is to have 60 per cent of African demand supplied locally by 2040, up from only 1 per cent today. To achieve this, the Africa CDC put in place the Partnerships for African Vaccine Manufacturing (PAVM) to develop a coherent continental strategy for a regional-manufacturing footprint.[23] Currently, 12 African countries[24] are considering developing or expanding their manufacturing capabilities, mostly in mRNA technology. This technology currently has no other approved products, but upfront costs and investment in mRNA facilities are less expensive than for other cell-culture-based vaccine platforms, and many other mRNA-based products are in the research and development (R&D) pipeline.

Building geographically distributed manufacturing capacity has trade-offs. For example, per-unit costs may initially be higher than the cost in the current market setup, and there will always be an associated opportunity cost to investing in one type of manufacturing capacity over another. On the other hand, greater distribution of manufacturing could incentivise regional specialisation of vaccine manufacturing, encouraging regions to create greater certainty of demand that is suited to their contexts and drives their production. In African countries, for example, there could be a greater focus on manufacturing vaccines for malaria, yellow fever and dengue.

Pandemic Preparation Through Financially Sustainable Vaccine Manufacturing

To ensure strong population health and PPR, governments, industry and global bodies must act now to build geographically distributed, technologically diversified and financially sustainable manufacturing capacity across regions. This will promote manufacturing capacity for required routine immunisations based on regional disease burden that can be ramped up rapidly and equitably during future outbreaks. Importantly, a recently released report by Gavi, the Vaccine Alliance, on Expanding Sustainable Vaccine Manufacturing in Africa[25] noted that focusing on products that have not fully achieved scale and products that are coming to market are two likely opportunities to create markets that will support a geographically distributed, technologically diversified and financially sustainable vaccine-manufacturing network. Many of the products in the pipeline with scalability potential or that are coming to market in the future target adolescents and adults, including vaccines for HPV, pneumonia and Covid-19 as well as diseases currently without a licensed vaccine, such as HIV, RSV, a new vaccine for tuberculosis and others. In an October 2022 paper, the Global Health Security Consortium (GHSC) identified some of the most promising adult vaccines and injectables.[26]

TECHNOLOGICALLY DIVERSIFIED MANUFACTURING

When government and industry are considering investment in manufacturing, it is critical to think about the most relevant vaccines, the respective categories and technologies used, and the potential interchangeability across categories and technologies, as this can inform investment. Producing multiple vaccines in a single facility while maintaining quality and safety is not a simple process, and complexity increases as manufacturing is scaled up. Investing in vaccine-manufacturing platforms without adequately assessing the needs of the market can mean vaccine requirements continue to go unmet, despite the investment of more resources to establish a broader manufacturing footprint.

It is imperative that global manufacturing capacity is diversified not just across regions but also across respective vaccine and injectable technologies, and that new facilities meet World Health Organisation (WHO) and relevant regional and national standards for vaccine quality and safety so that manufacturing plants can produce and export quality products in a financially sustainable way. Diversification of the manufacturing network does not necessarily mean having a broad portfolio of all types of equipment but rather a set of plants that have the most flexible and versatile technologies to cover the routine and pandemic demand when it arises.

In the case of pandemics, most experts agree that mRNA-based vaccines allow for rapid response. In the spirit of the Coalition for Epidemic Preparedness Innovations' (CEPI) 100 Days Mission – which aims to make vaccines, therapeutics and diagnostics available within 100 days of any future pandemic[27] – those mRNA technologies must be well spread globally to put a stop to future outbreaks in their infancy and minimise economic disruption. On the back of the success of mRNA vaccines during the pandemic, multiple countries are making commitments to build domestic-manufacturing capability to produce Covid-19 vaccines using the technology.[28] This includes seven countries on the African continent alone (Egypt, Kenya, Nigeria, Senegal, South Africa, Tunisia and Rwanda).[29, 30] While these commitments are important, many vaccines use different antigens and technologies that cannot necessarily be produced in facilities set up to manufacture mRNA Covid-19 vaccines. Investors from both the public and private sectors need to diversify their investments into a broad range of technologies, including flexible manufacturing facilities that accommodate vaccines using different technologies, and need transparent market information to inform their investments.

While there is a shared enthusiasm for mRNA technology, as demonstrated by the growing R&D pipeline, the current and forthcoming portfolio of life-course vaccinations includes other critical technology platforms. If we do not invest correctly in mRNA technology, there could be a lack of manufacturing capacity for other technologies and the supply of forthcoming vaccines and injectables that are not mRNA-based will not be able to meet demand. In the latest survey by CEPI and the Developing Countries Vaccine Manufacturers Network (DCVMN), 33 to 54 per cent of manufacturers reported that they use

a “modern technology platform” for vaccines (defined as mRNA, DNA or viral-vector technologies).[31] It is equally important to ensure sufficient capacity to meet demand for products that use “traditional platforms” such as whole-pathogen vaccines and subunit vaccines.

Figure 2 shows a summary of different vaccine platforms alongside current and future products using each of them. It aims to illustrate that investments in new manufacturing capacity should be based on clear demand forecasts across all products using a shared technology platform. This figure does not include biologics or preventative injectables, which can share some of the same manufacturing steps as some vaccines. The products listed below are not an exhaustive list, but they do show the types of diseases and conditions that could be combatted using vaccines and preventative injectables in the very near future. The WHO Global Observatory’s *Health Products in the Pipeline From Discovery to Market Launch for All Diseases*,[32] which is included in the Resource List, is a similar, regularly updated tool for forecasting vaccine-manufacturing requirements.

FIGURE 2

Demand forecasting should be specified by technology platform, not just individual products

Category	Technology platform	% of developing country vaccine manufacturers that use each platform	Average annual non-Covid doses procured (see Figure 3 in the Technical Deep Dive for more details)		Approved products	Products in R&D pipeline (examples)		
					Target diseases	Target diseases	Product	Phase
Whole-pathogen vaccines 	Live attenuated	62%	2.4bn	0.26bn*	Rotavirus; measles, mumps and rubella; varicella; yellow fever; typhoid; cholera; tuberculosis; influenza; dengue; Japanese encephalitis; polio; shingles; tularaemia; hepatitis A	Dengue	TAK-003	Regulatory review/ pre-approval
	Inactivated	77%			Polio; pertussis; hepatitis A; rabies; typhoid; Japanese encephalitis; influenza; cholera; tick-borne encephalitis; shingles			
Subunit vaccines** 	Recombinant protein	65%	1.1bn		HPV; hepatitis B; meningitis B; malaria; influenza	RSV	AReSVi 006	Phase III
							PF-06928316	Phase III
						Tuberculosis	M72/AS01E	Phase III
							GamTBvac	Phase III
						Malaria	R21/Matrix-M	Phase III
	Toxoid	Data not available**			Diphtheria; tetanus; anthrax			
	Conjugate	58%			Haemophilus influenzae type B; typhoid; pneumococcal meningitis; meningitis A			
	Virus-like particles	Data not available**			Hepatitis B; HPV	Chikungunya disease	PXVX0317	Phase II
Viral-vector vaccines 	Replicating	4%	Limited procurement of non-Covid-19 vaccines		Ebola	Lassa fever	rVSVΔG-LASV-GPC	Phase I
	Non-replicating	23%			Covid-19 (Oxford University/ AstraZeneca, Johnson & Johnson)	RSV	Ad26.RSV.preF	Phase III
						HIV	HIVconsvX	Phase I
						MERS	MERS002	Phase I
						Rift Valley fever	ChAdOx1 RVF	Phase I

Category	Technology platform	% of developing country vaccine manufacturers that use each platform	Average annual non-Covid doses procured (see Figure 3 in the Technical Deep Dive for more details)	Approved products	Products in R&D pipeline (examples)		
				Target diseases	Target diseases	Product	Phase
Nucleic-acid vaccines/ treatments 	RNA	15%	Limited procurement of non-Covid-19 vaccines	Covid-19 (Pfizer-BioNTech, Moderna)	RSV	mRNA-1345	Phase III
					HIV	BG505 MD39.3 mRNA; BG505 MD39.3 gp151 mRNA; BG505 MD39.3 gp151 CD4KO mRNA	Phase I
					Nipah virus	mRNA-1215	Phase I
	DNA	19%	N/A	None approved[1]	N/A	N/A	N/A

Source: Data on vaccine doses procured detailed in Figure 3; GHSC analysis.

*This number refers to vaccines that can use whole-pathogen or subunit technologies, or that require a combination of both, including influenza, diphtheria, tetanus, pertussis, polio, haemophilus influenzae type B, hepatitis B.

**Survey indicated that 42 per cent of manufacturers used protein subunit manufacturing technology. Survey did not specify details on toxoid or virus-like particles manufacturing technologies.

[1]Melanoma, West Nile vaccines approved for veterinary use (Source: University of Oxford, Vaccines Europe).

Vaccine-Manufacturing Technologies and Materials

Within and across vaccine-specific categories and their associated technologies, there are different degrees of overlap and costs of goods sold. Generally, the vaccine value-chain steps are the same across all vaccines. Within each technology the equipment and processes are very similar, but raw materials differ from vaccine to vaccine. For example, the rotavirus vaccine and the MMR vaccine are both whole-pathogen, live-attenuated vaccines; although they require different raw materials, the equipment used is the same and the manufacturing processes are similar. A manufacturing plant that specialises in live-attenuated-vaccine technology will be more easily able to produce several vaccines within that same technology because the input needs – as well as the required staff knowledge and equipment – will be similar.

Across the different technologies (for instance, live-attenuated vaccine versus non-replicating viral-vector vaccines), it becomes slightly more complex. While the processes and equipment are only moderately different, the raw materials used are completely different. This means that greater diversification in equipment, staff and raw materials will be needed to produce several different types of vaccines – such as yellow-fever vaccines and AstraZeneca's Covid-19 jab – at a single plant. Some processes that are more similar across multiple vaccines and less technically complex, such as fill and finish, may be a reasonable capability for certain countries or regions to begin building as they establish their manufacturing footprint.

The exception to this is mRNA. As mRNA is a chemical process, different equipment, very different processes and very different raw materials are required. There is little crossover between mRNA and the other categories of vaccine technology, making the upfront costs and investment in mRNA manufacturing facilities expensive.

03

A Global Manufacturing Network Starts With a Better Understanding of Demand and Supply

Creating a geographically distributed, technologically diversified and coordinated manufacturing footprint is a complex exercise that can only be realised by enabling governments, global health organisations and industry to gain an in-depth understanding of the various products and technologies in terms of their demand scenarios, the commensurate manufacturing capacity required to fulfil them and the gap between the current manufacturing capacity and possible surge demand during pandemics. Such an integrated understanding will help global health actors implement the right mix of incentives and policies to allow governments and industry to strategically shape the manufacturing market and to support investors in making well-informed, risk-based decisions.

This integrated information about demand and supply can act as a common point of reference to provide an indication of the gaps in manufacturing capacity, thereby enabling investment and market-shaping approaches that can address these gaps. Market-shaping approaches can enhance the effectiveness of vaccination efforts by reducing transaction costs associated with structural hurdles (for example, lower the barriers to accessing the market for buyers and sellers), increasing market information and the visibility of existing data (for example, information about levels of demand and capacity to supply), and balancing the risks between supply and demand (for example, mitigating the risks associated with a transaction before and after). Market-landscape analysis and strategic demand forecasting in particular can strengthen the latter two enablers.[33]

DEMAND FORECASTING

Demand forecasting is critical in planning manufacturing capacity and vaccine supply, including for drug substance (the active pharmacological ingredient), and filled and finished doses of drug product (a finished dosage form that contains a drug substance and other ingredients). Forecasting at these different levels will allow for the quantification of products other than the active pharmaceutical ingredient (for example, adjuvants, lipid nanoparticles for mRNA vaccines and syringes). DCVMN and CEPI note that improving data access and demand forecasting will enhance the ability of vaccine manufacturers to grow in and enter markets in developing countries, helping them seek commercial opportunities and inform their strategic thinking, which is particularly important in accessing markets that procure their own vaccines, such as the middle-income countries that are not eligible for Gavi funding.

However, demand forecasting in this context is very difficult for several reasons. Critically, the global community is currently trying to develop a coordinated manufacturing network that spans multiple companies and types of products; this is a unique, multi-stakeholder coordination challenge that is far more complex than a single company planning its manufacturing portfolio for a series of products. Planning for adult vaccines in the global-health context is even more difficult because it will vary in different local contexts and over time based on changing factors including available financing for products, prices for products, changes to clinical guidelines, the results of clinical trials for multiple products, the strength of health-system infrastructure and delivery, and community acceptance of vaccines. Surveillance systems that would help estimate the epidemiological need for these products are weak in many countries.

Forecasting demand for individual products under a range of circumstances is the only way to accurately predict the amount of manufacturing capacity needed and respond with appropriate investment. There are already a variety of demand forecasts for individual vaccines carried out by individual companies, governments and organisations like Gavi that purchase vaccines at scale, as well as Africa CDC's PAVM Framework for Action; we listed some of these in the Resource List. Understandably, Gavi's forecasts typically do

not include major adult vaccines that are on the market, such as influenza, or in the R&D pipeline, such as the novel tuberculosis vaccine entering phase III trials, which are currently outside Gavi's scope. While these demand forecasts can help in understanding the market, expanding them to include adult vaccines would have the benefit of guiding government and industry decisions about the type and quantity of vaccine manufacturing to invest in to meet anticipated future demand, thus shaping the vaccine-manufacturing market. Africa CDC's PAVM Framework for Action includes legacy, expanding and outbreak diseases and vaccines, as well as the breakdown of doses by manufacturing modality (both traditional and innovative) and serves as a strong starting point to determine network strategy (for example, bioreactor and fill-and-finish capacity) on the continent of Africa, but, of course, not in other regions.

We recommend conducting more holistic demand forecasting for a broader range of vaccines than the Gavi portfolio, including adult vaccines and vaccines still in the R&D pipeline. This broader set of demand forecasts represents a missing global public good that would inform investments in manufacturing capacity. We also support regular updates to the Africa CDC PAVM demand forecasting so that it includes current information as well as taking a similar approach globally and in other regions to minimise "patchwork" forecasting across geographies. Working backwards, these analyses of potential demand on the individual vaccine level can be translated into requirements for drug product, drug substance, manufacturing capacity and other supply-chain inputs. To materially inform financing requirements and financial feasibility and sustainability of new manufacturing capacity, the time horizon of the demand forecasts needs to extend into the period at which novel manufacturing capacity would be up and running. Long-term demand forecasts that span multiple vaccines and manufacturing platforms would inform decisions by individual investors as well as multilateral efforts to strengthen regional vaccine manufacturing, such as those by Gavi, CEPI and PAVM.

Long-term demand forecasts can also support efforts to create an investment case for donors and governments to support broader life-course vaccination programmes. By forecasting potential demand,

donors and governments can begin to estimate the budgets needed for expanded vaccination programmes and their potential economic and population-health benefits.

The quality of the parameters and data to be included in the forecasts is also key. Demand and supply forecasting are only as good as the information available to put into models. In order to ensure effective demand forecasts, rigorous approaches are needed to account for the multiple variables (including lack of demand, acceptability, catch-up cohorts and other vulnerabilities) that affect the market for adult vaccines more than the childhood-vaccine market. Transparent documentation of the assumptions used in these demand forecasts and their impact on various scenarios is critical.

SUPPLY MONITORING AND FORECASTING

Equally important for informing manufacturing-investment decisions is an understanding of the existing and forecasted manufacturing capacity. As with demand forecasting, individual companies already undertake global forecasting for supply. While some individual global health organisations such as CEPI, DCVMN and Market Information for Access to Vaccines (MI4A) have begun publishing their own forecasting exercises as indicated in the Resource List, greater collective collaboration to forecast supply is required. This collaboration should be facilitated by a neutral broker of information, such as an independent global health organisation, so that companies are not asked to share confidential information with each other. This planning should also account for the level of interchangeability among manufacturing plants (that is to say, whether they have the technical capacity to contribute to different aspects of the supply chain for different vaccines), variability in yields and other considerations that would affect the ability to translate this capacity into both finished doses for routine immunisation and products to respond to outbreaks.

Some examples of what transparency in manufacturing capacity could look like are compiled by CEPI, which has published manufacturing-survey results, analysis and landscaping, including with the DCVMN,[34] and by the WHO, which operates MI4A[35] to provide global vaccine-market information on both the supply and demand sides.[36, 37]

Of course, industry also undertakes forecasting for demand (and supply) at the company level that covers – among other things – doses required, prices and approaches to differential pricing for different markets. Given the commercial competition among industry players and the sensitivity of proprietary information, the results of these forecasts are not readily available and the level of collaboration required to capture an accurate forecast for the full market could raise antitrust issues. Despite these valid concerns, collective collaboration is required to increase the necessary market information to accurately forecast global supply and inform governments, global health organisations and industry.

LINKING DEMAND AND SUPPLY FORECASTING

The real added value of coordinated forecasting will be in integrating the demand-forecast scenarios with existing and forecasted manufacturing capacity so that industry can have accurate market information to make informed upstream-investment decisions, and so that governments can make informed regulatory decisions about how to meet health and market needs. These demand and supply forecasts would be public goods available for use by industry, governments and the global health community.

To this end, global health organisations such as the WHO, Gavi and CEPI, and regional organisations such as Africa CDC, the Pan American Health Organisation (PAHO) and the Association of Southeast Asian Nations (ASEAN), relying on data and information from industry and governments, should create (or augment where appropriate) integrated demand and supply forecasts that show:

- Demand-forecast scenarios for vaccines and injectables (including products targeting adults) across the world.

- A market-information dashboard of the current manufacturing capacity for governments, global health actors and industry to inform decision-making.

These will directly support the creation of a geographically distributed, technologically diversified and financially sustainable vaccine-manufacturing network by providing an integrated understanding of the predicted demand and supply for respective vaccines across regions. For example, one recent analysis by the Wellcome Trust found that publicly announced commitments to increase manufacturing capacity on the continent of Africa were misaligned with Africa CDC's priority pathogens.[38]

Because many established vaccines used at scale, including childhood vaccines, are already made in well-established manufacturing plants, introducing and scaling other vaccines, including vaccines across the life course, could help ensure sufficient demand for new manufacturing capacity. The introduction of novel manufacturing capacity in LMICs can be used to begin making new vaccines and upscaling existing vaccines that are not as widely used as they could be. With the correct market information, governments, regional bodies and industry will be better equipped to identify where the vaccine-manufacturing gaps are, including capacity required for forthcoming vaccines listed in our paper *One Shot to Prevent Disease and Prepare for Future Pandemics: Identifying the Most Promising Adult Vaccines and Injectables.*

Through this understanding, global health actors and investors in the public and private sectors can design the incentives, policies and specific investments needed to meet global demand for manufacturing capacity under various scenarios in a way that also strengthens a distributed manufacturing network for pandemic response. These investments could involve capacity-reservation agreements, operation of certain facilities as contract development and manufacturing organisations, "walk-in" rights for governments to temporarily use the facilities in emergencies with clear governance and financing arrangements in the event of certain "triggers" (such as a novel outbreak of a new pathogen), and other arrangements. This will help to ensure that the global and regional-manufacturing capacity will be sufficient to supply the market between and during outbreaks, and that investment targets the right technologies and capacities.

04

Using a Better Understanding of Demand to Help Shape Markets

Integrating demand forecasting and supply planning is not a silver-bullet solution for creating a geographically distributed, technologically diversified, financially sustainable vaccine-manufacturing network, but it is an indispensable first step. Predictable demand from purchasers of vaccines (including governments and multilateral organisations) is key to guiding investments, and therefore efforts should be focused on enhancing predictability by tackling affordability, planning and procurement issues, and by boosting political will and fortifying health systems.

The global health community has a strong track record of using various market-shaping approaches to create the needed conditions to roll out health products, some of which are included in the Resource List. One Shot proposes using these successful interventions to shape the vaccine-manufacturing market upstream, especially by growing demand for manufacturing with the introduction and scaling of adult vaccinations.

Here, we identify six categories of interventions that would be relevant for shaping the global manufacturing base and describe how they would specifically be relevant for adult vaccines. Importantly, these six interventions are not product-specific, but rather shape markets at the level of a portfolio of products or manufacturing technologies. These categories of interventions are consistent with the recommendations that Gavi "find ways to provide more predictability around future African demand" and "explore the creation of a targeted financial instrument such as an Advanced Market Commitment to incentivise capital investment in facilities that directly meet public health needs".[39]

1. **Creating a mechanism to review and ensure inclusion of products in the WHO's Essential Medicines List (EML) and other guidelines.**

Vaccines targeted at adults have traditionally had low levels of demand, especially in LMICs. Adding a product to the EML acts as an endorsement of the product, thereby incrementally increasing demand and enabling the product to be brought into routine service delivery.

2. **Harmonising registration systems and strengthening quality-assurance systems that will allow for exports of products across borders.**

Regulatory challenges pose some of the greatest barriers to producing high-quality vaccines in a financially sustainable manner.[40] Regulatory systems that are harmonised and simplified across multiple countries and regions, including with regard to registering new products, will lower the barriers to entry for new suppliers and reduce transaction costs. This will make nascent markets, such as certain countries in Africa, more attractive to suppliers and to direct upstream investment in vaccine manufacturing. While this intervention is not specific to adult vaccinations, it could help expedite their approval.

3. **Providing advance market commitments (AMCs), demand assurances and volume guarantees for manufacturing capacity or specific products.**

AMCs and other forms of demand guarantee are an explicit agreement by buyers to provide a market for products, often at an agreed price. These interventions will enable a predictable supply of products targeting adults and stimulate R&D for the development of new adult vaccines and injectables. It will be important for Gavi to define whether this AMC will support manufacturing for any vaccine or only those in the Gavi portfolio.[41]

4. **Investing in "resilience payments"[42] to subsidise or offset the costs of manufacturing in countries with nascent capabilities.**

In pursuit of the geographically distributed manufacturing network that is central to the One Shot concept, financial support to nascent suppliers that offsets capital expenditures and high prices compared to established plants will help diversify the global manufacturing base. This intervention is not specific to adult vaccines, but it would help new manufacturing plants that choose to make adult vaccines achieve commercial viability.

5. **Setting up or leveraging an existing pooled-procurement mechanism for adult vaccines and injectables.**

Pooled procurement is the consolidation of orders from multiple buyers by a third party who acts as a procurement agent. Such orders could be pooled among global donors or across countries within a region or of a similar income level. Pooled procurement is a well-established market-shaping tool for both vaccines and treatments, including those that target adults (for example, antiretrovirals), and it would help strengthen buying power and guarantee demand not only among low-income countries, but also among small countries that have relatively small orders.

6. **Government investment in demand-creation programmes for vaccines and injectables, including the use of clinical data to demonstrate the impact of new and established technologies as the portfolio of vaccines and target pathogens is broadened.**

One of the biggest barriers to the success of One Shot is the widely recognised low demand for adult vaccines and other products for adults. Therefore, long-term investment in demand-creation programmes targeted at building public acceptance and uptake of these medical interventions will be crucial.

05

Conclusion

The scientific developments that were accelerated by Covid-19 have led to a robust pipeline of game-changing adult vaccines and preventative injectables. To use life-course vaccines both for routine preventative health and as a pandemic prevention, preparedness and response (PPR) strategy, it is now incumbent on the key players – governments, industry, funders, international norm-setting agencies, civil society and multilateral platforms such as the G20 and G7 – to drive a global effort to harness and deploy these products to significantly reduce mortality and morbidity.

Life-course vaccination programmes have the potential to increase demand for manufacturing capacity through the introduction and scaling of new products. Such increased demand could help improve the commercial viability of new geographically distributed manufacturing plants as well as the capacity and resilience to respond to outbreaks and pandemics.

However, to realise this path to investment in the right global network of manufacturing capacity, governments, global health organisations and the private sector need to know what types of manufacturing capacity to invest in. These decisions should be informed by evidence about the demand for vaccines, the existing and forecasted manufacturing base, and clear market signals and assurances.

06

Technical Deep Dive: Estimated Global Vaccine-Production Capacity

To provide an understanding of the total manufacturing capacity for Covid-19 and non-Covid-19 vaccines, and the relevant technologies used, analysis undertaken for this paper[43] shows that the estimated three-year average of the total number of all other vaccine doses purchased in a calendar year is 3.7 billion. This has been compiled through rigorous analysis of publicly available data across dispersed and decentralised platforms. Unfortunately, these databases are currently not structured according to manufacturing platform and may vary from other sources, making disaggregation for the purposes of supply planning across the industry difficult.

The total number of Covid-19 vaccine doses that can be produced per annum if all facilities maintain 100 per cent capacity is around 21.3 billion – however, this differs from what the industry estimates could be produced, and this estimate has a wide confidence band. This reflects the difficulty and uncertainty in understanding total manufacturing capacity using current publicly available data and limits the ability to rely on this information to inform upstream investment in manufacturing capacity.

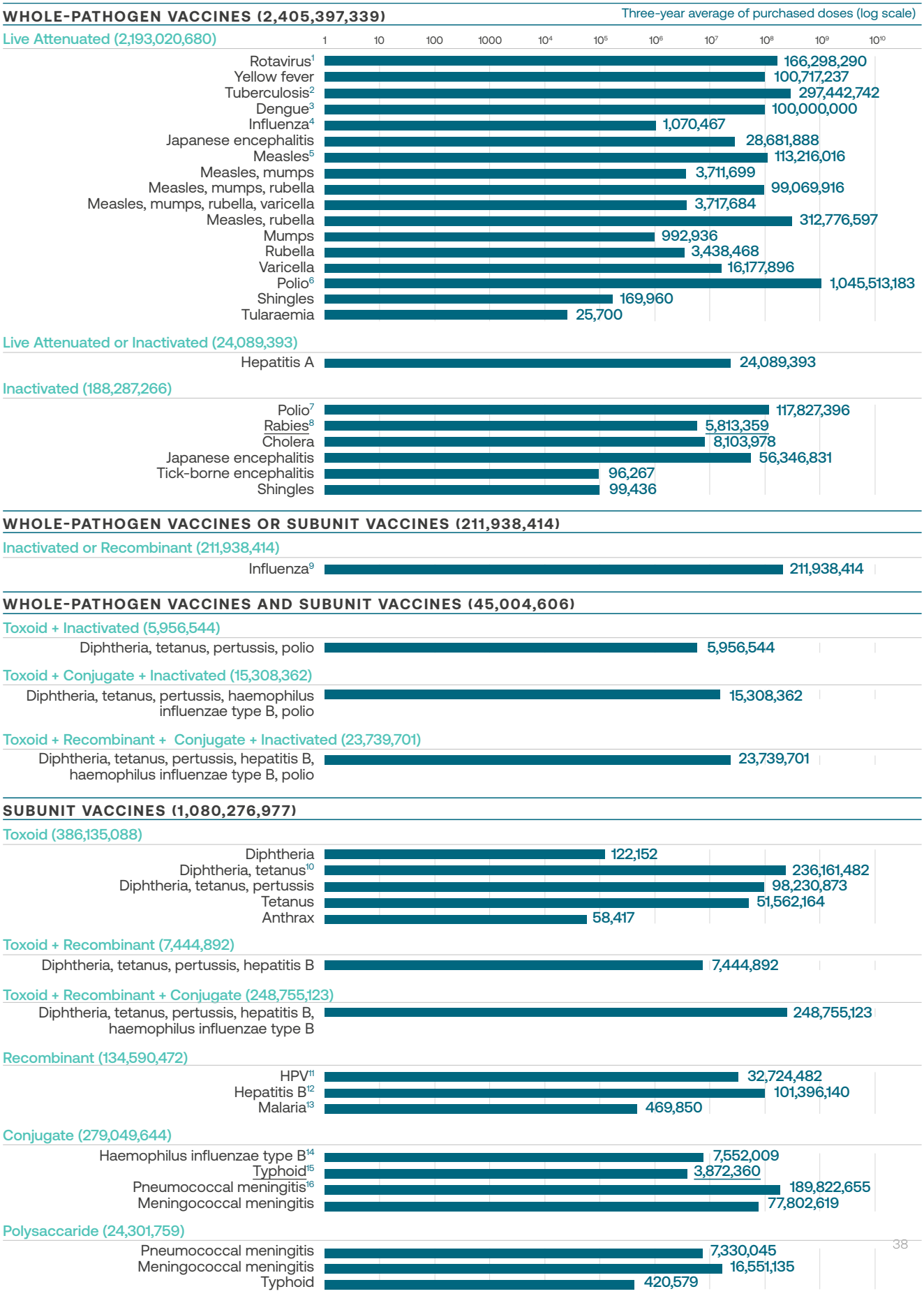
The number of non-Covid-19 vaccines manufactured on an annual basis is certainly lower than Covid-19 vaccines, and these products all use technologies besides mRNA. In addition to a number of mRNA vaccines in clinical-trial-stage development such as RSV and HIV, a significant number of vaccines in clinical-trial-stage development utilise other technologies such as recombinant subunit, adenovirus and live attenuated virus. Therefore, in addition to the focus on the potential of mRNA platforms, we also need to ensure a geographically distributed, technologically diversified and financially sustainable manufacturing capacity that can make sufficient use of other vaccine technologies in the

future. Demand forecasting and guaranteeing demand are indispensable in improving the commercial viability and prospects of diverse manufacturing, which is essential for crowding in private-sector co-investment.

Figure 3 gives an estimate of capacity based on non-Covid-19 vaccines. The figure was created using the "total number of vaccine doses purchased in a calendar year" variable from the MI4A vaccine-purchase database.[44] The "three-year average of purchased doses" was used to calculate the "total doses per manufacturing technology" and "total doses per category" rows. Underscored diseases are those where figures greatly vary from the available WHO market-study reports and underreporting in the MI4A vaccine-purchase database is presumed because the database is based on self-reporting from countries.

FIGURE 3

Average number of non-mRNA vaccine doses purchased annually, 2018–2020



Notes to Figure 3

1 According to a UNICEF market study, 214,300,000 rotavirus doses were produced in 2020.

2 According to a WHO market study, in 2019 there was a supply of 620,000,000 doses and a demand of 325,000,000 doses of Bacillus Calmette–Guérin (BCG) vaccine.

3 No data available in the WHO database but according to Sanofi, in 2016 they had a 100,000,000-dose production capacity for the only vaccine available in the market.

4 Live-attenuated influenza vaccines are nasal sprays.

5 According to a WHO market study, in 2020 there was a demand for 455,000,000 measles-containing vaccines, with an available supply for commercialisation (ASC)/demand ratio of 1.3.

6 Live-attenuated polio vaccines are oral.

7 7 per cent of the diphtheria-containing vaccine doses also include the polio vaccine (inactivated).

8 Average underscored because it greatly varies compared to a WHO market study, which indicated there was a global demand for 64,000,000 rabies vaccine doses, with an ASC/demand ratio of 1.7, in 2020.

9 Not enough information to separate the data between inactivated or recombinant.

10 According to a WHO market study, in 2019 there was a demand for 1,000,000,000 diphtheria and tetanus-containing vaccines, with an ASC/demand ratio of 1.3.

11 According to a WHO market study, in 2022 there is a demand for 80,000,000 HPV vaccine doses, and the same figure for supply.

12 44 per cent of diphtheria-containing vaccine doses also include hepatitis B vaccine.

13 WHO reported a world-production capacity of 15,000,000 in 2022; this is a new vaccine.

14 45 per cent of the diphtheria-containing vaccine doses also include the Hib vaccine.

15 Average underscored because it greatly varies compared to a WHO market study, which indicated there was a global demand for 28,000,000 typhoid TCV vaccine doses and a supply of 60,000,000 in 2021.

16 According to a WHO market study, in 2019 there was a demand of 245,000,000 pneumococcal meningitis vaccine doses, with an ASC/demand ratio of 1.1 to 1.4.

Figure 4 gives an estimate of the Covid-19 vaccine-manufacturing capacity globally; this provides an idea of the potential capacity that could be pivoted to non-Covid-19 products. It presents the aggregated Covid-19 vaccine-dose production capacity reported for 2022; the data were extracted from the United Nations Children's Fund (UNICEF) Covid-19 Market Dashboard.[45] The data sources for this figure, as indicated by UNICEF, are information made publicly available by manufacturers, manufacturers' responses to UNICEF's Expression of Interest, and UNICEF's and PAHO's joint Covid-19 vaccine tender on behalf of the COVAX Facility.

In the header row of the figure, the phrase "all development stages" is the aggregated projected production capacity of Covid-19 vaccine doses in the discovery, pre-clinical, clinical, regulatory-review and approved-for-use stages. Two filters have been applied to the "all development stages" data. One is "licensure experience". This is the aggregated projected production capacity of Covid-19 vaccine doses from developers whose vaccine has received emergency or conditional approval, or who have at least one other (that is to say, non-Covid-19) vaccine in their current portfolio that has been licensed for use by a national regulatory authority. The other filter applied is "WHO prequalification experience".[46] This is the aggregated projected production capacity of Covid-19 vaccine doses from developers whose vaccine, in addition to having been licensed by a national regulatory authority, has been granted Emergency Use Listing by the WHO or who have at least one other non-Covid-19 vaccine in their current portfolio that has been prequalified by the WHO.

It should be noted that publicly reported production-capacity estimates have not been validated by UNICEF and no attrition rates have been applied to adjust for the probability of technical and regulatory success of vaccines in the pipeline. Also, depending on the development stage of the vaccine, manufacturers may not know their production yields at scale, for example, or the quantity of antigen per dose needed for each vial. These estimates can therefore lead to a highly optimistic view of the potential production capacity, particularly for those vaccines still in pre-clinical and clinical trials. This means that the 40.1 billion projected production capacity ("vaccines in all development stages") might be an overestimate. Also note that some numbers may not represent numbers included in the UNICEF dashboard due to rounding.

FIGURE 4

Estimated global Covid-19 vaccine-dose production capacity in 2022

		Dose-production capacity per manufacturing technology			Total dose-production capacity per vaccine category		
		All development stages	Licensure experience	WHO prequalification experience	All development stages	Licensure experience	WHO prequalification experience
Whole-pathogen vaccines	Live attenuated	80,000,000	80,000,000	Live	5,732,000,000	5,130,000,000	4,100,000,000
	Inactivated	5,652,000,000	5,050,000,000	4,100,000,000			
Subunit vaccines	Recombinant	15,675,000,000	4,660,000,000	3,400,000,000	15,775,000,000	4,660,000,000	3,400,000,000
	Virus-like particles	100,000,000					
Viral-vector vaccines	Replicating	280,000,000	230,000,000	230,000,000	10,837,000,000	7,620,000,000	7,030,000,000
	Non-replicating	10,557,000,000	7,390,000,000	6,800,000,000			
Nucleic-acid vaccines	mRNA	7,270,000,000	7,270,000,000	6,700,000,000	7,766,676,000	7,120,000,000	6,800,000,000
	DNA	496,676,000	100,000,000	100,000,000			

Source: UNICEF.
Note: the data presented here encompass the reported, projected production capacity of all vaccines being developed and those with licensure experience and WHO prequalification experience.

Endnotes

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9 We recognise that other factors are critical for developing bankable public-private partnerships (PPPs) and investments in manufacturing. The steps and best practices for structuring individual PPPs and investments, while critical for setting up this network, are beyond the scope of this paper. For an overview of how to effectively structure PPPs in LMICs, please refer to the World Economic Forum's paper "*Strategic Infrastructure: Steps to Prepare and Accelerate Public-Private Partnerships*".

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