



Shining a light on COVID-19 vaccine supply chains

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Efforts to defeat the COVID-19 virus have taken a giant leap forward in recent weeks as three pharmaceutical companies have released promising interim results from their clinical Phase III trials—raising hopes that several vaccines will be widely available in 2021.

Yet as new vaccines gain approval, the global vaccine supply chain gains complexity and public concerns increase. Are logistics companies ready? Is there enough air freight and cold-chain capacity? Will distribution be a major factor in vaccine costs?

Given the growing concerns about successful vaccine production and delivery, Boston Consulting Group researched some of the most complex issues around the vaccine supply chain, from air freight capacity and the dry ice supply to cold chain resources and the cost of vaccine distribution. And our findings were surprisingly reassuring. The overall costs of the vaccine will be relatively low vis-à-vis the toll of the virus on the global economy—and the supply chain costs will represent just a fraction of the total. The air freight capacity is in place. The cold chain requirements can be met through existing dry ice production for the vaccines that need it, and new container solutions have been specially developed. In addition, key stakeholders along the vaccine supply chain already have the experience to take on the issues and have formed contingency plans.

While there's no doubting the complexity inherent to global delivery of a new vaccine, we find the potential constraints to be manageable. Of course, all the information is not yet known. It is therefore essential that stakeholders along the value chain, from developers and manufacturers to logistics players and the authorities, work together to mitigate these constraints as transparently as possible and take decisive action to address them.

An Increasingly Complex Supply Chain

There are currently seven vaccines supported by the US government under its Operation Warp Speed initiative, and several vaccine candidates are getting close to launch, with four candidates already in Phase III trials and a fifth candidate, Novavax, on track to begin its own Phase III effort. (See Exhibit 1.) The vaccine candidates of Pfizer and BioNTECH, Moderna, and AstraZeneca-Oxford have already reported high levels of efficacy from their interim Phase III results, and Emergency Use Authorizations have been granted to Pfizer in the US and UK and to Moderna in the US.

Exhibit 1: Vaccine Candidates Approach Critical Window for Emergency Use Authorization (EUA)



Sources: [nytimes.com](https://www.nytimes.com); press search; BCG analysis.
 Note 1: Dates are based on trials and approvals in the US; Pfizer has already received UK approval.
 Note 2: Timeline is indicative and highly dependent on Phase III vaccine results; candidates are not guaranteed to receive EUA or full FDA approval.

These pharma companies applied for rapid approvals to launch their vaccines due to the severity of the crisis. Nonetheless, they remain aware that delivering a global vaccine requires diligence and rigor at every step of the way and they are prepared to do their best to ensure that they can deliver safe and effective solutions, minimizing the number of adverse events. The long-term effectiveness and performance of the vaccines will only become available as real-world data is collected over the next years, but governments and pharma companies are doing all that is needed to ensure proper tracking.

Pfizer's and Moderna's messenger RNA (mRNA) candidates in Phase III have now reported approximately 95% efficacy in their interim results, while AstraZeneca's viral-vector vaccine has reported approximately 62% to 90% efficacy after its first tests. In addition, Johnson & Johnson has started the Phase III trials for its one- and two-shot vaccine candidates.

With multiple vaccines preparing to launch (and Russian and China launching independent vaccination programs), there will be more options for inoculating the global population. However, the growing landscape of options is also increasing the complexity of the process. While several candidates may receive regulatory approval, each will clearly show different levels of efficacy and effectiveness and will have its own manufacturing and logistical requirements, with different implications.

We examine here the potential constraints that may result in the supply chain, from manufacturing to the point of delivery, and take a deep dive into some of the more complex issues surrounding the global distribution of the COVID-19 vaccine.



Dedicated Manufacturing Capacity

Manufacturing enough vaccines to reach a large percentage of the global population by the end of 2021 will be a Herculean task. Complete success will depend on a few “must believes:” no delays in starting vaccine production, no major quality problems, and very limited vaccine waste.

Nonetheless, various pharma companies and conglomerates have already dedicated significant manufacturing capacity to supplying their vaccine candidates once approved. In fact, the producers of the seven US government-supported vaccine candidates have each announced the capacity to manufacture 1 billion to 3 billion doses by the end of 2021, totaling approximately 11 billion doses, of which 50% have already been contracted by various nations.

To support this global effort, pharma companies whose candidates are still awaiting approval might want to consider offering their manufacturing capacity to vaccines that have already been approved. Should they do so, a rapid transfer of manufacturing technology and knowhow will be imperative.

In addition, the manufacturing community and all supply chain partners must cooperate if the COVID-19 vaccine(s) is to be administered successfully. For the next few months, it will be critical for these stakeholders to monitor the number of companies that gain approval for their products and the amount of product likely to be available on the market. If only a few products are approved, there could be a shortage in 2021 (based on public manufacturing capacity), and if multiple products are approved and used around the globe, there could be an excess. Flexibility in the supply chain will therefore be critical.

Cold Chain Requirements

Along the length of the potential vaccine supply chain, cold chain requirements present the most dominant challenge, as mRNA vaccines—including two of the leading vaccine candidates— are highly temperature sensitive. Moderna’s vaccine, for example, must be stored at -20°, and Pfizer’s vaccine at -80°. While Moderna’s temperature requirements can be handled at regular freezer temperatures for up to six months—of which up to 30 days can be normal refrigerator temperatures—Pfizer’s vaccine will require dry ice and a special chain of custody and may only be stored in a refrigerator for up to five days, setting it apart from other vaccine types.

Dry ice, made by condensing carbon dioxide, is usually generated from captured CO₂ emissions of large industrial or energy plants. There has been some concern about potential bottlenecks in the supply chain due to an insufficient supply of dry ice at the production site or along the vaccine delivery route, as well as the risk of inadequate cold chain infrastructure. However, there are many such plants in the region around Pfizer’s



sites. In addition, the sourcing of bulk dry ice in insulated boxes from manufacturers across Europe is realizable.

We calculate that demand for vaccine shipping will represent only around 5% of the global daily production of dry ice, with half needed for initial packing at only two manufacturing sites and the other half used for replenishment along the route when sensors indicate a need, or after ten days when the vaccines are stored. Dry ice suppliers are also ramping up their production capacity and preparing to ship higher volumes. As a result, the supply of dry ice should not be a bottleneck to vaccine distribution.

As to cold chain infrastructure, most developed countries have substantial refrigerated warehouse storage, and some major logistics players are already investing in additional capabilities to ensure a smooth vaccine distribution. Logistics companies are also investing in premium facilities and specially designed containers, such as those produced by va-Q-tec, to ensure an uninterrupted cold chain at the necessary levels, including -80°C, -20°C, and 2° to 8°C. Some are talking about expanding their warehouse solutions and “freezer farms” to support distribution activities as well.

As an example, global transport and logistics provider Kuehne+Nagel has developed a regional hub strategy that will offer COVID-19 vaccine storage at all three temperature ranges. Many of these warehouses are strategically located near today’s vaccine manufacturers, with access to air and road logistics that comply with industry standards and practices and can reach every country in the world, including low-to-middle-income markets. Kuehne+Nagel has also developed a COVID-19 Temperature Pod solution that will allow countries to set up storage locations supporting distribution at these temperature ranges in their markets.

Transport Capacity

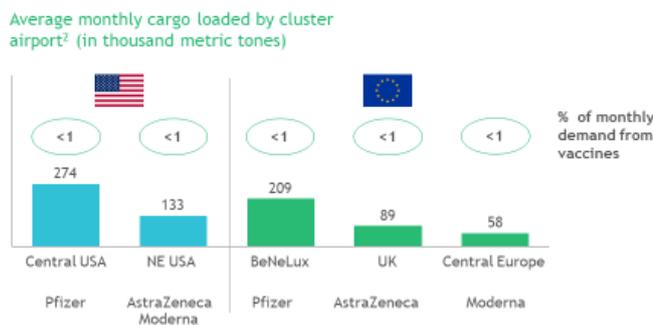
As with the production of the vaccine, several logistical challenges naturally present themselves as pharma companies and governments attempt to deliver it across the globe and into every urban, suburban, and rural community—although spread out over the course of a year or more. Not surprisingly, there is no single response to these challenges. Each vaccine manufacturer’s method of getting its supply out to the public will be determined in part by its handling requirements; in addition, it will be influenced by factors such as geography, existing logistics infrastructure, available resources, and even political agendas.

Many variations are feasible. For example, companies may use a hub-and-spoke model, with central stock keeping in specially equipped warehouses to ensure greater control, and distribution dictated by demand. Others may choose point-to-point delivery, with some cooling and freezing infrastructure in place at the vaccination centers, but no intermediate storage. A third variation is that of a fully state-run program such as Operation Warp Speed, which will utilize the US military’s coordination capabilities and a large distributor, McKesson, to aid distribution.

Nonetheless, every model relies primarily on global freight capacity, and on airline capacity in particular. Vaccines must be shipped from airports that have the required pharma capabilities to ensure appropriate storage and transport conditions. Our analysis indicates that airports with the required capabilities located within trucking distance of vaccine distribution facilities should be able to deal with the demand for vaccine shipment, as monthly demand will only represent less than 1% of their average monthly load. (See Exhibit 2.) In addition, outbound airports have enough space in their cold chain facilities to store the vaccines locally, as demand will represent less than 2% of their total capacity.

Exhibit 2: Outbound Airports have Ample Capacity to Ship the Vaccines

Analysis based on the airport hubs that are close to the manufacturing sites of the most advanced candidates¹



Sources: Eurostat, US airport official website, BCG analysis.
 Notes: Moderna and AstraZeneca distribution facilities are in a similar area covered by the same airport cluster; selected major airports in each cluster; other airports in the same area can also be used to distribute the vaccine by air.
¹ Advanced candidates are considered to be those that have reported interim efficacy data at the time of this publication.
² Average cargo loaded in selected airports close to pharma companies' facilities, comparing only the loading volume in airports and assuming that 50% of airport volume is loaded and 50% unloaded in US airports, as US data is not split by volume.

<1%
of monthly cargo loaded in outbound airports²

Volume of vaccine shipments can be absorbed by outbound airport infrastructure

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As to air freight capacity, our research indicates that the projected freight demand to ship COVID vaccines is highly sensitive to a few key factors, including weight assumptions about vials, doses, and containers. With this in mind, the required doses to vaccinate the global population translate into air transport capacity of about 1,100 freighter flights, based on a mix of 10% deep-frozen (-80°C), 10% frozen (-20°C), and 80% cold (2° to 8°C) vaccines. In all, this represents only 1% or less of the 2019 air freight capacity in the logistics industry.

Logistics providers across the globe, in turn, are rapidly preparing to manage the transportation of the vaccine from manufacturer to clinic. Kuehne+Nagel, for example, offers door-to-door services focused on 32 vaccine-capable airports around the world, each of which has the required carrier capabilities and capacity, infrastructure, staff expertise, service levels, and quality support and is located near known manufacturing locations and vaccine destinations. These services will include dry ice, container, and



packaging availability and airside service (tarmac visibility) and will be overseen by a team focused solely on COVID-19 customers.

Prior to commercial product release, Kuehne+Nagel's QuickSTAT team is also providing logistical services at each stage of launch, from pre-clinical to Phase III clinical trials. This type of service will be essential to ensuring a smooth transition from clinical trials to the distribution of commercial products at scale.

Note that shipments within the US will benefit from the extensive coordination capabilities of the US military, as stated earlier, likely in combination with regional delivery services such as UPS, FedEx, and DHL. In Europe, individual governments will organize delivery.

Delivery Costs

The discussion of costs is as complex as that of delivery. In preparation for the vaccinations, the global community has taken both individual and collaborative approaches to secure and support the supply of vaccines; the chosen approach will affect both the way the vaccines are delivered and the cost structures.

Operation Warp Speed in the US will take advantage of the support and capacities of the US military in this area as well. The European Union, in turn, has contracted volumes of vaccines for its member states, but supply and logistics will be supported on a national level. China and Russia have both funded state-led research and development to manufacture and supply their own vaccines, with further options to offer their vaccines to other countries.

Adding to this complexity, the COVAX Facility—an alliance supporting the research, development, and manufacturing of vaccine candidates—and the Coalition for Epidemic Preparedness Innovations (CEPI), as well as private foundations such as the Gates Foundation, will play an essential role in distributing a supply of vaccines to relatively small and less wealthy countries.

Once the various supply chains are established, however, our analysis indicates that distribution costs will be relatively small—approximately seven cents per dose—including the cost for dry ice and warehousing, with variations driven by airfreight costs and last-mile delivery costs. (See Exhibit 3.)

Exhibit 3: Distribution Costs Are Anticipated to Make Up Only a Fraction of Expected Vaccine Costs

Distribution costs, including intermediate, short-term storage

Cost types (cold chain)	Assumptions per box of 5,000 doses (\$)	Cost per dose in cents (assuming 60% shipped by air transport)
Total cost¹	326-358	7.2
Air	390-410	4.9
Road ²	6-9	0.07
Warehousing ³	0.4-0.5	0.01
Dry ice ⁴	4-8	0.2
Last Mile ⁵	85-100	2.0

Sources: Upply; BME; FTR; BCG analysis.
 Note 1: Model assumes 80% of vaccines are shipped at 2° to 8°, 10% are shipped at -20°, and 10% are shipped at -80°.
¹ Assumes 60% air shipments and 40% road shipments. ² Road costs of \$6 to \$9 per box, assuming premium service, 15 pallets per truck (not full load). ³ Assuming five-day warehouse storage, i.e., six turns a month. ⁴ Total costs for one-time dry-ice replenishment operation. ⁵ Assumes average mileage of 330 kilometers and average rate of \$0.25 to \$0.30 per kilometer.



In addition, the costs of producing and delivering the vaccine will be low compared to the enormous toll the virus is taking on the global economy. GDP losses are estimated to have reached \$4.1 billion per day in Europe and \$3.7 billion per day in the US as of October 7, 2020—equaling 12% and 25% of total EU and US vaccine costs, respectively. (The difference appears because the EU, as a collective of nations, is expected to need twice as many vaccines as the US). In other words, total vaccine costs will be surpassed by current GDP losses in an estimated 9 days and 4 days in the US and Europe, respectively.

Point of Delivery

Several concerns have been raised around the final point of vaccine delivery to the individual, including whether to have centralized or decentralized distribution, what the training requirements will be, and how the delivery of vital materials such as vials and syringes will be coordinated. These concerns will be augmented or reduced in each region by factors such as existing infrastructure, development levels, rate of urbanization, and affluence.

Whether a country can establish a decentralized vaccination campaign that reaches even the most isolated individuals or must use a centralized campaign will be determined by the supply chain requirements of the vaccine, paired with the local infrastructure. Pfizer’s vaccine, for example, may be limited to centralized distribution in urban centers due to its cold-chain requirements, while Moderna’s vaccine may be more suitable to broader and decentralized distribution. Other vaccine candidates from companies such

as Johnson & Johnson, AstraZeneca, and Novavax, in turn, have less-sensitive cooling requirements and may be suitable for broader and more rural deployment.

In terms of training, vaccination center staff must learn to administer each type of vaccine correctly, to monitor which person received which vaccine if the center gives out more than one type, and to track the vaccinations of individuals in order to schedule potential booster shots correctly. For the mRNA vaccines, staff must also be trained to follow the correct thawing, dilution, and visual inspection protocols for each shot.

In response, vaccination centers need to organize the training of vaccination workers in a timely manner, strictly following the recommendations set by the manufacturer and approving authorities. Vaccination workers, in turn, must understand and implement protocols that will enable companies to track the long-term effectiveness of the vaccines that were administered.

The availability of the vaccine, syringes, and even personal protective equipment (PPE) must also be synchronized. Material procurement will be critical to a successful vaccination campaign. Yet experiences in previous pandemics, including Ebola, SARS, and MERS, show that logistics companies have the capabilities and the knowledge in place to address these challenges, despite the seemingly unprecedented scale of the current pandemic. Manufacturers have already put in place contingency plans to stock extra materials, and glass manufacturers such as Corning and Schott have begun preparing the necessary supplies of vials and syringes, which must be coordinated with evolving vaccine production to ensure that they are available at the right time and place.

Action Steps

As manufacturing, transportation, and delivery complexity grows due to the multitude of requirements and constraints for so many vaccines, stakeholders along the value chain should consider taking the following important steps:

- Developers and government authorities should mitigate the long-term safety concerns generated by rapid vaccine approval by pushing for the highest levels of data transparency and working to increase the lessons learned along the way.
- Manufacturers that do not have a vaccine approved by the first quarter of 2021 should consider supporting those candidates that do have a successful early rollout in launching their vaccine even more quickly.
- Logistics companies should collaborate to establish a chain of custody and end-to-end supply chain transparency in order to guarantee uninterrupted cold chains and minimize losses.
- Authorities, manufacturers, and logistic companies should determine how best to ensure that their vaccination campaigns are not bottlenecked by a lack of medical material supply, such as syringes and personal protective equipment.



Throughout the research, BCG experienced strong confidence and support from many stakeholders in the vaccine supply chain. We see these essential players moving away from “can we do it?” to “how are we going to do it?” There are doubtless many challenges ahead, and our world depends on how they respond to this need. Yet many companies have been distributing vaccines for years; the key difference now is that the world is watching.