# Oxygen sources and distribution for COVID-19 treatment centres

Interim guidance

4 April 2020

World Health Organization

## Background

This is interim guidance on oxygen sources and distribution strategies for COVID-19 treatment. It has been adapted from WHO and UNICEF's technical specifications and guidance for oxygen therapy devices, which is part of the WHO *medical device technical series*,[1] and is based on current knowledge of the situation in China and other countries where cases have been identified.

This guidance is intended for health facility administrators, clinical decision-makers, procurement officers, planning officers, biomedical engineers, infrastructure engineers and policy-makers. It describes how to: quantify oxygen demand, to identify oxygen sources that are available, and select appropriate surge sources to best respond to COVID-19 patients' needs, especially in low-and-middle income countries. WHO will update these recommendations as new information becomes available.

## COVID-19 and oxygen

Data from China suggests that although the majority of people with COVID-19 have mild illness (40%) or moderate illness (40%); about 15 % of them have severe illness requiring oxygen therapy, and 5% will be critically ill requiring intensive care unit treatment. In addition, most critically ill COVID-19 patients will require mechanical ventilation.[2,3] For these reasons, COVID-19 treatment health-care facilities should be equipped with pulse oximeters, functioning oxygen systems including single-use oxygen delivery interfaces.[4]

Oxygen therapy is recommended for all severe and critical COVID-19 patients, with low doses ranging from 1-2 L/min in children and starting at 5 L/min in adults with nasal cannula, moderate flow rates for use with venturi mask (6-10 L/min); or higher flow rates (10-15 L/min) using a mask with reservoir bag. In addition, oxygen can be delivered at higher flow rates and in higher concentrations, using high-flow nasal cannula (HFNC) devices, non-invasive ventilation (NIV) and invasive ventilation devices.[4]

Compared with standard oxygen therapy, HFNC and NIV devices may reduce the need for intubation,[5] which may be a consideration in settings where there is limited availability of mechanical ventilation. However, HFNC and NIV devices. carry a risk of aerosol generation and thus requiring airborne precautions by the health workers using them.

**CAUTION**

- Oxygen supports combustion. The addition of concentrated oxygen to a fire increases its intensity considerably and can even support the combustion of materials that normally do not burn.
- Do not go near any open flames when using oxygen – Do not smoke near to oxygen sources!

## Oxygen sources

Oxygen therapy or supplemental oxygen is the provision of medical oxygen as a health-care intervention. Medical oxygen contains at least 82% pure oxygen, is free from any contamination and is generated by an oil-free compressor. **Only high quality, medical-grade oxygen should be given to patients.**

Oxygen systems must consist of an oxygen source, or production combined with storage. Common oxygen sources are: oxygen generating plants and liquid oxygen in bulk storage tanks, and oxygen concentrators. The most common source of oxygen storage used in health-care settings is a cylinder.

The appropriate choice of oxygen source depends on many factors, including: the amount of oxygen needed at the treatment centre; the available infrastructure, cost, capacity and supply chain for local production of medicinal gases; the reliability of electrical supply; and access to maintenance services and spare parts, etc. Details about these different oxygen-source options are provided in this guidance, and in more depth in WHO-UNICEF *technical specifications and guidance for oxygen therapy devices*.[1]

**Liquid oxygen plants**: Cryogenically produced liquid oxygen is always generated off-site (not at a medical facility). Medical facilities can be equipped with large bulk liquid oxygen tanks that are refilled periodically by a truck from a supplier. The liquid oxygen tank supplies a centrally piped system throughout the health facility by self-vaporization and for which a power supply is not required. Although an economical option in some settings, the use of liquid oxygen relies on external supply chain mechanisms and needs a bit more caution with respect to transport and storage due to the risks associated with higher pressures. Extra care should be taken in more extreme environments. It is best practice to also have cylinders as a backup supply.[1]

**PSA oxygen plant:** A pressure swing adsorption (PSA) oxygen plant serves as a large, central source of oxygen generation using PSA technology (similar to concentrators) that can be located on-site at medical facilities.

Oxygen from a PSA plant can either be piped directly to bedside terminal units within patient areas or, with a booster compressor, be used to refill cylinders for oxygen distribution (either on-site or to neighbouring health facilities) or for backup oxygen supply. Oxygen plants require a reliable source of power. It is best practice to also have cylinders as a backup supply.

**Oxygen concentrators**: An oxygen concentrator is a self-contained, electrically powered medical device designed to concentrate oxygen from ambient air. An oxygen concentrator uses PSA technology to draw in air from the environment, removing the nitrogen to produce a continuous source of more than 90% concentrated oxygen. It should not be used if the oxygen concentration falls below 82%.[1]

Oxygen concentrators are portable and can be moved between clinical areas, but they are also often set up to be stationary fixtures in patient areas. Concentrators designed for portable medical support are available in models that can deliver maximum flow rates of between 5 and 10 L/min.

When used with a flowmeter stand for splitting flow, concentrators can provide a continuous supply of oxygen to multiple patients at the same time. Concentrators can provide a safe and cost-effective source of oxygen, but they do require a source of continuous and reliable power and regular preventive maintenance to ensure proper functioning. It is best practice to also have cylinders as a backup supply.[1]

## Oxygen storage and intra-hospital distribution

**Oxygen cylinders:** Oxygen gas can be compressed and stored in cylinders. These cylinders are filled at a gas manufacturing plant, either via a cryogenic distillation or a PSA plant,[6] and then transported to health facilities. Cylinders can be used in one of two ways. One, by installing them directly within patient areas or, similar to direct piping and two, by connecting them to sub-central manifold systems (groups of cylinders linked in parallel) at the facility. Thus, oxygen can be piped to specific areas of the health facility, even at the ward level. When cylinders are the only source of oxygen in a health facility, a strong supply-chain is required to ensure ongoing availability.

Once filled, cylinders themselves do not require electricity, but they do require several accessories and fittings to deliver oxygen, such as pressure gauges, regulators, flowmeters, and in some cases, humidifiers. Cylinders also require periodic maintenance, commonly provided by gas suppliers at the point of refilling.

Additionally, storage or transportation of medical oxygen in cylinders must be done carefully and by trained personnel as the contents are under extreme pressure.

**Pipeline intra-hospital distribution networks** are helpful to supply oxygen at high pressure to equipment such as anaesthetic machines and ventilators. A key advantage of pipeline systems is that they obviate the need for handling and transporting heavy cylinders between hospital wards. However, the high cost and complexity of installing centralized oxygen sources with copper pipelines and the associated specialized maintenance required for this make pipeline systems less accessible for turn-key installations.

**Demand and supply**

Given the global supply-chain issues resulting from the COVID-19 pandemic, WHO urges Ministries of Health to estimate their countries' oxygen needs and recommends using the WHO COVID-19 Essential Supply Forecast Tool (ESFT)[7] and other tools available at the WHO website: Essential resource planning including the WHO Biomedical Equipment Inventory Tool to determine existing oxygen sources and supply mix in order to leverage these for their COVID-19 response. Additionally, WHO urges Ministries of. Health to contact local oxygen producers and/or suppliers to benefit from locally available resources.

More information on oxygen sources is available in Table 2: Description and comparison of oxygen sources and storage.

## Oxygen needs estimation

Another aspect of selecting the most appropriate source of oxygen is taking into consideration the gross flows of oxygen that will be needed for treatment. To determine the total flow needs, the anticipated case load has to be estimated. This can be done using the WHO COVID-19 Essential Supply Forecast Tool (ESFT).[7] From the total patients expected, the ratio of patient severity can be ascribed as outlined above: mild, moderate, severe or critical. Thus, the required flows can be estimated to meet the oxygen therapy needs for the hospitalized severe and critical patients, representing 20% of the total.

About 75% of the COVID-19 patients requiring hospitalization will be classified as "severe", and 25% as "critical". Thus, the total supply of medical oxygen required can be estimated based on the recommended flow rates for each patient severity category (shown in the Table 1 below).

**Table 1: Sample oxygen flow planning per 100 bed facility**

| Hypothetical 100 bed COVID-19 treatment facility | | | | |
|---|---|---|---|---|
| Disease severity | Avg. $O_2$ flow rate | | Size of solutions of scale* | |
| | per patient | Total | PSA Plant | Bulk liquid |
| Severe 75 patients | 10 L/min | 75 * 10 * 60 = 45,000 L/hr | = 45 $m^3$/hr | = 1.25 $m^3$/day |
| Critical 25 patients | 30 L/min | 25 x 30 x 60 = 45,000 L/hr | = 45 $m^3$/hr | = 1.25 $m^3$/day |
| | | | = 90 $m^3$/hr | = 2.5 $m^3$/day |

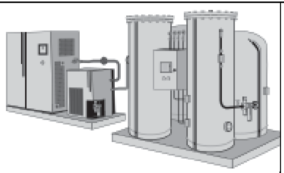
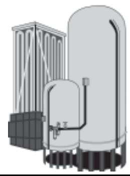
This sample scenario is based on a patient count. Typical quantification of this nature would be calculated based on availability of equipment. **It is important to re-assess needs once the equipment has been commissioned, as there are likely to be equipment-specific changes in demand.**

All assisted ventilation implies a mix of medical air and oxygen. Flows for critical patients indicated here represent only the oxygen portion of the total gas flow required to achieve target therapeutic fraction of inspired oxygen ($FiO_2$), which is the total % oxygen in the lungs available for gas exchange. $FiO_2$ will change over the course of a treatment, and vary from one patient to the next. The oxygen flow rate indicated here represents an average of the proportion of oxygen flows over the course of a patient's time on assisted ventilation. A simple equation to determine flow proportion at any time is as follows:

$$Target\ FiO_2 = \frac{O_2\ L/\min + (air\ L/\min x\ 21\%)}{Total\ flow, L/min}$$

The WHO COVID-19 ESFT[7] can also help to estimate other needs that will have to be included, such as ancillary devices, accessories, consumables and spares, etc. These tools and other associated documents can be found at WHO website: [Essential resource planning](Essential resource planning).

**Table 2: Description and comparison of oxygen sources and storage[1]**

| | Cylinders | Concentrators (PSA) | Oxygen plant (PSA) | Liquid oxygen |
|---|---|---|---|---|
| General characteristic | | | | |
| Image |  |  |  |  |
| Description | A refillable cylindrical storage vessel used to store and transport oxygen in compressed gas form. Cylinders are refilled at a gas generating plant and thus require transportation to and from the plant | A self-contained, electrically powered medical device designed to concentrate oxygen from ambient air, using PSA technology. | An onsite oxygen generating system using PSA technology, which supplies high-pressure oxygen throughout a facility via a central pipeline system, or via cylinders refilled by the plant. | Bulk liquid oxygen generated off-site and stored in a large tank and supplied throughout a health facility pipeline system. Tank requires refilling by liquid oxygen supplier. |
| Clinical application and/or use case | Can be used for all oxygen needs, including high-pressure supply and in facilities where power supply is intermittent or unreliable. Also used for ambulatory service or patient transport. Used as a backup for other systems. | Used to deliver oxygen at the bedside or within close proximity to patient areas. A single concentrator can service several beds with the use of a flowmeter stand to split output flow. | Can be used for all oxygen needs, including high-pressure supply. | Can be used for all oxygen needs, including high- pressure supply and in facilities where power supply is intermittent or unreliable. |
| Distribution mechanism | Connected to manifold of central/sub-central pipeline distribution system, or directly connected to patient with flowmeter and tubing. | Direct to patient with tubing or through a flowmeter stand. | Central/ sub-central pipeline distribution system, or can be used to refill cylinders that can be connected to manifold systems in the facility. | Central pipeline distribution system. |
| Electricity requirement | No | Yes | Yes | No |
| Maintenance requirement | Limited maintenance required by trained technicians. | Moderate maintenance required by trained technicians, who could be in-house. | Significant maintenance of system and piping required by highly trained technicians and engineers, can be provided as part of contract. | Significant maintenance of system and piping required by highly trained technicians and engineers, can be provided as part of contract. |
| User care | Moderate; regular checks of fittings and connections, regular checks of oxygen levels, cleaning exterior. | Moderate; cleaning of filters and device exterior. | Minimal; at terminal unit only. | Minimal; at terminal unit only. |
| Merits | – No power source. | – Continuous oxygen supply (if power available) at low running cost.<br>– Output flow can be split among multiple patients. | – Can be cost-effective for large facilities.<br>– Continuous oxygen supply. | – 99% oxygen obtained.<br>– High oxygen output for small space requirement. |
| Drawbacks | – Requires transport/ supply chain.<br>– Exhaustible supply.<br>– Highly reliant upon supplier.<br>– Risk of gas leakage.<br>– Risk of unwanted relocation. | – Low pressure output, usually not suitable for CPAP or ventilators.<br>– Requires uninterrupted power.<br>– Requires backup cylinder supply.<br>– Requires maintenance. | – High capital investments.<br>– Requires uninterrupted power. Needs adequate infrastructure.<br>– High maintenance for piping.<br>– Requires backup cylinder supply.<br>– Risk of gas leakage from piping system. | – Requires transport/ supply chain.<br>– Exhaustible supply.<br>– High maintenance for piping.<br>– Needs adequate infrastructure.<br>– Requires backup cylinder supply.<br>– Risk of gas leakage from piping system. |

## Oxygen surge plan

The ability to boost capacity to deliver oxygen therapy is the cornerstone of the overall approach to managing the COVID-19 outbreak and it has implications for the functioning of the entire system. The principles, set out here, of building surge capacity should be integrated into a health system's readiness and response capacities for all functions – either centrally, or at facility level.[8]

Oxygen supply and delivery systems are limited in many resource-limited settings. Each supply option needs to be examined with attention to access and distribution. Liquid oxygen will accommodate great volumes; however, health systems must leverage existing facilities' operations where they exist (geographically). More localized (e.g. in-facility) PSA plants are an option, but if not already in-situ, there will be some lead-time for delivery and operationalization. With respect to bedside oxygen concentrators, these are a very tangible plug-and-play options, that are limited in terms of sheer volume that could be delivered.

Once the oxygen need has been estimated with the COVID-19 ESFT[7] and oxygen survey assessment have been completed, perform a rapid gap analysis. This means taking the estimated forecasted need and comparing this to existing oxygen supply availability. This method provides a way to identify a feasible, contextually appropriate oxygen surge strategy based on structures, capabilities, practices and technologies. Decision makers can then rapidly recommend next-steps, including product needs, that will help to frame and implement the surge plan.

The following describes different approaches, with key factors to be considered to help determine feasible and efficient solutions and expected impact. The oxygen surge plan should be integrated into the overall COVID-19 response plan. For instance, if a new COVID-19 treatment centre is planned, the location and layout of the construction site will be a key factor for the oxygen surge planning.

**Liquid oxygen**

1. Assess availability, locally and in neighbouring countries, considering importation and movements constraints.
2. Evaluate transport capacity, bulk tank availability, distances, road condition and security. NOTE: bulk tanks are supplier-specific. Smaller/ portable tanks are often readily available, but larger tanks for permanent installation must be ordered.
3. If bulk tanks are already in-situ at health facilities, assess storage capacity.
4. Evaluate capacity to vaporize liquid oxygen into gas, either with existing installations or as component on smaller/portable tanks.
5. Determine if gas can be piped directly to patients through an existing piping system or if it needs to be compressed into gas cylinders.
6. Ensure sufficient ancillary accessories, including valves and pressure and flow regulators.
7. Ensure sufficient medical devices for delivery oxygen therapy. Refer to WHO Essential resource planning.
8. Ensure sufficient resources (both HR and equipment) to carry out necessary maintenance.

**Need quantification units:** liquid oxygen for medical use is expressed in $m^3$ of liquid. Once the total flows are known, in L/min of gas, total volume of liquid can be determined over a specified period of time, using the following factor:

1 L of liquid oxygen = 861 L oxygen gas

$1\ m^3 = 1{,}000\ L$

**PSA Plants**

1. Assess if any plants are available and functioning locally, or if plants elsewhere nationally have any extra capacity.
2. PSA plants are designed to function 24 hours/day.

**If available:**

3. Maximize production capacity of PSA.
4. Augment transport capacity through excess supply via cylinders, when available. If not available, order appropriate quantity and type of cylinders.
5. Assess potential for installation of piping systems to optimize in-facility distribution (not a short-term solution).

**If not available,** assess local and international market for purchasing a plant according to specific context and needs. Details to consider:

a. Production quantity in m3/hr, booster pump for cylinder filling.
b. Delivery time.
c. Facility installation needs: housing for plant and filling ramp/manifold, cylinder3-phase electrical supply and reliability, cylinder storage.
d. Training and maintenance.

6. Ensure sufficient medical devices for delivery of oxygen therapy. Refer to the WHO website: Essential resource planning.
7. Ensure sufficient resources (both HR and equipment) to carry out necessary maintenance.

**Need quantification units:** PSA plants are sized according to output capacity, in $m^3/hr$, where $m^3$ is in oxygen gas. Once the total flows are known, in L/min of gas, total hourly flows can be calculated using the following conversion factors:

L/min * 60 min/hr = L/hr

$L/hr * 1m^3/1000\ L = m^3/hr$

**Power essentials:**

PSA plants rely on consistent, quality power.
A rule-of-thumb requirement is that 1.22 kWh ±5% of power is needed per $m^3$ of total flow.

It is imperative that the plant be connected to a reliable power supply along with voltage stabilization to avoid any interruption.

These are indicative requirements. Always consider manufacturer's technical specification for a more detailed power requirement estimation.

**Bedside concentrators**

1. Increase bedside oxygen concentrators in the immediacy, if supply permits, as complementary approach while waiting for higher-flow solutions to be delivered, such as a PSA plant or liquid oxygen capacity.
2. Once a PSA plant has been installed and commissioned, bedside concentrators can be used to increase geographical flexibility as they can easily be reallocated to other health facilities.
3. Ensure sufficient medical devices for the delivery of oxygen therapy. Refer to the WHO website: Essential resource planning
4. Ensure sufficient human resources and equipment to carry out necessary maintenance.

**Power essentials:**

Oxygen concentrators rely on consistent, quality power. A 10 L/min oxygen concentrator will require between 350-600 W, which is NOT variable with flows.

It is imperative that the plant be connected to a reliable power supply along with voltage stabilization to avoid any interruption.

All operations should be monitored and accompanied by diligent planned preventative maintenance activities. The use of logbooks is essential for documenting production and consumption. This will allow for optimization of resources and, where possible, further allocation of additional resources to support near-by health facilities with their COVID-19 response should there be any excess oxygen supply.

## References

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## Acknowledgements

This interim guidance draws extensively WHO-UNICEF technical specifications and guidance for oxygen therapy devices.[1] WHO thanks those who were involved in developing the report.

WHO continues to monitor the situation closely for any changes that may affect this interim guidance. Should any factors change, WHO will issue a further update. Otherwise, this interim guidance document will expire 2 years after the date of publication.

WHO reference number: WHO/2019-nCoV/Oxygen_sources/2020.1