Technical oxygen group

Medical Surge Capacity

Recommendations for the adoption and procurement of pressure swing adsorption oxygen generator plants

PAHO
Pan American Health Organization
World Health Organization
REGIONAL OFFICE FOR THE Americas

Version April 2022

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Abbreviations and acronyms

COPD	chronic obstructive pulmonary disease
PLC	programmable logic controller
PSA	pressure swing adsorption
PSI	pound-force per square inch

Introduction

Health technology assessment is becoming increasingly common, and necessary, for developing countries. It is relevant to say that this practice often reveals hidden costs and allows health facilities to incorporate elements that increase the service life of adopted technologies, such as oxygen generator plants. Although these are apparently complex pieces of equipment, the evaluation process before procurement marks the actual start of incorporation of any health technology, and helps ensure that a rational, sustainable, and safe system will be implemented.

Liquid oxygen can be advantageous as the main source of supplemental oxygen in large health centers, yet this technology is not applicable in all settings. This is mostly due to issues such as a lack of suppliers, price variability as a function of demand, and logistical difficulties (lack of viable routes or very long journeys). In these settings, oxygen generator plants can be more advantageous, provided that all relevant aspects – both technical and administrative/financial – are properly evaluated before their implementation.

It bears stressing that a complete oxygen supply solution for a health facility is composed of three types of supplies: the primary (main) supply; a secondary supply, of equal capacity to the primary one, to ensure continuity of operations in case the primary supply fails; and an emergency supply, which must take over in case both the primary and secondary fail.

This publication aims to give an overview to professionals who wish to begin the process of assessment, procurement, and adoption of pressure swing adsorption (PSA) oxygen generator plants by providing comparative data on technical, administrative, and financial aspects. It is divided into the following two sections: the first one describes PSA technology and the advantages and disadvantages of its adoption in the medical facility; the second one focuses on the key aspects necessary for professionals to carry out a more efficient procurement procedure.

1. The choice for pressure swing adsorption oxygen plants

The COVID-19 pandemic has often caused shortages of supplemental oxygen in many health facilities. One solution to address this gap is to acquire oxygen generator plants, preferably with PSA technology, through national or international procurement procedures.

Many health facilities and systems have been or are being forced to replace their usual means of supply (liquid oxygen or oxygen cylinders) with PSA plants to cover the primary, secondary, and emergency components of their supply matrix. However, having no experience with this new technology in their system, they have experienced (or could experience) issues during the procurement processes – e.g., buying equipment that may not meet the oxygen supply needs of the facility, not only in quantity and quality, but also in terms of technical, administrative, or financial aspects.

This first section explains how a PSA oxygen generator plant works, describing its components and its main operating challenges, and briefly describing its advantages and disadvantages compared to other oxygen supply methods. It is intended to help decision-makers better understand how this technology works and make an informed decision in order to select it, if it is deemed the best solution at the time to address a potential supply deficit.

Operating principles of a pressure swing adsorption oxygen plant

A PSA oxygen plant relies on a physicochemical process called adsorption (figure 1) to separate oxygen (O_2) from nitrogen (N_2) present in ambient air, which is the key input processed by the plant. When air (21% O_2 + 78% N_2 + 0.93% argon) comes into contact with the adsorbent material (zeolite), nitrogen adheres to the surface of this material, while oxygen passes through freely. The zeolite works as a "molecular sieve" for nitrogen molecules until it is completely saturated and loses its ability to separate oxygen from the air. For this reason, PSA plants employ two columns of adsorbent material, so that while one is producing oxygen, the second is preparing for the next cycle. This gives such plants virtually uninterrupted output capacity.

Figure 1. Differences between adsorption and absorption processes.

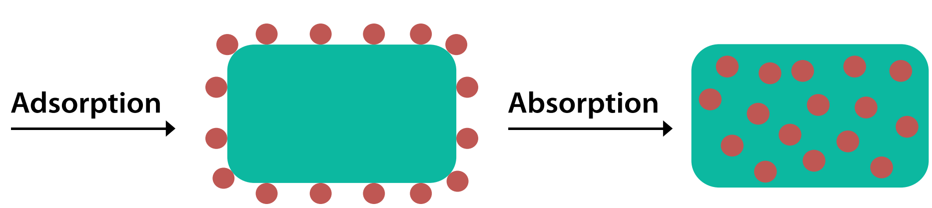
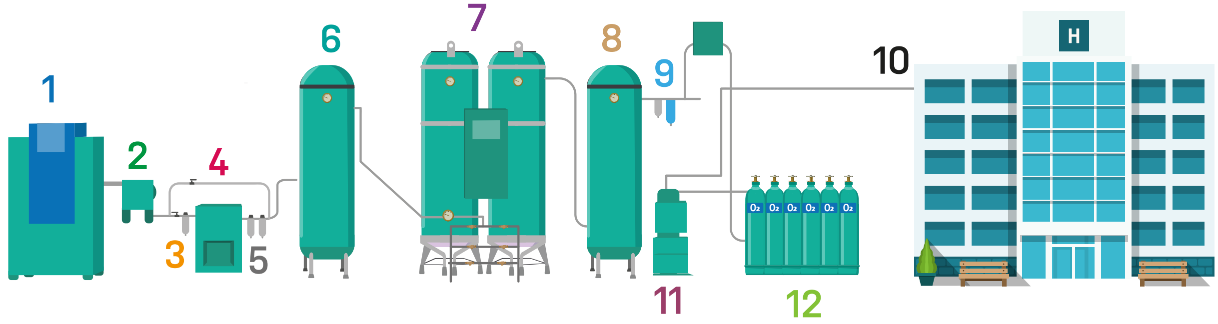


Figure 2 shows the key parts of the operating process of a PSA oxygen plant, which will be described in detail below.

Figure 2. Schematic diagram of the installation and its main components



- 1 - Air compressor
- 2 - Air cooler (heat exchanger)
- 3 - Pre-filter
- 4 - Air dryer
- 5 - Post-filter
- 6 - Compressed air storage tank
- 7 - PSA columns
- 8 - Oxygen storage tank
- 9 - Oxygen filter
- 10 - Hospital
- 11 - Booster compressor
- 12 - Cylinder manifold

PSA: pressure swing adsorption.

Ambient air

Ambient air (figure 3) and electricity are the main inputs for the production of oxygen by a PSA plant. As oxygen is taken from the ambient air, a compressor is required to ensure that the necessary amount of air is obtained and the optimum pressure for gas production is achieved.

The location of the PSA plant and the air quality of the surroundings will determine the level of treatment required. Filters are commonly used to ensure air purity and the removal of water and oil particles, odors, and contaminants such as carbon dioxide (CO_2) and carbon monoxide (CO).

Figure 3: Ambient air.

Compressor

The compressor (figure 4) captures air at room temperature and nominal pressure and introduces it into the system at a higher pressure. Although all components of the PSA plant are essential for the production of high-quality oxygen, the compressor requires the most upkeep throughout the life cycle of the facility. The compressor contains moving parts and is subject to wear and tear. Thus, a good maintenance plan should be considered when planning to purchase a PSA oxygen plant. On the other hand, as air compressors are widely used worldwide, the maintenance plan can usually be developed and implemented by the engineering team of the health facility.

The compressor is the component that consumes the most electricity in the whole PSA process. It will essentially define the plant's production costs. As compressors draw a great amount of power, it is essential to check whether the facility's electrical system is able to withstand this new load. Otherwise, the space and cost needed to increase this capacity must be taken into account. The higher the power rating of the compressor in kW (kilowatts), the more electricity it will consume.

Figure 4. Air compressor for medical oxygen production

Note: Left (yellow) shows an example of an air compressor used in medical oxygen generation. These compressors are usually cubic shaped and their dimensions are variable.

Air purification

Air purification makes the ambient air physically and chemically fit for the nitrogen adsorption process. It is an extremely important step in the process, as it not only ensures a higher-purity oxygen output but also extends the service life of the adsorbent material.

In addition to CO_2 and CO removal, the moisture content of the air to be compressed and treated should be reduced to the lowest possible percentage. This step relies on the filter disposition (figure 5) and the devices known as air dryers.

It bears noting that, when air is compressed, so is any water vapor it contains; therefore, all the water content in the air must be purged immediately after its compression.

Figure 5. Examples of air filtration systems

Note: They have filtering elements that need to be replaced periodically. Some of them have indicators to show exactly when the filter should be replaced.

In order to achieve this, a combination of technological resources available on the market can be used; it is relevant to take into account the moisture content (relative humidity) of the air where the plant will be installed. In areas where relative humidity is high, air drying is essential, but also more complex. Conversely, in regions where the air is naturally drier, the system may be less complex. Air drying usually comprises two steps:

The first step aims to remove the bulk of the water present in the air after compression. This can be done with condensers (figure 6) or an air cooler (heat exchanger), which use ambient air to cool the compressed air and induce condensation of the water contained therein.

Figure 6. Moisture condenser

Note: Moisture condenser placed before the actual air drying unit. This device may contain a pre-filter, which cools the air as it exits the compressor and carries out a preliminary drying stage.

The second step of the drying process aims to remove any water vapor that may still be present in the air. For this purpose, manufacturers can use two methods: refrigeration drying (figure 7) and adsorption drying. Some countries have laws or regulations that mandate the use of one system or the other.

Refrigeration drying employs a refrigerator cycle, similar to that of household refrigerators, to cool the air and condense residual moisture.

Figure 7. Air dryer

Note: In yellow, an example of an air dryer that extracts moisture from the air to make it suitable for oxygen production.

Adsorption drying (figure 8) employs the same physicochemical principle used in PSA plants. However, in this case it is water, not nitrogen, that is removed from the air. Adsorption drying allows more water to be removed than with refrigeration drying, although the decision on the best technology to use should always be based on the characteristics of ambient air at the installation site.

Figure 8. Adsorption air dryer

Note: In blue, an example of an adsorption air dryer; it extracts moisture from the air to make it suitable for oxygen production.

Compressed air storage

Once compressed, filtered and dried, the air is considered treated, and can then be stored in a tank or vessel (figure 9) in preparation for the nitrogen adsorption process from which oxygen will be obtained. Manufacturers may employ more than one reservoir in the process, e.g., one or two before the air treatment step and one or two after the treatment. Therefore, before making a procurement decision, it is important to make sure that if you are considering buying more than one plant, these use the same technology and share the same components, as well as having the same number of storage tanks.

Figure 9. Compressed air storage tank

Note: To the left, an example of a compressed air storage tank. Pressure swing adsorption allows the use of one or more such reservoirs.

Columns 1 and 2 and programmable logic controllers

Oxygen concentrators were introduced in the late 1960s, and have since undergone iterative improvement. One of the most interesting features is the ability to control how the plant switches between columns 1 and 2. Historically, this was controlled by electromechanical means, which made it difficult to monitor and evaluate plant performance. This is now done by programmable logic controllers (PLCs), which increase the accuracy of the operation and its adjustability.

The columns, valves, and the PLC (figure 10) that control their output are the components of a PSA plant generating oxygen. The columns are used to store the adsorbent material (zeolite), and are sized according to the desired oxygen output volume. The controller performs a series of functions, such as measuring flows, pressures, oxygen concentrations, and the operating times of each phase of the production cycle.

Figure 10. Adsorption columns

Note: Example of adsorption columns of the pressure swing adsorption plant, their valves, and the programmable logic controller.

Oxygen storage

Once the ambient air is separated, the oxygen is stored in another reservoir (figure 11) and it is then ready for use in one of the following ways: piped directly into the existing oxygen distribution network of the health facility; or pumped into cylinders for backup storage or for onward distribution to places where they are needed, such as patients receiving home health care or during transport situations.

Figure 11. Tanks for oxygen storage produced by adsorption

Note: In the middle, two stainless steel oxygen tanks to store oxygen produced by adsorption.

Distribution network

The distribution network is the set of pipes (figure 12) as well as safety and control elements that allow oxygen to be delivered from its source (generator or supply) to the point of use in patient care areas of the hospital.

Figure 12. Medical gas supply system

Note: Example of a medical gas supply pipe. The color green denotes that it supplies medical-grade oxygen, and the black arrow points in the direction of the gas flow.

The facility and the type of medical care it provides will determine the size or output capacity of the PSA plant. The capacity of the plant should preferably take into account the number of oxygen outlets (such as those shown in Figure 13) present in the facility. Each outlet, as well as the area where the plant will be installed, should be assigned a required oxygen flow. The sum of these represents the total capacity needed. Some countries may have their own recommendations for sizing oxygen plant capacity.

Figure 13. Oxygen outlets

Note: Example of gaseous oxygen outlets as denoted by the color green. These may be gang-mounted on panels or boxes or as isolated outlets.

Table 1 details an example of how to size the amount of oxygen needed for COVID-19 patients.

Table 1. Recommended oxygen consumption for treatment of patients with COVID-19

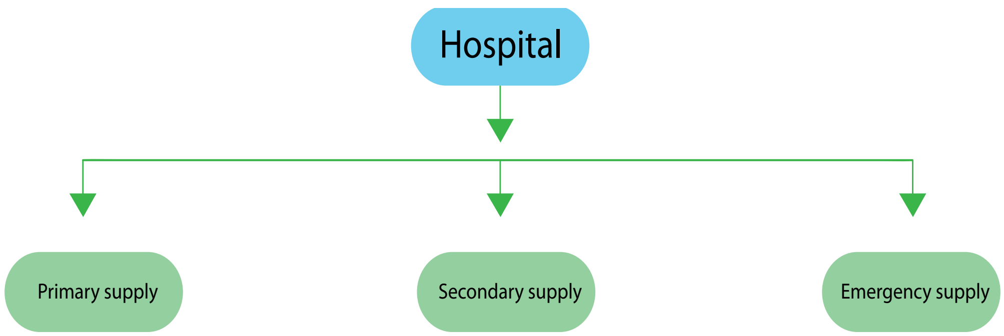
Hypothetical 100-bed COVID-19 treatment facility				
Severity of illness	**Avg. oxygen flow rate**		**Solution Sizes**	
	Per patient	**Total**	**PSA plant**	**Bulk liquid**
Severe 75 patients	10 L/min	75 × 10 × 60 = 45.000 L	= 45 m³/h	= 1.25 m³/h
Critical 25 patients	30 L/min	25 × 30 × 60 = 45.000 L	= 45 m³/h	= 1.25 m³/h
		90.000 L/h	= 90 m³/h	= 2.5 m³/h

PSA: pressure swing adsorption.

When sizing the distribution network, the facility should consider the potential for future expansion or addition of an oxygen supply to be used in filling cylinders, in case there is a need to transport the oxygen produced at the plant to other sites in the area.

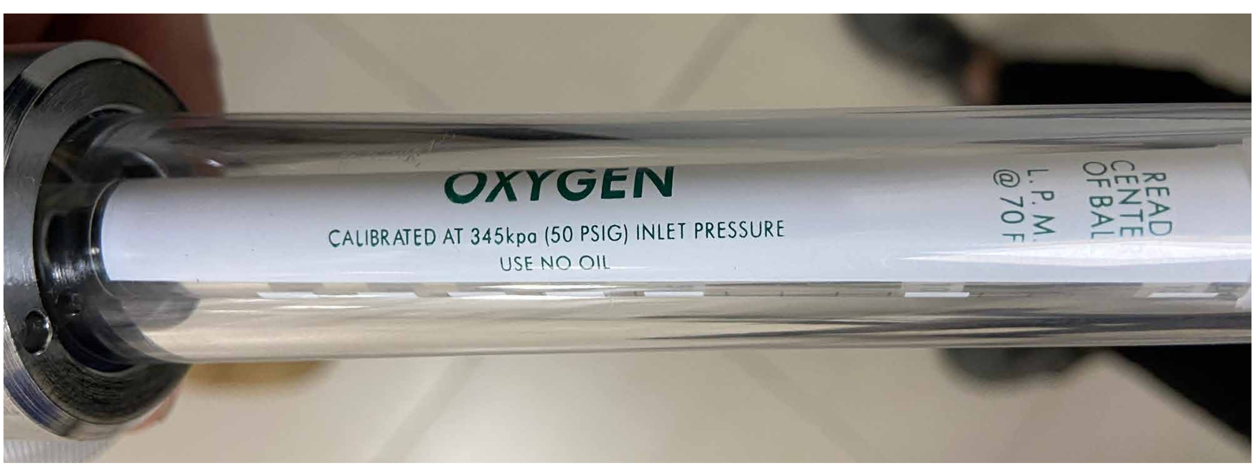
The facility should also consider other aspects and take advantage of this opportunity to adjust its oxygen supply system (figure 14). They may choose to purchase two plants, i.e., one for the primary supply and the other for secondary supply. An inventory should also be taken of all oxygen therapy equipment and delivery devices, and used to check whether planned capacity will be sufficient or if further adjustment is necessary. It is also important to consider that both the network or pipeline pressure and the internal pressure of the cylinders can be adjusted at this time.

Figure 14. Supplies



It is relevant to note that the pressure of the oxygen distribution network should be set to 50 pounds-force per square inch (psi) or thereabouts (345 kPa; 3.45 bar; 3.52 kgf/cm²), this avoids the need for a pressure reducing valve and ensures a more precise oxygen delivery at the flowmeters connected to the network (figure 15).

Figure 15. Flowmeter



Note: Oxygen flowmeter. The markings state that its calibrated inlet pressure is 50 pounds-force per square inch.

Booster compressor

In order to store a large amount of oxygen in a small-volume container (such as a cylinder), one must first increase its pressure. Therefore, PSA plants may include a cylinder filling ramp, or manifold, attached to one or more booster compressors. These compressors (figure 16) are different from the air compressors previously mentioned in this document in that they generally operate at lower flow rates but reach extremely high pressures, on the order of 2200 psi (15,168 kPa; 151.7 bar; 154 kgf/cm²); If the facility uses this system, the PSA plant must offer surplus output capacity. To achieve such high pressure levels, booster compressors rely on at least two compression stages.

Figure 16. Booster compressor for cylinder filling.

Cylinders

Cylinders store oxygen in a gaseous state. If a facility chooses to acquire an oxygen compressor to fill its own cylinders, it must also purchase or own additional cylinders (figure 17). The number of cylinders will depend on how long it takes for the compressor to fill each cylinder, the number of consumers who need oxygen, and the number of patients seen by the facility.

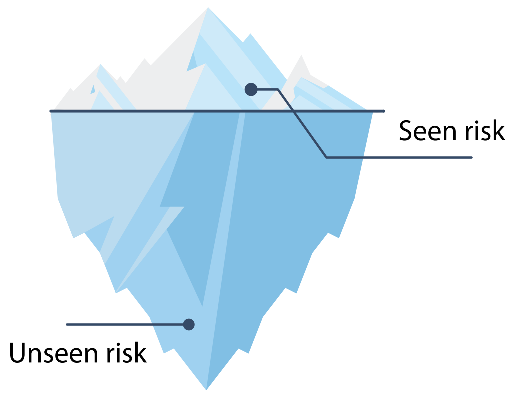
Figure 17. Cylinder filling station

Note: Example of a cylinder filling station. The number of cylinders depends on the output capacity of the pressure swing adsorption plant.

Challenges of pressure swing adsorption technology

Although all health technologies have positive aspects, it is important to know the hidden risks they also carry (figure 18). The following section describes several aspects that should be taken into account before choosing to adopt PSA oxygen plant technology. Planning for the incorporation of PSA plants should cover all the positive aspects, while still maintaining awareness and understanding of potential problems and preparing for them.

Figure 18. Seen risk and unseen risk



Electrical supply

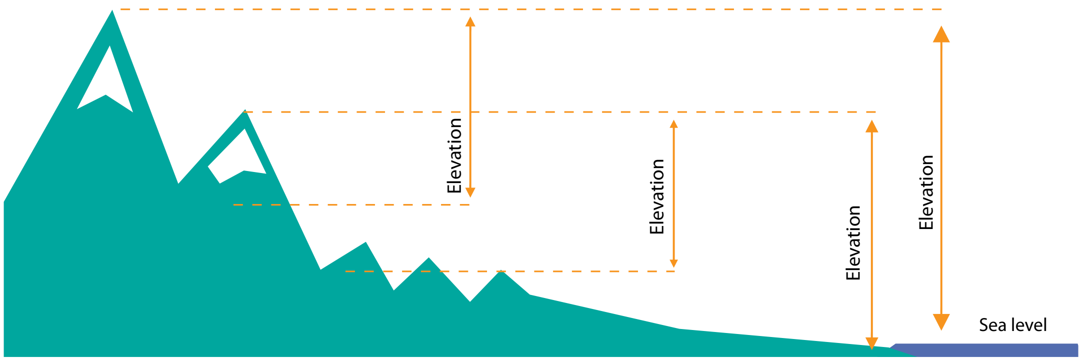
As discussed above, electrical power is an essential input for the operation of a PSA plant. Given the possibility of a power shortage, the establishment must provide for a generator (figure 19) and check whether the generator can supply sufficient power to withstand this new electrical load. If there is no generator or if the existing generator lacks sufficient capacity, the facility should consider procuring a new one to ensure uninterrupted operation of the oxygen plant.

Figure 19. Emergency power generator

Altitude of the health facility

Just as the oxygen concentration in the air is lower at high altitudes than at sea level, the productivity of a PSA plant will be compromised by placement at higher altitudes (figure 20). In these cases, particular care in sizing the output capacity of the oxygen plant is recommended.

Figure 20. Elevation above mean sea level



Concentration of produced oxygen

This type of equipment is somewhat limited in terms of the concentration of produced oxygen. It cannot produce high-purity oxygen (99.5%), thus its output may not be useful for some types of patients affected by more serious conditions. In these cases, the facility should pursue alternatives to obtain and deliver higher-purity oxygen.

The concentration of oxygen produced by the plant may fall below the estimated minimum value due to equipment failures or lack of maintenance. PSA plants should include an audible and visible alarm system for low oxygen concentration.

Depending on the manufacturer, this alarm system may contain various triggers and may be designed to alert the staff if a malfunction occurs.

In some countries, oxygen produced by PSA plants cannot be used for closed-circuit inhalational anesthesia. Therefore, it is advisable that anesthesiologists be included in the planning and implementation process.

Training of technical staff and health care providers

One of the most significant issues of a PSA plant is not related to the plant itself, but to the way oxygen production is managed. It is of the utmost importance that the facility understands that it has ceased to be a consumer and is now a manufacturer of medical oxygen. Therefore, a thorough training program must be planned, implemented, and presented to all personnel in the facility.

Because oxygen is considered a medicine, it is critical that pharmacy staff be trained in risk management methods that can be employed to ensure the quality of production.

Since the oxygen produced by PSA plants has lower purity than usual medical oxygen, all providers handling this gas should be clearly informed that its concentration does not reach 99.5%. One way to do this is to identify the concentration of gas offered at each terminal unit, e.g., with labels clearly marked "O_2 93%". Another way is to offer portable concentration meters (figure 21) for providers administering oxygen therapy.

Figure 21. Oxygen concentration meter

Plant operation is usually the responsibility of clinical engineering personnel at the health facility, who need to be thoroughly trained on how to operate the plant and how to perform preventive and corrective maintenance of all its component equipment. These activities help increase the consistency of the quality control plan to be implemented by the health facility.

Depending on conditions such as the distance to large cities and obstacles to outside access, the procurement process should include ensuring manufacturer-provided training of hospital technical staff.

In addition, given the potential legal implications of mismanagement of a PSA plant, training should include testing for evidence of learning and subsequent certification of participants. Assessments of evidence of learning should be recorded, and should be carried out regardless of the complexity of the training program. It is advisable that the level of complexity of maintenance to be carried out by the facility be defined in advance. Maintenance can be divided into four levels of complexity, as shown in table 2.

Table 2. Levels of complexity for maintenance of pressure swing adsorption oxygen plants

Level of complexity	Type of maintenance
First level (least complex)	Operator maintenance
Second level	Maintenance involving measurement and recording processes
Third level	Maintenance involving calibration, adjustment, and configuration of equipment
Fourth level (most complex)	Maintenance carried out by the manufacturer when justified

Factors affecting oxygen output and quality

Factors that can affect the output capacity of a PSA plant in relation to its nominal performance include the following:

- Purity and relative humidity of the ambient air
- Environmental pollution
- Altitude where the plant is installed
- Contamination of the adsorbent material (zeolite) with water vapor or oil particles
- Obstruction of the air inlet and outlet

- Failure to clean filters or change the filter element
- Lack of ventilation in the surroundings
- Lack of training support for staff involved in operations
- Lack of measurement instruments, such as industrial oxygen meters
- Lack of maintenance
- Malfunction of security systems, etc.

All of these factors need to be taken into account and analyzed during pre-procurement planning. In addition, possible solutions for each of these issues must be sought in advance, in order to increase the safety of the production process.

Safety: fire hazard

Oxygen is an extremely oxidizing gas and, in the presence of fuel, requires very little heat to burn materials such as fabric, paper, plastic, wood, and even some metals such as aluminum, which has a low melting point, and aluminum-containing alloys. A full assessment of fire hazards should thus be carried out during planning for installation of a PSA plant.

One way to reduce fire hazards is to refrain from using any combustible products within or near the plant. Flammable lubricants, fuels, disinfectants, etc., should be banned from all oxygen production and cylinder filling areas. This must be clearly displayed on signage placed in strategic areas throughout the facility.

The facility should bear in mind that risks are always present, even with conventional oxygen supply systems. Adopting a proactive attitude towards these long before the plant is installed or even acquired can reduce or eliminate the likelihood of accidents. In case of emergency PSA plant commissioning, this is particularly important.

Pros and cons of a pressure swing adsorption oxygen plants

Oxygen concentrator plants are used to produce oxygen gas in large quantities and at higher pressures than those offered by portable concentrators, which allows them to meet greater demand, such as those of small and medium-sized hospitals and other health facilities. Plant-generated oxygen is useful for patients with breathing difficulties, such as hypoxemia caused by COVID-19 or severe chronic hypoxemia, chronic obstructive pulmonary disease (COPD), or pulmonary edema, as well as patients requiring mechanical ventilation, drug nebulization, or inhalational anesthesia. Table 3 shows the key pros and cons of these plants compared to other sources of supply.

Table 3. Pros and cons of different oxygen supply sources

	Bulk liquid	Oxygen cylinders
Advantages of PSA over	• Continuous supply, not dependent on external suppliers • Long-term cost reduction • No freezing risks • Easy installation of cylinder filling systems • Owned by facility	• Continuous supply, with no need for cylinder replacement or dependence on external suppliers • Long-term cost reduction • Minimizes risks due to source manipulation
Disadvantages of PSA compared to	• Lower oxygen quality • Need for continuous maintenance of components • Higher short-term cost of acquisition • Owned by facility • Flow limited to plant output	• Need for continuous maintenance of components • Short-term cost • Requires a pipeline oxygen network, even for small facilities treating only non-serious/non-critical patients • Time to commissioning • Reduced mobility

PSA: pressure swing adsorption.

During the COVID-19 pandemic, oxygen generating plants have proven to be very useful to ensure oxygen supply and effective for this purpose in practically all settings and levels of demand, above all, by providing independence from external sources of supply and, consequently, by making medical oxygen – an essential medicine for the treatment and care of countless patients worldwide, and that which has become particularly critical in the response to the ongoing COVID-19 pandemic – more accessible to the population.

This guide does not recommend the use of one supply source over another; all are valid. However, the efficiency of any supply will depend on factors associated with the situation at hand.

2. Procurement of a pressure swing adsorption oxygen plant

The procurement of a PSA plant involves defining a set of technical, administrative, and economic or financial aspects that can be complex for first-time buyers. The procurement process is one of matching: the better the job one does of defining the technical, administrative, and financial specifications during the process, the closer the final product (in this case, a PSA oxygen plant) will match the purchaser's wants and needs.

This section of the document will list the main factors that must be taken into account when purchasing a PSA oxygen plant, including tips to reduce operating costs and a list of frequently asked questions that may arise during the process.

Finally, a comparative checklist for the procurement of PSA oxygen plants is given in the appendix. This should help prospective buyers ask suppliers the right questions to understand the product and ascertain whether their needs are met, whether any part of the offer should be amended or improved, or whether the PSA plant that is being offered should simply be ruled out as an option.

Relevant considerations when purchasing a pressure swing adsorption plant

When purchasing a PSA plant, certain points must be considered in order to obtain a sustainable, rational, and safe outcome, not only for patients but also for staff, visitors, the health network, and other stakeholders. These considerations will help determine which supplier is best placed to support the health facility in the procurement process - a critical aspect of any purchase, including that of a PSA plant.

To facilitate procurement planning, these points will be divided into three categories: technical, administrative, and economic/financial.

Technical considerations

These points will be relevant at the different stages of the process, from the comparison between products to the evaluation of maintenance requirements and of the obsolescence of each plant option offered. The following technical considerations should facilitate specific assessment by the facility which is planning to adopt a plant.

Table 4. Technical points to consider when purchasing a pressure swing adsorption oxygen plant

Point	Specifics
Training	Assess the quality of training offered by the supplier. A good training program can generally be evaluated in terms of its content and duration (hours). As maintenance requirements are not complex, at least at the hospital level, it is important that the training program include robust content on the principles of system operation and on any relevant particulars concerning the programming stages of the plant.
Technical documentation	A comprehensive set of technical documents will greatly facilitate plant maintenance over the years. The potential supplier should preferably provide the engineering department of the facility with all technical documentation concerning the plant and its components.
Tools and equipment	Upkeep of a PSA plant may require equipment, tools, and instruments that the facility will not own beforehand; these must be provided for during the planning stage.
Oxygen concentration	Oxygen concentration must be monitored continuously as a means of ensuring output quality. The use of redundancies in the oxygen concentration measurement process can be considered as a means of increasing reliability in this respect.
Gas flow	Whenever the required flow rate is greater than the output capacity of the plant, the oxygen concentration decreases. Therefore, plant sizing must take into account possible losses and potential surges in the need for oxygen.
Gas pressure	PSA plants do not normally operate at high pressures, but do have enough capacity to maintain 50 psi across the distribution network. Narrow pipelines can offer greater resistance to gas passage, so the network design must be assessed to check if the plant configuration is adequate or if an additional boost compressor will be needed to raise the pressure to values compatible with the downstream distribution network.
Power outages	Power outages may occur; indeed, blackouts are frequent in certain regions. Therefore, it is important to review the electrical system of the facility and check whether it is suitable.
Maintenance	The technical capabilities of the engineering team should be assessed to determine whether additional training needs to be provided by the manufacturer before the system is commissioned.

PSA: pressure swing adsorption. PSI: pound-force per square inch.

Administrative considerations

These aspects seek to assess and reduce the administrative risks involved in the oxygen production process. Most health facilities are oxygen buyers. When a facility commissions an oxygen plant, it becomes an oxygen producer. This entails a change in several administrative processes, which must be managed.

Table 5. Administrative points to consider when purchasing a pressure swing adsorption oxygen plant

Point	Specifics
Backup	A backup supply of oxygen must be determined and guaranteed by the supply system of the health facility. Aspects such as future expansion plans should be taken into account when planning to adopt PSA plant technology.
Emergency	Emergencies affect the dynamics of the entire facility. These can include major accidents in the vicinity of the facility leading to an unexpected surge in hospital occupancy, power outages, fires, etc. All existing sources of risk must be taken into account, as well as mechanisms of action for the development of technical measures to be approved by facility management.
Quality	Quality is a key factor; the whole production process must be built with this goal in mind. Definition of production batches, performance measurements, oxygen concentration measurements, and an analysis of maintenance history can all be defined or performed in advance prior to purchase to improve and meet current quality requirements for medical oxygen.
Safety	In addition to safety concerning risks to personnel and users, the administrative risks of any breakdown in the production process must be taken into account. Therefore, it is valid for the facility to consider the possibility of taking out insurance against the risks associated with oxygen production activities.

Economic/financial considerations

Assessment of operating costs can take several scenarios into account, considering that the optimal situation (in addition to health outcomes) is to be able to derive economic and financial gains from the adoption of PSA technology, obtained through proper planning of the procurement process.

Table 6. Economic/financial points to consider when purchasing a pressure swing adsorption oxygen plant

Point	Specifics
Price of oxygen on the market	Although the price of oxygen on the market is not always a reason for adopting PSA plant technology, it is an important aspect to take into account, because it helps evaluate the financial performance of the facility. If the cost of production is lower than the market price, this is a good indicator of economic feasibility of adoption.
Production cost	Accurate determination of production costs allows for a fairer comparison with market values and measurement of the facility's financial performance. It is important to note that certain costs are fixed, while others vary with the output of the plant. These costs include the actual cost of purchasing and commissioning the PSA plant, electrical power required (kW) and consumed (kWh), operating costs, preventive maintenance costs, corrective maintenance costs, calibration and adjustment costs, part costs, and plant performance evaluation costs, as well as the cost of cylinders, accessories, and distribution logistics.
Economic and financial performance	When determining production costs, the technique for calculating the break-even point of the operation can be applied beyond calculation of the cost of the life cycle of a PSA plant, which should be 10 years or longer
Maintenance contracts	Several types of maintenance contracts are available, depending on the particular aspects of each health facility; nevertheless, these can generally be divided into: labor only; labor and selected parts (to be defined); and full (or total) maintenance and repair agreements, which include parts, labor, and calibration. It is advisable that evaluations of plant performance be carried out by the facility's own personnel or by an independent contractor other than the supplier responsible for preventive and corrective maintenance.

PSA: pressure swing adsorption.

Cost containment in oxygen production

The best way to contain the costs of adopting PSA plant technology is to understand them in detail. Table 7 covers key costs, but is not an exhaustive list; other costs may be incurred, and can be included in each specific case.

Table 7. Key costs to consider when choosing to adopt PSA plant technology

Costs	Specifics
Electricity	Electricity generally implies two values: demand (measured in kW) and consumption (measured in kWh). The higher the nominal power of the PSA plant, the higher the cost of demand, which in this case is fixed, because it does not depend on how long the plant runs. On the other hand, the longer the plant runs, the higher its power consumption in kWh. The health facility should evaluate its electricity contract or consult the local utility company to determine these values.
Compressor maintenance	Compressor maintenance is of the utmost importance. Its cost can be determined by asking the bidder/supplier and taking into account the information mentioned above.
General maintenance	General maintenance essentially includes consumables such as filters, lubricating oil, leak repairs, replacement of oxygen cells, inspection, and recording of activities.
Oxygen cells	Different manufacturers can use different technologies to measure oxygen concentration. The sensors used to measure oxygen concentration can be permanent or consumable. If they are consumable, they should be replaced as often as recommended by the manufacturer; the periodicity of replacement will usually depend on the time of exposure to oxygen. The price of replacement sensors should be evaluated before purchase.
Replacement of adsorbent material	Although adsorbents do not have a nominal service life, they may need to be replaced. Again, it is advisable to determine the replacement cost of these materials before purchase. This activity usually includes both labor and material costs.

PSA: pressure swing adsorption, kW: Kilowatt; kWh: Kilowatt-hour.

Frequently asked questions and answers about purchasing a pressure swing adsorption oxygen plant

Assessment of health technologies, beyond their potential impact on health outcomes, often involves a detailed analysis of the costs involved in the adoption process.

The following frequently asked questions should help facilities gain a better understanding of PSA oxygen plants, especially if they are planning to adopt this technology in the medical field.

1. Which essential aspects should a health facility consider in relation to medical oxygen?

The facility should first conduct a self-assessment to identify the structure of its existing oxygen supply matrix. This matrix consists of three levels: primary, secondary, and emergency. If one source of supply malfunctions, the next source takes over; if this fails, the emergency backup is deployed. The facility should consider drawing up an emergency plan in case of oxygen shortages. An audible and visible alarm should be triggered whenever the supply switches from primary to secondary.

2. When should a health facility consider adopting a PSA plant?

Several reasons may lead a facility to implement a PSA oxygen plant, such as: lack of access to bulk liquid oxygen due to distance to large cities and logistical issues; absence of suppliers in the country or region where the facility is located; exponential increases in oxygen demand, especially during the COVID-19 pandemic; and the price of bulk liquid oxygen and oxygen gas cylinders.

3. If the facility is eligible to adopt a PSA plant, which are the key steps it should plan for?

The facility must devise a plan which, in brief, includes the following steps:

- Demand sizing
- Request for information from suppliers on the market
- Comparison between bids/offers made
- Comparison between proposals offered by suppliers on the market
- Site preparation

- Construction work
- Delivery of the plant
- Installation and training of technical personnel
- System commissioning
- Qualifications
- Use
- Maintenance and quality control

4. How should a PSA plant be sized?

Some countries define a minimum oxygen flow required at each terminal unit (outlet) and area of use, allowing engineers to calculate the likely maximum consumption of the health facility as a whole. Another method that can be employed is averaging effective consumption, i.e., calculating the arithmetic mean volume of gas consumed in the last 12 months. Management should take into account the possibility of increasing the number of terminal units in the future.

5. Which questions should the health facility ask the manufacturer before purchasing a PSA plant? How can different proposals or bids be compared?

Several questions should be prepared and organized to ask suppliers in advance of a purchasing decision. These questions are of an economic, administrative, and technical nature. A list of these questions is given in the annex "Comparative checklist for PSA plant procurement", developed by the Oxygen Technical Group of the Pan American Health Organization, which contains material to facilitate comparisons both of technical and administrative aspects and of financial ones as proposed by prospective suppliers. As many of the answers are of a quantitative nature, comparison between answers is objective and easily interpreted.

6. How should the health facility prepare a budget request for acquisition of a PSA plant?

Once the facility has analyzed and compared market offers, it should identify how and where to adjust the information it has requested. Once an offer has been made and the set of information obtained allows identification of prospective suppliers, a purchase order can be prepared, including any desired adjustments that can be better defined during the negotiation process.

7. **Once the potential supplier of the PSA plant has been chosen, which aspects should be brought to the negotiating table?**

All points that remained unclear in the request for information should be brought to the negotiating table. Issues related to the price of equipment, parts, spares and replacements, and maintenance and calibration agreements are often analyzed and negotiated with the prospective supplier of a PSA plant, as well as issues concerning: technical and operational training; access to technical documents and technical information; warranty terms and extended warranty, etc.

8. **Once the supplier has been chosen, how should the future site of the PSA plant be prepared?**

Installation of a PSA plant is not a complex procedure. Depending on the selected output capacity, a larger or smaller area may be required. Compact plants are also feasible; however, the main point to consider is that, once the plant is commissioned, the facility will become an oxygen manufacturer and, therefore, both technical and administrative infrastructure must be provided. The most common areas to be provided for are:

- Plant installation area
- Cylinder filling station
- Administrative/office area
- Cylinder loading dock (if the plant will perform cylinder filling)

9. **What care is required when taking delivery of the plant and its components?**

A PSA plant consists of the following main parts: an air compressor, an air dryer, air and oxygen storage tanks, the oxygen generator plant itself, filter components and elements, a power supply panel, and the programmable logic controller. Therefore, the facility must provide an area for this equipment to be stored as soon as it is offloaded. The receipt of tax documents and invoices is equally important, and the supplier can be notified in advance (at the time of purchase) of which information should be present in these documents.

10. **What happens during plant assembly and installation? How will it affect operation of the health facility?**

The installation of a PSA plant involves installation of the components and electromechanical assembly. These assembly and installation procedures are not noisy and do not generate particulate matter, and are usually completed without any major issues. However, it is essential that the facility provide all assurances to the winning bidder that it has enough electrical capacity to power the plant, which must operate uninterruptedly around the clock once commissioned. Therefore, the facility should consider installing an emergency electric power generator if it does already have one; if one is in place, the facility must check if it can withstand the additional load that will be imposed by the new plant.

11. What kind of training should health facility staff receive before the PSA plant is commissioned?

Essentially, two types of training must be provided. The first is clinical training, which aims to educate health care staff on the differences between the oxygen produced by PSA plants and conventional 99.5% oxygen. The facility must ensure that all providers are aware of these differences. The second involves training of the facility's own technical staff on the upkeep and maintenance (corrective and preventive) of the plant, to ensure a service life of at least 10 years.

12. Which tests should be done at a PSA plant before it can be considered fully operational?

Before a PSA plant is fully operational, it must undergo a process of qualification to ensure that it has been installed in accordance with all of the manufacturer's requirements. After first starting the system, operational qualification must be carried out to ensure that the equipment works exactly as it was designed to. This usually involves going through a checklist, which can be provided by the manufacturer itself. After this step, the plant must be tested under worst-case operating conditions, i.e., at maximum load. Under these conditions, the purity of the gas produced, as well as its pressure and flow, must comply with the specifications given by the manufacturer in their response to the request for information before the purchase.

13. Which aspects should the facility consider regarding maintenance of the PSA plant over the course of its service life?

The main requirements for proper operation of a PSA plant are ambient air, electricity, and preventive and corrective maintenance of its components. Although it has low preventive maintenance requirements, advanced technical training can and should be negotiated with the supplier during the procurement stages. The facility must ensure that its technical staff has access to the same knowledge and tools as a technician sent by the manufacturer. The technical knowledge obtained by the facility must be sufficient to ensure uninterrupted operation and stable performance of the entire system throughout its service life, which is estimated at a minimum of 10 years. Equally important is evaluation of the economic performance of the plant, which can be done by determining the unit cost of production in U.S. dollars per m^3 of oxygen output.

14. How should the facility prepare to conduct quality control of its oxygen output, with a view to the safety of personnel in general and patients in particular?

The purity of the medical oxygen produced by the plant can be easily measured with a portable oxygen concentration meter. Furthermore, the plant must ensure that oxygen flows at the maximum nominal pressure reported by the manufacturer. It is important that oxygen concentration meters be kept calibrated to ensure accurate measurements.

15. Can the oxygen produced be kept in cylinders for storage and distribution? If so, which safety measures should the facility take?

Once the gas is available, it can be compressed and stored in cylinders. It should be borne in mind that very high pressures are involved; thus, the potential for serious accidents exists. Nevertheless, if filling of cylinders is carried out in a controlled manner and in accordance with the manufacturer's guidelines, no major problems should occur. Local and national safety requirements must be checked and compliance ensured.

16. Under what conditions should the possibility of replacing, expanding, or decommissioning a PSA plant be considered?

The main reasons for decommissioning are maintenance costs, access to spare parts, and overall cost of production (fixed and variable). The facility should systematically evaluate production costs and compare them with those of bulk liquid and gaseous oxygen in the region where the facility is located. The facility may also need to expand its output capacity every time it goes through an expansion. These aspects must be considered from the very start, during the planning stage. The facility should consider upgrading its existing plant if costs and warranties are acceptable.

Supplier information form template

Having a form to collect product information from prospective suppliers can be convenient, not only to compare the advantages of one offer over another from a technical point of view, but also to help managers involved in the administrative decision-making process.

For this purpose, the annex given at the end of these recommendations contains a supplier information form template for comparison of the characteristics of the different PSA plants and of the options and after-sales services provided by manufacturers. The form covers a condensed set of information that facilitates analysis and helps reveal the hidden costs involved in the operation of a plant, both in terms of purchasing cost and regarding the total cost throughout its service life cycle.

Table 8 provides a set of guidelines for completing the supplier information request form given in the annex.

Table 8. Guidelines for completing the supplier information form template

Parameter	Specifics
Item	Because a PSA plant is made up of different parts, it is reasonable to consider each element separately for a more detailed evaluation.
Number	The numbered list is in sequence to facilitate communication between the health facility and the bidder. It is critical that the bidder not make any changes to the structure of the spreadsheet, as that would make it difficult to compare different proposals. Any additional information should preferably be written in the "Notes" field or below the last line mentioning the number to which the information refers.
Stakeholder	As there are a significant number of questions and different stakeholders, the health facility can use this column to identify individuals or sectors that will analyze the answer given by the bidder.
Answers	Bidders can enter their answers to the questions (or offers) in this column.
Options 1 and 2	The same manufacturer may offer two or more plant options; e.g., one with a refrigeration dryer and the other with an adsorption dryer. This will allow the facility to understand the underlying technology of each model and choose the option that best suits their needs.

PSA: pressure swing adsorption.

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Glossary

Bar	Metric unit of pressure measurement. One bar is equal to 0.99 standard atmospheres.
°C	Metric unit of temperature measurement.
CO	Carbon monoxide.
CO_2	Carbon dioxide.
FSC	*Free sales certificate.* A document certifying that certain goods, such as foods, cosmetics, biologics, or medical devices, are legally sold or distributed on the open market without any restrictions and are approved by the regulatory authorities of the country of origin.
HP	*Horsepower.* A unit of power measurement used in the imperial system. It is equivalent to 745.69 watts.
Hz	Hertz. An SI derived unit of frequency measurement, which expresses the number of cyclical events that occur in one second. It is used to describe cyclical events. In this document, it refers to the frequency of electrical power required by electromechanical equipment.
kgf/cm^2	Kilogram-force per square centimeter. A metric unit of pressure measurement. 1 kgf/cm^2 is equal to 0.97 standard atmospheres.
kPa	Kilopascal. An SI derived unit of pressure measurement. One kPa is equal to 0.01 standard atmospheres.
kW	Kilowatt. An SI derived unit of power measurement. One kW equals 1.34 hp.
kWh	Kilowatt-hour. A unit of energy measurement commonly used to express electrical energy consumption.
L	Liter.
L/min	Liter(s) per minute. In this document, a unit used to express the volume of oxygen in liters delivered by a given device per minute.

N_2	Nitrogen.
m	Meter. The metric unit of length measurement.
m^3	Cubic meter. The metric unit of volume measurement.
m^3/h	Cubic meters per hour. In this document, a unit used to express the volume of oxygen in liters delivered by a given device per minute.
mmHg	Millimeters of mercury. A unit of pressure measurement.
m^3 aire/m^3 O_2	Cubic meters of air per cubic meter of oxygen. Expresses how many cubic meters of air are needed to produce one cubic meter of oxygen.
O_2	Oxygen.
Pressure	The mathematical relationship between the value of a given force and the value of the area on which the force acts. The term pressure is used in this document as a scalar quantity that measures the action of one or more forces over a given area. For the purposes of this document, the following ratios have been adopted: 1 standard atmosphere (atm) = 101 325 Newton/m^2 = 1.01 bar = 1.03 kgf/cm^2 = 14.7 psi.
psi	Pound-force per square inch. An imperial unit of pressure measurement. 1 psi equals 0.7 standard atmospheres.
V	Volt. The SI derived unit of voltage (electric potential difference).

Annex. Comparative checklist for procurement of pressure swing adsorption plants

Request for information regarding:
Pressure swing adsorption (PSA) oxygen generator plant

Overview The required system must operate at ____ (volts), at a frequency of ____ (Hz), and at _____ (m) above mean sea level.

General conditions of supply (example). Option 1 should include information on a plant with refrigeration air drying, and Option 2, a plant with water vapor adsorption air drying.

Notes:

				Answers	Answers
ITEM	NUMBER	STAKEHOLDER	EQUIPMENT OFFERED	OPTION 1	OPTION 2
OVERVIEW	1.0		Name of device/equipment	PSA	PSA
	1.1		Device/equipment model (trade name)		
	1.2		Output capacity (m^3/h)		
	1.3		Nominal power (kW)		
	1.4		Minimum space required for installation (m^2)		
	1.5		Plant productivity: how many m^3 of air are needed to produce 1 m^3 of oxygen (m^3 air/m^3 O_2)		
	1.6		Brands		
	1.7		Name of manufacturer		
	1.8		Name of sales representative		
	1.9		Name of person in charge of technical support and customer service Address		
	1.10		Names of three clients that already use of the proposed technology, with contact information		
PATIENT SAFETY	2.0		All equipment must have a minimum service life of 10 years. This life span must be guaranteed by a letter from the manufacturer. This means that technical support for equipment and parts cannot cease to be provided during this period (yes/no)		
	2.1		The plant has a favorable free sales certificate (FSC) (yes/no)		
	2.2		The plant has FDA approval and EC certification (yes/no)		
	2.3		The components of the plant, including any pressure vessels, are in accordance with ISO, ASME, and ASTM standards (yes/no)		
	2.4		The plant provides means of verifying its output capacity in m^3/h or an equivalent unit of measurement (yes/no)		
	2.5		The plant meets the following risk classifications: Class C (GHTF Rule 11); FDA Class II (United States of America); Class IIA (EU and Australia); and Class II (Canada) (yes/no)		
	2.6		Year of first sale		
	2.7		Number already installed in the country where the plant will be housed (number)		

ITEM	NUMBER	STAKEHOLDER	EQUIPMENT OFFERED	OPTION 1	OPTION 2
MEDICAL APPLICATIONS	3.0		The plant will be used for the production of medical oxygen, and thus provides a minimum concentration equivalent to 93% ± 3 (yes/no)		
AIR COMPRESSOR	4.0		The compressor has its own PLC to control production and safety aspects (yes/no)		
	4.1		Maximum compressor output capacity (m^3/h)		
	4.2		Maximum allowable working pressure (bar)		
	4.3		Compressor working pressure (bar)		
	4.4		The compressor has a working pressure greater than 750 kPa (7.5 bar or 108 psi) (yes/no)		
	4.5		If the compressor has an optional "soft start" or variable speed drive function, please state the additional cost for the entire plant if this optional feature is selected by the purchasing facility. If this cost is already included in the proposal, write "zero" (USD)		
	4.6		The compressor must have a display showing the number of hours of operation (yes/no)		
	4.7		The compressor must have an audible and visual alarm for high operating temperature (yes/no)		
	4.8		The compressor must have an audible and visual alarm for high and low working pressure (yes/no)		
	4.9		The unit must have audible and visual alarms for power outage or system malfunction (yes/no)		
	4.10		If the compressor has the ability to offer remote fault monitoring, please state the additional cost for the entire plant (in USD) if this optional feature is selected by the purchasing facility.		
	4.11		If the compressor has internal capacity to purge/drain water condensed in the compression process, it must have an automatic purge system (yes/no)		
	4.12		If the compressor does not have an automatic purge system but one is offered as an optional feature, please state the additional cost for the entire plant (in USD) if this optional feature is selected by the purchasing facility.		
	4.13		Compressor power (hp)		
	4.14		The compressor must have a pre-filter (yes/no)		
	4.15		Air compressor weight (kg)		
	4.16		Dimensions (width × height × depth) (m)		
	4.17		Sound pressure level during normal operation (dBA)		
COMPRESSED AIR STORAGE TANK	5.0		Compressed air storage tank material is in accordance with ASME or AISI classification (yes/no)		
	5.1		Compressed air storage pressure after compression (bar)		
	5.2		Maximum working pressure of the compressed air storage tank (bar)		
	5.3		The air tank has an internal pressure gauge (yes/no)		

ITEM	NUMBER	STAKEHOLDER	EQUIPMENT OFFERED	OPTION 1	OPTION 2
COMPRESSED AIR STORAGE TANK	5.4		The air tank has a safety valve for relief of overpressure (yes/no)		
	5.5		The tank has a drain valve for drainage of water condensed in the compression process (yes/no)		
	5.6		If the air tank has an automatic purge system offered as an optional feature, please state the additional cost for the entire plant if this optional feature is selected by the purchasing facility. If this cost is already included in the proposal, write "zero" (USD)		
	5.7		Air tank weight (kg)		
	5.8		Dimensions (width × height × depth) (m)		
CONDENSATE SEPARATOR	6.0		If the tank does not have an automatic purge system before the air dryer pre-filter, it should have a compact condensate separator (yes/no).		
	6.1		Condensate separator work flow when operating at a pressure of 7 bar (m^3/h)		
	6.2		Condensate separator weight (kg)		
	6.3		Dimensions (width × height × depth) (m)		
AIR DRYER PRE-FILTER 1	7.0		The filter has a pressure gauge to indicate pressure drop and an indicator designed to show the exact timing of filter replacement (yes/no)		
	7.1		The filter has a pressure gauge to indicate pressure drop and an indicator designed to show the exact timing of filter replacement (yes/no)		
	7.2		The filter is able to retain particles up to 1 µm in size, including oil and water (yes/no)		
	7.3		The filter is able to deliver air at 21 °C with a residual oil content of 0.5 mg/m^3 (yes/no)		
	7.4		Flow rate allowed by the filter at 20 °C and 7 bar (m^3/h)		
	7.5		Filter working pressure (bar)		
	7.6		Filter maximum working pressure (bar)		
	7.7		Filter weight (kg)		

ITEM	NUMBER	STAKEHOLDER	EQUIPMENT OFFERED	OPTION 1	OPTION 2
AIR DRYER PRE-FILTER 2	8.0		The filter has a pressure gauge to indicate pressure drop and an indicator designed to show the exact timing of filter replacement (yes/no)		
	8.1		The filter is able to retain particles up to 0.01 μm in size, including aerosols, oil, and water (yes/no)		
	8.2		The filter is able to deliver air at 21 °C with a residual oil content of 0.01 mg/m^3 (yes/no)		
	8.3		Flow rate allowed by the filter at 20 °C and 7 bar (m^3/h)		
	8.4		Filter working pressure (bar)		
	8.5		Filter maximum working pressure (bar)		
	8.6		Filter weight (kg)		
	8.7		Dimensions (width × height × depth) (m)		
REFRIGERATED AIR DRYER	9.0		State whether the oxygen plant as offered will include a refrigeration-based drying system. If so, please answer this and the following questions (yes/no)		
	9.1		Refrigerated air dryer working pressure (bar)		
	9.2		Refrigerated air dryer maximum working pressure (bar)		
	9.3		Refrigerated air dryer minimum working pressure (bar)		
	9.4		Air dryer work flow at a pressure of 7 bar, an air temperature of 38 °C and a relative humidity of 100% (m^3/h)		
	9.5		The refrigerated air dryer is able to work with R134a refrigerant (yes/no)		
	9.6		The refrigerated air dryer is able to work with R22 refrigerant (yes/no)		
	9.7		The refrigerated air dryer is able to work with R407C refrigerant (yes/no)		
	9.8		Air dryer maximum working temperature (°C)		
	9.9		Refrigerated air dryer power (W)		
	9.10		Refrigerated air dryer mains voltage (yes/no)		
	9.11		Refrigerated air dryer mains frequency (Hz)		
	9.12		Dimensions (width × height × depth) (m)		
	9.13		The PLC of the refrigerated air dryer must display whether the equipment is energized (yes/no)		
	9.14		The PLC of the refrigerated air dryer must display whether the refrigerated compressor is on (yes/no)		

ITEM	NUMBER	STAKEHOLDER	EQUIPMENT OFFERED	OPTION 1	OPTION 2
REFRIGERATED AIR DRYER	9.15		The PLC of the refrigerated air dryer must display whether the fan/blower motor is on (yes/no)		
	9.16		The PLC of the refrigerated air dryer must display whether automatic condensate drainage is on (yes/no)		
	9.17		The PLC of the refrigerated air dryer must be able to trigger the high pressure and temperature alarms (yes/no)		
	9.18		The PLC of the refrigerated air dryer must display the ambient temperature (yes/no)		
	9.19		The PLC of the refrigerated air dryer must display the temperature of the compressed air at the dryer inlet (yes/no)		
	9.20		The PLC of the refrigerated air dryer must display the temperature of the compressed air at the dryer outlet (yes/no)		
	9.21		The PLC of the refrigerated air dryer must display the cooling temperature of the compressed air at the dryer outlet (yes/no)		
	9.22		The PLC of the refrigerated air dryer must display the evaporation temperature of the refrigerant fluid (yes/no)		
	9.23		Dryer weight (kg)		
ADSORPTION AIR DRYER	10.0		State whether the oxygen plant as offered will include an adsorption-based drying system. If so, please answer this and the following questions (yes/no)		
	10.1		Adsorption air dryer working pressure (bar)		
	10.2		Adsorption air dryer maximum working pressure (bar)		
	10.3		Adsorption air dryer minimum working pressure (bar)		
	10.4		Air dryer work flow at a pressure of 7 bar, an air temperature of 38 °C and a relative humidity of 100% (m^3/h)		
	10.5		Air dryer maximum working temperature (°C)		
	10.6		Air dryer minimum working temperature (°C)		
	10.7		Adsorption air dryer power (kW)		
	10.8		Adsorption air dryer mains voltage (yes/no)		
	10.9		Adsorption air dryer mains frequency (Hz)		

ITEM	NUMBER	STAKEHOLDER	EQUIPMENT OFFERED	OPTION 1	OPTION 2
ADSORPTION AIR DRYER	10.10		Dimensions (width × height × depth) (m)		
	10.11		The PLC of the adsorption air dryer must display whether the equipment is energized (yes/no)		
	10.12		The PLC of the adsorption air dryer must be able to trigger the high pressure and temperature alarms (yes/no)		
	10.13		The PLC of the adsorption air dryer must display the ambient temperature (yes/no)		
	10.14		The PLC of the adsorption air dryer must display the temperature of the compressed air at the dryer inlet (yes/no)		
	10.15		The PLC of the adsorption air dryer must display the temperature of the compressed air at the dryer outlet (yes/no)		
	10.16		Dryer weight (kg)		
CO_2 AND CO CATALYTIC CONVERTER	11.1		The plant must include a catalyst element capable of retaining both carbon monoxide (CO) and carbon dioxide (CO_2) (yes/no)		
	11.2		Flow rate allowed by the catalyst at 20 °C and 7 bar (m^3/h)		
	11.3		Catalytic converter working pressure (bar)		
	11.4		Catalytic converter maximum working pressure (bar)		
	11.5		Catalytic converter weight (kg)		
	11.6		Dimensions (width × height × depth) (m)		
ACTIVATED CARBON FILTER	12.0		The plant must include an activated carbon filter (yes/no)		
	12.1		The filter is able to deliver air at 21 °C with a residual oil content below 0.003 mg/m^3 (yes/no)		
	12.2		Flow rate allowed by the filter at 20 °C and 7 bar (m^3/h)		
	12.3		Filter working pressure (bar)		
	12.4		Filter maximum working pressure (bar)		
	12.5		Filter weight (kg)		
	12.6		Dimensions (width × height × depth) (m)		
PROGRAMMABLE LOGIC CONTROLLER / OXYGEN GENERATOR UNIT	13.0		The information presented on the unit display is available in English or in the local language (yes/no)		
	13.1		The equipment continuously displays the operating status of the unit, including any preventive or corrective maintenance needs (yes/no)		
	13.2		The unit has a display showing the number of hours of operation (yes/no)		
	13.3		The unit must have an audible and visual alarm for high operating temperature (yes/no)		
	13.4		The unit must have an audible and visual alarm for high and low working pressure (yes/no)		
	13.5		The unit must have an audible and visual alarm for outlet pressure < 300 kPa (3 bar or 44 psi) (yes/no)		

ITEM	NUMBER	STAKEHOLDER	EQUIPMENT OFFERED	OPTION 1	OPTION 2
PROGRAMMABLE LOGIC CONTROLLER / OXYGEN GENERATOR UNIT	13.6		The unit must have audible and visual alarms for power outage or system malfunction (yes/no)		
	13.7		The unit must have an audible and visual alarm for dew point > 3 °C (yes/no)		
	13.8		The PLC must be able to continuously display oxygen concentration values and gas output pressure (yes/no)		
	13.9		The unit must have an audible and visual alarm for output oxygen concentration < 90% (yes/no)		
	13.10		If the unit has an automatic purge system for low-purity oxygen offered as an optional feature, please state the additional cost for the entire plant (in USD) if this optional feature is selected by the purchasing facility.		
	13.11		The unit must have an audible and visual alarm for switch to secondary supply (whether this is another PSA plant, a bulk liquid oxygen tank, or backup cylinders) (yes/no)		
	13.12		If the unit has the ability to offer remote fault monitoring, please state the additional cost for the entire plant (in USD) if this optional feature is selected by the purchasing facility.		
	13.13		The unit must, under all circumstances, be able to deliver oxygen at a continuous outlet pressure ranging from 300–600 kPa (3–6 bar or 44–87 psi) (yes/no)		
	13.14		The unit must display the oxygen supply pressure to the distribution network (bar)		
	13.15		The unit must have a system for microbial filtration of generated oxygen before it is fed into the distribution network (yes/no)		
	13.16		The unit must allow access to the maintenance menu, and access by technical staff must be password-protected (yes/no)		
OXYGEN CONCENTRATOR UNIT / PSA	14.0		State the construction material of the oxygen concentrator columns		
	14.1		State the total internal volume of the two oxygen generator columns (m^3)		
	14.2		State the amount of adsorbent material contained in the oxygen concentrator columns (kg)		
	14.3		State whether if the plant is compact or skid-mounted/preassembled		
	14.4		State the total area required for installation of the oxygen concentrator plant as offered (m^2)		
	14.5		The plant columns have safety valves to guard against overpressure (yes/no)		
	14.6		The plant columns have a pressure gauge to display the internal gas pressure (yes/no)		
	14.7		Filter weight (kg)		
	14.8		Dimensions (width × height × depth) (m)		
	14.9		State the type of connector used to link the oxygen output of the concentrator plant to the facility's oxygen distribution network		

ITEM	NUMBER	STAKEHOLDER	EQUIPMENT OFFERED	OPTION 1	OPTION 2
POST-PRODUCTION OXYGEN RESERVOIR	15.0		State the construction material of the compressed oxygen reservoir according to the ASME or AISI classification (code).		
	15.1		Compressed oxygen storage pressure after compression (bar)		
	15.2		Maximum working pressure of the compressed oxygen storage tank (bar)		
	15.3		The oxygen tank has an internal pressure gauge (yes/no)		
	15.4		The oxygen tank has a safety valve for relief of overpressure (yes/no)		
	15.5		The oxygen tank has a drain valve for drainage of water condensed during the oxygen concentration process (yes/no)		
	15.6		If the oxygen tank has an automatic purge system offered as an optional feature, please state the additional cost for the entire plant if this optional feature is selected by the purchasing facility.		
	15.7		Air tank weight (kg)		
	15.8		Dimensions (width × height × depth) (m)		
BOOSTER COMPRESSOR	16.0		The compressor as offered must operate in at least two stages. State the number of compression stages (stages)		
	16.1		Maximum oxygen compression pressure (bar)		
	16.2		Output capacity at maximum compressor working pressure (m^3/h)		
	16.3		Electrical power required at maximum working pressure (kW)		
	16.4		Working mains frequency (Hz)		
	16.5		The compressor is oil-free (yes/no)		
	16.6		Booster compressor weight (kg)		
	16.7		Dimensions (width × height × depth) (m)		
	16.8		Permissible oxygen temperature range at compressor intake (°C)		
	16.9		Ambient temperature range of booster compressor operation (°C)		
	16.10		The compressor as offered is designed to operate in an area protected from the elements (yes/no)		
VACUUM PUMP	17.0		Maximum vacuum pump flow at a pressure of 760 mmHg (m^3/h)		
	17.1		Maximum vacuum pump pressure (mmHg)		
	17.2		Electrical power required by vacuum pump at maximum pressure (kW)		
	17.3		Vacuum pump working mains frequency (Hz)		
	17.4		Vacuum pump working voltage (V)		
	17.5		Vacuum pump weight (kg)		
	17.6		Dimensions (width × height × depth) (m)		

ITEM	NUMBER	STAKEHOLDER	EQUIPMENT OFFERED	OPTION 1	OPTION 2
CYLINDER FILLING STATION	18.0		Offer includes a cylinder filling station (yes/no)		
	18.1		If yes, the proposal should consider a manifold composed of two-cylinder batteries (yes/no)		
	18.2		Each cylinder battery must consist of 5 cylinders with an internal volume of 50 L (yes/no)		
	18.3		The offer includes the complete filling system (manifold and cylinders) (yes / no)		
	18.4		Price of oxygen cylinder filling station (USD)		
CORRECTIVE AND PREVENTIVE MAINTENANCE	19.0		Operation and maintenance manuals are updated by the manufacturer or their representatives whenever changes in their content are necessary to ensure the safety of operations (yes/no)		
	19.1		The supplier commits to installing all available diagnostic software for maintenance and troubleshooting at no additional cost. The manufacturer must propose routine maintenance and a pre-established system for the procurement of spare parts for the offered make/model of plant (yes/no)		
	19.2		A telephone support hotline staffed by qualified technical personnel should be provided as long as the equipment is in use at the health facility. This technical support should include access to the appropriate technical staff to discuss configuration issues, error codes, possible trouble shooting solutions, etc. This service should be provided at no additional cost to the facility (yes/no)		
	19.3		The representative's telephone number and the manufacturer's identification number are clearly visible to facilitate communication whenever necessary (yes/no)		
	19.4		Full maintenance training will cover all components of the oxygen generator plant, and will be provided to at least one member of the hospital's engineering team during the warranty period. This training will be provided at no additional cost to the customer and will have the overall objective of better preparing the facility's engineering personnel to provide first-call service, before contacting the manufacturer, and thus facilitate greater manufacturer access to any problems arising with the equipment (yes/no)		
	19.5		The manufacturer/representative commits to correcting any unit malfunction that occurs during the commissioning period. If they cannot address the issue in a proper and timely manner, the representative will take back the equipment and reimburse all expenses incurred as a result of the import or procurement process (yes/no)		
	19.6		The supplier commits to starting the warranty period only after the date of equipment acceptance (yes/no)		
	19.7		The supplier commits to providing technical support and coordination of services with the facility's engineering department over the course of the warranty period (yes/no)		
	19.8		The representative commits to performing periodic inspections and maintenance activities on the equipment, during the warranty period, at no additional cost to the customer		
	19.9		The representative commits to providing documentation containing the procedures for cleaning, calibration, periodic replacement of parts, and assessment of proper functioning. These services are to be performed by facility technicians, trained by the manufacturer, who may also carry out maintenance procedures during this period, under the direction of the technical representative, without shortening or voiding the warranty (yes/no)		

ITEM	NUMBER	STAKEHOLDER	EQUIPMENT OFFERED	OPTION 1	OPTION 2
CORRECTIVE AND PREVENTIVE MAINTENANCE	19.10		A copy of the service report is provided during all maintenance procedures performed by the manufacturer or the manufacturer's representative (yes/no)		
	19.11		The service report will contain a description of the problem, a description of the solution, all parts and materials used (with part numbers), the cost of the parts, the cost of travel, the time spent and the serial number of the plant (yes/no)		
	19.12		The supplier commits to providing an annual summary of all service reports pertaining to the plant one month before the expiration of the warranty period. This summary will be reviewed together with the facility's technical team, with a view to identifying, addressing, and solving any predetermined trends or patterns, malfunctions, or user errors (yes/no).		
FINANCIALS	20.0		A direct and exclusive line of communication to the supplier's or manufacturer's technical team will be provided during the warranty period or if a maintenance agreement is in place, at no additional cost (yes/no)		
	20.1		A direct and exclusive line of communication to the supplier's technical team will be available outside the warranty period or if a maintenance agreement is in place, at no additional cost (yes/no)		
	20.2		The supplier shall provide refresher maintenance training. Cost of additional training (USD)		
	20.3		Number of hours of training mentioned in the preceding item (hours)		
	20.4		Number of years in which the company providing maintenance services has been on the market (years)		
	20.5		Location of the technicians responsible for maintenance of the oxygen generator plant (city and country)		
	20.6		Maintenance services are provided directly by the manufacturer or through a distributor/representative		
	20.7		Number of preventive maintenance instructions available for this equipment; How frequently preventive maintenance will be performed: monthly, twice yearly, once yearly (months)		
	20.8		Total value of equipment as offered (USD)		
	20.9		The equipment must come with a 3-year spare parts kit. This kit, in accordance with the recommended preventive maintenance program, must be clearly defined by the manufacturer in a disaggregated list comprising part numbers, descriptions, and unit cost, as well as indicating make/model specifics (e.g., for circuit breaker, printed circuit board, sieve beds, compressor components, valves, wheels, motor capacitor, analyzer, etc.). It must also include a set of all filter supplied with the equipment (yes/no)		

ITEM	NUMBER	STAKEHOLDER	EQUIPMENT OFFERED	OPTION 1	OPTION 2
FINANCIALS	20.10		Price of the spare parts kit mentioned above (USD)		
	20.11		Value of the preventive and corrective maintenance agreement including full equipment coverage and any need for replacement of displays, resistors, PLC, moldings, buttons, keypads, etc. (USD)		
	20.12		Value of the preventive and corrective maintenance agreement including full equipment coverage and any need for replacement of displays, resistors, the PLC, cover plates, buttons, keypads, etc., including out-of-hours, weekend, and holiday service. The supplier must ensure that the equipment works continuously (at least 97% uptime) (USD)		
	20.13		Value of the preventive and corrective maintenance agreement (labor only). Parts not included (USD)		
	20.14		Value of the preventive and corrective maintenance agreement (labor only) including out-of-hours, weekend, and holiday service. Parts not included (USD)		
	20.15		Cost of hourly labor if the facility decides not to enter into a maintenance agreement (USD)		
	20.16		The operating manual must be provided as an integral part of the equipment (yes/no)		
	20.17		The maintenance manual must be provided as an integral part of the equipment. If the computer requires passwords, usernames, etc., these must be provided. The maintenance manual must have the exact same technical content as that used by the manufacturer's technical staff (yes/no)		
	20.18		The installation guide must be provided as an integral part of the equipment. Value (USD)		
	20.19		The installation qualification manual must be provided as an integral part of the equipment (yes/no)		
	20.20		The performance assessment manual must be provided as an integral part of the equipment (yes/no)		
	20.21		Energy consumption of the plant under the above conditions (kWh/24 hours)		
	20.22		Calibration frequency required by the plant and recommended by the manufacturer (once yearly, twice yearly, daily, automatic...)		
	20.23		Value of the calibration procedure, if it is performed by the manufacturer and not part of the maintenance agreement if one exists (USD)		
	20.24		Average annual cost of preventive maintenance of the plant under favorable and appropriate operating conditions (USD)		
	20.25		Whether the plant infrastructure includes sufficient technology for software maintenance and updating, data acquisition and transfer, error code and message code analysis, and, if these are optional features, the cost of this feature set (USD)		
	20.26		Cost of a condensate separator (USD)		
	20.27		Cost of pre-filter 1 (USD)		
	20.28		Cost of pre-filter 2 (USD)		
	20.29		Cost of refrigerated air dryer (USD)		
	20.30		Cost of adsorption air dryer (USD)		
	20.31		Cost of activated carbon filter (USD)		
	20.32		Cost of catalytic converter (USD)		
	20.33		Cost of replacement of adsorbent material in adsorption air dryer (USD)		
	20.34		Cost of replacement of adsorbent material in the PSA plant (USD)		
	20.35		Cost of an air compressor oil change (USD)		
	20.36		Cost of an air dryer refrigerant gas refill (USD)		

ITEM	NUMBER	STAKEHOLDER	EQUIPMENT OFFERED	OPTION 1	OPTION 2
FINANCIALS	20.37		Cost of a set of spare parts for the booster compressor, enough for 6 months of operation or 4320 working hours (USD)		
	20.38		Cost of a set of spare parts for the booster compressor, enough for 12 months of operation or 8640 working hours (USD)		
	20.39		The manufacturer commits to providing training in operation and use of the equipment to its users at any time, after the warranty period, with a workload similar to that of initial training. Number of course hours and cost of such training if requested in the future (hours/USD)		
	20.40		The supplier commits to offering a warranty period of 4 years (48 months) from the date of acceptance, after the equipment has been fully installed and commissioned (yes/no))		
	20.41		Cost of extended warranty against manufacturing defects for an additional year (USD)		
	20.42		Address the time, in weeks, to offer and provide updates on the software required to keep the equipment running and in safe conditions. There are no fees considered for expiration dates.		
	20.43		Cost of oxygen generating plant installation qualification (USD)		
	20.44		Cost of oxygen generating plant operation qualification (USD)		
	20.45		Cost of oxygen generating plant performance qualification (USD)		
TRAINING	21.0		The supplier commits to providing additional refresher training for at least one member of the hospital's engineering department during the warranty period. This training will be offered by the provider at no additional cost.		
	21.1		The manufacturer commits to providing training on operation and use of any software for configuration, operation, diagnosis, and maintenance of all PLCs present in the oxygen generating plant, and to include this in the service training package, at no charge to the customer. This training aims to increase the capacity of the facility's technical team to provide on-site, first-call service before contacting the manufacturer as necessary (yes/no)		
	21.2		The manufacturer commits to providing training on operation and use of the plant to its operators before and during first use. If yes, please report the number of training hours to be provided (yes/no)		
	21.3		The content of each of the required training programs (technical and operational) must be forwarded (within 15 days of formal purchase) to the engineering department of the facility, whose staff will evaluate and formally adopt them with the users and within the organization's continuing education program. Professionals trained in this activity by the provider must have proven experience in the hospital specialty. The content of the operational training should be in line with the main medical and administrative line of action of the facility, as required by the facility (yes/no)		
	21.4		During the warranty period and while under maintenance contract, the bidder must provide specialized clinical support to the operators, both by telephone and online, including, as appropriate, remote access to the equipment. State whether this service is offered as part of the proposal (yes/no)		
LEED	22.0		The installer commits to removing all waste from the premises once the installation is completed. The installer must also be responsible for appropriate disposal of this waste, in accordance with the hospital's quality standards and HCWMP.		

AISI: American Iron and Steel Institute; ASME: American Society of Mechanical Engineers; ASTM: American Society for Testing and Materials; EC: European Community; PLC: programmable logic controller; FDA: U.S. Food and Drug Administration; GHTF: Global Harmonization Task Force; ISO: International Organization for Standardization; LEED: Leadership in Energy and Environmental Design; HCWMP: Health Care Waste Management Plan; PSA: pressure swing adsorption. psi: pound-force per square inch; EU: European Union; USD: United States dollar.

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