BASIC CONSIDERATIONS FOR PLANNING A PSA SYSTEM

1. **What does "PSA", "VPSA" and "OGP" mean? What technologies are used, and how do they work?**

PSA is the acronym for "Pressure Swing Adsorption", which is the name of the process that takes place inside the Oxygen Generator Plant. PSA plants extract oxygen using a molecular sieve, which expels nitrogen and leaves a more purified oxygen product, which is stored in a tank until ready for distribution by a pipe system. The basic technologies of the PSA plant include: the air (feed) compressor, the air dryer, prefilter systems, the PSA generator, and the booster compressor. Review our first webinar "Essential Considerations Related to a PSA Plant" HERE for more details. You may have also heard of "VPSA" – "Vacuum Pressure Swing Adsorption". For a detailed explanation on VPSA see: https://www.trimechindia.com/blog/oxygen-plants-whats-difference-psa-vpsa-oxygen-plant/

2. **What is the role of the air compressor, and do you recommend oil-free or oiled air compressors for PSA plants?**

The air compressor is required to supply the OPG with dry air. Generally, when procuring a "PSA plant" the manufacturer will include the required air compressor. If procuring an "OPG", the air compressor will need to be added. Oil free air compressors are better for PSA plants, to avoid contamination of the air or oxygen.

3. **Is liquid medical oxygen (LOX) recommended for ICUs… or is a PSA plant recommended?**

Liquid oxygen is converted to gas for use in any clinical settings – whether an ICU or any other department. Therefore, the patient is always getting gaseous oxygen regardless of whether the manufactured source was liquid, or through a PSA generator.

Of note, the difference between PSA plants that provide 93 (+/- 3) % versus LOX 99% pure oxygen does not matter to patients, because patients are getting a mix of air and oxygen anyways. It is having adequate oxygen supply that is important.

4. **What is the disadvantage or advantage of using highly purified oxygen for medical treatment (e.g., 99.9%)?**

This is something that we talked about a lot from a clinical perspective. You do not give patients 100% or close to 100% oxygen. WHO guidelines state 93% +/- 3% is okay. Even during surgery, you tend to mix oxygen with something else and do not go close to 100%. Even in normal circumstances, patients will be breathing 20% oxygen at room air. If you give 100% for too long, reversal to normal use becomes difficult. In reality, we can give people 90%+ when they are sick.

Because PSA plants use zeolite separation, they cannot achieve 99% purity, but we can do very well with 93-95%. With locks, we can achieve 99.5% but from a clinical perspective, there is no extra benefit if you have the appropriate delivery channels. In Kenya – some manufacturers advocated to the WHO to set 99% as the standard; and Kenyan Society of Anesthesiologists, Kenyan Society of Pediatrics and Critical Care Society all reviewed this matter extensively and came to conclusion that there are no extra benefits when giving 99.5% versus anything above 90% to a patient.

5. **What threshold considerations should individual hospitals use to decide on their main and backup supply sources? And can PSA plants supply direct piping and filling cylinders ramp at the same time?**

The primary consideration should be to ensure that the oxygen system is dependable and sustainable. The best main supply source of oxygen to a patient is a direct piped system that connects to the patient bedside from a PSA plant (or oxygen reservoir supplied by an LOX source). The direct pipe system is highly recommended and preferred. The alternative is to bring cylinders to the bedside. The back-up supply source for a direct pipe system would be a manifold of cylinders and additional spare cylinders to adequately supply the pipe system if the main supply is temporarily not operating.

On the second question – yes, they can and often do, this is not a problem. A PSA plant should be designed and built according to an assessment of how much oxygen is needed to supply a direct pipe system plus how much oxygen should be produced to fill cylinders, simultaneously.

6. **What materials do you recommend for PSA plant site preparation before installation? And what is the advantage versus disadvantage of installing PSA in containers instead of a room built for it?**

It depends on many local factors. Consider the materials used locally, how dusty the area is, and how hot the area is. Generally, we prefer to use masonry block and concrete for the walls and concrete floor. For the roof, consider factors such as tropical storm frequency in the area. If the area is subject to tropical storms with high winds, then consider a concrete roof. Also consider thermal mass and/or insulation of roof to minimize heat transmission.

PSA plants are much more expensive if provided in a container (also the time to build is longer). The advantage is ease of installation without a building, but a support building will be needed to manage cylinders that are being filled and the manifold for the cylinder supply (primary supply or backup supply) to a pipe system.

7. **PSA plant staff- how many should be hired, what should be their qualifications? What training is available for staff at PSA plants?**

For staff qualifications, first determine if the staff is expected to simply *operate* the plant or if the staff is also expected to provide maintenance-service for the plant.

If the staff is expected to simply *operate* the plant, then the minimum qualification of the should be 1 staff that is a certified/qualified electrical, mechanical, or biomedical technician, plus if cylinders are to be filled, then add staff of 1 or 2 basic laborers to handle cylinders (the number of added laborers needed will depends on the number of cylinders to manage).

If the staff is expected to perform basic and/or advanced maintenance/service to the PSA plant then a certified electrical, mechanical, or biomedical engineer should be added to the staff.

The total number of staff to be hired should be based on the plan of operational hours of the plant. For example, a PSA plant is typically planned to operate for 24 hours per day, 7 days per week, therefore the total number of staff to be hired should be planned accordingly.

Initial Basic Training for PSA plant technicians and engineers is recommended to begin at the time of plant installation and commissioning by the manufacturer's installation team. The manufacture should provide complete instruction regarding *how to* operate the plant, monitor, understand and record the proper performance parameters of the plant, instruction of simple and routine maintenance for the plant according to manufacturer's specification, basic trouble-shooting, and standard operating procedures for acquiring support for service and maintenance when needed.

Advanced levels of service should only be performed by competent trained engineers and technicians, and this usually means that an "outside" service contract will be required to provide the advance levels of service that will be needed. Overall, the availability of advanced level training for PSA services is scarce and will require the PSA owner to prioritize and finance efforts to locate training opportunities to increase the knowledge, skill and abilities of their own technicians and engineers.

8. **Why is it challenging for Governments to engage in public private partnerships for oxygen delivery?**

Public private partnerships are new and often, public procurement laws are geared towards buying and owning things- not getting services which is what PPPs are all about. The earliest PPPs, and maybe the most developed, in the UK were very much geared towards extremely large infrastructure projects so if you are looking at how to do PPPs, most likely you will get information or the tools on how to do a bridge, a port, an airport, or something like that. Services have not been the major concern of most of these PPPs and you will find that there is just not much experience. So, to do a successful PPP, it requires a lot of education or capacity-building for governments for them to understand what you are trying to do and to demonstrate the benefits.

The other common misconception is that PPPs are supposed to be cheaper and that you are supposed to do them when you do not have money. In reality, they are not. What they should do is to guarantee you a more efficient service delivery and take away the risks from the government to a party that can manage them in the best way possible. Another challenge we see often still linked to government procurement, is that they want to purchase things or services and goods on an annual basis based on allocated government budget. So, if you are going to get into a PPP to set up and operate a plant, you need at least a 5–7-year commitment from the government or public entity for it to make economic sense. These challenges can be overcome in demonstrating experience. In our operations, we are seeing that conversations with governments of public entities are becoming much easier because we can bring them to talk to their government counterparts where we have been implementing to see for themselves how it works and to discuss the benefits. So having experience, or a pilot run that they can go to learn is very helpful. Discussing at a theoretical level is often very difficult at the beginning.

ENERGY CONSIDERATIONS FOR A PSA PLANT

9. **Does energy consumption differ depending upon the manufacturer?**

Not really. Most of the compressors are made by the same two companies. VSA technology uses less energy than PSA but has other draw backs. Plants greatly vary in consumption based on size.

10. **Are solar powered PSA plants a good option? And what does PV refer to?**

Solar is a very good power option. (PV = photovoltaic – which refers to the parameters by which panels harness electricity.) Electricity is a major cost in PSA systems, so if it's free, oxygen is essentially free. However, there are so many factors involved in solar design: latitude, how much sun you have, irradiance, cloud cover – it's hard to generalize. In many parts of the world, including India and much of Africa, we see solar systems with batteries that have a 3-year payback. Problem is lack of funding.

Some of the challenges/considerations that need to be made when using solar options include:

Size: You need to know the size needed. E.g., if your generator requires 12 kW, solar should be sized 60kW to take care of the needs of the entire system. Solar power does not work 24 hours, depending on where you are, so you need to consider this.

Area: For a 280 LPM system, electricity requirements are 20 kW, and require 120 kW with solar, and 12000 sq foot area. Managing area is a big challenge. If you can manage to allocate a 6000 square-foot area, you can maybe install solar in this area so that at least 50% of energy will be through solar means. There are also companies that can provide space to help. Electricity boards allow you to generate electricity in one place, and you can manage the electricity where you need it. The availability of this set up varies state by state.

Investment: Solar can be costly, but there are companies in India giving solar with a 15-year contract and fixed unit charges. In Bombay and Delhi – electricity rates average 9-10 rupees per unit, but with solar you can achieve 6, 6.5 rupees/unit – so it's cheaper.

If you are using solar then it should be 5 times the actual electricity requirement of a generator.

You can also do a combination of solar and direct electricity supply.

11. **Is Aluminum wire better or copper wire as an electricity feeder to the PSA plant?**

Our suggestion is to use Aluminum from electric meter to generator control panel, and copper from control panel to compressor for 22 KW onwards size.

12. **Is it advisable to have UPS as well as Generators?**

We always advise to have a small 1Kw UPS feeding the control circuit and PLC. It is inexpensive protection.

13. **How do you calculate power consumption?**

For Air Sep manufactured PSA plant = 1.5 kWh for 1m3 of Oxygen production

14. **What are the key considerations when designing a sustainability plan?**

Key points for sustainability begin by identification of a cost analysis for operational expenses:

- Cost of power to operate 24/7 - include cost of grid power and diesel fuel for back-up generators.
- Cost of spare parts package that is specific for the type of equipment to be installed. For example: key equipment for spare parts includes the air compressor, PSA generator and the booster compressor for filling cylinders (if filling cylinders). Budget for the spare parts and confirm the supply chain to order and import the spare parts.
- Staffing costs of Engineers for service and daily operations.
- Cost of service contracts for outside service provider to do regular maintenance

CALCULATIONS – TRACKING CONSUMPTION AND ESTIMATING COSTS

1. **How to calculate total demand of oxygen for a health care facility?**

From our experience in numerous countries, the first best thing to do is to talk to clinicians in the hospitals and understand their common patient mix, burden of disease, and what they understand to be the demand for oxygen in their setting, whether it be a health clinic or hospital department. Consider this as well though: in many hospitals clinicians may not be trained to a very high level, so in providing clinical training opportunities we have seen a resulting increase in the demand of oxygen due to increased usage of pulse oximeters to properly diagnose and understand the oxygen needs of their patients. Pulse oximetry also helps to prevent over-oxygenating a patient. Therefore, clinical training components are important.

We would also advocate looking at duplex systems – 2 smaller PSA systems than a large plant because compressors do not modulate, and electricity can be 70% the cost of 1 L of oxygen. Moreover, in some hospitals where we have converted from cylinders to piped oxygen, we have seen in some cases a 300% increase in use of oxygen. Note that the direct pipe system does not require a PSA plant at your hospital, it can be supplied by cylinders.

Not everyone is going to have plants at their hospital. Why? If someone has to go a pick up a cylinder- heavy, time consuming, difficult, might actually be neglected altogether. But when piped it is readily available at the patients' bedside and you just have to hook up a nasal cannula or mask. This means patients are getting low flows of oxygen much earlier and higher flows when they need it. So, your oxygen consumption can often go up. Distribution system also depends on if you are piping filling cylinders, working hours, size, etc.

The tool that we use to calculate this is from the OGSI website, found at this link here: https://www.ogsi.com/product/hospital-systems/. You should check this against what your facility is doing in terms of treatment and clinical services, you may need to adjust accordingly. Here is the formula:

Hospital System Sizing Estimator:
[# of beds x 0.75 liters per minute (LPM)] + [# of other outlets (ICU, Operating Theatre, etc.) x 10 liters per minute (LPM)] = total liters per minute (LPM)
*Liters per minute (LPM) x 2.1 = Standard Cubic Feet per Hour (SCFH)

2. **What is the formula for determining the size of oxygen cylinder manifold system needed?**

In the WHO toolkit, there are a number of tools to assist in this process to help you do these calculations. These tools guide you to basically assess the number of patients you want to serve and how many total cubic meters or liters per minute of oxygen you need to produce. Then, you will calculate according to your design whether that oxygen should be distributed through piping or through cylinder. The formulas essentially count the number of beds you have for certain departments, there is a factor to multiply by for this, plus considerations for surgical centers and ICUs that take a little more oxygen, among other things. That will tell you what your target rate of production should be then based on your own needs assessment, decide whether or not you are going to have a pipe system or cylinder system, that will tell you the method to which you will make your distribution. Those tools are available, they are formulaic, and the links are included on our resource library.

This is a really complex issue that many people struggle with in both high and low resource settings. Even in the USA, there are guidelines for oxygen consumption but there is still a lot left up to the engineers. If you follow the British or American guidelines, you end up with PSA plants that are much too large and are very expensive to run or a huge cylinder capacity that most find unachievable. Many of the tools that are out are better than nothing but some of them also understate, especially in the age of COVID, the capacity. It really varies from hospital to hospital and country to country. In countries with weak public health systems, and not many referral hospitals, we see over 70% of COVID patients needing 20-40 L of oxygen to stabilize them. This requires huge amounts of oxygen, depending on the mix of adults and pediatrics because infants have very low needs. We encourage you in your sizing of plants to really put effort into determining this because a plant that is too small can be disastrous- that can impact the longevity of the plant and the purity level of the oxygen. A plant that is too large can also be very problematic.

The #1 cost of running a PSA plant, especially if you have a filling component, is electricity. So, the bigger the plant, the bigger the compressor, the higher cost of electricity. So, in places like Kenya where electricity is very expensive, you need to be very careful with sizing, so you do not have redundant capacity that makes costs go really high. Whatever choice you make, it will fail sometimes. Therefore, every hospital needs to have 1 major source of oxygen and at least one reliable backup system.

3. **How do you calculate the conversion between a PSA plant's rate of oxygen production and cylinder volumes that can be filled?**

Long story short: If you have an oxygen plant that can fill and produce 32 cubic meters per hour, can expect 100-120 cylinders (42L) to be filled in a 24-hour period. Manufacturer gives you rate of capacity if operating every minute, every hour. Assume 80% in real life. Plants are also rated at 1000ft above sea level or lower – much of Sub Saharan Africa is above this so have to derate the plants significantly. Also, need to consider what size of cylinder you are using – too small, too large cylinders not good – middle is where you get best economy and life span.

Additional details for understanding these conversions:

Cylinder sizes are commonly referred to by volume of liquid (water) such as 42 Liters. Then you must covert the liquid liter size to gas volume. For example, a cylinder that is 42 Liters (liquid) actually contains 6.287 (or round to 6.3) CM of oxygen in a gas state, *when* the cylinder is filled under pressure to 152 Bar (or 2200 psi).

PSA Plants are built to a specification that identifies a "rated" capacity of production. For example, the plant is rated to produce 16 Cubic Meters per hour. Therefore, you may calculate that 24 hour in a day X 16CM Per hr. = 384CM per day. Once the total CM per day is understood you can divide by the common size of cylinder to know how many cylinders of a given size can be produced per hr or per day. However, it is not likely that the plant will operate every minute of every hour, therefore it is reasonable to assume 80%-90% of the rated capacity will be the actual working capacity. When a PSA plant is ordered, the manufacturer will need to know the location where the plant is to be installed to design the plant with consideration to altitude above sea level, and environmental common temperature range.

4. **How do you determine the entire cost of a PSA plant?**

Add the local cost of human resources of plant managers, operators, laborers and security and the operational cost of grid power and/or diesel fuel for the backup generator to the other costs of a 200 LPM capacity plant. The other costs of the 200 LPM oxygen plant cost with cylinder filling capacity will vary by vendor but estimate $200,000 USD. Time to order, deliver and install is approximately 4-6 months depending on the vendor and the supply chain efficiency. Maintenance of spare parts is estimated at $12,000 -$15,000 USD per year, plus service contract at local price. Added cost of infrastructure support for power supply, backup generator power supply, shipping, taxes, and installation cost is based on location and local costs.

5. **How much does a compressor cost?**

For a PSA oxygen plant of 200 LPM plus cylinder filling- estimate $200,000 USD, but cost will vary by vendor.

6. **Is it cost effective to install a 200 lpm plant in set up where daily consumption is of 1 jumbo?**

It is not cost effective because 1 Jumbo cylinder, with 8000 Liters of compressed oxygen gas can flow 10LPM for 800 minutes. (800 minutes = 13.3 hours) The cost of a jumbo cylinder will vary but estimate $20 USD or 2X20 USD per 26 hours. The 200 LPM oxygen plant cost with cylinder filling capacity will vary by vendor, but estimate $200,000 USD, then calculate $200,000 / $40 per day (the cost of 2 Jumbo cylinders) = 5000 days of cylinder procurement or about 13.7 years.

7. **How does the cost of LMO compare to PSA plants?**

Liquid oxygen is generally more expensive than PSA due to the cost of equipment procurement, infrastructure to support the management, and distribution. After the initial investment for a very large-scale LMO production and distribution system, however, the cost will be diminished over time.

PRODUCT QUALITY, MONITORING AND SAFETY CONSIDERATIONS

15. **How can we assess quality of oxygen produced?**

This depends on if the source is liquid or PSA. Plant manufacturers are required to provide and meet certified quality standards and the machine will indicate the purity level during production. If the device is new, you should request the quality certificates. Please download the WHO generic specifications for PSA plants (See our supplementary resources). For periodic checkups, you will need oxygen analyzers.

All devices, including medical devices, should have a quality assurance process that is related also to the documents that the manufacturer provides, or can provide you, from the manufacturing site. We have published the WHO technical specifications that help to have a generic idea of what the standards and certifications are that you need to have in the output of the oxygen generator plants. If the plants are already in style and working, and you want to monitor the oxygen purity…normally in the control panel you will be able to look at what the purity is that they are giving to you. From there you could troubleshoot accordingly. You may also ask the manufacturer or authorized distributor to provide you with specific oxygen analyzers that can help you do the required maintenance and change the filters.

16. **What should be monitored on a daily or weekly basis by staff?**

Assist International's approach to checks and monitoring is adapted from AirSep guidelines, which we have made available in the supplementary resources. The guidelines show monitoring daily parameters, performance of air compressor, PSA generator, cylinder filling station status, purity, and pressure of system – as mentioned, all of these have operating parameters that should be recorded on a daily basis. If there is any indication of performance being outside of the normal, they can arrange a service response.

17. **Is oxygen being quality tested in India right now? How many labs are doing quality testing?**

Very frankly – it's not a good situation. Before the second wave of COVID, the government was overseeing quality standards. But now – because of the significant shortage of oxygen, hospitals and health centers are taking oxygen without quality standards, including industrial oxygen. As per India's Health Ministry – PSA oxygen should be generated in a regulated lab, and there are only 2 labs – Delhi and Hyderabad that should verify content. But all these new systems people are using because they are desperate for oxygen, are failing quality tests, and people aren't aware of this. This issue is growing – everyone wants oxygen, let it be industrial, or medical. But industrial oxygen should not be used in hospitals.

18. **Can you comment on the safety and explosive nature of PSA plants?**

PSA plants need to be operated and maintained safely just like any other industrial motor and machinery, but they are not inherently explosive or combustible. The electrical system must be installed properly and safely. However, oxygen is an accelerant for combustion (fire). So, if there is an open flame or ignition source, an enriched oxygen atmosphere can highly accelerate fire. If oxygen is being exhausted even around the plant, there should be no ignition sources, no open flame, no smoking, no sparks allowed. If high pressure oxygen cylinders are being filled, there are additional safety considerations. NOTE: Electricity requirements are pertaining to the model and specification of each individual PSA plant, this specification must be provided by the PSA manufacturer.

19. **Can you comment on secondary room exhaust?**

The first exhaust system directly exhausts the large compressor. The second exhaust would exhaust the room and make sure the room has good air circulation and the temperature is moderated. Also, sometimes the air dryer needs exhaust.

20. **How do frequency fluctuations affect the plant - in terms of spare parts?**

Frequency fluctuation over time can damage the large motors which are a very expensive part of the plant.

21. **The pressure of oxygen in the oxygen plant is low in our hospital, what could be the probable reason and what should be done to reduce oxygen wastage in our hospitals?**

There could be many reasons for this. If it is connected to the pipe network, it is possible the design of the pipe was not done correctly. Under “Supplementary Resources”, there are recommendations posted about rational use of oxygen that can provide further detail.