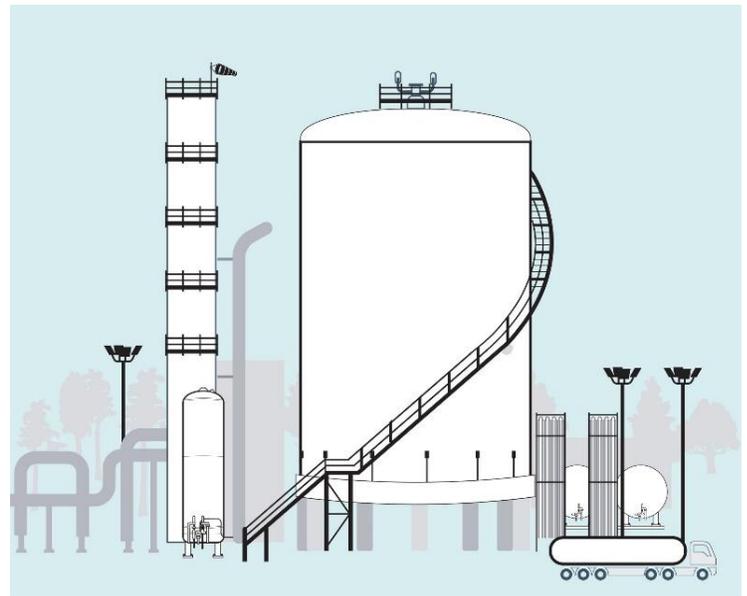


# Oxygen Generation and Storage: Air Separation Unit

## Technical overview

A cryogenic air separation unit (ASU) is a plant that utilizes the distinct properties between the primary components of air to produce highly purified oxygen, nitrogen, and sometimes other gases, such as argon. The ASU technology uses a process referred to as cryogenic fractional distillation, where the components of the air are separated by compressing the gas until it liquefies at extremely low temperatures (-173°C to -193°C), then selectively distilling the components at their various boiling temperatures. As it is a very energy-intensive process, ASU technology is generally reserved for medium- to large-scale production. An ASU can be designed for the required product purity and delivery pressures. Skilled technicians are required on-site at all hours to ensure smooth operation of the plant.



## Key specifications

An ASU can produce 100 to over 5,000 tons of oxygen per day at purity levels of 95% to 99.5% or higher. The process of air separation consists of the following main steps:

- **Filtration**, to remove dust and other impurities.
- **Compression**, where the air is compressed between 72 to 144 psig and water is condensed out in inter-stage coolers.
- **Removal of contaminants**, using a molecular sieve bed, which is constantly regenerated to remove any remaining water vapor, hydrocarbons, and carbon dioxide, which would freeze and plug the cryogenic equipment.
- **Heat exchange**, where the air is passed through integrated heat exchangers and cooled against product and waste cryogenic streams to produce liquefied air enriched in oxygen and nitrogen. This happens in separate low- and high-pressure distillation columns using refrigeration.
- **Product compression**, where oxygen is compressed to a prescribed settled pressure.
- **Storage**, where the liquid oxygen produced from the ASU is stored in cryogenic insulated storage tanks.

The construction of an ASU plant varies depending on the production capacity, purity, and pressure requirements for the application and may influence the materials used in its construction. For oxygen, carbon steel is commonly preferred due to cost and its effectiveness at the extreme temperatures endured during ASU operation.

## Regulatory considerations

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If the product is intended for medical application, an ASU must be certified for medical oxygen production and all liquid oxygen (LOX) storage tanks must be certified both at the site of the ASU and at the medical facility. Analytical equipment using high-purity oxygen analyzers are used in the ASU production process to ensure that the oxygen produced by the ASU is of medical-grade quality and complies with European and US pharmacopeia directives. A quality system or testing validation process of the product is carried out on a regular basis to ensure the oxygen produced complies with the international medical gas standards. Refrigerants used to facilitate the low temperatures necessary for an ASU plant, such as hydrochlorofluorocarbons and some halocarbons, may need to be regulated by local authorities. An evaluation of local environmental regulations and guidelines may be required, and pressure vessels may need to be built to comply with local codes.

## Infrastructure requirements

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Two key infrastructure requirements for ASU technology include electricity and cooling water:

- **Electricity:** An ASU relies on large amounts of energy (either from electricity or other fuel sources) to maintain the cryogenic temperatures necessary for the process. For example, a 1,200-metric ton per day ASU uses over 16 megawatts of power when operating and will require a local utility company to install a dedicated power supply.
- **Cooling water:** An evaporative cooling water system (either open or closed) is required to cool the compressors and process air during the production process.

## Supply/shipping

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**For the plant:** Depending on the size and location of the facility, the duration—from the onset of the project to the first delivery of oxygen—can exceed 18 to 24 months. In addition to the mechanical equipment supplied by a manufacturer of ASU facilities, plant construction may depend on the services of multiple contractors, including excavation, concrete installation, piping installation, electrical and instrument installation, column assembly and aluminum welding, and oxygen cleaning and lube oil flushing, among others, and any one service may depend on the successful completion of another. Additionally, construction can be delayed during wet seasons in certain geographies, sometimes in excess of 45 days per year. Thorough project planning in close collaboration with the manufacturing partner will help optimize construction timelines.

**For the oxygen generated:** Given the scale of production, energy requirements, and associated risks, liquid oxygen is always produced off-site. In order to use liquid oxygen for medical application, there are additional equipment needs for transport, storage, and use. Different network supply and distribution options are used by different companies. The structure of a company's network can determine how quickly a supplier can respond to orders and how costly shipping is. Any liquid oxygen provider's anticipated lead-times will have to be factored in when planning for refill frequency to ensure continuity of supply.

If demands are larger, consideration should be given to installing a vacuum-insulated evaporator (VIE) tank at the health facility, sized according to refill frequency, and an evaporator, sized to meet demand. If demands are smaller, or for back-up considerations, high-pressure gas cylinders are used. There is also the option of liquid cylinders, which have built-in vaporizers and connect to a distribution manifold. However, given the potential usable volume, they are rarely the most efficient option. All storage vessels must be certified for use with medical oxygen. For delivery, cryogenic tanker trucks are used for liquid oxygen and must be certified for medical use. Trucks transporting oxygen cylinders should comply with safety protocols for transporting compressed gases.

## Dependencies for use

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Related equipment needed with an ASU are static vacuum-insulated storage vessels for the storage of LOX, a vaporizer at the site of production, a high-pressure gaseous cylinder filling plant to fill cylinders, and trucks to transport LOX and cylinders. For

delivery purposes, cryogenic trucks and storage vessels must be validated for use with medical oxygen and cryogenic vacuum-insulated storage vessels must be present at or adjacent to the medical facility.

## Maintenance

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Major maintenance requires the plant be taken offline for hours to days, and supply chains must plan accordingly to accommodate the gap in production. Key requirements for appropriate maintenance of ASU technology include:

- **Labor:** Well-trained operators (typically 3 operators operating 3 shifts of 8 hours each) and technical maintenance support staff (operation managers, millwrights, and instrument technicians) are required to operate and maintain the production facilities 24/7.
- **Liquid oxygen transport:** LOX is a hazardous good and countries typically have specific regulations in place to guide its safe transportation. LOX intended for large medical facilities is usually transported by specialized road tankers to be decanted into a cryogenic vacuum-insulated storage tank located at the medical facility. For large industrial gas users, gaseous oxygen may be supplied via pipeline directly to the point of use.
- **Cylinder filling:** Depending on the facility, LOX can be vaporized into a gas and filled into cylinders using high-pressure compressors, or via a cryogenic pump and vaporizer, and transported in cylinder trucks or a flatbed truck modified for the safe transport of high-pressure gas cylinders.

## Cost

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The capital cost for an ASU plant is significant, and there are critical factors to consider. The first is plant size; determining the requisite size may be informed by demand and its anticipated growth rate. If demand growth is 8%, for example, plant size should allow for an initial loading of 50% capacity to enable it to reach full capacity in approximately 9.5 years. The second critical factor to consider is the distance to the user base, as transportation costs will affect the cost of the product and, ultimately, the return on investment of the ASU plant. Third, the cost of power will determine whether a more efficient plant should be built at the expense of a higher capital outlay. On average, 75% of a 200-metric ton per day ASU plant's total lifetime costs are energy costs. When taken together, capital costs can range from approximately US\$25 million for a 200-metric ton per day plant to US\$125 million for a 3,000 ton per day plant.

From a gas supplier's perspective, a high level of capital investment is common for an ASU due to the equipment requirements to support the production facilities. To ensure optimized plant operation, the gas supplier will enter into long-term contracts with medical facilities as well as large industrial gas users who will pay for service on a monthly, quarterly, or another period of frequency as determined by the contract. Accompanying infrastructure—including cryogenic vacuum-insulated storage tanks, generators, appliances, cylinder filling plant, trucks, and offices—will also require notable capital outlay. In order for the plant to achieve cost-effective production, its capacity utilization must be optimized. For the gas supplier, key operating costs include electricity, labor, and maintenance.

## COVID-19 considerations

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In the context of a global pandemic like COVID-19, additional considerations should be raised. Liquid oxygen offers the most affordable cost-per-liter pathway to deliver oxygen to facilities with high demand and is suitable for large referral hospitals with high patient loads related to COVID-19 or acute respiratory distress syndrome. This cost benefit is realized when facilities are located close to an existing liquid oxygen production plant or bulk storage hub, depending on the distribution model. However, although an ASU can affordably provide a large supply of oxygen, the time required to build and begin production will take longer than other generation modalities available, and construction is resource intensive. (For additional considerations, see 'Vacuum-insulated evaporator system' brief.)

## Acknowledgements

This brief is part of a larger series on technologies and equipment related to *Oxygen Generation and Storage*. It is intended to serve as a concise primer for decision makers that govern, lead, support, or manage health systems and provide a starting point for understanding the solutions available to meet a health system's need for medical oxygen and its delivery.

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## For more information

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