Making Medical Oxygen Work

A synthesis of supply chain analyses across the medical oxygen ecosystem in low-resource settings

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PATH

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The work described within the report was carried out as part of the Strengthening Oxygen Utilization and Respiratory Care Ecosystems (SOURCE) project, which is an initiative led by PATH to improve equitable access to high-quality respiratory care services at all levels of the health care system and, ultimately, to reduce maternal, child, and overall mortality from hypoxemia-related causes. Working closely with global and country stakeholders, the initiative supports governments and partners in focus geographies to advance efforts to reinforce oxygen and respiratory care systems as necessary components of national health care systems, pandemic preparedness, and global health architecture.

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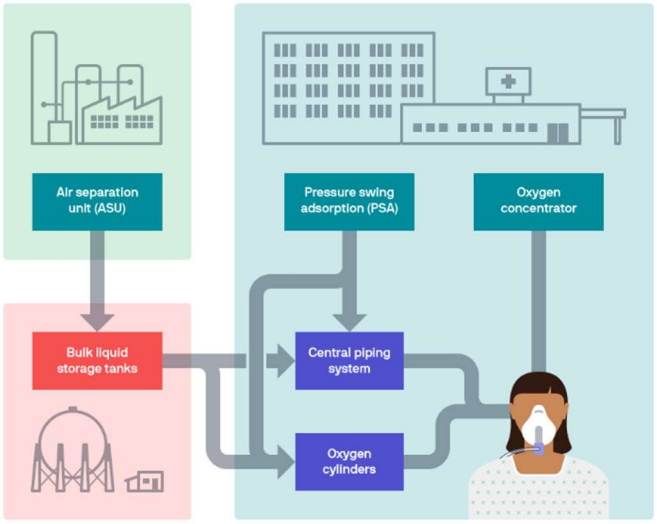
Abbreviations

BMES	biomedical equipment survey
DRC	Democratic Republic of the Congo
INNOVATE	Innovations for Enhanced Access to Oxygen
LOX	liquid oxygen
MGPS	Medical gas piping system
MOH	Ministry of Health
ODGF	Oxygen Delivery Gap Fund
OPEX	operational expenditure
PSA	pressure swing adsorption
RCE	respiratory care equipment
SCALE	Scaling Access to Lifesaving Equipment
SOURCE	Strengthening Oxygen Utilization and Respiratory Care Ecosystem

Introduction

Oxygen is an essential medicine and a key treatment for a wide range of conditions that affect all parts of the population, including obstetric emergencies, premature births, and pneumonia. Medical oxygen is primarily produced in three ways:

Figure 1. A snapshot of oxygen production and delivery methods.



1. **Air separation units** produce highly purified liquid oxygen (LOX), which can be converted into gas and stored in cylinders or taken via tanker truck to facilities with a liquid storage tank.
2. **Pressure swing adsorption (PSA) plants** are stand-alone oxygen generation systems—either at central filling hubs or on-site at health facilities—that extract oxygen from the air. The oxygen can be piped directly to patients' bedsides or stored in cylinders and administered from there.
3. **Oxygen concentrators** extract and concentrate oxygen from ambient air to provide a continuous supply to the patients' bedsides. In particular, spare parts, such as compressor kits, filters, valves, and circuit components, are required to ensure safe and proper functionality of PSA plants and oxygen concentrators as respiratory care equipment (RCE).

Producing oxygen is only one part of the system. To deliver oxygen therapy to patients, additional accessories and consumables are required, including nasal cannula and tubing; accessories to control pressure, flow, and concentration; and pulse oximeters to monitor patient's blood oxygen levels.

Appropriate maintenance and use of RCE and related devices require training of biomedical engineers and health care workers to manage this delivery system. Determining what the best oxygen generation and storage solutions are varies between and within countries. The oxygen production ecosystem in just one country can be incredibly complex and may require a mix of different business models to serve the context of each individual hospital and facility. Considerations like upfront capital, operating costs and maintenance, and infrastructure requirements will play into these decisions.

This report summarizes PATH's supply chain analyses for critical RCE and related products, highlighting key gaps, challenges, and opportunities for improvement. It provides background and recommendations for strengthening supply chain systems, and explores alternative models to improve reliability, affordability, and sustainability. Drawing on PATH's work across consumables, accessories, spare parts, piping systems, oxygen cylinders, PSA plants, and LOX, the report synthesizes insights to inform strategies that ensure continuous access to life-saving respiratory care in resource-constrained settings.

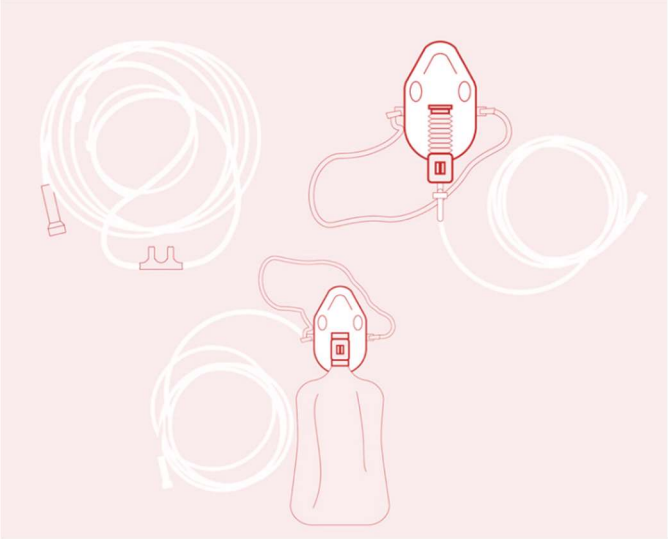
Accessories and consumables

Accessories and consumables refer to the essential items that support the safe and effective use of medical devices.

Accessories are components that connect to and ensure the proper operation of equipment, while enabling or enhancing its functionality, such as masks, tubing, or humidifiers for RCE.

Consumables are items that are depleted or require regular replacement during routine use, such as single-use nasal cannulas, disposable masks, or bacterial filters.

Figure 2. A visual of oxygen accessories and consumables.



In limited-resources settings, reliable access to these accessories and consumables is critical for maintaining continuity of care, preventing the spread of infections, maximizing the lifespan of often scarce respiratory devices, and making sure the limited respiratory devices available can continue to serve the greatest number of patients possible.

Current supply chain challenges

In many low-resource settings, the availability of accessories and consumables that support respiratory care remains severely constrained, undermining the effective use of available oxygen and respiratory support devices. Supply chain constraints, brand proliferation, and lack of systemic prioritization in national budgets and procurement plans frequently pose challenges to the consistent availability and inventory of critical accessories and consumables in health facilities.

In a 2023 respiratory care inventory conducted as part of biomedical equipment surveys (BMES) in DRC, Kenya, Senegal, Tanzania, and Zambia, consumables and accessories essential for delivering oxygen therapy, such as nasal cannulas, oxygen masks, and other oxygen delivery interfaces, exhibited wide variability in availability and frequent stockouts at health facilities.

- In the **Kenya** BMES, although many facilities reported having some consumables, distribution among 113 surveyed facilities was uneven: Only 72 percent had at least one nasal cannula, and 73 percent had at least one oxygen mask. This demonstrates that substantial proportions of facilities lacked these key items.[1] In many cases, the quantity of consumables varied greatly between facilities, reflecting inconsistencies in supply and inventory management.
- In the **Tanzania** BMES, although consumables like nasal cannulas and oxygen masks were present in some facilities, the majority of facilities surveyed reported having no stock of each measured consumable; for example, only 65 percent of 160 facilities reported having any nasal cannulas and 64 percent reported having any oxygen masks, leaving a significant share of facilities without these basic interfaces at the time of the survey.[2]

- In the **Senegal** BMES, findings also point to varying availability of small respiratory care devices and delivery interfaces, further demonstrating that consumable supplies are not uniformly present across health facilities and may limit access to oxygen therapy even where sources of oxygen are available.[3]

Together, these BMES data highlight that gaps and volatility in consumable and accessory stocks are common challenges in oxygen delivery systems. The many facilities that possess incomplete sets of necessary items for respiratory care underscores the need for strengthened supply chain and inventory management to ensure reliable access to oxygen therapy across health systems.

Further, gaps in access stem from broader weaknesses in the availability of respiratory care consumables and accessories: Tubing, masks, humidifiers, flowmeters, and filters are often missing, incompatible, or unaffordable. As a result, even when equipment is available, the lack of correct consumables can make it unsafe or unusable, increasing maintenance burdens and reducing performance. This leads to inconsistent care, protocols adjusted to fit limited supplies, and underuse of respiratory devices. In short, despite increased investment in equipment—especially during COVID-19—access to consumables remains a critical barrier that limits safe and reliable respiratory therapy.

Alternative supply chain and business models

Pooled procurement for accessories and consumables

Pooled procurement of RCE accessories and consumables consolidates demand across countries or subnational regions, enabling larger-volume purchases under shared agreements (see **Box 1** for examples). By aggregating demand, pooled procurement increases purchasing power, enables more favorable supplier terms, and reduces transaction and logistics costs—an important consideration for low-priced, high-volume items such as single-use adult Venturi oxygen masks (approximately US$1.13 per unit). This approach helps reduce stockouts, stabilize and lower prices, and ensure consistent product quality across participating facilities.

In addition to traditional framework agreements, regional pooled procurement can be implemented through:

- **Prime vendor models**: Purchasing is consolidated through a single primary supplier who sources and distributes products from multiple manufacturers.
- **Vendor-managed inventory**: A single supplier monitors and replenishes inventories.
- **Subscription-based models:** These provide recurring shipments based on forecasted demand and real-time consumption data.

Together, these coordinated approaches aim to improve forecasting and support reliable, uninterrupted access to essential oxygen delivery supplies.

Box 1. Examples of pooled procurement of accessories and consumables

The **Oxygen Delivery Gap Fund** (ODGF), under the Strengthening Oxygen Utilization and Respiratory Care Ecosystems (SOURCE) project, identified and used pooled procurement to address immediate gaps in RCE value chains to ensure global investments in bulk oxygen translate into oxygen availability at the facility level.

Requests from priority facilities—those with large catchment areas and/or a strong focus on maternal, newborn, and child health—in the DRC, Malawi, Kenya, Tanzania, and Zambia were consolidated into a single request for proposal for 119,101 products and fulfilled through a minimal number of suppliers. The impact reached an estimated 967,080 patients across 39 health facilities. Accessories and consumables proved to be the most cost-effective, with unit costs per patient of just US$0.15 and US$0.76.

This effort underscored the importance of locally driven and sourced procurement, particularly for widely available items like accessories and consumables, and positioned oxygen accessories as a high-impact investment area for future funding.

Under the **Innovations for Enhanced Access to Oxygen (INNOVATE)** project, which focuses on addressing critical barriers to oxygen access in India, Kenya, Malawi, Nigeria, and Senegal. Under this project, PATH and partners will pilot and evaluate models to simplify the procurement of RCE accessories and consumables. The INNOVATE approach combines pooled procurement with complementary mechanisms such as prime vendor and subscription-based models.

By shifting from reactive ordering to predictive, supplier-managed fulfillment, these approaches are expected to improve product availability, smooth procurement cycles, and reduce administrative burden for health systems, ultimately strengthening the sustainability of oxygen delivery systems in priority geographies.

Spare parts

Spare parts refer to components of medical equipment, such as compressor kits, filters, valves, and circuit components, used to maintain medical devices and ensure safe and proper functionality for the lifespan of a given device. In the medical- and respiratory-care space, spare parts and spare parts kits are essential for routine, manufacturer-recommended maintenance for many medical devices and equipment.

Spare parts kits are also essential for emergency maintenance needs, such as when a device breaks down or unexpectedly becomes nonfunctional. Proper management of spare parts, the procurement of spare parts, and inventory management systems are essential supply chain components to maintain safe health facility operations and ensure medical device functionality and patient access.

Current supply chain challenges

In resource-limited settings, supply chains for RCE spare parts face persistent challenges that undermine the reliability and sustainability of oxygen delivery systems. In Malawi, a PATH assessment of priority medical devices found that 18 percent of available devices were reported as nonfunctional, with a lack of spare parts supply cited as a contributing factor.[4]

Spare parts are often difficult or impossible to source locally, requiring importation that can cause long lead times, high costs, and frequent delays. Spare parts are also often needed in low quantities at individual health facilities and at intervals that are challenging to predict.

These unplanned or reactive ad hoc procurement practices create significant procurement limitations and implications in the public sector. This is often further exacerbated by a lack of data availability and inventory management systems at the facility level. Because of this, orders for spare parts are often placed reactively and in very limited quantities when spare parts or kits are already urgently needed to restore functionality.

Furthermore, because spare parts are often specific to the make and model of medical device, there are often a limited number of suppliers, many of which are based outside the country. In the absence of reliable forecasting and standardized maintenance systems, these constraints lead to frequent delays in repair and prolonged equipment downtime, leaving RCE underutilized despite substantial capital investment.

Alternative supply chain and business models

Pooled procurement and local inventory holding for spare parts

Like for accessories and consumables, a pooled procurement mechanism consolidates demand across multiple countries or subnational regions to purchase products in larger quantities (see **Box 2** for an example). As any one facility likely procures spare parts in very small quantities, pooling procurement is essential to achieving the volumes necessary to incentivize regional distributors to hold inventory locally rather than ordering them reactively upon request.

Locally held inventory would reduce lead times to receive spare parts, which is particularly important given the often-responsive nature of spare parts ordering; when a health facility orders a spare part, they

need it quickly to minimize equipment downtime and ensure lifesaving medical oxygen can be delivered. Stocking spare parts locally reduces transportation distances and timelines, which then decreases both lead times and logistics costs.[5]

Effective pooled procurement models for spare parts rely on three enabling elements:

- A defined essential spare parts list linked to commonly deployed equipment.
- Demand-forecasting mechanisms that translate maintenance requirements into aggregated demand signals.
- Procurement arrangements that provide distributors with sufficient volume certainty to justify holding stock locally.

When implemented well, this approach shifts spare parts supply from ad hoc, emergency purchasing toward a more proactive, planned, and sustainable system.

Box 2. Example of pooled procurement of compressor service kits

In partnership with i+solutions and RIX Industries, PATH piloted a **centralized procurement mechanism for RIX oxygen compressor service kits** to improve timely access to critical spare parts for PSA oxygen generation plants. The pilot tested whether consolidating demand could ease supply bottlenecks and decrease lead times for facilities. This particular consolidation model pilot provided supply chain advantages and demonstrated cost-effectiveness, including a 50 percent reduction in logistics costs and 26 percent reduction in average purchasing costs. The pilot also demonstrated a 3- to 6- month reduction in product lead time.

The experience of Botsabelo Hospital in Lesotho illustrates the impact of this approach. Biomedical engineers at the facility historically relied on importing parts and contracting external maintenance teams from South Africa, leading to delays of weeks or months before repairs could occur. This would leave the oxygen plant offline, losing over 12,000 L of oxygen during a one-month outage. Once the hospital obtained its service kits and bolstered local technical capacity, downtime dropped such that the plant experienced no more than two days of non-operation. This case illustrates how spare parts scarcity, long lead times, reliance on external suppliers, and weak local maintenance infrastructure jeopardize continuity of care, and how targeted supply chain interventions can mitigate those risks.

Demand forecasting and market engagement to enable pooled procurement

Reliable pooled procurement requires improved visibility into spare parts demand. Historically, forecasting this demand has been difficult due to equipment brand proliferation, limited maintenance record keeping, and inconsistent reporting from facilities. To address this challenge, a structured forecasting technique such as the Delphi method, which gathers expert opinions through repeated questionnaires, can offer an alternative way to estimate spare parts demand for respiratory care equipment (see **Box 3** for examples).

Data from multiple sources, such as facility equipment inventories, essential spare parts lists, manufacturer-recommended maintenance schedules, and expert validation from biomedical engineers, can be used to estimate annual spare parts demand across device types and health system levels. By translating fragmented and often qualitative information into quantified, aggregated demand estimates, the process generates credible demand signals for governments and partners to plan budgets, engage suppliers, and enable pooled procurement.

Designed to be adaptable across contexts, the Delphi method offers a practical solution for strengthening spare parts market access and reducing equipment downtime in resource-constrained health systems.

Box 3. Examples of forecasting spare parts demand in Malawi and Kenya

As part of the **Strengthening Oxygen Utilization and Respiratory Care Ecosystems (SOURCE)** project, PATH collaborated with the Malawi Ministry of Health (MOH) to develop spare part demand forecasts in the country using the Delphi method. PATH developed an essential spare parts list, quantified annual needs for 12 device types, and estimated annual budget requirements ranging from 23,965 to 73,581 spare parts (median 32,036 units) at an approximate cost of MWK 801 million. The forecast has allowed the Malawi MOH and partners to translate maintenance needs into predictable, aggregated demand signals that can reshape how the market responds. Building on this forecast, PATH is assessing pooled procurement models designed to encourage distributors to maintain local stock, which has the potential to reduce delays, minimize stockouts, and strengthen the sustainability of respiratory services.

Under the SOURCE and **Scaling Access to Lifesaving Equipment (SCALE)** projects, PATH supported the Kenya MOH with scalable tools for strategic spare parts management, which has resulted in quantification and costing tools and improved procurement guidance and recommendations. Further, PATH developed a tool that estimates the return on investment for device maintenance, with assumptions and outputs validated by the Nairobi-based medical engineers. This work and additional findings will be presented to the county health management team to support budgeting decisions and prioritize maintenance within those budgets. In practice, however, supply chain gaps remain a major vulnerability.

Medical gas piping

Medical gas piping systems (MGPS) deliver medical oxygen through fixed piping, enabling more efficient patient treatment compared with oxygen cylinders or bedside concentrators. Given a bulk oxygen source, such as a PSA plant or LOX, is available and operational on-site, an MGPS ensures oxygen is conveniently available at patients' bedsides.

Pre- and post-MGPS installation surveys conducted by PATH with biomedical engineers at Livingstone Hospital in Zambia found that patients could be connected to oxygen via piping in as little as 2 to 5 minutes, compared with approximately 15 minutes when using cylinders.[6] The longer connection time for cylinders is driven by transport delays, including the time required to locate a full cylinder, transport it from storage areas to the ward, maneuver it within crowded clinical spaces, and safely secure and connect it at the patient's bedside.

In health facilities lacking MGPS infrastructure, reliance on bedside cylinders and concentrators limits continuous and efficient oxygen delivery. In critical wards, such as surgical units, high-dependency units, and intensive care units, an MGPS can reduce reliance on bedside cylinders—easing supply chain constraints and reducing the burden on health facility staff.[7]

Current supply chain challenges

In well-resourced settings, hospitals and a number of lower-level health facilities are often equipped with an MGPS and bedside outlet infrastructure, offering hypoxemic patients uninterrupted medical oxygen supply.[8] In very low-resource settings, few facilities are equipped with piped oxygen and instead rely on one of the two decentralized methods of oxygen delivery. This entails either performing the logistically intensive operation of constantly refilling and swapping out bedside cylinders or having a fleet of concentrators that require regular maintenance and reliable electricity.

PATH's 2023 BMES in the DRC, Kenya, Senegal, Tanzania, and Zambia found that only 19 percent of facilities with bulk oxygen sources (PSA, LOX, and/or cylinder manifold) had MGPS installed in at least one ward, typically in secondary and tertiary hospitals. Even in facilities with piping, availability was limited to critical wards for oxygen therapy, such as intensive care units, neonatal intensive care units, surgical wards, or emergency rooms. This pattern demonstrates the large gap in critical infrastructure for efficiently delivering available oxygen to patients at the bedside.

Alternative supply chain and business models

Technical options to address facility design, materials, and installation challenges

Under the SOURCE project, PATH and Build Health International investigated five innovative technical options spanning facility design, material and component sourcing, and installation that could help alleviate barriers to piping installation and therefore increase MGPS adoption in low-resources settings.[9] The goal of this initiative was to prompt global discussion on increased adoption of high-quality MGPS and address the unmet need for sustainable and uninterrupted lifesaving oxygen in resource-constrained settings. Of the innovative solutions proposed, the following two were found to have the potential to alleviate piping-related supply chain challenges:

On-site cleaning of copper piping rather than cleaning via manufacturer

Instead of relying solely on pre-cleaned, bagged, and capped copper piping furnished by manufacturers—which is often supply-constrained and frequently imported—on-site cleaning under controlled conditions allows health systems to leverage the more readily available, locally produced, non-bagged, non-capped copper more commonly found in African markets.

By enabling locally sourced copper to be cleaned to medical-use standards at the installation site, rather than being shipped abroad for cleaning and recapping and then re-imported, this approach can significantly reduce cost and logistic burdens. It also minimizes contamination risks during shipping and handling, gives installers immediate control over cleanliness verification, and offers greater flexibility to adapt processes to specific project needs.

Together, these advantages can shorten lead times, decrease dependence on imported cleaned stock, and strengthen regional supply chain resilience.

Air-conditioning/refrigeration (ACR) copper tubing for medical gas piping

This model proposes expanding procurement options by using materials that are readily available in local markets. ACR copper tubing is typically more widely available and has a lower cost than specialty medical gas tubing. Using it offers potential cost savings and greater supply chain flexibility, provided it is appropriately cleaned and qualified for medical gas use. The innovation lies in adapting ACR copper tubing for clinical environments and ensuring compatibility with the standards for medical gas service standards.

By broadening material choices and reducing reliance on highly specialized imports, this model could make it easier, cheaper, and faster to procure the materials needed for piping installation, improving the ability to expand piping infrastructure across low-resource settings.

Oxygen cylinders

Oxygen cylinders remain one of the most widely used modalities for delivering medical oxygen in low-resources settings, where an estimated 73 percent of health facilities rely on cylinders as their primary oxygen source for both routine and emergency care.[10] Cylinders are often the only feasible option for remote or lower-level facilities that lack the infrastructure, power reliability, or financing needed for on-site generation systems such as PSA plants.

Yet in many low-resource health systems, oxygen cylinders move through complex, fragmented distribution networks that depend on long transport routes, manual record keeping, and limited supplier competition—conditions that heighten the risk of stockouts and interrupt continuity of care. These challenges are compounded by maintenance backlogs, unpredictable turnaround times for refilling, and limited visibility into consumption and availability across facilities.

Figure 3. A visual of typical oxygen cylinders.

As a result, cylinders—despite remaining essential to oxygen delivery in low-resource settings—often fail to reach the facilities and patients that need them most, underscoring the importance of supply-chain strengthening and new service delivery models.

Current supply chain challenges

Despite their central role in oxygen delivery in low-resource settings, health facilities face significant challenges in ensuring an uninterrupted supply of oxygen cylinders to meet patient needs. Health facilities often face severe information gaps that stifle their ability to know when cylinders should be transported, refilled, or replaced.

Central to these challenges is a lack of robust cylinder inventory tracking systems. Without such systems, health facilities cannot effectively monitor cylinder inventory levels, track oxygen usage, accurately predict oxygen needs, and optimize cylinder distribution, refill, and replacement processes. This often results in cylinder shortages in health facilities with oxygen demand, excesses in facilities without demand, and an accumulation of empty or broken cylinders at facilities that are waiting to be refilled or replaced.

Alternative supply chain and business models

Cylinder tracking technology for cylinder inventory management

Traditional supply chains for cylinders are plagued by inefficiencies caused by weak inventory management, long refill lead times, and frequent mismatches between supply and demand. Facilities often face shortages in high-demand areas while other sites accumulate excess or empty cylinders awaiting replacement. A central barrier is the absence of robust tracking systems that allow health ministries, facilities, and suppliers to monitor cylinder locations, usage rates, and maintenance needs in real time.

An alternative business model involves introducing cylinder inventory tracking systems in resource-constrained settings. These systems use simple and affordable technologies, such as bar codes, quick

response (QR) codes, near field communication (NFC) tags, and RFID tags (as described in **Box 4**) to monitor cylinder movement, consumption, and availability. Additional options on the market include GPS and weight-sensing platform technologies.

By providing visibility into stock levels and distribution patterns, these systems help facilities and governments predict demand, optimize delivery schedules, reduce losses from misplaced or damaged cylinders, and enhance patient safety through leakage and theft detection. Payment models for such tracking technology could include leasing or subscription options to spread costs and reduce upfront investment.

With support for governments in cost-benefit analyses, procurement decisions, and pilot implementation, this approach offers a scalable and sustainable pathway to strengthen oxygen cylinder supply chains and ensure uninterrupted patient access in resource-constrained settings.

Box 4. Example of cylinder inventory tracking pilot in India

PATH piloted three oxygen cylinder tracking models in India during the COVID-19 pandemic, each with distinct benefits and trade-offs.

- In **Delhi**, a QR code system tracked 40,000 cylinders at low cost (US$0.20–$0.24 per tag) but required manual scanning by staff.
- In **Uttarakhand**, a hybrid RFID and QR code system enabled simultaneous tracking of multiple cylinders and detailed data capture, though high scanner costs (US$700–$1,000 each) limited scalability.
- In **Karnataka**, an intelligent weight-sensing platform monitored real-time consumption, predicted shortages, and automated reorders using 48 units, but leasing costs (US$75 per platform for two months plus installation fees) posed barriers to scale.

Collectively, these pilots showed how different technologies can improve visibility, efficiency, and reliability in oxygen cylinder supply chains, though affordability and sustainability remain key considerations for adoption in low-resources settings.

Hub-and-spoke model for filling and distributing oxygen cylinders

A hub-and-spoke model for cylinder filling and distribution is a coordinated service delivery approach in which a centrally located *hub* facility fills oxygen cylinders, using either an on-site PSA plant or liquid oxygen, for distribution to surrounding *spoke* facilities.

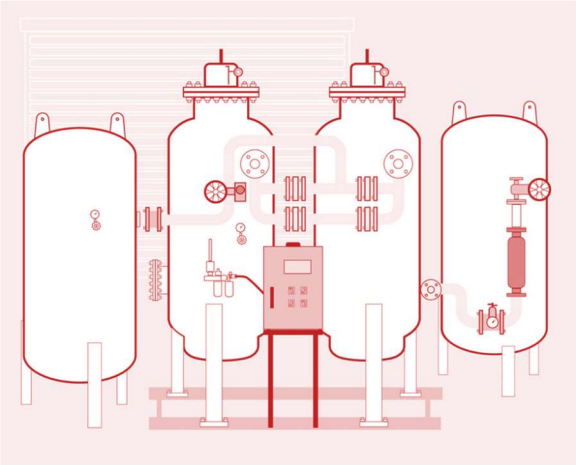
To serve as a hub, a facility must have excess oxygen production capacity, meaning its PSA plant can produce more oxygen than required for its own clinical use. Spoke facilities then receive filled cylinders on a scheduled or demand-driven basis, reducing the need for redundant infrastructure and technical capacity at smaller or lower-volume sites.

By aggregating cylinder demand across both hub and spoke facilities, the PSA plant operates at a higher and more consistent utilization rate, closer to its full capacity. Higher use improves cost-effectiveness, as PSA plants running for longer hours—ideally approaching continuous (24/7) operation—achieve lower costs per unit of oxygen produced.

Overall, the hub-and-spoke model aims to strengthen supply reliability, reduce per-unit oxygen costs, and improve last-mile access. This is particularly beneficial for facilities unable to justify or sustain on-site oxygen production, while also supporting a more efficient and financially viable subnational or regional oxygen system.

Pressure swing adsorption plants

Figure 4. A visual of a pressure swing adsorption plant.



Pressure swing adsorption (PSA) oxygen generation plants play a central role in respiratory care ecosystems across low-resources settings, serving as a primary on-site source of medical oxygen production for secondary and tertiary facilities. PSA plants extract oxygen from ambient air and deliver it directly at the bedside or via cylinder filling, reducing dependence on external oxygen suppliers and enabling more self-sufficient oxygen systems.

Hundreds of PSA plants were procured during the COVID-19 pandemic to close urgently needed oxygen gaps across low-resource settings, yet these systems now operate within a market characterized by fragmented demand, variable infrastructure, and unpredictable funding cycles.[11] As a result, PSA plants have become an important focus within market-shaping and RCE supply chain planning efforts, especially as countries seek sustainable models that protect the large capital investments made during the pandemic.

Current supply chain challenges

Despite their importance, PSA plants in low-resource settings face persistent operational, financial, and supply chain constraints that threaten their long-term sustainability. Ongoing operational expenditures (OPEX), including electricity, skilled labor, maintenance kits, and spare parts, make up more than 70 percent of total plant lifetime costs, far exceeding initial capital expenditures. Many facilities struggle to forecast effectively for these recurring costs. This can lead to frequent downtime, delayed repairs, and reduced plant lifespan, often shortening the expected 15–20 years to as little as 5–10 years due to inadequate maintenance and long spare-part lead times.[12]

Additionally, PSA plants are often customized to individual facility needs, resulting in dozens of plant configurations and long manufacturing lead times of 12–16 weeks or more. This customization, combined with disaggregated purchasing and fragmented demand, makes it difficult for manufacturers to forecast component needs, contributing to market inefficiencies and long lead times for PSA plant maintenance and repair.

These structural issues are compounded by environmental and system-level constraints. Electricity costs in low-resource settings can range from 5 to more than 60 percent of total production cost depending on the setting—making oxygen generation highly sensitive to grid reliability and energy prices.[13] Moreover, donors and governments face uncertainty around true national oxygen needs, creating unpredictable demand patterns that complicate oxygen production planning and contribute to periodic shortages or overproduction.

The COVID-19 pandemic amplified these dynamics: Sudden surges overwhelmed manufacturer capacity, while post-pandemic declines have left suppliers unsure how to scale future production. Finally, many

facilities lack the infrastructure (e.g., piping, adequately ventilated plant rooms, or stable power) required to install or fully utilize PSA plants.

PATH estimates that roughly 200 facilities across 95 countries could immediately benefit from PSA plants, as they have the infrastructure to support them; around 300 more could also benefit, but only after significant upgrades.[14]

Together, these challenges illustrate that sustaining PSA plant operations in low-resource settings requires not only equipment procurement but also deeper investment in market-shaping strategies, standardized plant design, reliable financing for OPEX, and strengthened supply chains for spare parts, maintenance services, and skilled personnel.

Alternative supply chain and business models

Plant size standardization and demand consolidation

An alternative business model for PSA-based oxygen generation includes standardizing plant sizes and consolidating demand to reduce supply chain inefficiencies.[15] Specifically, rather than each hospital ordering a custom-built PSA unit, the alternative model offers a few standardized plant sizes that meet the needs of the vast majority of facilities.

This approach helps improve predictability and enables several supply chain and cost-efficiency advantages, including:

- Manufacturers can pre-produce components and maintain inventory (“produce to stock”) rather than wait for bespoke orders, helping reduce lead times and enable faster deployment.
- Standardization reduces the complexity and diversity of spare parts and maintenance kits, easing spare-parts proliferation and simplifying logistics for maintenance over the plant’s lifetime.
- This approach makes it more feasible to deploy innovative financing or service-oriented business models (e.g., leasing plants with a contracted maintenance provider).

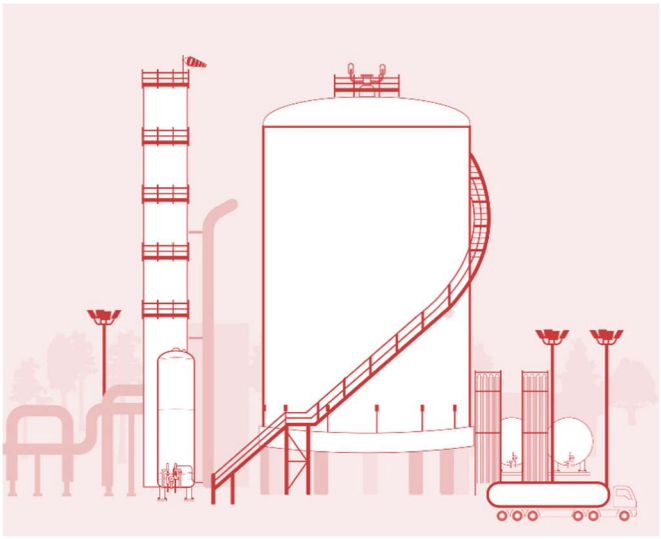
This model transforms the PSA-plant market from a highly fragmented, custom-order system into a more coordinated, demand-aggregated, and maintainable supply chain ecosystem. It also helps align manufacturer incentives, loosen supply bottlenecks, and support the long-term sustainability and scalability of oxygen generation infrastructure in low-resource settings.

Liquid oxygen (LOX)

Liquid medical oxygen is oxygen produced by cooling ambient air to extremely low temperatures until it condenses into liquid form, allowing it to be separated from other gases, then stored and transported in large volumes. Once delivered to a health facility, LOX is converted back into gaseous oxygen using an evaporator.

Once ready, the gaseous oxygen can be piped directly into wards or used to fill cylinders, depending on health facility infrastructure. In high-income countries, LOX is commonly used in health systems as a highly efficient mechanism for oxygen supply, transport, and storage: 1 L of LOX equates to around 860 L of gaseous oxygen, meaning hospitals can store large amounts of oxygen in a relatively small footprint.

Figure 5. A visual of an air separation unit where liquid oxygen is produced.



Additionally, LOX infrastructure, once installed, has minimal maintenance needs in comparison with PSA plants, concentrators, and cylinders. Currently, LOX is the premium choice for large hospitals with large oxygen demand where roads, electricity, and suppliers are both available and reliable.

While LOX has the potential to provide reliable oxygen access to regional hospitals and act as a buffer during demand surges, its integration into low-resource health systems is shaped by the availability of production facilities, transportation infrastructure, and the readiness of hospitals to safely store and maintain bulk liquid oxygen supply.

Current supply chain challenges

In low-resource settings, LOX supply chains face four major challenges that limit their reliability and scalability for health facilities:

1. **Production is not available everywhere.** LOX can only be generated at large air separation units, which are unevenly distributed across regions, leaving many facilities dependent on distant plants.
2. **Transportation logistics are complex** because LOX is a hazardous material that requires specialized trucks, trained drivers, and strict safety protocols, all of which increase costs and risk.
3. **There are limited distributors**. The high costs of distribution, combined with the need for driver training and accurate supply-demand matching, make the business model less appealing, which can lead to frequent shortages or inefficiencies.
4. **Destination limitations constrain facility readiness**. Many health facilities lack the necessary tank infrastructure, evaporators, or safety systems for LOX storage and use, and while maintenance requirements are not extensive, they still require oversight.

Alternative supply chain and business models

Dynamic delivery scheduling and subscription-like replenishment services

Alternative supply chain structures for LOX can improve availability in low-resource settings by shifting away from ad hoc, order-based procurement toward more proactive delivery models. Dynamic delivery scheduling uses real-time or regularly updated data on on-site oxygen levels and consumption to adjust delivery timing and volumes, reducing stockouts and enabling more efficient production and logistics planning.

The same data infrastructure can also support subscription-like replenishment services, where suppliers commit to maintaining agreed-upon minimum oxygen levels at health facilities in exchange for predictable, recurring payment. This aligns supplier incentives with continuous availability rather than per-delivery sales.

By improving visibility across the supply chain, distributors are better positioned to coordinate deliveries across multiple facilities in a single run, reducing costly last-minute trips and strengthening overall system sustainability. Together, these approaches stabilize demand for LOX suppliers, improve logistics efficiency, and enhance accountability for reliable oxygen supply.

LOX micro bulk tanks

LOX micro bulk tanks offer a promising alternative supply chain model for extending reliable oxygen access to facilities underserved by traditional oxygen sources (see **Box 5** for an example). In this model, micro bulk LOX tanks are installed at multiple health facilities within a LOX distributor's catchment area.

Because a single micro bulk tank represents a relatively small volume (substantially below the capacity a LOX truck carries), distributors cannot cost-effectively deliver LOX to just one micro bulk tank. Instead, multiple tanks across several nearby facilities must be refilled in a single delivery run.

Compared with cylinders, micro bulk tanks provide higher-volume, on-site storage—enabling smaller facilities to maintain reliable oxygen supply, improve system resilience, and access LOX at competitive per-unit prices.

Box 5. Example of LOX micro bulk tank pilot

Under the **Innovations for Enhanced Access to Oxygen (INNOVATE)** project, PATH aims to pilot LOX micro bulk tank refilling. With new investments in LOX production facilities in East Africa, micro bulk tanks offer an opportunity to expand the impact of new air-separation units beyond large regional facility needs—potentially solving for oxygen production shortages in more rural facilities. While the micro bulk tank pilot will address the limitations of smaller facilities that may lack consistent electricity, other limitations would remain, including the regional production capacity of LOX and the challenging logistics required for transport.

Conclusion

Across the respiratory care ecosystem, access to medical oxygen in low-resource settings is hindered by interconnected supply chain weaknesses spanning accessories and consumables, spare parts, cylinders, medical gas piping, PSA plants, and LOX. Even where oxygen generation capacity exists, inconsistent availability of consumables, delayed access to spare parts, fragmented procurement, limited inventory visibility, and infrastructure constraints frequently prevent oxygen from reaching patients reliably and safely.

The supply chain analyses described in this report highlight common patterns—disaggregated demand, reactive procurement, and lack of data—which undermine system performance, leading to equipment downtime, inefficiencies, and inequitable access.

The findings also point to a number of specific recommendations:

- Strengthening oxygen systems requires shifting from ad hoc, product-by-product procurement toward coordinated, data-driven supply chain and service delivery models that prioritize reliability, sustainability, and scale.
- Pooled procurement, demand consolidation, standardized equipment configurations, inventory tracking technologies, hub-and-spoke distribution models, and subscription-based or service-oriented approaches can collectively reshape oxygen markets and improve supplier incentives.
- For governments, donors, and partners, the *so what* is clear: investments in oxygen must extend beyond hardware to include supply chain design, maintenance ecosystems, and market-shaping interventions.

By addressing these structural barriers, countries can protect prior capital investments, reduce total system costs, and ensure that lifesaving oxygen is consistently available to the patients who need it most.

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