BRING O2

LESSONS LEARNED

Partners In Health

Building Reliable Integrated and Next Generation Oxygen Services

Lessons learned and future directions

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Partners In Health

ABBREVIATIONS

BHI	Build Health International
BRING O2	Building Reliable Integrated and Next Generation Oxygen Services
C19RM	COVID-19 Response Mechanism
COVID-19	2019 novel coronavirus
CHU-A	Centre Hospitalier Universitaire Andrainjato
DALY	Disability Adjusted Life Years
DHMT	District Health Management Team
ECC	Emergency and critical care
EWS	Early warning system
HCW	Health care worker
L/min	Liters per minute
M&E	Monitoring and evaluation
MOH	Ministry of Health
NCD	Non-communicable disease
OEM	Original equipment manufacturer
PIH	Partners In Health
PSA	Pressure swing adsorption
PSI	Pounds per square inch
SLA	Service level agreement
SpO2	Oxygen saturation
VIE	Vacuum insulated evaporator
WHO	World Health Organization

A patient receives treatment at Lurin Oxygen Center, Peru
Photo: Socios En Salud/PIH

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A specialized BRING O2 cylinder truck delivers oxygen in Lesotho
Photo: Zach DeClerk / PIH

INTRODUCTION

Partners In Health (PIH), a non-profit, social justice organization striving to make health care a human right for all people, is committed to strengthening oxygen ecosystems. Unfortunately, access to oxygen therapy—a lifesaving treatment for numerous acute and chronic conditions, including COVID-19, bacterial pneumonia, HIV/TB, and non-communicable diseases and essential for safe birth, protecting premature newborns, and operative care—remains limited in many countries. As a result, 80% of the nearly 40 million patients who need oxygen each year in low- and middle-income countries don't get it,[1] leading to countless unnecessary deaths.

For decades, PIH has worked to ensure the facilities we support have the right staff, stuff, space, systems, and social support to help patients in need of timely and lifesaving oxygen therapy. PIH and our partners focus on addressing the fundamental barriers to equitable oxygen access, from policy to plant to patient. This work became even more urgent due to the COVID-19 pandemic, which drew new levels of attention to the global oxygen crisis and strained already weak oxygen ecosystems beyond the point of collapse. By the time COVID-19 was declared a pandemic, PIH was already urgently working across its care delivery country site network, leveraging decades of oxygen ecosystem expertise, to accompany our ministry of health partners in augmenting and reinforcing oxygen ecosystems.

BRING O2

In December 2021, with funding from Unitaid and in partnership with Build Health International (BHI) and Pivot Madagascar, PIH launched Building Reliable Integrated and Next Generation Oxygen Services, or BRING O2, to accelerate access to safe, reliable, and quality oxygen in Malawi, Rwanda, Peru, Lesotho, and Madagascar (Figure 1). BRING O2's main objectives were to increase oxygen delivery capacity and access by alleviating oxygen supply and demand pressures; to improve oxygen equipment, delivery, and logistics; and to provide technical assistance, training, and systems support.

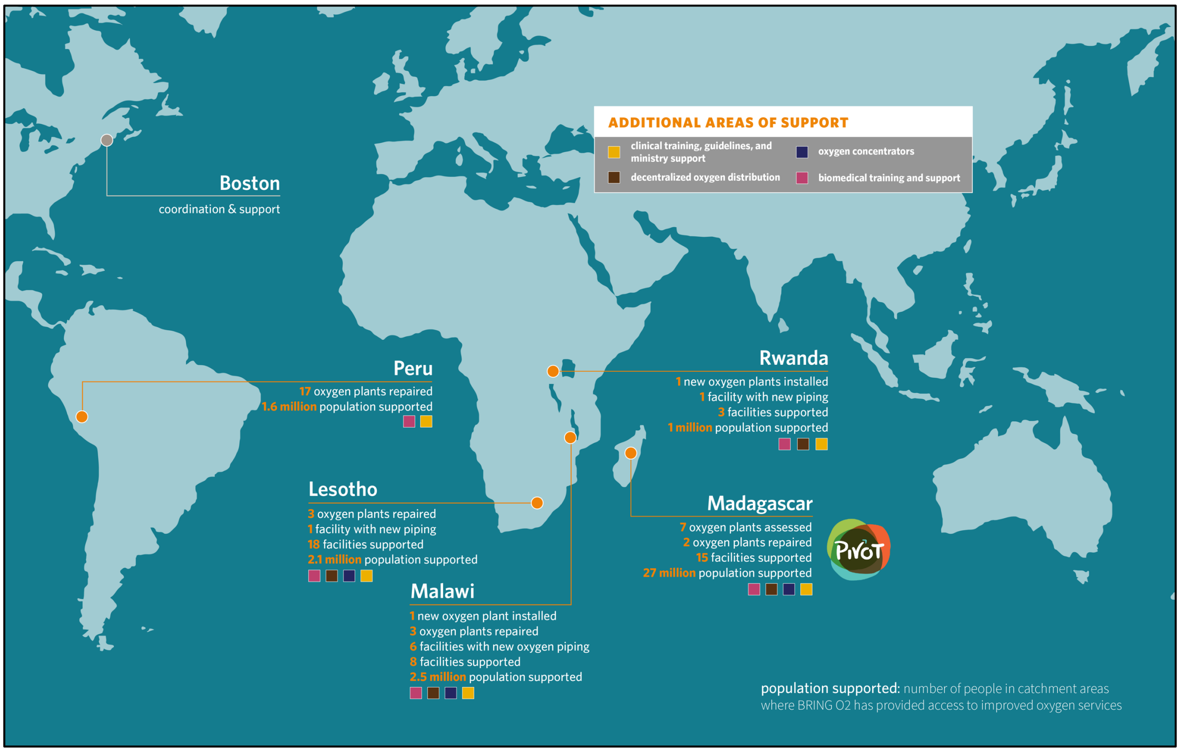
Accomplishments

Over the course of the grant period, which ended in December 2023, BRING O2 has met or exceeded all project milestones (Appendix A) and made tremendous advancements in oxygen access on a global scale. Over two years, BRING O2 purchased or repaired 27 oxygen plants, repaired or installed 234 oxygen concentrators, installed piping to deliver oxygen to over 500 hospital beds, established several strong regional oxygen distribution networks, and trained 146 biomedical staff and 479 clinical staff. Overall, the project has unlocked over 14,395m^3 per day of oxygen capacity—enough to treat over 130,375 patients per year.

Document aims

Drawing on the experience and insights of the PIH BRING O2 team over the past two years, this document aims to identify and describe key challenges, lessons learned, and future opportunities in implementing oxygen ecosystem strengthening initiatives.

Figure 1. Map of BRING O2 activities



PART I: GOVERNANCE AND COORDINATION

Every oxygen ecosystem is reliant on engagement from multiple stakeholders. Avoiding duplication and aligning efforts within coherent regional and national strategies can present a challenge and requires significant coordination.

Whole of government approach

Due to the cross-cutting nature of oxygen work, multiple government offices and authorities needed to review and approve BRING O2 activities. It is important to distinguish this issue from stakeholder coordination—external stakeholders have limited influence over internal government approval processes. Experience from BRING O2 led to the observation that oxygen ecosystems require additional mechanisms to ensure a "whole-of-government" approach. A recent WHO report, *Promising practices and lessons learnt in the South-East Asia Region in accessing medical oxygen during the COVID-19 pandemic,* made similar observations:

> The whole of the government working together to strengthen the oxygen infrastructure has been the standout feature of the pandemic response. For example, in many countries, either the Ministry of Industries or the Ministry of Commerce was responsible for procuring oxygen and oxygen devices, whereas the Ministry of Transport or its equivalent was managing oxygen logistics. Other ministries, apart from the Ministry of Health, were engaged in deploying oxygen solutions at health facilities. These interdepartmental collaborations were observed in several Member States, such as India, Indonesia, Nepal and Sri Lanka.
>
> The whole-of-the-government approach improved coordination, reduced interdepartmental squabbles and enhanced response to the pandemic.[2]

Intra-governmental coordination in Malawi

Within the Malawi Ministry of Health, the primary entities coordinating oxygen work are the Directorate of Health Technical Support Services and the Physical Assets Management Section, with some decentralized responsibilities falling to District Health Management Teams (DHMTs). This diffusion of responsibility likely contributed to the time BRING O2 has spent coordinating among these offices.

Intra-governmental coordination in Madagascar

In 2022, Madagascar organized an intra-governmental oxygen coordinating team within the Unité de Coordination des Projets of the Ministère de la Santé Publique. This team has helped facilitate approvals for BRING O2 activities. Of note, Lesotho's national oxygen strategy, to which the BRING O2 team has contributed, includes a provision establishing a similar intra-governmental coordinating office.

EXAMPLES FROM BRING O2	
Activity	**Details**
2.3.6. Implement recommended repairs for minimum of 15 plants in Peru	For each PSA plant repair, the BRING O2 team had to meet with three levels of government (municipal, regional, and national) to obtain approvals.
2.5.1. Procure and install one PSA plant at Chikwawa facility in Malawi	The process for finalizing PSA plant specifications was complex and at times ad-hoc. After securing approval from multiple government offices, a last-minute request to revise specifications was made by the MOH, which necessitated re-securing approvals.

Electricity for oxygen infrastructure

Unreliable electricity poses significant short- and long-term risks to key oxygen infrastructure, including PSA plants. In the short-term, interruptions in power supply can lead to unplanned PSA plant downtime, disrupting oxygen production and potentially putting patients at risk. Over the long-term, recurrent electrical disruptions accelerate the deterioration of sensitive equipment including compressors, sieve beds, sensors, and control units, increasing operation and maintenance costs while shortening the PSA plant's service life.

Connecting a new PSA plant to the electrical grid is a multi-step process, starting with an assessment of existing electrical infrastructure capacity and reliability. These assessments often identify critical repairs and upgrades, such as installing transformers, ensuring proper grounding, and upgrading power lines, which must be undertaken before installation of the PSA plant. Preventative measures to protect the plant from power disruptions and poor-quality electricity, including surge protectors, voltage regulators, and backup power systems, should also be considered. Correcting issues such as voltage stability or frequency fluctuations requires collaboration with the local utility provider. BRING O2 has found that it is important to initiate discussions with local utility providers early in the process.

At Chikwawa District Hospital in Malawi, BRING O2 completed a series of electrical infrastructure upgrades based on assessments performed early in the project. The work included upgrading the hospital's main distribution board and improving the overall safety and quality of electricity delivered to the facility. In addition, BRING O2 upgraded electrical utility feeder cables, which would allow the new PSA plant, once installed, to operate on power from the electricity utility, ESCOM. Finally, the team installed a diesel generator to provide a reliable backup power source, ensuring continuous electricity supply during ESCOM outages and the continuous availability of high-quality medical oxygen.

Stakeholder coordination

In general, duplication risks are significantly reduced in the presence of active, multi-stakeholder coordination mechanisms (e.g., national oxygen taskforces). In Malawi and Lesotho, where oxygen taskforces are well-established, BRING O2 encountered relatively few challenges related to duplication of effort. Furthermore, any issues that did arise were easily addressed. In contrast, Madagascar did not have a well-established oxygen taskforce prior to BRING O2.

EXAMPLES FROM BRING O2

Activity	Details
2.3.2. Implement recommended repairs for four plants in Madagascar	Several months into the grant period, BRING O2 became aware of overlapping activities planned by Unicef Madagascar. To avoid duplication of effort and align activities for maximum impact, BRING O2 collected and synthesized all available information related to Unicef's activities and convened several stakeholder meetings to coordinate reprogramming.
3.1.3. Produce technical drawings, procure, and install medical oxygen piping for 3 facilities in Rwanda	Several months into the grant period, the Rwanda Biomedical Centre launched a piping initiative at 11 hospitals, including BRING O2 piping sites (Butaro, Kirehe, and Rwinkwavu). To avoid duplication of effort and enhance impact, BRING O2 has reprogrammed Rwanda piping activities to focus on the ICU in Rwinkwavu.

Oxygen ecosystems and climate change

To date, the impact of climate change on oxygen ecosystems has not been considered in detail or integrated into project planning. The experience of BRING O2 suggests that this needs to change. There are multiple interfaces between climate and oxygen ecosystems, including equipment operating conditions, oxygen network vulnerability, supply chain vulnerability, and air quality.

Oxygen infrastructure, such as PSA plants, is designed to function within strict operating conditions. For example, manufacturer specifications for PSA plants typically set an upper ambient temperature limit of 40°C to 42°C. These limits are non-trivial, considering that PSA plants generate heat during operation and are often housed within shipping containers.

Installation of PSA plants must include planning for adequate ventilation and, if needed, air conditioning. However, this planning often uses assumptions based on historical temperature trends. In a rapidly warming world, these assumptions are unreliable. Before installing a new PSA plant in Chikwawa, BRING O2 reviewed temperature projection models to better understand the likely future operating conditions.

Additionally, there is evidence that the pressure swing adsorption process produces lower oxygen concentrations at higher operating temperatures.[3] This phenomenon is present even at temperatures within the manufacturer-specified operating range.

Oxygen ecosystems must be prepared for the increasing frequency of climate disasters, such as hurricanes and floods. BRING O2 experienced several challenges due to climate disasters, including delays in procurement of an oxygen distribution truck due to flooding in KwaZulu Natal, South Africa that shut down factory production lines.

Finally, climate impact on transportation systems and electrical grids can translate into vulnerabilities to oxygen ecosystems. Washed out roads may mean that cylinder deliveries cannot be made, and the increasing frequency of electrical outages may damage PSA plants and shorten their operating lifespans.

Future directions

Oxygen ecosystem climate vulnerability assessments

To inform planning and improve resilience of oxygen ecosystems, PIH is considering developing and piloting an oxygen ecosystem-specific climate vulnerability assessment. This tool could be integrated into national or regional-level oxygen ecosystem strategy and help improve long-term oxygen security.

PART II: PRODUCTION

Planning for oxygen security

Effective treatment with medical oxygen requires the right amount at the right time, with close to zero margin for error—oxygen shortages lasting just minutes can be catastrophic. The BRING O2 experience has reinforced the importance of designing oxygen ecosystems that provide oxygen security:

> What does oxygen security look like? Every referral hospital in the world should have a large volume oxygen source, such as a liquid oxygen tank or pressure swing adsorption plant, delivering piped oxygen to every bed. They also need enough filled oxygen cylinders to provide at least 24 hours of emergency backup. These higher-resourced referral hospitals would then distribute oxygen cylinders to primary facilities, where oxygen concentrators can supplement and serve as a backup. In short, we need comprehensive and redundant regional networks of oxygen supply.[4]

To prevent disastrous shortages, oxygen ecosystems must have the capacity to generate and maintain a strategic surplus exceeding projected demand. This not only ensures oxygen security during normal operations, but it also provides a sturdy foundation for pandemic preparedness and response.

Demand quantification

The first step in planning for oxygen security is quantifying oxygen demand. Accurate estimates of oxygen demand require rigorous methodology, robust assumptions, and reliable data. Unfortunately, most attempts to quantify demand have produced significant underestimates. For example, a retrospective independent assessment found that Bangladesh's peak oxygen demand during the COVID-19 pandemic was three-fold higher than real-time government estimates.[2]

Uncertainty and imprecision in estimating oxygen demand present challenges for consensus-building during the policy-making process. BRING O2 observed how national oxygen strategy development can become mired in debate over quantification methods and assumptions, leaving stakeholders unable to proceed with urgently needed oxygen interventions. From November 2021 to April 2022, Lesotho's national oxygen taskforce made multiple revisions to its oxygen demand estimate. Unable to proceed outside of a coordinated national strategy, many projects, including those run by BRING O2 and the Global Fund COVID-19 Response Mechanism (C19RM), were significantly delayed.

Insight: Underappreciated aspects of oxygen demand

Below are several examples of practical aspects of oxygen ecosystems that should be considered and accounted for when estimating oxygen demand.

Efficient oxygen delivery and administration

Adherence to the principles of efficient oxygen administration—such as providing the lowest amount of oxygen necessary to achieve a patient's SpO2 goal—is often impractical in resource-limited settings.[i] However, consumption increases when patients are receiving more oxygen than needed to achieve their target SpO2. Furthermore, many oxygen demand estimates do not account for oxygen leakage (e.g., via piping and wall outlet O-rings).

Oxygen is not always a fungible commodity

If oxygen piping is unavailable (i.e., hospitals are delivering oxygen from bedside cylinders or concentrators), oxygen cannot be treated as a strictly fungible commodity. Ten oxygen concentrators producing a total of $6m^3$ per hour cannot treat the same number or types of patients as a PSA plant delivering the same hourly volume via piping. When oxygen supply is aggregated across different sources, the presence of oxygen concentrators will create a bias towards overestimating the ability of supply to meet clinical demand. This is one of the reasons BRING O2 considers oxygen piping to be essential for all hospitals with inpatient services.[ii]

Organic growth in demand

In Malawi, where 23% of secondary hospital medical wards did not have a reliable oxygen supply prior to the pandemic,[5] the Ministry of Health estimated the national oxygen demand at $115{,}156m^3$ per month, while acknowledging that the true demand is significantly higher because the calculation "reflects only the baseline situation in Malawi and neither the oxygen need due to COVID-19 nor the expected increase in need from a growing population."[6] Additionally, changes in the health care system itself can trigger oxygen demand growth. BRING O2 has seen dramatic increases in oxygen demand following the installation of new infrastructure (e.g., piping) and the expansion of clinical services (e.g., operating theatres and ICUs).

Unlocked demand

When oxygen service availability is insufficient to address the full burden of hypoxemic disease, as is the case in BRING O2 countries, true oxygen demand will be underappreciated. Clinicians will be less likely to check pulse oximetry when oxygen is unavailable—why test for something you can't treat? —leading to undiagnosed cases of hypoxemia. Referral facilities will receive fewer hypoxemic transfers when first-level facilities are unable to provide oxygen for transport. Stories about respiratory diseases going untreated at hospitals will erode trust in the health system, leading to less care-seeking for respiratory illnesses. On the other hand, as oxygen availability increases, these barriers recede, leading to an increase, or unlocking, of demand. BRING O2 has regularly observed

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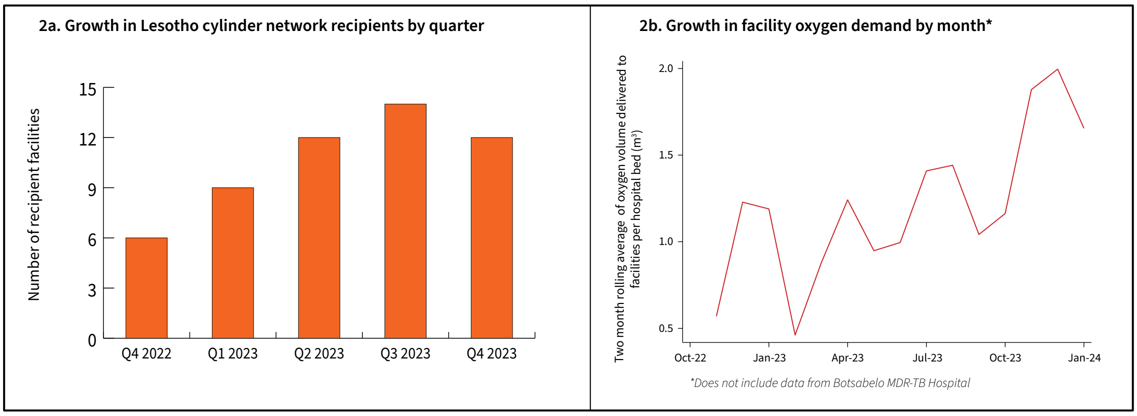
[i] See p. 21 in Part IV for additional discussion and analysis of the barriers to efficient oxygen administration

[ii] See p. 18 in Part III for additional discussion of medical gas piping as essential infrastructure

this phenomenon, most notably in the context of cylinder distribution networks—over time, more facilities requested to join the network (Figure 2a) and the volume of deliveries increased as well (Figure 2b).[iii]

Figure 2. Unlocked demand by Lesotho cylinder network



Oxygen distribution networks

Well-run regional distribution networks have the potential to align oxygen supply with demand. Through appropriate coordination and planning, cylinder distribution networks can allocate "excess" oxygen production capacity throughout a health system.[iv]

Future directions

Data to inform oxygen demand calculation

Including additional M&E activities within conventional oxygen ecosystem strengthening projects can address critical gaps in our understanding of oxygen ecosystems and inform future interventions and policies. Through BRING O2 and other activities, PIH has developed key insights into oxygen ecosystem supply and demand dynamics. The following steps will allow PIH to develop highly accurate and generalizable estimates for oxygen demand at the individual, facility, and regional levels:

- Procure and install mass flowmeters at PSA plants
- Dedicate human resource to ensure documentation and tracking of on-site oxygen production and delivery
- Procure continuous pulse oximeters with ability to record and export data
- Dedicate human resources to document oxygen source, flow, and interface on a regular basis

[iii] See p. 16 in Part III for additional discussion of cylinder distribution networks

[iv] Ibid.

- Dedicate human resources to ensure SpO2 is checked for all patients on arrival and at least twice daily

Tools for accurate modeling of oxygen demand

Leveraging data collected on oxygen supply and demand, PIH aims to develop a generalizable tool, grounded in empiric observation, to estimate oxygen demand in a way that minimizes the biases inherent in current approaches.

Repair assessments

Formal PSA plant repair/maintenance assessments often require external expert support, typically from the original equipment manufacturer (OEM). These assessments frequently uncover unanticipated deficiencies that require intervention to return the plant to its original operational state. These unanticipated repairs add a layer of complexity and cost to PSA repair interventions, as they are not typically covered under typical service level agreements (SLAs).

PSA plants consist of multiple interrelated sub-systems, and even "minor" repairs at "small" plants (e.g., oxygen production capacity at or under 5m^3 per hour) can be complex and expensive. In several cases, the BRING O2 team assessed smaller plants for repair and determined that the technical and financial resources required to return these plants to operation would be better invested elsewhere. Furthermore, even when the decision is made to proceed with repairs, it is not uncommon for new deficiencies to emerge during the repair process, requiring a re-evaluation of the cost and benefits of proceeding with repair.

EXAMPLES FROM BRING O2

Activity	**Details**
2.3.1. Implement recommended improvements at 3 plants in Lesotho	BRING O2 initially targeted a PSA plant at Scott Hospital in Lesotho for repairs. However, after receiving an extensive repair proposal, repairing the plant was deemed to be impractical and not cost effective. Instead, BRING O2 leveraged its cylinder distribution network to help alleviate oxygen demand pressures at Scott Hospital.
2.3.6. Implement recommended repairs for minimum of 15 plants in Peru	While implementing repairs, BRING O2 uncovered several deficiencies that were not apparent during the PSA plant assessments. In response, BRING O2 adjusted and expanded repair scopes of work for plants at Santa Rosa Hospital and Tingo Maria Hospital.

Insight: prioritizing equipment repair interventions

Given the inherent complexity of PSA plants and their multiple sub-components, the risk of scope creep when it comes to PSA plant repair is relatively high, making it critical to ensure project budgets and initial scopes have some degree of flexibility. Among the key lessons learned from

BRING O2 was the importance of a dynamic and flexible approach to PSA plant repairs, particularly when it comes to budget allocation. This provides a hedge against the risks of scope creep.

This flexible approach must be balanced by a robust evaluation framework to guide decision-making and prioritization in response to new or changing information. Employing a structured decision-making process is critical when weighing options such as investing in PSA repair versus installing a new PSA plant.

Project teams should develop an evaluation framework with criteria that include immediate costs and impact on PSA plant efficiency, the service life of remaining equipment, feasibility, sustainability, and the needs of the broader oxygen ecosystem.

Operating in inefficient markets

In all BRING O2 implementation countries there is a limited pool of vendors with sufficient technical expertise to install, service, and repair medical oxygen equipment. While every effort was made to source with domestic vendors, in some situations that was not possible. International procurement adds to operational complexity, extends project timelines, and increases costs.

The over-consolidation of the private sector can increase inefficiencies and create counter-productive financial incentives for vendors. For example, if a PSA plant breakdown forces a facility to procure oxygen cylinders from the same local firm responsible for plant maintenance, the firm may be disincentivized from rushing to return the PSA plant to operation.

In response, BRING O2 worked to create opportunities for domestic vendors to bid on medical gas pipeline projects in target countries. This provided an opportunity for vendors to develop technical capacity through additional medical gas pipeline installation projects. BRING O2 also leveraged a partnership with BHI to help provide remote support and/or assessment of work projects, as needed.

CASE STUDY #1

Exclusivity agreements in Peru

Challenge

In all BRING O2 countries, the limited availability of technical expertise means that the market for PSA plant service and repair is highly concentrated. Further complicating the matter, many original equipment manufacturers (OEMs)—producers of oxygen infrastructure and equipment—have exclusivity agreements with a sole in-country service provider. In other words, OEMs frequently grant monopolies over the installation, maintenance, and repair of their equipment within a country.

Proponents of this approach claim that it ensures work is done by vendors with appropriate expertise and direct access to OEM support. On the other hand, these service monopolies can lead to inflated prices for goods and services. Peru is one of several countries where BRING O2 received quotes from exclusive service providers that were significantly higher than fair market rates. Specifically, the BRING

O2 team identified that the quoted cost of filters from the exclusive service provider for PSA plants at two hospitals, Tarapoto and Rioja Hospitals, was prohibitively expensive.

Solution

BRING O2 worked to identify an alternative product to avoid paying above market rates through the exclusive service provider. BRING O2 experts conducted a compatibility and technical review of all domestically available PSA plant filters. When this review did not identify any products meeting the specifications, the search was expanded to include suppliers outside of Peru. This required a labor-intensive process of contacting companies directly and requesting product specifications. Eventually, BRING O2 was able to identify an affordable filter that satisfied technical and compatibility requirements. This approach, characterized by systematic compatibility and technical review, allowed BRING O2 to confidently purchase non-OEM parts.

Lessons learned

The benefits of this approach extended beyond immediate cost savings. It provided the project with more flexibility in procurement processes and reduced the potential impact of disruptions on the supply chain. Effectively navigating these types of market challenges was critical to the success of BRING O2 and highlights the potential value added by innovative procurement strategies and technical assessments in the context of a highly concentrated market.

BRING O2 is committed to sharing insights and innovations with other facilities and stakeholders across Peru's medical oxygen ecosystem, including the approach of conducting compatibility and technical reviews to facilitate procuring non-OEM parts. In fact, BRING O2 has shared the data on product compatibility with other facilities in Peru that are facing the same problem. **By unlocking alternative procurement options, BRING O2 has identified a potential method for exerting competitive pressure on existing monopolies in the oxygen sector.**

More broadly, creating interoperability guidance for PSA plants, with a specific emphasis on standardized spare parts and filters, is essential for optimizing supply chain efficiency. A strategy that ensures components are interchangeable across different systems would strengthen maintenance and resource management. Standardization of spare parts enhances the resilience of medical oxygen PSA plants, minimizing downtime and maximizing oxygen purity, and supports a more robust medical oxygen supply network for health care facilities.

Service level agreements at scale

SLAs are an essential tool for ensuring long-term sustainability of oxygen infrastructure, including PSA plants. Across the five BRING O2 countries, PIH negotiated and executed SLAs for nearly 30 PSA plants across five countries. BRING O2 encountered many PSA plants with SLAs in place, but the facility or government fell behind on payments during the agreement period, so the plant was not maintained. This led to delays or deviations from the manufacturer-recommended maintenance schedule. In some cases, PSA plants went over a year without any maintenance. Late or incomplete maintenance was a major contributor to unplanned PSA plant downtime, ultimately leading to increased spending on repairs and having to purchase filled cylinders from other sources.

Additionally, BRING O2 observed oxygen ecosystem stakeholders, particularly in the public sector, under the mistaken impression that an SLA can be used to replace the need for skilled plant operators. In reality, an SLA is necessary, but not sufficient, to ensure PSA plant operations.

Furthermore, SLAs are not designed to provide coverage for all possible types of PSA plant breakdowns and repairs. Remediating these misconceptions and, more generally, adapting SLAs to work in different contexts required flexibility on the part of BRING O2.

Ministries of health and their implementing partners must have access to the necessary expertise and tools to facilitate drafting, negotiating, funding, and monitoring SLAs. Unfortunately, many oxygen ecosystem stakeholders have limited knowledge and experience when it comes to SLAs.

Developing an SLA template

At the outset of the project, PIH developed an SLA template intended for use at all non-PIH operated PSA plants across all BRING O2 sites. This was determined to be preferable to a case-by-case approach, which would have placed a significant burden on PIH to draft, negotiate, and review each SLA.

The first step in developing the template was to create a checklist of key SLA provisions (Appendix B). The checklist was adapted from multiple sources, including PIH's existing SLAs and publicly available SLAs, and refined through an iterative consultative process with BRING O2 leadership, PIH biomedical staff, the PIH legal team, and the Unitaid grant management team.

Because this template was intended for PSA plants not owned or operated by PIH, it was initially structured as a tri-partite agreement between a Ministry of Health, a service provider, and PIH. However, as the project proceeded, it became clear that a single SLA template would not be feasible—varying implementation contexts demanded a more flexible and adaptive approach to SLAs.

CASE STUDY #2

Service level agreements in Peru

Challenge

In Peru, two inter-related challenges emerged: payment terms and the tri-partite structure of the template. The BRING O2 grant deliverables for SLAs required a contract period that extended beyond lifetime of the grant. In effect, this meant that PIH would have to provide up-front payment for most of the costs of the SLA. However, there was no mechanism to mitigate the potential risk of non-performance following payment. This was a significant concern for the BRING O2 team in Peru as it deviated significantly from their standard practices. Concerns about ensuring service provider performance were heightened by the fact that the Peru Ministry of Health generally does not enter into formal service agreements, preferring instead to utilize local "letters of responsibility" between supporting agencies and hospital management, meaning that the SLAs could not be structured as tri-partite agreements and PIH would need to engage in bilateral agreements with service providers.

Solution

A new SLA, specific to Peru, needed to be developed. BRING O2 leadership compiled a list of context-specific needs, informed by input from the PIH legal team. This list was paired with the original SLA checklist to create a new two-party (i.e. between PIH and a service provider) SLA template for Peru. Instead of treating this new Peru SLA template as a fixed and final version, BRING O2 used it as a starting point for negotiations with potential service providers. This provided needed flexibility while increasing the efficiency of the initial SLA negotiation phase. Using this approach, BRING O2 was able to successfully negotiate and execute SLAs for all PSA plants within the grant timeline.

A key innovation was the inclusion of a performance guarantee mechanism. To ensure disbursement of all BRING O2 funds prior to the end of the grant period, the Peru SLA template stipulated that the full value of the SLA be paid upon signing. To mitigate risk associated with providing full payment prior to vendor performance, PIH inserted two new clauses. The first clause required joint execution of the SLA with a letter of assurance issued by a qualified bank. If the obligations of the SLA were not fulfilled, the letter of assurance specified that the bank would reimburse PIH. The second clause established the process for claiming failure of the vendor to satisfy the terms of the SLA, triggering reimbursement.

Lessons learned

This case study illustrates the challenges of managing multiple SLAs and provides a proof-of-concept for a flexible, semi-templated approach. Implementing SLAs at scale requires striking a balance between efficiency and customization. In general, rigid templates cannot accommodate context-specific needs, both technical and administrative. Although it is possible to anticipate some context-specific items, such as manufacturer-recommended spare parts and service schedules, others cannot be ascertained a priori (e.g., tri-partite vs. two-party structure). On the other hand, developing bespoke SLAs at scale is highly labor-intensive and inefficient.

In Peru, BRING O2 was able to take a flexible approach that was also efficient enough to be implemented at scale across multiple service providers. The bank guarantee mechanism is one approach that can potentially be adapted by partners. Although it provides a degree of risk mitigation, challenges remain. For example, there would be complex compliance issues related to any funds received by PIH through this mechanism following the completion of BRING O2. Additionally, the legal framework for this mechanism may be established in other countries.

Future directions

Biomedical support package for PSA plants

While the installation of new equipment and systems receives significant attention from funders, sustaining system operations and maintenance over the system's useful lifespan is often neglected. Installing a PSA plant requires significant capital expenditure, well above $100,000 USD, but there are also significant operating expenses, which are often overlooked. With proper maintenance, a PSA plant's lifespan can easily exceed five years. During the pandemic, unprecedented amounts of funding have been mobilized for oxygen capital expenditures, but operational expenses have often been left unaddressed. To address these gaps, PIH aims to create a replicable model of sustainable oxygen capital investments, coupled with biomedical support.

The model is anchored by a biomedical engineer, hired for several years to oversee new PSA plants. With support and mentorship, the engineer's responsibilities would be to ensure sustained maintenance of the new PSA plant while training and mentoring a cadre of plant operators. At the end of the contract, the position would transition to the MOH. To ensure success and replicability, PIH would also develop a comprehensive and generalizable toolkit with job aids, competency goals, and educational tools.

PART III: DISTRIBUTION

Cylinder networks: aligning supply and demand

BRING O2 established oxygen cylinder distribution networks in Lesotho and Malawi. These networks were designed to ensure the continuous availability of medical oxygen to health care facilities that lacked capacity to generate enough oxygen to meet patient demand. Through these activities, BRING O2 demonstrated that, with careful planning and monitoring by multidisciplinary teams, oxygen cylinder distribution networks can serve as a key link in the oxygen delivery chain, making oxygen ecosystems more efficient and resilient and improving pandemic preparedness.

In Lesotho and Malawi, BRING O2 provided logistics, technical expertise, and specialized equipment to connect hubs—facilities with oxygen generation plants capable of providing excess supply—with health care organizations without enough oxygen to meet patient needs. The networks operated by retrieving cylinders that have been filled at hubs and transporting them to recipients based on identified needs. At the time of delivery, any empty cylinders are also picked from the recipient and transported back for refilling at a hub. Depending on monthly variations in supply and demand, a given facility could participate in the network as both a hub and recipient. For example, several hubs temporarily became recipients during PSA plant breakdowns.

A poster abstract (Appendix C) reporting data from the Lesotho cylinder distribution network was presented at the 15th Annual Consortium of Universities for Global Health Conference (March 7-10, 2024; Los Angeles, CA).

Insight: distribution networks enhance oxygen security

The cylinder distribution network in Lesotho included four hub facilities with on-site oxygen plants where empty cylinders were filled with oxygen and distributed to recipients located throughout the country. During the 10-month period from November 2022 through August 2023, filled cylinders were delivered to a total of 17 unique recipients, including two hub facilities (Botsabelo MDR-TB Hospital and Motebang Hospital) that received cylinders during periods of oxygen plant down-time. The network had broad geographical coverage, with at least one recipient in nine of Lesotho's 10 districts.

During the 10-month period from November 2022 through August 2023, the network distributed 1,981 cylinders containing enough oxygen to treat over 1,200 patients with severe COIVD-19. Botsabelo MDR-TB Hospital served as the primary hub, providing most cylinders. The other three hubs—Motebang, Mafeteng, and Paray—were used to supplement capacity during periods of high demand or when the Botsabelo oxygen plant experienced down-time.

Figure 2 in Appendix C illustrates how integrating multiple hubs into a single network of recipients made it possible to compensate for periods when PSA plants break down. For roughly two months starting in June 2023, the Motebang PSA plant broke down and was no longer able to produce oxygen. During this period, Motebang Hospital was unable to fill cylinders for the network. It was also facing an oxygen shortage for its patients. In response, the Botsabelo and Paray hubs increased production to meet network demand, including the delivery of over 40 cylinders to sustain Motebang Hospital's oxygen supply until the PSA plants were repaired. **The BRING O2 oxygen cylinder network provides a proof-of-concept for how distribution networks can enhance security by aligning supply and demand on regional and national levels.**

Future directions

Additional investment in hub-and-spoke cylinder distribution systems would enable the BRING O2 team to formalize a toolkit of resources for implementing hub-and-spoke cylinder distribution systems. This toolkit would facilitate the rapid adoption and scale-up of hub-and-spoke cylinder distribution systems worldwide.

Medical gas piping as essential infrastructure

Primary and secondary referral hospitals in low- and middle-income countries often rely on bedside concentrators and cylinders. In Europe and the United States, it is standard practice in all hospitals when installing piping systems to include outlets for oxygen, compressed air, and vacuum.[7] Although it is reasonable to install piping systems with only oxygen outlets in areas of a hospital treating patients with mild hypoxemia, the inclusion of compressed and vacuum outlets is an essential part of piped oxygen systems serving critical care beds. PIH believes that all inpatient facilities should be equipped to deliver oxygen directly to the bedside via piping systems and all inpatient areas with critically ill patients should also be equipped with compressed air and vacuum piping.

EXAMPLE FROM BRING O2

Activity	Details
3.1.3 Produce technical drawings, procure, and install medical oxygen piping for 3 facilities in Rwanda	With Unitaid support, CHAI procured and installed oxygen piping at 11 initial hospitals in Rwanda, catalyzing funding from the Global Fund C19RM to pipe an additional 11 hospitals. Building on these investments, BRING O2 established a new piping standard at Rwinkwavu Hospital with the installation of oxygen, compressed air, and vacuum systems. Rwinkwavu serves as an example piping system capable of providing support to critically ill patients, which can be replicated with future investments.

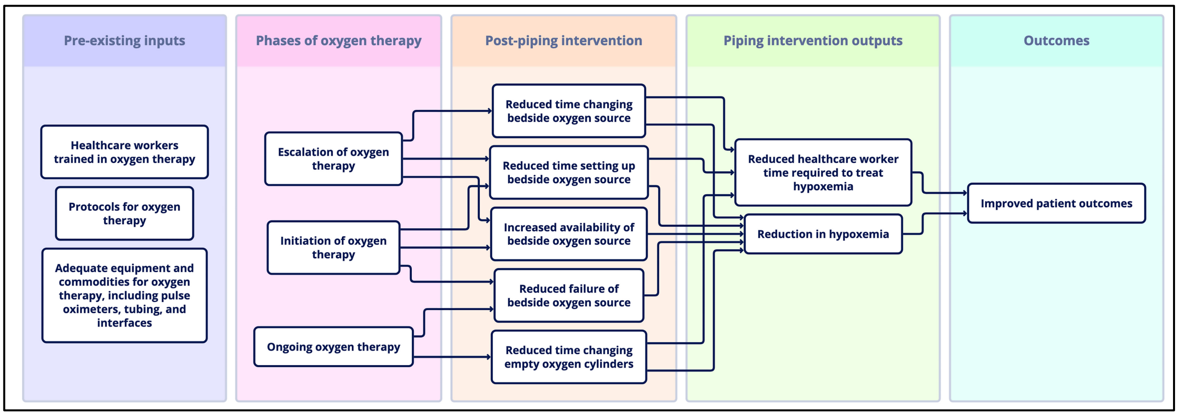
Benefits of medical gas piping

Delivering oxygen via piping provides several benefits compared to bedside concentrators and cylinders. Unlike concentrators, oxygen piping is not necessarily dependent on a continuous electrical supply. Additionally, the use case for concentrators is more limited than piping. Piping delivers oxygen at a flow and pressure that is suitable for treating the entire spectrum of hypoxemia, while the lower flows and pressures generated by concentrators are only suitable for patients with mild hypoxemia.

Compared to bedside cylinders, piping offers a more continuous and reliable source of oxygen. Bedside oxygen cylinders require manual exchanges on a regular basis. Depending on cylinder size and patient needs, a single bedside cylinder may last for as little as four hours. This means that hospital staff must closely monitor cylinder pressure and be prepared to quickly change out cylinders to prevent the patient from running out of oxygen, increasing the burden on an already strained workforce. Furthermore, repetitive and, at times, urgent exchanges of cylinders with weights regularly exceeding 70 kilograms poses an increased safety risk to staff.

As previously discussed,[v] oxygen piping also addresses a source of bias in facility-level demand quantification by permitting the aggregation of demand across an entire hospital. Overall, PIH believes that installation of oxygen piping leads to improved patient outcomes (Figure 3) and is therefore essential for all hospitals with inpatient services.

Figure 3. Conceptual framework of oxygen piping benefits

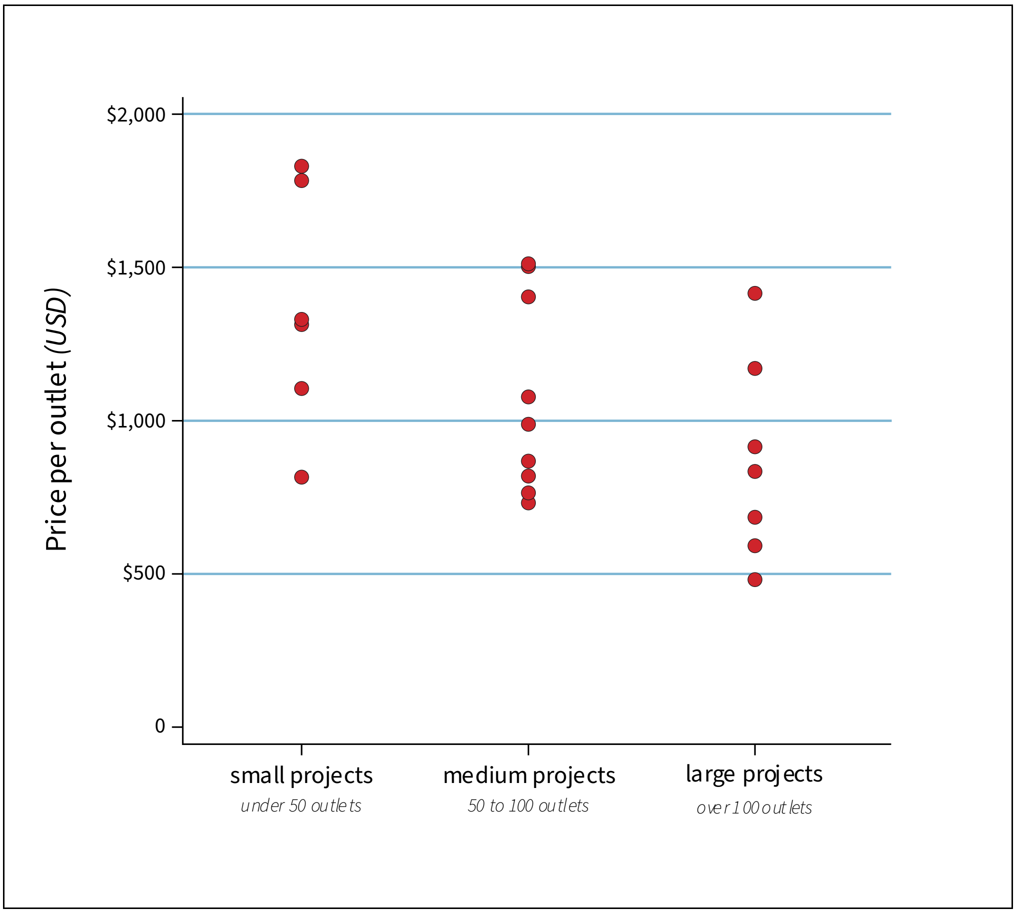


[v] See p. 8 in Part II for additional discussion of oxygen piping and demand quantification

Insight: cost efficiencies with scale

BRING O2 conducted a cost analysis of quotations from piping installation bids across multiple countries. The price-per-outlet was calculated to provide a basis for comparison across projects of various sizes. This analysis suggests a trend toward cost efficiency as the size of the project increased (Figure 4). BRING O2 has observed that many facilities opt to install piping in a piecemeal fashion (i.e., several units at time). However, it appears that this approach may not be the most cost-effective.

Figure 4. Piping quotes on per outlet basis, broken down by project size



PART IV: CLINICAL ADMINISTRATION

"Efficient" oxygen administration

Appropriate management of hypoxemia requires initial recognition, selection of oxygen interface (e.g. nasal cannula, simple facemask) followed by frequent reassessments to guide adjustments of oxygen flow and/or interface to achieve a target oxygen saturation (SpO2). Efficient oxygen administration is the process of providing the lowest amount of oxygen necessary to achieve a patient's SpO2 goal. Hypoxemia is harmful to patients, but so is giving too much medical oxygen. Efficient oxygen administration also has implications at the facility level—oxygen consumption will increase significantly if patients are receiving more oxygen than needed to achieve their target SpO2.

In well-resourced hospitals, the frequent reassessment and adjustment of oxygen therapy is the responsibility of respiratory therapists. However, in settings without respiratory therapists, this responsibility falls primarily on nurses. BRING O2 has identified two key factors mediating the relationship between clinical practice patterns and oxygen consumption: staff availability and training.

Staff availability

Efficient oxygen administration, with the lowest amount of oxygen necessary to achieve the patient's SpO2 goal, requires frequent bedside reassessments. The American Association for Respiratory Care estimates that each of these reassessments takes an average of 13.5 minutes per patient.[8] Assuming respiratory reassessments every four hours in a unit with 10 hypoxemic patients, this would require 13.5 hours of nursing time per day—an entire nursing shift devoted only to adjusting oxygen. This suggests that standard inpatient staffing models in low- and middle-income countries may not be appropriate in situations where there is a significant burden of hypoxemic patients and no respiratory therapists.

Faced with these staffing constraints, it would be *rational* for HCWs to administer oxygen in an "inefficient" manner. With limited staffing, a HCW could reasonably assume that frequent bedside respiratory reassessments would not take place. Based on this assumption, it is arguable that the best approach to oxygen administration would be to err on the side of too much oxygen. In other words, it is reasonable to deliver enough oxygen to provide patients with a "buffer" in case they develop worsening hypoxemia during the prolonged intervals when their oxygen saturation will not be checked. Based on this framing, PIH has come to believe that understaffing in clinical units is the primary driver of "inefficient" oxygen delivery.

Without additional support or interventions, a high burden of hypoxemia in many settings will cause the quality of patient care to suffer and the volume of oxygen lost to increase. This also has significant implications for pandemic preparedness planning.

Training gaps

Conducting trainings outside PIH-supported sites, BRING O2 observed many frontline HCWs without training on pulse oximetry and oxygen administration. In response to these observations, BRING O2 revised core oxygen curricula to increase emphasis on fundamentals (e.g., stepwise approach to monitoring oxygen saturation when starting oxygen or changing oxygen settings) and developed training materials to reinforce key concepts.

Future directions

An innovative and practical model of care to optimize oxygen therapy

PIH is developing an approach to improving oxygen delivery through an innovative respiratory nurse mentorship program. The program teaches dedicated respiratory nurses to train, mentor, and support bedside nurses in the delivery of high-quality respiratory care. Respiratory nurses lead the implementation of clinical processes, including the completion of respiratory flowsheets for all patients on oxygen, adherence to facility protocols, appropriate and timely titration of oxygen therapy, optimization of oxygen interfaces and sources (e.g., using concentrators instead of cylinders by splitting or combining using wye connectors), and prone positioning.

This intervention has the potential to improve patient outcomes while also improving the efficiency of oxygen consumption. Table 1 provides estimates for the impact of specific patient-level clinical process improvements on oxygen consumption and cost. Over time, these discrete interventions have the potential to provide tremendous benefits when scaled across an entire inpatient unit or health care facility.

Table 1. Estimated daily savings from interventions to optimize clinical oxygen delivery

Intervention	Reduced flow	Cylinders saved per day*	Cost saved per day (USD)^
Splitting concentrator for two patients on 5L/min	5L/min	1.2	$27 to $132
Switching to bubble humidifier with 6psi pressure relief valve (from 3psi) for a patient on 15L/min	7.5L/min	1.8	$41 to $198
Turning off ventilator bias flow	10L/min	2.4	$54 to $264
Using two concentrators for a patient on 15L/min	15L/min	3.5	$81 to $395
Titrating flowmeter from “flush” setting to 15L/min	60L/min	14.1	$324 to $1,581

*Assumes J-type cylinder with safe residual pressure of 200psi and 6,120 liters of effective oxygen

^Cylinder price estimates from: https://www.thebureauinvestigates.com/stories/2020-08-09/lack-of-oxygen-leaves-covid-19-patients-in-africa-gasping-for-air[9]

Strengthening clinical oxygen delivery through existing health programs

Because medical oxygen is an essential therapy for many acute and chronic conditions, oxygen ecosystems must be considered within the context of existing health programs. Experience from BRING O2 has shown that integrating oxygen ecosystem strengthening with existing health system programs creates synergies and is a key pathway to impact and sustainability. PIH has applied this insight as part of government accompaniment for national health policy development and implementation by advocating for integration and harmonization with oxygen activities across multiple health system programs.

Critical care

The COVID-19 pandemic provided dramatic evidence of the interdependence between emergency and critical care (ECC) and oxygen ecosystems. One study of 3,140 adults with suspected or confirmed COVID-19 infection, who were admitted to intensive care or high-care units in 64 hospitals across ten African countries, found that only 55.3% of all patients referred to intensive care or high-care units were actually admitted and 16.7% of patients who died in intensive care or high-care units never received oxygen.[10]

Addressing the current and future burden of severe respiratory illness, including pandemics, requires robust emergency and critical care (ECC) services. ECC is one of several clinical platforms providing an interface between patients and oxygen ecosystems. Indeed, recent resolutions passed by the 76th World Health Assembly on access to oxygen[11] and emergency, critical, and operative care[12] emphasize the important and complementary nature of oxygen ecosystems and critical care.

EXAMPLES FROM BRING O2

Activity	Details
4.2.3. Provide ongoing supportive supervision and mentorship to clinical staff at target facilities	In Lesotho, BRING O2 leveraged national and facility-level critical care initiatives to strengthen clinical delivery of oxygen. Activities included convening content experts to develop training materials, protocols, and clinical documentation; implementing and refining these clinical tools; and providing ongoing supportive mentorship to frontline HCWs.
4.3.1. Lead/contribute to the development of training materials with global and national partners	BRING O2 collaborated with PIH's cross-site nursing team to engage a critical care nursing consultant to provide mentorship and implement essential tools (e.g., critical care protocols and clinical documentation templates) emphasizing oxygen best practices.

On a national level, BRING O2 has been deeply involved with the development of ECC strategies in multiple countries. In Malawi and Lesotho, BRING O2 provided technical support and guidance for the ECC policy process, with an emphasis on oxygen planning and sustainability. At Botsabelo MDR-TB Hospital in Lesotho, BRING O2 demonstrated innovative approaches to integrating multiple health system priorities: oxygen therapy, critical care, and tuberculosis.

Future directions

Early warning systems for rapid identification and treatment of hypoxemia

Even with high-quality medical care, patients admitted to medical wards have the potential to rapidly deteriorate and develop critical illness. When this happens, delays in clinical response increase the risk of morbidity and mortality. This is particularly relevant when it comes to the recognition of hypoxemia, which is often delayed or missed entirely.[13–15]

Early warning systems (EWS) are a formal method to help health care workers recognize early signs of clinical deterioration and initiate additional measures, such as increased monitoring, reassessment by an interdisciplinary team, or transferring the patient to a higher acuity area. However, successful implementation of EWS in low- and middle-income countries (LMICs) remains a challenge.[16] PIH aims to develop and implement a simple vital sign-directed EWS, emphasizing the rapid identification and treatment of hypoxemia. This innovative clinical model could serve as a generalizable proof-of-concept for improving oxygen therapy in LMICs.

Enhanced accompaniment and technical support for integrating oxygen and critical care

PIH has received requests from multiple MOHs for enhanced technical support to ensure the ongoing integration of sustainable oxygen services across multiple health system platforms. Embedding experts into these processes presents an opportunity to develop a policy model for linking oxygen access with improving outcomes for conditions including severe malaria, maternal sepsis, tuberculosis, severe pneumonia, and non-communicable diseases (NCDs).

Home oxygen for chronic hypoxemia

In many countries, there is typically no treatment available for those with chronic hypoxemia. These patients are usually sent home without oxygen, with the expectation that they will not survive for long. PIH refuses to accept that poverty should turn chronic hypoxemia into a death sentence. Whenever possible, the BRING O2 team has sought to mobilize the necessary resources to provide oxygen and accompanying support to patients with chronic hypoxemia.

CASE STUDY #3

Providing home oxygen in Lesotho

Before becoming ill, Kaizer Mahapa, 44, worked as a street vendor in Maseru, Lesotho, selling jewelry, snacks, and fruits at two roadside stalls: one uptown in Maseru and another in his own yard. Mahapa, who grew up in rural Lesotho, was diagnosed with HIV in 2019. Two years later, he contracted tuberculosis. He'd never attended school, instead cared for the family's animals. Mahapa was living with his daughter when he fell ill.

Mahapa commenced antiretroviral therapy (ART) in 2019. But his battle with tuberculosis began after multiple hospital visits for symptoms that were initially misdiagnosed as a normal cold. He coughed up blood clots just before being admitted to the hospital again in 2021. The following year, he received a diagnosis of drug-resistant TB. Mahapa began treatment for his tuberculosis, but his health deteriorated further. Hospitalized yet again, he was treated for heart failure and anemia, in addition to the other conditions.

Despite his treatment, Mahapa developed severe, permanent lung damage and respiratory failure due to the TB, and he now requires supplemental oxygen to maintain normal blood circulation levels.

Mahapa was ultimately cured of TB, but it became clear he would need supplemental oxygen for the rest of his life. So, PIH staff rallied to help; they would do everything necessary to support their patient's recovery.

In Lesotho, there typically is no treatment available for those with chronic lung disease requiring supplemental oxygen. These patients are usually sent home without oxygen, with the expectation that they will not survive for long. PIH had already planned to help Mahapa with supplemental oxygen by giving him an oxygen concentrator. However, this requires electricity, which Mahapa did not have at home. So, the PIH infrastructure team conducted a home assessment while Mahapa was still in the hospital, so they would be able to provide electricity when he returned to the house.

The home assessment found multiple problems. In addition to the lack of electricity, there was no water supply, no proper ceiling, and several broken windows. "Mahapa's home was not fit for someone in his condition," said Kaoli Lerotholi, the operations and infrastructure manager at PIH. When it rained, the roof leaked, he said, and mold was developing. So, the PIH team got the house repainted and fitted with ceilings and fixed the broken windows.

Mahapa's illness took a significant toll on his business. He was forced to shut down both of his stalls, and his daughter had to discontinue her education during her final year of high school. He remains worried about his future, his daughter's future, and their financial situation. "I used to be able to provide for my family, my daughter was almost done with high school. I have big dreams too, but now I feel like a burden to my family because everyone wants to take care of me instead of focusing on their lives," Mahapa said.

He can no longer provide for his family, but he remains hopeful that he will eventually be able to breathe independently for extended periods. At present, he can go without oxygen for a maximum of one hour. His sister has taken on the role of the sole breadwinner, but her income is limited as she works in a factory.

"Government assistance to patients ought to mirror the way Mahapa was handled," said Dr. Chase Yarbrough, one of Mahapa's doctors. "He underwent and continues to endure a protracted struggle. His path is lengthy, even though he has been cured of tuberculosis."

Mahapa agreed that every TB patient who needs oxygen and other assistance should receive it. "At least, with the help of oxygen," he said. "I can experience improved breathing."[17]

PART V: HUMAN RESOURCES

Biomedical staff

Medical oxygen equipment is highly specialized, requiring significant technical expertise to install, operate, maintain, and repair. This expertise is often limited in low- and middle-income countries, limiting the overall capacity of biomedical engineering staff in the public sector and local vendors in the private sector.

The lack of a robust biomedical talent pool in BRING O2 countries has impacted the project in the areas of 1) recruiting, training, and retaining staff for sustainable O2 equipment operations and maintenance, 2) sourcing and maintaining oxygen generation and distribution equipment, and 3) having clear repair or maintenance scopes of work during initial assessment phases.

BRING O2 has faced challenges with the recruitment and retention of biomedical technicians/engineers. This is due in part to high demand for this expertise in the public and private sectors. In Lesotho, Malawi, and Rwanda, biomedical staff have prematurely left the BRING O2 team for other opportunities. These challenges recruiting and retaining staff restrict our ability to optimize current oxygen production capacity—particularly when we are attempting to extend cylinder filling operations into night and/or weekend hours.

Insight: negotiating training

The BRING O2 project has structured many of its SLAs to explicitly include plant operator/technician training as part of the deliverables for each preventive maintenance or repair trip, with the aim of building local capacity and thus reducing the number of external support trips required in subsequent years. In addition, BRING O2 teams in Malawi and Lesotho conducted workshops on oxygen concentrator assessment and repair training, with the dual outcome of both repairing oxygen concentrators and strengthening repair capacity in the public sector.

In the context of medical oxygen and gas capital project installations (e.g., new PSA plants), factory training for biomedical technicians and engineers is critical to sustainability. Factory training builds internal capacity and reduces reliance on external service providers. By equipping biomedical personnel with the necessary knowledge and skills through factory training, health care facilities can ensure optimal performance and efficient maintenance of PSA plants and medical gas infrastructure. For several large infrastructure investments, BRING O2 successfully negotiated the inclusion of factory training as part of the purchase agreement. It was clear that these trainings empowered biomedical technicians and engineers to not only manage routine maintenance and troubleshoot issues, but also to transfer knowledge and mentor their colleagues.

Future directions

Mechanism for advanced biomedical training

PIH recognizes the need to recruit, train, and retain qualified biomedical technicians and engineers to ensure sustainable operations and maintenance of oxygen infrastructure and equipment, like PSA plants. Building on our experience providing technical education in BRING O2 countries, PIH can leverage additional investments to establish a biomedical engineering fellowship program to facilitate advanced biomedical engineering studies and certification for both entry-level and professional staff.

Administrative staff

Fostering a strong oxygen ecosystem requires extensive support across multiple administrative disciplines including procurement, supply chain, logistics management, legal, finance, and project management. Adequate budgeting for these positions in addition to relevant technical, clinical, and leadership staff is essential for successful outcomes.

Establishing and maintaining oxygen infrastructure requires the procurement of specialized equipment and services. This is particularly difficult with a limited pool of qualified suppliers, manufacturers, and service providers. Conducting procurement within these constraints requires the facilitation of strong procurement processes and procedures and coordination with technical staff. Objective procurement processes that are well-documented protect organizations against potential conflicts of interest.

Supply chain

Supply chain challenges were a central driver of timeline delays in the BRING O2 project. Supply chain managers play a critical role in coordinating with suppliers, tracking orders, and managing shipments. Additionally, a point person should be identified to facilitate the timely release of materials through customs. Furthermore, strong asset management is required to maintain inventory and manage timely and well-documented handover of equipment to end-users.

Legal

There were several very complex legal agreements for structural works and PSA plant repair and maintenance that enabled the completion of BRING O2 deliverables. Legal support to draft and negotiate complex service agreements for works projects, repairs, and ongoing maintenance mitigated organizational risk and ensured accountability for high-quality deliverables on the BRING O2 project.

Finance

Finance staff are important contributors to the success of any project. Finance staff support accurate budget development and modification, timely payments, and enforcement of internal controls. Without these functions, organizations can face work slowdowns due to delayed payments and increased organizational risk if accounting processes and internal controls are not followed. In collaboration with other administrative functions, finance staff help prevent conflicts of interest and fraudulent activity.

Project management

Project managers coordinate across programmatic and operations teams to ensure that projects are accomplished on time and within scope and budget. Project management staff were necessary at each BRING O2 site and at a cross-site level to monitor workplans, ensure smooth communication and role clarity for team members, and problem-solve as issues arose. Their attention to the details of implementation guided the team toward success.

EPILOGUE: THE ROAD TO SUSTAINABILITY

Our collective efforts to resolve the global oxygen crisis stand at a critical inflection point. The COVID-19 pandemic brought new levels of attention and resources to strengthening oxygen ecosystems. But the global oxygen crisis extends far beyond COVID-19. Considering that COVID-19 accounted for less than a quarter of the 38 million patients admitted to LMIC hospitals needing oxygen in 2020,[1] it is clear that global efforts to achieve universal oxygen access must be consolidated and sustained in the post-pandemic period.

Over the past three years, resources have been mobilized to build and repair oxygen plants, install bedside oxygen piping, procure pulse oximeters, train biomedical engineers and technicians, create and update clinical guidelines, and teach clinicians to effectively administer oxygen. These same plants, pipes, and people can also be leveraged to treat all patients with hypoxemia, raising the overall quality of care at health care facilities, strengthening health systems, and preparing for the next pandemic.

While there has been significant progress, much work remains to ensure oxygen access for the tens of millions of patients in LMICs who develop hypoxemia each year. With additional investments over the next 3 to 5 years, it would be possible to achieve sustainable universal oxygen access. A three-year timeframe is relatively short given the scale of the global oxygen crisis. For context, consider efforts to expand the availability of HIV treatment. With sustained investment from 2010 to 2012, global access to antiretroviral therapy increased from 24% to 76%,[18] saving over 18 million lives.[19]

Like antiretroviral therapy, expanding access to oxygen is highly effective and affordable. Research has shown that training staff, building oxygen systems, and providing pulse oximeters is associated with up to a 40% decrease in the odds of all-cause pediatric inpatient mortality.[20] Improving oxygen access costs approximately $74 per patient[21], translating to $26 to $33 per DALY averted[22] (costs adjusted to 2024). Similarly, BRING O2 unlocked enough oxygen supply to treat approximately 126,000 patients at an annual cost per patient of $61.

BRING O2 progress toward sustainability

BRING O2 has found that the vast majority of public sector stakeholders consider oxygen ecosystem strengthening to be a major health system priority. The challenge is translating political will into effective and sustainable action. Oxygen ecosystems are complex and contain multiple interdependent components—although it is possible to achieve sustainable universal oxygen access, there is not a single simple solution. Furthermore, limited public sector experience and expertise creates barriers to effective assessment, planning, and implementation. From this perspective, it is understandable that governments perceive significant risk with investing their limited health care funding in new oxygen ecosystem activities. The framework for creating sustainable oxygen ecosystems must address these barriers, demonstrate feasibility, and provide tools to mitigate risk. This is achievable—BRING O2 has repeatedly encountered a willingness on the part of governments to adopt and sustain successful oxygen ecosystem initiatives.

Pilot programs to demonstrate feasibility and impact

BRING O2 cylinder distribution networks illustrate a path from external investments in pilot programs to national-level sustainability. As discussed in *Part III*, BRING O2 established proof-of-concept for the feasibility and impact of cylinder distribution networks. In response, the Ministries of Health in Lesotho and Malawi are in the process of expanding cylinder distribution operations throughout their countries. By providing initial investments (e.g., trucks, safe loading ramps, and cylinders) coupled with the necessary technical expertise to operationalize successful pilot programs, BRING O2 helped to overcome the barriers to engaging the public sector in these activities.

SLAs are another example. BRING O2 has observed that many oxygen ecosystem stakeholders have limited knowledge and experience when it comes to SLAs. Much like with cylinder distribution networks, overcoming these challenges takes several years of external investment and implementation support to allow governments to gain programmatic and technical familiarity, while also becoming convinced of the positive impact. This pattern has repeated itself across multiple BRING O2 countries. For example, after collaborating with BRING O2 to implement 18 PSA plant SLAs across the country, the national government of Peru decided to start allocating a portion of the annual budget specifically for PSA plant maintenance. With similar support over the next several years, it is very likely other countries will follow suit.

Although much progress has been made toward sustainable oxygen ecosystems, national governments will still require external investments and enhanced support over the next several years to reach this goal. During this transition period, there is an important role for pilot programs that demonstrate feasibility and impact. This approach to catalyzing sustainability should be applied across multiple countries and domains (e.g., effective oxygen administration, infrastructure maintenance, oxygen networks, etc.) within oxygen ecosystems.

Health system integration

BRING O2 has shown that integrating oxygen ecosystem strengthening with existing health system programs creates synergies and is a key pathway to impact and sustainability. PIH has applied this insight as part of government accompaniment for national health policy development and implementation.

At Botsabelo MDR-TB Hospital in Lesotho, BRING O2 effectively applied innovative approaches to integrating multiple health system priorities: oxygen therapy, critical care, and tuberculosis.

Combining oxygen infrastructure investments, clinical training, and biomedical capacitation created a synergistic effect. Supported by reliable medical gas systems, clinicians learned how to apply principles of advanced oxygen therapy to patients with tuberculosis and critical illness, providing a direct benefit to patients at Botsabelo MDR-TB Hospital. These new skills were shared outside of Botsabelo, with training and mentorship provided to clinicians across multiple hospitals. Additionally, Botsabelo MDR-TB Hospital served as a catalyst for the Lesotho MOH when crafting national oxygen roadmaps and critical care[23] strategies.

Partners In Health and oxygen: a roadmap for future activities

PIH has long prioritized oxygen as a key component of strong health systems, an approach rooted in PIH's commitment to building and strengthening all the Five S's—staff, stuff, systems, space, and social support—as the key to health system strengthening (Figure 5).

Figure 5. PIH's Five S's approach to health system strengthening

PIH also applies the same approach to respond to crises, treating them as opportunities to build and strengthen health systems by focusing on all the Five S's. Starting with the AIDS pandemic, PIH responded by building hospitals, not for AIDS alone, but for comprehensive care from maternal health to surgery. After the 2010 earthquake hit Haiti, leveling hospitals across the country, PIH responded by building and equipping Mirebalais Hospital, a tertiary teaching hospital. PIH's comprehensive health systems strengthening response to the Ebola epidemic in Liberia and Sierra Leone included the installation of oxygen production plants at health facilities.

This is the reason that when the first COVID-19 patients arrived at PIH-supported facilities, robust oxygen systems were already in place, helping save countless lives. Mirebalais Hospital opened the first COVID-19 treatment center in the country, providing high-quality oxygen therapy, including mechanical ventilation. Throughout the pandemic, PIH's oxygen plants in Liberia, Sierra Leone, and Lesotho worked around the clock to provide oxygen for patients with COVID-19. In fact, during the initial months of the pandemic, PIH operated the only oxygen cylinder filling plants in Liberia and Lesotho.

BRING O2 closeout meeting: planning future priorities and activities

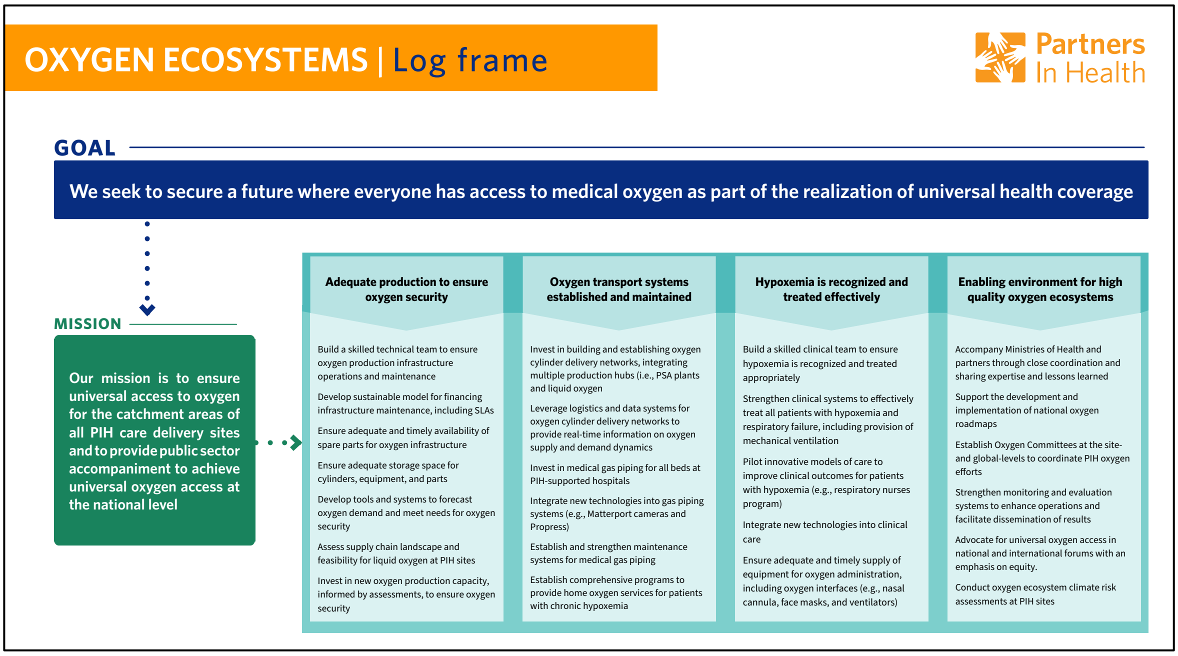
In October 2023, staff representing biomedical, clinical, and project management functions gathered at the University for Global Health Equity in Butaro, Rwanda for a four-day closeout meeting. The objectives of the meeting were to:

1. Strengthen relationships across sites and establish a shared understanding of BRING O2 work
2. Distill lessons learned for internal and external audiences
3. Develop an initial framework for a post-BRING O2 strategy
4. Generate a shared understanding of the processes required for award close out and audit preparedness

A total of 17 participants from four care delivery sites (Lesotho, Malawi, Peru, and Rwanda) and the United States coordination site participated in the BRING O2 closeout meeting. The closeout meeting was led by experienced facilitators employing participatory learning strategies, including methodologies from Liberating Structures. Interpreters were hired to ensure all staff could fully participate.

During the meeting, participants shared successes and best practices. They also relayed challenges, analyzing potential root causes and brainstorming mitigation strategies. The meeting culminated with a collaborative exercise that produced a draft PIH oxygen strategy to guide post-BRING O2 activities (Figure 6).

Figure 6. PIH draft oxygen ecosystems log frame



Conclusion

The BRING O2 project represents a significant milestone in oxygen ecosystem strengthening, translating Unitaid's vision and investment into tangible and sustainable impact. Looking to the future, PIH will continue building oxygen security within the context of UHC, leveraging lessons and insights from the BRING O2 experience to guide future directions. Through continued collaboration with stakeholders, ranging from local communities to national governments to global coordination bodies such as the Global Oxygen Alliance, PIH remains committed to building and sustaining strong oxygen ecosystems worldwide, rooted in the deeply held belief that every patient deserves to breathe.

Acknowledgements

BRING O2 was made possible thanks to Unitaid's funding and support. Unitaid accelerates access to innovative health products and lays the foundations for scale-up by countries and partners. We are deeply grateful for Unitaid's vision, leadership, and investments in oxygen ecosystems. The members of the Unitaid Secretariat are incredible colleagues and advocates. We express our appreciation for the remarkable and dedicated members of the Unitaid Secretariat with whom we worked closely during the BRING O2 project: Alexandre Debrun, Katerina Galluzzo, Thomas Gradel, Tanya Guenther, Gamu Gwaza, Ombeni Mwerinde, Kenny Onasanya, Dr. Pablo Vega Rojas, Dessie Tarlton, and Essien Ukanna.

We also acknowledge the partnership and collaboration of Build Health International, which provided technical expertise and support throughout BRING O2, and Pivot Madagascar, which led implementation of BRING O2 activities in Madagascar.

We honor ministries of health and hospital leadership across the five BRING O2 countries for their guidance and partnership, which informed and facilitated BRING O2 strategy and implementation.

Finally, BRING O2's achievements would not be possible without the outstanding and dedicated project staff working in Lesotho, Madagascar, Malawi, Peru, Rwanda, and the United States; their tireless commitment to helping patients breathe was vital to the project's success.

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APPENDIX A. BRING O2 indicators as of 26 March 2024

	Indicators		Project level targets		
	Key Performance Indicators	Units	Completed	Target	*Target - Completed % difference*
Work area 2	2.1 PSA plant assessments conducted		**10**	9	*11%*
	2.2 PSA repairs conducted		**25**	25	*0%*
	2.2.1 Associated unlocked production capacity from PSA repairs	m3/day	**10,993**	11,497	*-4%*
	2.3 PSA contracts with maintenance clauses and/or warranties		**28**	27	*4%*
	2.4 New PSA plants installed		**2**	2	*0%*
	2.4.1 Associated new production capacity from installation of new PSA plants	m3/day	**1,056**	1,056	*0%*
	2.5 Facilities with increased supplies to maintain and repair PSA plants		**26**	25	*4%*
	2.6 Concentrators repaired or installed		**234**	118	*98%*
	2.6.1 Increased oxygen production capacity from repaired and installed concentrators	m3/day	**2,345**	1,383	*70%*
Work area 3	3.1 Number of oxygen cylinders procured		**368**	368	*0%*
	3.2 Number of facilities with new oxygen manifold/piping installed		11	15	*-27%*
	3.3 Number of patient beds with new access to high pressure oxygen outlets		622	506	*23%*
	3.4 Oxygen cylinders filled and distributed	total cylinders	**4,165**	500	*733%*
Work area 4	4.1 People trained in maintenance of oxygen equipment and systems		146	66	*121%*
	4.2 Number of countries with updated clinical guidelines, practical reference tools		**5**	5	*0%*
	4.3 Health care workers trained in administration of oxygen		**479**	454	*6%*
Outcomes	Oxygen capacity: Total additional oxygen supply	m3/day	**14,395**	13,936	*3%*
	Oxygen access (direct): Patients receiving oxygen from BRING O2	people/year	**130,376**	126,219	*3%*
	Decentralized oxygen access (direct): Patients receiving oxygen from BRING O2 with new access	people/year	**723**	557	*30%*
	Oxygen access (indirect): Number of people with improved access to medical oxygen (thousands)	thousands of people/year	**34,926**	34,316	*2%*

APPENDIX B. Service level agreement checklist

Partners In Health

BRING O2 Service Level Agreement Checklist

- ☐ Period of Performance
- ☐ Process for extending SLA beyond expiration date
- ☐ List of PSA plant equipment Covered under SLA
- ☐ List of manufacturer-recommended spare parts
- ☐ Recommended service schedule
- ☐ Set number of scheduled service visits
  - ☐ Scheduled service visits can also be used for visits for unplanned repairs
- ☐ Description of how repairs or maintenance outside the scope of the SLA agreement will be handled
- ☐ Description of customer support services/mechanisms
- ☐ Key performance indicators
- ☐ Roles/responsibilities of each party
  - ☐ Specific roles for service provider to include conducting training for plant operators during service visits
  - ☐ Specific roles for PIH to include procure and provide manufacturer-recommended spare parts to the third party (e.g. MOH)
- ☐ Detailed budget
- ☐ Payment schedule
  - ☐ All payments must be made before 12/1/2022 (the end of the BRING O2 grant period)
- ☐ Details on service provider's insurance/liability coverage for: theft, breakdowns, material damage or any type of incident that could cause injuries to staff
- ☐ Warranty information against defects in workmanship for maintenance performed under this SLA; equipment should be covered until the expiration date of the agreement
- ☐ Exclusions
- ☐ Termination clauses

APPENDIX C. Lesotho cylinder network poster abstract

Bo-mphato Litšebeletsong Tsa Bophelo
Partners In Health

Making Medical Oxygen Available in Lesotho: Lessons Learned from Partners In Health's BRING O2 Project

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BOPHELO

Unitaid SAVE LIVES FASTER

BACKGROUND

The COVID-19 pandemic unmasked long-standing deficiencies in medical oxygen ecosystems worldwide

In November 2020, Partners In Health (PIH) installed Lesotho's first oxygen production plant at the Botsabelo MDR-TB Hospital

In December 2021, with funding from Unitaid, PIH launched the multi-country Building Reliable Integrated and Next Generation Oxygen Services (BRING O2) project

BRING O2 recruited and trained biomedical engineers and technicians, maintained and repaired oxygen plants, and implemented a national oxygen cylinder distribution network (Figure 1).

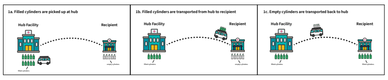

Figure 1. Schematic of cylinder network operations

METHODS

We assessed BRING O2's impact in Lesotho by analyzing data from monthly REDCap surveys designed to capture information on oxygen plant operations and the tracking logs used by the cylinder distribution network.

Data collection began in July 2022 and is reported through August 2023.

Continuous and ordinal variables were summarized by medians and interquartile ranges (IQR).

The BRING O2 cylinder distribution truck making oxygen deliveries in Lesotho
Zack DeClerk/PIH

FINDINGS

OXYGEN PLANT PRODUCTION

Over 14 months, the Botsabelo oxygen plant produced 20,485m³ of oxygen and filled 1,635 cylinders.

On a monthly basis, the median production and cylinders filled were 1,365m³ (IQR: 1,054 to 1,618) and 115 (IQR: 74 to 141), respectively.

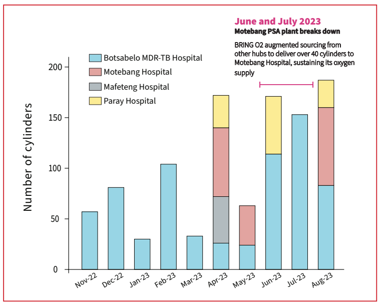

Figure 2. Oxygen cylinder distribution by month and hub

CYLINDER DISTRIBUTION

During the reporting period, a total of 1,981 cylinders were delivered to 17 facilities through the cylinder distribution network.

The median number of cylinders distributed and facilities served per month was 136 (IQR: 86 to 193) and 6 (IQR: 5 to 9), respectively.

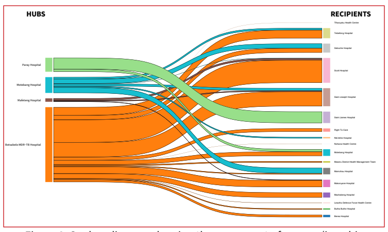

Figure 3. Sankey diagram showing the movement of oxygen (in cubic meters) from hubs to recipients

INTERPRETATION

With BRING O2 support, the oxygen plant at Botsabelo MDR-TB Hospital produced enough oxygen to treat over 1,200 patients with severe COVID-19.

The BRING O2 cylinder distribution network established a model for ensuring a continuous decentralized oxygen supply on a national scale. Ensuring adequate availability of medical oxygen requires investments in staff, equipment, and space to maintain production infrastructure, systems for monitoring of production and distribution.

BRING O2 was able to adapt cylinder distribution in response to oxygen plant downtime, ensuring a continuous supply of oxygen to facilities within the network.

The pressure swing adsorption oxygen plant at Botsabelo MDR-TB Hospital, Maseru, Lesotho
Tom Patterson/PIH

FUNDING

BRING O2 is supported with funding from Unitaid (Grant SPHQ15-LOA-045)

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