PIH TECHNICAL TOOLKIT:

BUILDING RESILIENT OXYGEN SYSTEMS

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INTRODUCTION

Medical oxygen is an essential component of treatment for COVID-19 patients who develop severe or critical disease, as well as other illnesses that restrict breathing. Despite tremendous global response to immediate pandemic relief and sustained health system strengthening, oxygen availability and improvements to oxygen systems remain unmet needs. While oxygen has become paramount to the survival of many COVID-19 patients, many low and middle income countries (LMICs) lack capacity to address current oxygen needs. This lack of oxygen has already affected millions of people globally: it is estimated that without medical oxygen, nearly 1 out of every 5 people infected with COVID-19 will die.

Currently, oxygen demand in most LMICs dramatically exceeds supply. Many barriers hinder the availability of oxygen, including a lack of oxygen production equipment, limited electricity supply and infrastructure, and limited technical expertise and funding to maintain existing systems. Finally, there are often difficulties in delivering oxygen to patients in need due to geographic distance from production sites and supply chain issues.

The barriers to oxygen administration extend beyond its physical availability. To effectively treat patients with hypoxemia, healthcare workers (HCWs) must understand the nuances of oxygen delivery methods and the risk of incorrect use. Diagnostics, medications and consumable supplies are required to maximize impact and improve patient outcomes. Emergency care and ICU capacity, human resources, and supply chains must be strengthened to avoid gaps in clinical care and excess mortality. Strong monitoring frameworks are needed for short- and long-term planning. Shortcomings in these areas magnify the scope and scale of the COVID-19 crisis and augment baseline inequities in health outcomes throughout the world.

Oxygen is an essential aspect of clinical care for many diseases, so investments in oxygen strengthen health systems long-term and prepare them for future health crises. Beyond COVID-19, oxygen is a life-saving treatment for diseases including pneumonia, heart disease, tuberculosis, severe malaria and opportunistic infections from HIV, and is critical to reducing neonatal and childhood mortality. Oxygen investment has been associated in reduction of childhood pneumonia mortality, as well as overall mortality.

Many low- and middle-income countries rely on imported oxygen cylinders, which are expensive and must be frequently refilled, or bedside concentrators, which require reliable electricity and can only deliver limited amounts of oxygen. In order to meet current and future oxygen demands, oxygen production capacity must increase. In addition, plans must be made to prevent oxygen insecurity. Oxygen insecurity arises from an over-reliance on any single system without an adequate back-up. In oxygen-insecure settings, a power-outage, mechanical failure, or surge in patients can easily lead oxygen supplies to run out. Effective treatment with medical oxygen requires the right amount at the right time, with close to zero margin for error—oxygen shortages lasting as little as 30 minutes can be catastrophic.

With effective planning, thoughtful investments in infrastructure and maintenance, and deliberate development of human resources, countries can develop resilient long-term oxygen systems that address the immediate COVID-19 crisis and reduce mortality from numerous diseases.

GOAL:

Strengthen all aspects of the oxygen ecosystem, including infrastructure design and maintenance, supply chain, training and ongoing mentorship, and clinical guideline development to improve the availability of medical oxygen in countries to stop the threat of COVID-19 and ensure continued resilience for the future.

ACRONYMS

LMIC	Low and middle income countries
HCW	Healthcare workers
ICU	Intensive Care Unit
UNICEF	United Nations International Children's Emergency Fund
PSA	Pressure Swing Absorption
EHR	Electronic Health Record
IPC	Infection Prevention Control
PPE	Personal Protective Equipment
WHO	World Health Organization
LPM	Liters Per Minute
PSI	Pound Per Square Inch

OBJECTIVE 1: Completed oxygen needs and availability assessments that define current scope of oxygen supply, quantify needs by level of health system, and establish a road map for future interventions.

It is imperative that oxygen system gaps and opportunities are assessed in order to establish and strengthen oxygen distribution networks. This model enables production capacity to expand while facilitating feasible maintenance.

Strategy 1.1 Performing oxygen needs assessment for all secondary and tertiary hospitals.

See assessment resources from PATH:

- PATH Baseline Assessment Manual
- COVID-19 Facility Assessment Resources

Intervention — Conduct stakeholder mapping and review existing stakeholder list from Every Breath Counts. Find out what work has already been done for assessments and planning. Every Breath Counts COVID-19 LMIC Oxygen Partners

Intervention — Assess current oxygen supply sources for each facility, oxygen cylinders, portable oxygen concentrators, PSA plants, or liquid oxygen tanks.

Intervention — Assess the oxygen consumption needed for each facility based on the number of beds and services provided.

- See quantification tools from PATH:
- PATH Quantification and Costing Tools
- Open Critical Care Demand Calculator
- OGSI size estimator based on beds and critical care beds
- UNICEF Oxygen System Planning Tool

Intervention — Assess electricity availability, reliability and cost. Constant electricity supply is needed for portable concentrators. PSA plants have substantial power requirements which could necessitate upgrading the electrical service or generator.

- See PIH guidance on Infrastructure and PATH Electricity Planning Guide.

Intervention — Assess long term maintenance and operation financing capabilities of stakeholders.

Intervention — Assess the oxygen delivery and monitoring equipment available at the ward level in a facility.

Strategy 1.2 Finding local or regional service providers that can supply and service oxygen equipment.

Intervention — Conduct stakeholder and supplier mapping. Find out if there are local or regional companies that could provide spare parts and service for key oxygen related equipment. It is important to understand what level of service is available for oxygen equipment before developing an oxygen strategic roadmap. For PSA plants, all facilities will likely require the occasional outsourced labor to repair or service the PSA, even with strong internal training and maintenance programs.

- For package PSA plant providers, see if they offer comprehensive service contracts in your area. Even with robust in house preventative maintenance plans, service provided by manufacturers or manufacturer’s representative is often required throughout the life of a PSA plant.
- For PSA, check for locally available service providers for rotary screw air compressors (Atlas Copco, Kaeser, Ingersoll Rand, etc).
- For cylinder filling PSA plants this would include oxygen compressors (RIX, Novair, etc).
- For portable concentrators, check for local or regional distributors of concentrators (Airsep, Devilbiss, Invacare, etc) or service providers.

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Strategy 1.3: Reviewing available oxygen production options, understanding the pros and cons of each one, as well as the Capex and Opex costs associated with each option.

Available oxygen production options include:

- Oxygen Cylinders: Large oxygen cylinders can hold around 7000L of usable oxygen, or enough oxygen to supply 5 LPM for almost 24 hrs. They can be refilled by commercial or industrial oxygen suppliers. This is often the most expensive source of oxygen, but some markets may have competitive pricing allowing this option to play a supporting role in an oxygen strategy. If the cost of filling large cylinders (40L water capacity, 7000L oxygen capacity) is greater than $15 per cylinder, then on site oxygen production (PSA) and cylinder filling can be a cheaper alternative.
- Portable Concentrators: These are mobile oxygen concentrators, often on wheels, with common sizes of 0-5 LPM and 0-10 LPM. These machines do not store oxygen so require 24/7 electricity to maintain oxygen flow. They also only deliver oxygen at low pressure making them not suitable for some applications. In general, portable concentrators have the cheapest total cost of ownership even considering a lifetime of 2-3 years. They are not energy efficient at low flows. For example, a 10 LPM concentrator operating at 1 LPM flow will still require 70% of the energy required for the full 10 LPM flow.
  - Note: There are a handful of oxygen concentrators that can deliver 20-30 LPM at 50 psi (3.4 bar) and there are ways to take oxygen produced by a portable concentrator and boost the pressure to 50 psi.
- PSA Plants + Pipeline: PSA plants use the same oxygen production technology found in portable concentrators, just at a larger scale. Oxygen produced from most PSA plants is supplied at 50 psi (3.4 bar). This oxygen can then either supply a pipeline system that delivers oxygen to the bedside through an oxygen outlet and flowmeter, or be used to fill cylinders. PSA plants utilizing a pipeline system can be price competitive long term and offer advantages to patients by providing continuous oxygen supply without the need for moving heavy cylinders or portable concentrators between patients. Oxygen pipeline systems have low maintenance requirements especially compared with cylinder filling systems.
- PSA Plants + Cylinder Filling: PSA plants can also utilize high pressure oxygen compressors to fill oxygen cylinders. The main advantage of high pressure cylinders is they can store large quantities of oxygen and can be transported and used to deliver oxygen without any need for electricity. The oxygen compressor that pressurizes the cylinders is the most costly and difficult piece of equipment to maintain of all PSA plant components.

Pressure considerations

Certain oxygen delivery devices require higher pressure sources (i.e. ~50psi). These include high flow nasal cannula, invasive ventilators (although travel ventilators can often be connected to low pressure sources), and many non-invasive ventilation devices. In order to select an oxygen source it is therefore important to consider the needs of the patients and oxygen delivery devices.

Oxygen Source	Total Cost* Per Equivalent Large Cylinder (7000L O2)
Cylinder Refilling Supplier	$15 - $120
Portable Concentrator	$2.5 - $5
Small PSA + Pipeline	$5 - $10
Large PSA + Pipeline	$4 - $8
Small PSA + Cylinder Filling	$12 - $22
Large PSA + Cylinder Filling	$6 - $10

**These costs are approximations as true costs will vary based on a variety of factors, principally cost of energy and cost of maintenance labor. This calculation looks at cost per equivalent cylinder after 10 years of operation. It includes initial purchase, installation, maintenance materials, maintenance & operation labor, cost of energy, and in the case of portable concentrators, the cost of replacing portable concentrators every 3 years. It assumes 24/7 operation.*

Additional resources on oxygen production types:

- PATH|CHAI Equipment Market Report
- PATH Costing Tool
- PATH Procurement Guide
- Oxygen sources and distribution for COVID-19 treatment centres

Strategy 1.4: Developing an oxygen strategic roadmap with key stakeholders

There is no one oxygen strategy that is the best for all health facilities or regions. Portable oxygen concentrators are a great solution for low pressure and low flow applications for any facility large or small that has reliable electricity. Any facility that has critical care beds or operating rooms requires oxygen at 50 psi (3.4 bar) that standard portable concentrators cannot provide, so other options need to be considered. Facilities without reliable electricity require oxygen cylinders or an investment into a micro grid system to provide continuous power for critical equipment.

It is important when developing a resilient oxygen strategy to consider equipment redundancy. All equipment, however well maintained, can and will fail from time to time. For severely ill hypoxemic patients, even a brief time without oxygen can be fatal. All facilities should have a backup plan. Large facilities with critical care beds should have fully redundant oxygen supply.

Below we have suggested a framework for medium to long term facility level planning based on our experience.

Suggested framework for medium to long term facility level oxygen planning

	Primary Supply	Backup Supply	Additional Considerations
Tertiary Referral	*Preferred:* Piped from on-site PSA plant *If available:* Piped from liquid oxygen tank	*Preferred:* Piped from cylinder manifold*. Cylinders filled by on site 2nd PSA plant *Alternatively:* Cylinders filled off site & portable concentrators	Emergency departments, operating rooms, and ICUs require high pressure backup (i.e. cylinders)
Secondary Referral	*Preferred:* Piped oxygen from PSA plant *Alternatively:* Piped from cylinder manifold & portable	*Preferred:* Piped from cylinder manifold*. Cylinders filled off site *Alternatively:* Individual cylinders for	Transport network for cylinders

	concentrators for low pressure/low flow uses. Cylinders filled off site *Alternatively:* Individual cylinders for high pressure/high flow use & portable concentrators for low pressure/low flow uses.	high pressure/high flow and portable concentrators for low pressure/low flow uses.	
Primary facilities**	Individual cylinders filled offsite for high flow, high pressure needs Concentrators for low pressure and flows below 10 LPM	Cylinders* *If electricity is unreliable:* Oxbox or additional cylinders	Transport network for cylinders

**Quantity of cylinders store enough oxygen to cover estimated hospital supply for 48 hours or more depending on the source of cylinders*
***All non-referral centers providing treatment for patients with COVID-19*

While we recommend PSA plants as a means of expanding access to oxygen long term, we recognize that short-term investments should be strategic and expedient. In our experience, PSA plants are most successful when the facility has demonstrated the ability to care for other complex medical equipment. For example, PSA plants are comparable if not simpler when compared with an X-Ray unit. The air compressor component of a PSA plant is quite similar to a diesel generator.

In the short-term, regions should balance existing infrastructure and maintenance capacity with the life-saving value and long-term return on investments in oxygen capacity. For many countries, hybrid models that include expanding access to portable concentrators (coupled with reliable electricity to run them) with strategic investments in larger oxygen infrastructure in select areas may be the best short-term strategy.

For additional resources on oxygen access and reliability, please see: PATH resource on Oxygen Access and Reliability

OBJECTIVE 2: Increased oxygen production, distribution and redundancy

The oxygen roadmap developed in Objective 1 will guide the plan to increase oxygen production, distribution and redundancy. In our experience in responding to COVID-19, the sites that were able to respond to the increased need for oxygen were sites with robust oxygen infrastructure, excess oxygen production capacity, and backup supply (see **Box 1**). This experience leads us to strongly recommend making long term investments into oxygen production and distribution systems, both for COVID-19 and beyond.

Box 1: University Hospital in Mirebalais case study on oxygen response during COVID-19

University Hospital in Mirebalais has a large PSA plant that feeds an oxygen pipeline and portable concentrators for a backup supply. The hospital was able to quickly construct a temporary COVID-19 ward and convert existing areas to COVID-19 wards. To meet the oxygen demand, the hospital deployed its supply of backup portable concentrators, installed a cylinder filling compressor to fill oxygen cylinders with the PSA's excess O2 capacity, and eventually expanded the pipeline network and installed portable oxygen outlets in these temporary COVID-19 wards. Other facilities without this existing robust capacity and backup supply were not able to rapidly meet the oxygen demand due to long lead times caused by unprecedented worldwide demand for any equipment and supplies related to oxygen production and delivery. In addition to lead times for new equipment, commercial oxygen suppliers that some sites relied on were completely overwhelmed leading to

Strategy 2.1 Increase PSA plant capacity in accordance with the country's oxygen road map

Intervention	Install PSA plants at secondary and tertiary level hospitals.
Intervention	Install PSA plants with cylinder filling capability at tertiary level hospitals to act as a backup supply for pipeline plants and to supply cylinders for surrounding facilities and any COVID-19 treatment centers.
Intervention	Purchase large and small oxygen cylinders. Small cylinders allow patients to be transported on oxygen either within or between facilities, and are essential to allowing critically ill COVID-19 patients to reach higher levels of care. Larger cylinders are used in cylinder manifolds connected to piped systems as well as for bedside oxygen delivery for facility based care.
Intervention	Purchase extra oxygen cylinders to be kept at facilities as reserve backup supply in the case of PSA breakdown or breakdown in logistics and oxygen supply chain.
Intervention	Pair investments in PSA plants with investments in strengthened biomedical capacity and in service contracts and maintenance plans (see also Objective 3).
Intervention	Prioritize repairs and expanding capacity for existing PSA plants, particularly those with cylinder filling capacity that can serve more than one facility.
Intervention	Allocate funding for needed upgrades for electricity infrastructure, and budget for generator fuel if required.

➔ See PIH infrastructure toolkit for additional details on electricity infrastructure

- See more on PSA plant specifications at: Technical specifications for Pressure Swing Adsorption(PSA) Oxygen Plants (who.int)

Strategy 2.2 Increased piped oxygen availability

We recommend investing in oxygen pipelines because of the major advantages they offer in patient care as well as lower operational costs compared to cylinder filling PSA plants. Cylinder filling oxygen compressors are expensive to maintain and operate, both due to cost of parts and because they often require specialty labor for preventative maintenance which is required every 2 ½ months. Further, piping oxygen to the patient's bedside means staff do not have to transport heavy cylinders and cylinders do not have to be monitored and changed out as they become empty. Oxygen pipelines themselves are relatively easy to maintain with the only maintenance being repairs to the outlets involving changing rubber O-rings. Ideally, pipelines connect to a PSA plant producing oxygen, but they can also be installed so that they connect to oxygen cylinder manifolds. Investing in pipelines is a worthwhile long term investment for all secondary and tertiary hospitals.

Intervention	Install oxygen piping network. This should be designed and installed by an experienced oxygen

	piping contractor. If an international contractor is used, select a contractor that will commit to train local staff on installation and maintenance of the pipeline system. The size of pipe size is important to avoid pressure losses, and accessible and clearly labeled isolation valves are important for safety and maintenance.
Intervention	Ensure sufficient access points within the oxygen pipeline for each patient bed. Add redundancy by purchasing Y blocks for the outlets to add additional in case of account for possible patient surges.
Intervention	Train staff on use and safety considerations for oxygen pipeline systems.

Strategy 2.3 Increasing portable concentrator access

Intervention	Purchase concentrators that have local distributors and service providers. If none available, purchase concentrators with strong remote service support and spare parts availability. OpenO2 has suggested that Airsep and Devilbiss are showing to be more reliable based on data collected from visits to hospitals in Malawi.
Intervention	Fit concentrators with under voltage/surge protection devices. Examples include devices such as ones offered by Sollatek.
Intervention	Consider supplemental equipment such as splitters to expand the number of patients who can benefit from portable concentrators in the event of patient surges. See How to set up an oxygen flow splitter from opencriticalcare.org for additional information..
Intervention	For facilities that do not have reliable electricity or COVID-19 treatment centers, consider solar microgrid powered portable concentrators such as OxBox concept from BHI.
Intervention	Train users on the operation and maintenance of portable concentrators.

Strategy 2.4 Increasing access to cylinders through spoke and hub delivery model

In many countries, oxygen cylinders will remain critical to meeting oxygen supply needs. Cylinders are often used to add redundancy when a primary oxygen source fails. Countries can consider regional hub and spoke distribution models where cylinders are filled in a central location and then distributed regularly to surrounding facilities.

Intervention	In areas where commercial cylinder filling suppliers charge high prices (>$40) to fill cylinders, consider investing in PSA oxygen cylinder filling plant as a social enterprise to introduce competition to the marketplace. See Assist International and Hewatele who have been able to do this successfully..
Intervention	Select key regional locations for cylinder distribution locations.
Intervention	Invest in oxygen delivery trucks fitted for the safe transport of cylinders, as well as in the staff and fuel to operate the delivery truck. BHI/Tuck school distribution model

OBJECTIVE 3: A comprehensive maintenance ecosystem exists that promotes continuous availability of oxygen, durability of equipment, and quality assurance

A comprehensive oxygen maintenance ecosystem is necessary for short-term oxygen strengthening for COVID-19 as well as long-term stability and reliability of oxygen systems for other diseases including TB, HIV, and Malaria. When procuring and installing oxygen equipment, it is essential to plan for the required maintenance to ensure equipment continues to function over the long term. These investments prevent small issues from escalating into major and/or permanent disruptions in oxygen supply.

Strategy 3.1: Maintenance Training

A comprehensive oxygen maintenance ecosystem is necessary for short-term oxygen strengthening for COVID-19 as well as long-term stability and reliability of oxygen systems for other diseases including TB, HIV, and Malaria. When procuring and installing oxygen equipment, it is essential to plan for the required maintenance to ensure equipment continues to function over the long term. These investments prevent small issues from escalating into major and/or permanent disruptions in oxygen supply.

Intervention	Train local staff on maintenance for PSA air compressors. Many maintenance tasks can be done by local technicians and mechanics, including oil, oil filter, oil separator, and air filter changes, testing and cleaning condensate drains, and cleaning oil cooler and dryer components.
Intervention	Provide local staff with a hard copy of Air Compressor Troubleshooting Guide. This is a generalized guide that explains overall operation of the compressor, the function of different components, and also provides troubleshooting and solutions for common problems.
Intervention	Train local staff on maintenance for PSA components and general plant maintenance. Specific tasks include testing for leaks, replacing or rebuilding check valves and solenoids, calibration of sensors, etc.
Intervention	Provide maintenance training on oxygen safety: flammability, transporting cylinders, high pressure awareness and safety.
Intervention	Provide maintenance training on pipeline and outlet maintenance: checking for and isolating leaks, replacing o-ring on oxygen outlets and rough in assemblies.
Intervention	Provide maintenance training on oxygen compressor preventive maintenance and repair. The skills for maintaining oxygen compressors is very specialized and not commonly available like in the case of air compressors. To pass on the skills needed, we recommend extensive hands on training. One option would be to incorporate training into a service contract. The oxygen compressor company Novair offers factory training, but Novair compressors are not commonly used by PSA manufacturers.
Intervention	Make sure facilities and biomedical staff have hard and soft copies of all operation, service, and parts manuals for their specific equipment.
Intervention	Develop vendor and technical support contact list for each piece of equipment. Often staff do not realize they can call a phone number and get technical support.

Strategy 3.2: Spare parts and Tools

Intervention	Purchase large quantities of spare parts and consumables for PSA plants. PIH can provide further detailed generalized parts lists on request. We recommend procuring 3 years of consumables and the most commonly used spare parts with the initial plant purchase.
Intervention	Purchase spare parts kits for oxygen cylinder filling compressors.
Intervention	For pipeline systems, purchase spare oxygen outlets, outlet maintenance kits, and spare flowmeters. These components are inexpensive to replace, but when not planned for result in life-threatening disruptions of the oxygen supply.
Intervention	Purchase an oxygen analyzer for all facilities with PSA plants and portable concentrators. We recommend ultrasonic oxygen sensors such as the Maxtec UltraMaxO2 for their longevity. This allows staff to validate oxygen purity and flow rate from all sources.
Intervention	Purchase spare pressure regulators and flowmeters for oxygen cylinders. These components can be damaged during the use and transport of oxygen cylinders and are easily replaced.
Intervention	Purchase at least 1 spare cabinet and 4 product filters for each concentrator. Spare power cables and fuses (if applicable) are also important. For larger quantities of concentrators, also

consider stocking spare parts such as circuit board, compressor service kit, capacitor, and solenoid valves.

Intervention Monitor supply chain data to assure adequate parts and consumables for the amount of oxygen delivered and consumed.

➔ See PIH supply chain toolkit for further information on data systems for stock monitoring

Strategy 3.3: Service contracts

Intervention If local or regional service providers are identified, consider service contracts for PSA plants. This is often the best way to ensure short term plant reliability while building long term in house maintenance capacity.

Objective 4: Healthcare workers at each facility are able to safely manage hypoxemic COVID-19 patients

Sufficient oxygen supply is only one component in the ecosystem of care that hypoxemic COVID-19 patients require. Health care workers must know when and how to use and titrate oxygen to ensure high quality care and maximize use of oxygen resources. Oxygen, like all medications, can be ineffective when too little is administered and harmful when too much is administered. Empowering a knowledgeable healthcare workforce through training and mentorship will reduce COVID-19 mortality and ensure HCWs will be better equipped to treat life-threatening respiratory illnesses such as pneumonia and TB.

Strategy 4.1: Develop and disseminate national clinical protocols for safe management of hypoxemic COVID-19 patients.

Intervention Establish content areas to be covered in national guidelines. While some guidelines will be COVID-19 specific (such as the care of severely ill COVID-19 patients), others will be more effective if they take an integrated approach to all disease areas. For example, recognition and initial management of hypoxemia is the same in most disease areas, including COVID-19, tuberculosis, and pneumonia. Examples of important topics to include in protocols are:

- Recognizing hypoxemia
- Care of severe COVID-19 patients, including indications for oxygen therapy and indications for dexamethasone
- Indications for transfer between health facility levels and treatment centers
- Monitoring patients receiving oxygen
- Titrating oxygen therapy
- Care of critically ill patients

Intervention Adapt existing guidelines to the national context.
Available resources include:

- www.covidprotocols.org
- WHO COVID-19 Clinical management: living guidance
- WHO Clinical care of severe acute respiratory infections – Tool kit

Intervention Convene interdisciplinary working group to review reference guidelines and draft and validate national guidelines with appropriate adaptations to available resource levels and facility levels when indicated.

Intervention Publish and distribute protocols to facilities, coupled with trainings to improve HCW knowledge and capacity (see strategy 4.2).

Intervention Develop and distribute implementation tools to support protocol uptake, such as single page flow charts for key clinical processes including oxygen titration. Consider poster-sized flow charts for display in clinical areas at COVID-19 treatment facilities.

Intervention For mobile health and point-of-care EHR systems, integrate and implement protocols as job aids and alerts

Strategy 4.2: Develop a national training strategy to train HCWs on the management of hypoxemic COVID-19 patients

Intervention Adapt and develop a training curriculum for identification, monitoring, and management of hypoxemic patients incorporating national and standardized clinical protocols.
Available resources include:

- WHO Clinical management of patients with COVID-19 - General considerations
- www.opencriticalcare.org
- www.covidprotocols.org.

Content should include:

- Basic pathophysiology and clinical signs of hypoxemia
- Basic epidemiology, pathophysiology, and clinical course of COVID-19
- Patient assessment and indications for oxygen therapy
- Use of pulse oximetry to monitor patients with COVID-19
- Prone positioning for COVID-19
- Oxygen sources (i.e. cylinder, wall oxygen, and concentrator)
- Oxygen administration interfaces (e.g. nasal cannula, simple facemask, non-rebreather facemask)
- Oxygen titration guide by pulse oximetry

Intervention Adapt and develop a training curriculum for advanced management of hypoxemic patients in emergency departments and intensive care units (if applicable).
Available resources include:

- www.opencriticalcare.org
- www.covidprotocols.org.

Topics to be covered include:

- Respiratory failure (hypoxemic and hyperbaric)
- Non-invasive ventilation
- High flow nasal cannula
- Indications for intubation
- Airway management
- Mechanical ventilation

Intervention Incorporate hypoxemia management job aids into community and clinical health eHealth applications.

Intervention Determine mode(s) of content delivery (live remote learning, learning management system, in person lectures, bedside teaching, simulation, etc.). Ideally, training curricula should include didactic based modules as well as clinical mentorship and supervision.

Intervention Plan for which facilities should receive the basic and advanced curricula.

Strategy 4.3: Identify and train master trainers/clinical mentors

Trainers and clinical mentors are important for initial training delivery as well as for ongoing support of clinical staff.

When possible, build the capacity of existing staff to improve long-term health systems strengthening.

Intervention	Conduct a training of the trainers for at least one nurse and one clinician from every target facility. Equip trainers with the needed supplies and tools to carry out training at their own facilities.
Intervention	Facilitate communities of care with ongoing mentorship for facility level trainers. Examples of communities of care include development of WhatsApp groups to address questions and provide continuing support. Encourage mentors to establish similar communities at their own facilities, as well as to establish ongoing continuing education through case review and discussion.
Intervention	Instruct master trainers on effective strategies for bedside teaching. Develop checklists and protocols to facilitate bedside supervision (see PIH Mentorship and Enhanced Supervision for Healthcare and Quality Improvement (MESH-IQ))

Strategy 4.4: Train and mentor HCWs caring for hypoxemic patients

Intervention	Deliver trainings from master trainers to all trainees at target facilities. When considering who to train, consider the need to cross-train staff to cover facility needs in the event of surges and/or staff outbreaks.
Intervention	Provide ongoing mentorship and support through a longitudinal mentorship system. Plan for refresher training at least annually, or more frequently if needed.
Intervention	Periodically monitor training impact through assessments of trainee knowledge and confidence.

Objective 5: Adequate availability of clinical equipment and supplies to care for hypoxemic patients with COVID-19 and other respiratory illnesses

A range of inexpensive diagnostic and therapeutic supplies are needed for COVID-19 patients to benefit from life-saving oxygen therapy. Facilities frequently lack basic essential equipment, limiting the ability to deliver oxygen even when oxygen supply is sufficient. It is essential that healthcare facilities are supported by the necessary equipment, supplies, and supporting systems to diagnose and treat hypoxemia.

Strategy 5.1: Develop and implement oxygen formularies adapted to national guidelines and facility level.

Intervention	Convene an interdisciplinary working group to review existing equipment and supply lists and develop a master oxygen formulary list, adapted to national treatment guidelines and to facility level. Lists should include separate components for biomedical equipment (pulse oximeters, vital sign machines, ultrasounds, patient monitors), consumable supplies (oxygen tubing, nasal cannula, and face masks) and medications relevant to the care of severely ill COVID-19 patients (dexamethasone). The biomedical and consumable equipment relevant for the care of severely ill COVID-19 patients is the same as that required for the care of other severely ill hypoxemic patients; for this reason, we recommend a unified approach to oxygen formularies wherever possible, with disease specific adaptations to medications when needed. Available resources include: ▪ WHO Model Lists of Essential Medicines ▪ WHO COVID-19 essential supplies forecasting tool (COVID-ESFT)
Intervention	Identify essential equipment on the formulary where equipment redundancy is important in the event of a failure. For example, redundancy in oxygen supply, pulse oximeters, and in basic

oxygen delivery equipment is essential to avoiding gaps in treatment of COVID-19 patients in the event of stock outs or equipment failures.

Intervention Implement supply chain forecasting system and create processes for emergency procurement of essential commodities to address stock outs.

➔ See PIH supply chain toolkit for more information on supply chain forecasting and procurement processes

Intervention Assess current needs through a commodity and equipment availability and needs assessment for all facilities. When possible, leverage patient-level data systems such as EMRs for needs assessment analysis, for example, to determine the volume of hypoxic patients.

Strategy 5.2: Facilities implement measures to make equipment immediately available to clinicians caring for COVID-19 patients

Even when supplies and equipment are available at a facility, they are not always immediately accessible to HCWs. For hypoxemic COVID-19 patients, treatment delays can be fatal. Governments and facilities should ensure that equipment is accessible and ready to be used, and remove barriers to equipment use for the care of severely ill patients, including user fees.

Intervention Implement an organized storage area for essential equipment in all COVID-19 clinical areas. Storage areas should be easily accessible from COVID-19 suspected and confirmed wards, but should be designed with IPC procedures in mind so that equipment and supplies do not become contaminated.

Intervention Distribute and implement appropriate equipment cleaning and reuse guidelines in facilities. Implement protocols to ensure timely processing of dirty equipment. (e.g. ensuring any equipment cleaned with chlorine is properly washed and dried according to WHO guidelines) WHO guidelines for cleaning and disinfection of environmental surfaces in the context of COVID-19

➔ See PIH IPC guidelines for ensuring infection prevention within facilities

Intervention Clinicians have access to a simple mechanism for reporting stockouts

➔ See PIH supply chain toolkit for managing and reporting stockouts

Intervention Where relevant, facilities establish emergency stocks of critical supplies accessible to clinicians off hours, for example, with a back-up supply or medication room containing a small stock of critical consumables or drugs.

COST CONSIDERATIONS:

Objective 1:

- Costs related to oxygen needs assessments (travel costs, meetings costs)
- Oxygen strategic planning meeting or workshop costs

Objective 2:

- PSA plant installation costs
- Large and small oxygen cylinders
- Extra oxygen cylinders for backup supply
- Upgrades for electricity infrastructure
    - Generator fuel (if required)
    - Oxygen piping network installation
    - Materials costs
    - Costs for international contractor
    - Y blocks for outlets
- Training for staff on use and safety for oxygen pipeline systems
- Concentrators (Airsep, Devilbiss for example)
- Voltage/surge protection devices
- Slitters and other supplemental equipment
- Solar microgrid powered portable concentrators
- Trainings for staff on operation and maintenance of portable concentrators
- PSA oxygen cylinder filling plant
- Oxygen delivery trucks, staff, and fuel

Objective 3:

- Trainings on maintenance for PSA air compressors
- Printing and distribution of Aiar Compressor Troubleshooting Guide
- Training on PSA components and general plant maintenance
- Refresher training on oxygen safety
- Refresher training on pipeline and outline maintenance
- Refresher training on oxygen compressor preventive maintenance and repair
- Print and distribute hard copies of operation, service, and parts manuals for specific equipment
- Print and distribute vendor and technical support contact list for equipment
- Spare parts and consumables for PSA plants
- Spare parts kits for oxygen cylinder filling compressors
- Spare oxygen outlets, outlet maintenance kits, spare flowmeters
- Oxygen analyzer for all facilities with PSA plants and portable concentrators
- Spare pressure regulators and flowmeters for oxygen cylinders
- At least 1 spare cabinet and 4 product filters for each concentrator
- Spare power cables and fuses
- Other spare parts (circuit board, compressor service kit, capacitor, solenoid valves)

Objective 4:

- Costs for interdisciplinary working group meetings
- Printing and distribution of clinical protocols for safe management of hypoxemic COVID-19 patients
- Printing / publishing costs for flow charts, posters of clinical processes including oxygen titration
- Print protocols as job aids or other alerts

- Training of trainers/clinical mentors (1 nurse and 1 clinician for every target facility) on caring for hypoxemic patients
- Tools and supplies for trainers on caring for hypoxemic patients
- Development and printing of checklists for supervision
- Costs for trainings from master trainers to all trainees at target facilities on caring for hypoxemic patients
- Refresher trainings on caring for hypoxemic patients
- Costs for monitoring training impact via assessments of trainee knowledge

Objective 5:

- Convene interdisciplinary working group to review existing equipment and supply list (meeting costs)
- Meetings costs for formulary and supply chain forecasting for oxygen
- Costs for storage area for essential equipment

RESOURCES:

Improved oxygen systems for childhood pneumonia: a multihospital effectiveness study in Papua New Guinea
PATH Baseline Assessment Manual
COVID-19 Facility Assessment Resources
Every Breath Counts COVID-19 LMIC Oxygen Partners
PATH Quantification and Costing Tools
Open Critical Care Demand Calculator
OGSI size estimator based on beds and critical care beds
UNICEF Oxygen System Planning Tool
PATH Electricity Planning Guide
How to set up an oxygen flow splitter
Every Breath Counts COVID-19 LMIC Oxygen Partners - Google Sheets
PATH|CHAI Equipment Market Report
PATH Costing Tool
PATH Procurement Guide
Oxygen sources and distribution for COVID-19 treatment centres
PATH resource on Oxygen Access and Reliability
WHO PSA Plant Specifications
Assist International
Hewatele
BHI/Tuck school distribution model
OpenO2
Sollatek
OxBox concept from BHI
WHO technical specifications for oxygen concentrators
Novair
Maxtec UltraMaxO2
www.covidprotocols.org
COVID-19 Clinical management: living guidance
Clinical care of severe acute respiratory infections – Tool kit
Clinical management of patients with COVID-19 - General considerations
www.opencriticalcare.org
www.covidprotocols.org
WHO Model Lists of Essential Medicines
Cleaning and disinfection of environmental surfaces in the context of COVID-19
PIH Mentorship and Enhanced Supervision for Healthcare and Quality Improvement (MESH-IQ