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The Medical Oxygen Innovation Landscape

Technologies and business models to improve access

August 2024

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Acknowledgements

This report was prepared by Pablo Vega Rojas, Evan Spark-DePass (Unitaid) in collaboration with Elizabeth Johansen, Gordon Adomdza and David Hutchful (Spark Health Design) with research support from Foster Gomado, Awula Adei Quaye and Ebenezer Harry Dzanie (Spark Health Design). The following individuals also provided valuable contributions during the development of the landscape: Alfonso Rosales, PAHO/WHO; Sandy Rousing, Air Liquide, Access Oxygen; Jim Ansara and Eric Buckley, Build Health International; Biniyam Bahiru, Ethiopia MOH; Jerad Musembe, HewaTele; Michael Hawkers and Qaasim Mian, University of British Columbia and IC Change; Michael Njuguna, Mediquip Global; Phoebe Kagame, Oxygen Alliance; Amarpreet Rai, Sanrai Group and Oxygen Alliance; Michael Hansen, UNICEF; John Graf, NASA; Tajudeen Raji, Africa CDC; Leith Greenslade, Just Actions; Carina King, Karolinska Institutet. Co-chair, Lancet Global Health Commission on Medical Oxygen Security; Freddy Kitutu, Department of Pharmacy Makerere University School of Health Sciences. Co-chair, Lancet Global Health Commission on Medical Oxygen Security; Lisa Smith, PATH; Lucas Hille, Touch Foundation; Florin Gheorghe, UNICEF; Alex Losneanu and Jason Houdek, Oxygen CoLab.

Abbreviations

ASU Air Separation Unit

BGMF Bill & Melinda Gates Foundation

CHAI Clinton Health Access Initiative

COPD Chronic Obstructive Pulmonary Disease

CPAP Continuous Positive Airway Pressure

GO2AL Global Oxygen Alliance

HFNC Heated Humidified High-flow Nasal Cannula Therapy

HICs High Income Countries

HIV Human Immunodeficiency Virus

LMICs Low- and Middle-Income Countries

LOX Liquid Oxygen

LPM Litres Per Minute

NCBI National Center for Biotechnology Information

NICUs Neonatal Intensive Care Units

PPP Public Private Partnership

PPPR Pandemic Prevention, Preparedness and Response

PSA Pressure Swing Adsorption

SDG Sustainable Development Goals

SSA Sub-Saharan Africa

UHC Universal Health Coverage

UNICEF United Nations Children's Fund

WHA World Health Assembly

WHO World Health Organization

Contents

1. Introduction

Medical oxygen is an essential medicine for healthcare delivery in both low- and middle-income countries (LMICs) as well as high-income countries (HICs). It is a vital therapeutic for the treatment of a variety of medical conditions, thus included on the 23rd World Health Organization (WHO) Model List of Essential Medicines[1] and the 9th World Health Organization Model List of Essential Medicines for Children. The recent COVID-19 pandemic also drew attention to the significance of improving access to oxygen related devices, infrastructure and consumption on a global scale.

In May 2023, the World Health Assembly (WHA) unanimously adopted Resolution WHA76.3,[2] titled "Increasing Access to Medical Oxygen." This resolution calls upon governments, the WHO, and its partners to ensure oxygen systems are a foundational component of both Universal Health Coverage (UHC) and pandemic prevention, preparedness, and response (PPPR) efforts. It emphasizes that achieving UHC, PPPR, and the health-related Sustainable Development Goals (SDGs) depends on universal access to high-quality medical oxygen and associated medical technologies for diagnosis and treatment.

1 The World Health Organization (WHO). WHO Model List of Essential Medicines - 23rd list, 2023

2 WHO (2023). 76 World Health Assembly Resolution on Increasing Access to Medical Oxygen. World Health Organization. Accessed at: https://globaloxygenalliance.org/

Approximately 25 million annual deaths are attributed to conditions where medical oxygen is often required, but not available. Of these, six million deaths are from pneumonia – one of the leading causes of death for children under five – and chronic obstructive pulmonary disease (COPD) alone.[3] Studies in low-resource settings have revealed that fewer than one in five children hospitalized with severe pneumonia and hypoxemia receive the vital oxygen therapy they require.[4] A recent review found that medical oxygen has the potential to reduce overall child mortality among hospitalized children by 25%, and that investing in oxygen infrastructure is as cost-effective as vaccination.[5]

Access to medical oxygen could substantially reduce deaths, accelerating progress toward achieving five out of the nine health-related SDG targets including reducing maternal, newborn and child mortality, deaths from communicable and non-communicable diseases, as well as achieving universal health coverage.[6]

The objective of this oxygen innovation landscape report is to describe the current gaps in oxygen access and identify emerging technologies and business models that could help close these gaps. By identifying and scoping these innovations, the report aims to outline potential solutions at various stages of development that could contribute to improving access to oxygen, which has the potential to save hundreds of thousands of lives each year. It is important to note that this report is intended as a knowledge product to highlight relevant innovations; it is not meant to be exhaustive and should not be interpreted as an intention to fund any specific product.

3 Institute for Health Metrics and Evaluation (IHME) (2015). GBD Compare. IHME, University of Washington. Accessed at: http://vizhub.healthdata.org/gbd-compare.

4 Bakare, A. A., Graham, H. Ayede, A. I., et al. (2020). Providing oxygen to children and newborns: A multi-faceted technical and clinical assessment of oxygen access and oxygen use in secondary-level hospitals in southwest Nigeria. International Health, 12(1), 60–68. https://doi.org/10.1093/inthealth/ihz009

5 Lam F, Stegmuller A, Chou VB, Graham HR. Oxygen systems strengthening as an intervention to prevent childhood deaths due to pneumonia in low-resource settings: systematic review, meta-analysis and cost-effectiveness. BMJ Glob Health. 2021 Dec;6(12):e007468. doi: 10.1136/bmjgh-2021-007468. PMID: 34930758; PMCID: PMC8689120.

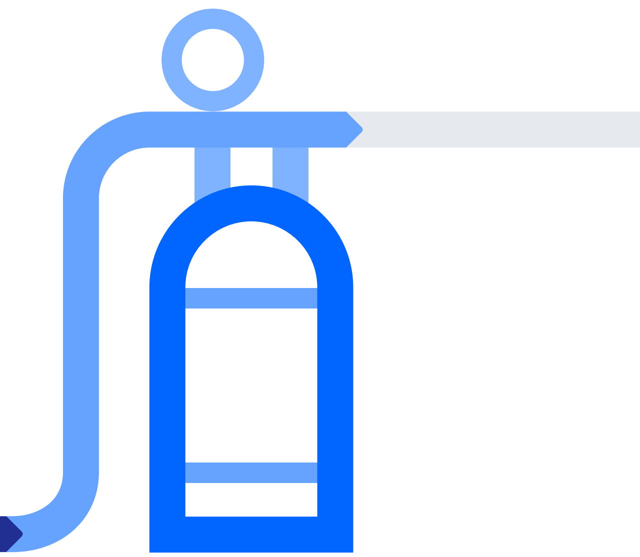
6 Global Oxygen Alliance Strategy: executive summary 2024-2030. https://globaloxygenalliance.org/ [Accessed 16 May 2024]

2. Methodology and scope

The methodology for developing this medical oxygen innovation landscape report involved primary and secondary research to profile and understand the oxygen value chain, describe current gaps, and identify innovations being deployed to fill these gaps.

This report was compiled between May and November 2023 using the following sources: previous work conducted by Unitaid, peer-reviewed published literature, institutional and corporate websites, product instructions for use, and semi structured videoconference interviews with subject matter experts and innovators working on medical oxygen from public health organizations, non-governmental organizations, academia and industry.

This report aims to provide ministries of health, international organizations, donor agencies, innovators and industry with a broad overview of emerging solutions that have the potential to improve access to medical oxygen. This report does not aim to be exhaustive and does not provide detailed information on quality and regulatory controls - some products or models may have been omitted due to a lack of publicly available information and rapid rate of change in the oxygen landscape since the COVID-19 pandemic.



3. Background

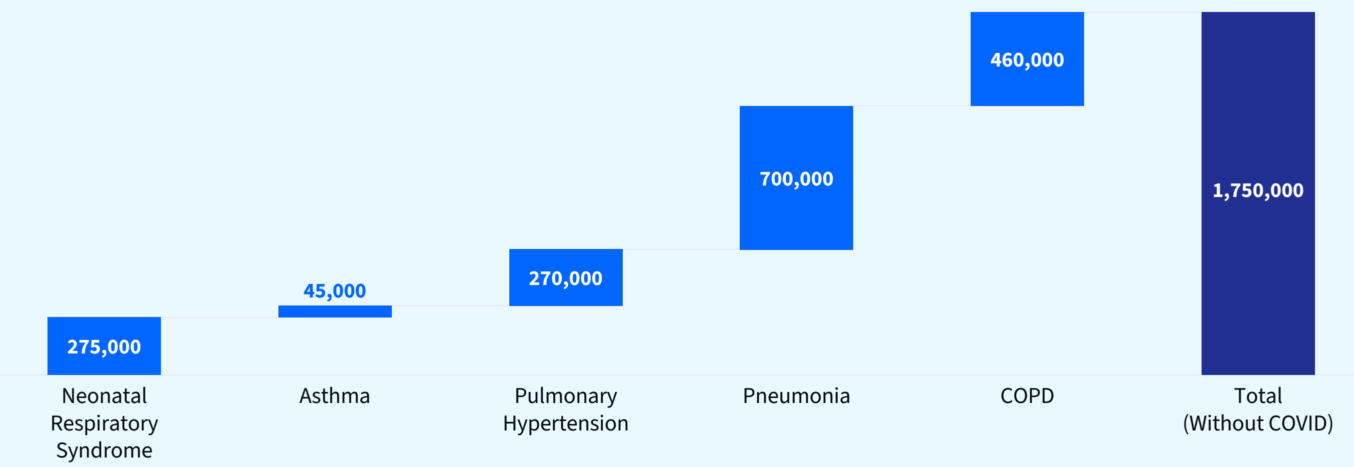
3.1 Need and Demand

Medical oxygen is an essential medicine to treat patients facing respiratory diseases that cause hypoxemia. Oxygen is needed for a variety of conditions like tuberculosis, pneumonia, advanced HIV disease, COVID-19, women in labor, asthma and in emergency medicine.

Long-term oxygen therapy may be necessary for individuals with chronic respiratory conditions or those needing palliative care. It is also crucial in surgery requiring anesthesia and in critical care. It is vital for premature infants and newborns with respiratory distress, ensuring the proper functioning of their developing lungs in neonatal intensive care units.

In sub-Saharan Africa alone, 1.75 million people die each year from respiratory conditions without accounting for COVID-19 (Figure 1). This figure is indicative of the far larger volume of medical oxygen needed across a broader range of indications and geographies.

Figure 1: Annual deaths across SSA from various respiratory-related conditions[7]



Source: https://transformativetechnologies.org/wp-content/uploads/2021/01/ClosingO2GapinSSA.pdf

7 Closing the medical-oxygen gap in Sub-Saharan Africa. Institute for Transformative Technologies (ITT) and Oxygen Hub. January 2021. https://transformativetechnologies.org/wp-content/uploads/2021/01/ClosingO2GapinSSA.pdf [Accessed 16 May 2024]

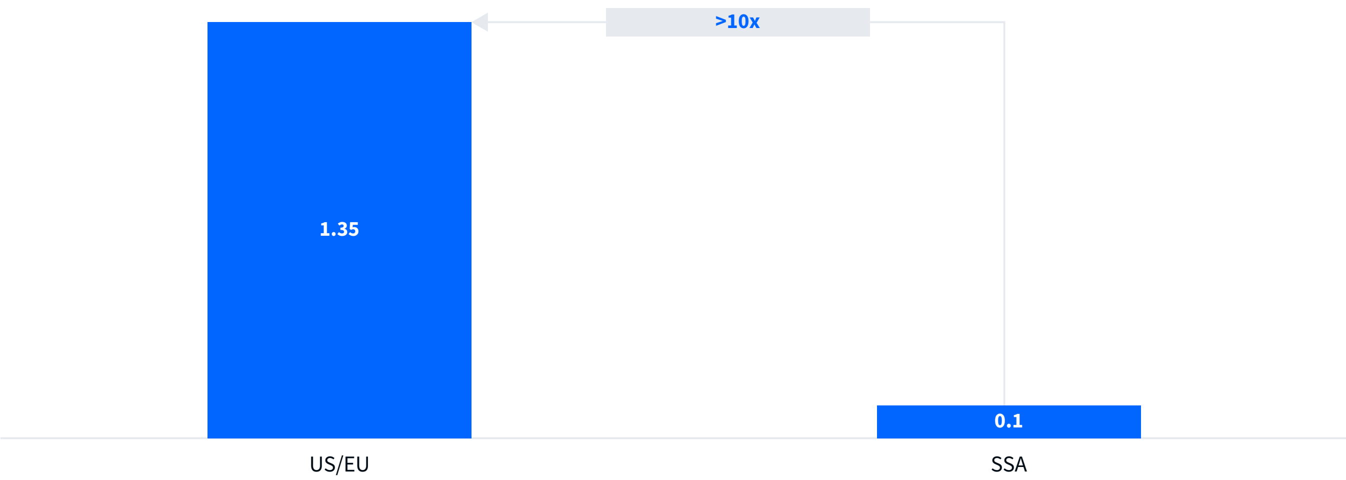
The need and demand for oxygen is expected to increase in LMICs due to high birth rates, epidemiological shifts in the burden of disease (people being prone to diseases earlier and the risk of non-communicable diseases) and the wider availability of pulse oximeters to diagnose hypoxemia (low oxygen) since the pandemic.[8] Catalytic investments, such as those made by Unitaid, together with increased donor funding for medical oxygen (e.g., via The Global Fund, the World Bank, USAID, and other agencies) might be expected to increase LMIC government demand.

Despite the vast current and future needs for oxygen in LMICs, there are significant disparities globally from a consumption standpoint. The average per capita oxygen consumption in sub-Saharan Africa is one tenth the oxygen consumption in the US/EU (Figure 2).[9]

Despite the vast current and future needs for oxygen in LMICs, there are significant disparities globally from a consumption standpoint. The average per capita oxygen consumption in sub-Saharan Africa is one tenth the oxygen consumption in the US/EU (Figure 2).[10]

This discrepancy points to the pronounced differences in oxygen access between HICs and LMICs, and a high degree of unmet need in limited resource settings.

Figure 2: Average per capita medical oxygen consumption (cubic meters per year)[11]



8 8 US/Eu vs SSA (sub-Sahara Africa) - Institute for Transformative Technologies (ITT) and Oxygen Hub (2021)

9 Unitaid. US$ 83 million of investments from Unitaid to address global inequities in access to oxygen will drive long term benefits, Unitaid urges other donors to commit more funding for medical oxygen. https://unitaid.org/news-blog/us-83-million-of-investments-from-unitaid-to-address-global-inequities-in-access-to-oxygen-will-drive-long-term-benefits-unitaid-urges-other-donors-to-commit-more-funding-for-medical-oxygen/#en [Accessed 13 December 2023]

10 Institute for Transformative Technologies (ITT) and Oxygen Hub. (n 7)

11 US/Eu vs SSA (sub-Sahara Africa) - Institute for Transformative Technologies (ITT) and Oxygen Hub (2021)

3.2 Access to Medical Oxygen in LMICs

Oxygen is crucial for treating patients at all levels of healthcare (Figure 3). It is important to note that the challenges associated with accessing oxygen vary considerably according to facility size, proximity to urban areas, environment, access to electricity and available human resources, among others.

While there is limited global data on oxygen availability in LMICs, WHO surveys reveal that less than half of healthcare facilities have consistent access to oxygen.[12] In a 2020 study across four sub-Saharan African countries, only 43% of health facilities had both continuous power and some form of oxygen available.[13]

Figure 3: Medical units at various levels of the health system where oxygen or pulse oximetry is needed[14]

Primary level

(e.g. home, community care, health post, health centre)

- General ward
- Labour unit
- Neonatal resuscitation corner
- Emergency triage
- Transport to referral

Secondary level

(e.g. district hospital)

- Emergency triage
- Labour and delivery room
- Neonatal care
- Paediatric and/or adult ward
- ICU
- Operating theatre

Tertiary level

(e.g. regional, specialized hospital, specialized outpatient clinics)

- Emergency triage
- Labour and delivery room
- ICU (neonatal, paediatric, adult)
- Paediatric and adult wards
- Surgery and recovery wards
- Cardiopulmonary ward
- Emergency ward

12 WHO (2023), Oxygen. World Health Organization. https://www.who.int/health-topics/oxygen#tab=tab_2 [Accessed 16 May 2024]

13 Sowmya Mangipudi, Andrew Leather, Ahmed Seedat, Justine Davies. Oxygen availability in sub-Saharan African countries: a call for data to inform service delivery. The Lancet Global Health, Volume 8, Issue 9, 2020, Pages e1123-e1124,

14 WHO-Unicef. Technical specifications and guidance for oxygen therapy devices, 2019. ISBN 978-92-4-151691-4

The oxygen ecosystem in LMICs has historically struggled to meet the needs of patients due to a vast number of challenges (Figure 4). Many LMICs lack enough trained healthcare workers and engineers essential for oxygen provision and equipment maintenance. These countries often have significantly fewer engineers than high-income nations and retaining them in the public healthcare system is challenging. Infrastructure issues such as unreliable electricity, high energy costs and poor roads disrupt oxygen delivery and risk damaging oxygen plants. Even before COVID-19 access to oxygen was limited due to insufficient funding.

Many LMICs do not have clear plans in their health systems for a steady, safe, and cost-effective oxygen supply. Data on oxygen needs are limited, making system improvements difficult to achieve. The global oxygen market is fragmented, affecting affordability, quality and supply reliability. Further, inconsistent leadership promoting the use of oxygen and insufficient community engagement have made the situation more challenging. These constraints require comprehensive solutions to ensure everyone can access this essential resource.

Figure 4: WHO. (2023). Foundations of medical oxygen systems[15]

	Delivery and access gaps		Enabling environmental gaps				
	Shortage of trained workforce	Weak maintenance and availability of infrastructure and delivery systems	Lack of financing	Limited policy and planning ability and regulatory frameworks	Absence of data for routine reporting and tracking of KPIs	Fragmented market	Variable governance and community engagement
Needs	• Trained health workforce, including medical doctors, nurses and respiratory therapists • Biomedical engineers	• Production, stoage and distribution • High-quality electrical supply • Water supply • HVAC • Structural engineering	• Regular, adequate financial budget support • Partnerships • Affordability for patients	• Quality assurance and control • Regular needs assessments, planning	• System monitoring • Accountability	• Availability, affordability, quality, acceptability, secure supply & delivery	• Strong leadership, coordination and political will • Robust advocacy and demand generation

Source: WHO. WHO. (2023). Foundations of medical oxygen systems. World Health Organization. Accessed at: https://apps.who.int/iris/handle/10665/366149

15 The Global Oxygen Alliance (n. 6)

Cross-cutting barriers to access

1. **Quality:** Ensuring the quality of respiratory care equipment is a significant challenge. Traditional quality-assurance approaches such as procurement models or stringent regulatory approvals may not be universally applicable. Additionally, oxygen purity relies on consistent and appropriate maintenance of production technologies.
2. **Affordability:** Affordability challenges for medical oxygen, especially liquid oxygen (LOX), arise from market dynamics and transportation costs. High operational and capital expenditures for on-site production and cylinder procurement exacerbate these issues. Introducing affordable capital financing for suppliers in LMICs can alleviate initial expenses, providing a viable solution to reduce medical oxygen costs and improve access in low-resource environments.
3. **Supply and Delivery:** Efficient distribution is key to oxygen accessibility. However, a lack of infrastructural support, especially in rural areas, creates dependency on cumbersome cylinder swaps. This is compounded by issues with accessing spare parts, which can render equipment non-operational.
4. **Demand and Adoption:** Efforts to determine oxygen needs at the country or regional levels are scarce. There is also a gap in knowledge regarding cost-effective technologies and deployment strategies. Other challenges include under-prioritization of oxygen in healthcare budgets and training deficiencies among healthcare workers.
5. **Innovation and Availability:** The dominant technologies, particularly for production and distribution, were developed in the 1970s and have not experienced significant innovation since then.

To address the persistent challenges and gaps in oxygen access, the Access to COVID-19 Tools Accelerator (ACT-A) Oxygen Emergency Taskforce mobilized nearly USD $1 billion for LMICs during the COVID-19 pandemic. Despite this significant financial effort, medical oxygen access continues to fall short in many areas. Transitioning into a more comprehensive approach, the taskforce evolved into the Global Oxygen Alliance (GO2AL), a coalition of 19 diverse members including international organizations, NGOs, donor agencies and civil society groups. GO2AL is dedicated to creating sustainable and equitable access to medical oxygen and has set a bold target to secure USD $4 billion in funding by 2030.[16] This ambitious initiative aims to enhance infrastructure, introduce innovative financing models and forge strategic partnerships to dismantle the systemic barriers impeding oxygen delivery, thereby ensuring the durability and reach of these essential healthcare solutions.

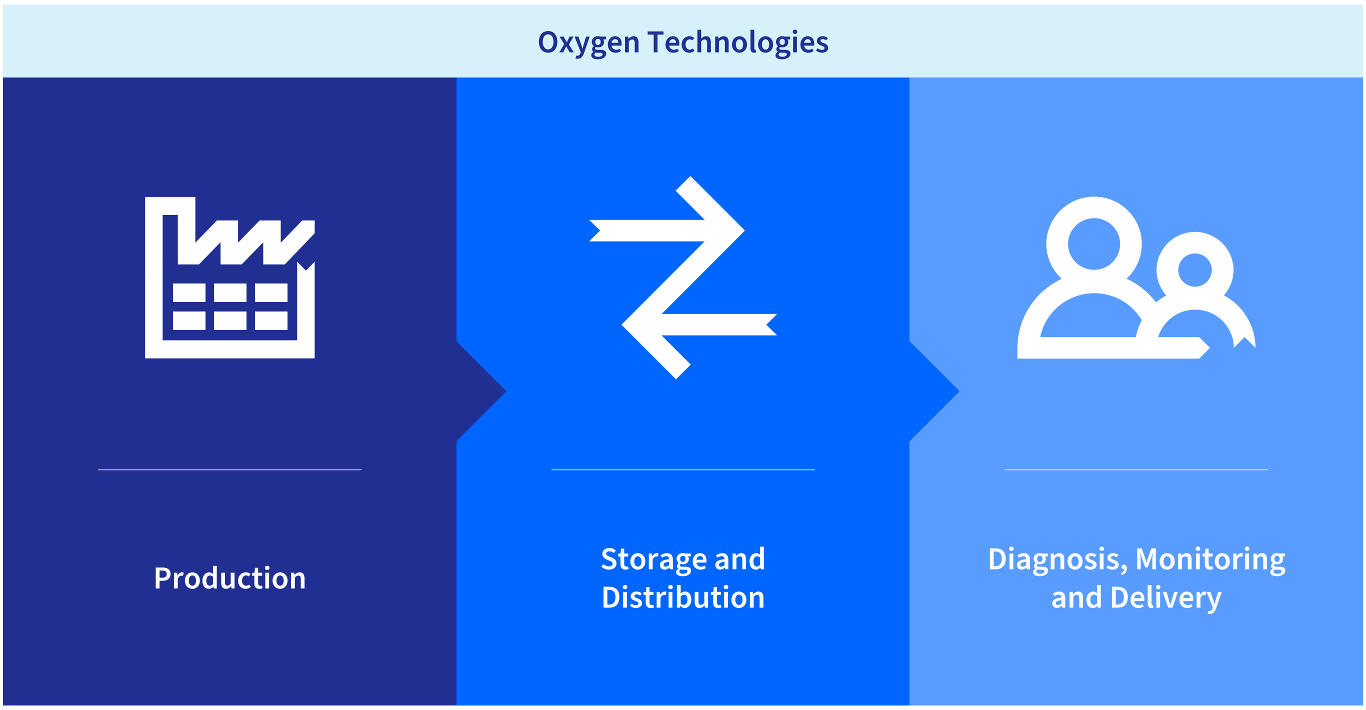
16 The Global Oxygen Alliance (n. 6)

4. Current Technologies and Business Models

This section provides an overview of existing technologies and business models employed in LMICs and the challenges posed by these approaches. The current technologies have been categorized into the classification proposed by the World Health Organization:[17]

- Oxygen production, storage, and distribution technologies
- Oxygen delivery technologies
- Patient oxygen monitoring
- Oxygen conditioning, regulation, and testing devices

Figure 5: Oxygen Product Systems



17 WHO (n. 15)

4.1 Oxygen production, storage, and distribution technologies:

Medical oxygen production occurs either directly within health facilities or externally at specialized manufacturing sites.

The core technology enabling medical oxygen production is the Air Separation Unit (ASU), which effectively separates oxygen from nitrogen and, in some cases, argon and other inert gases, from the air we breathe. This separation is achieved through various methods, each resulting in different forms of oxygen:

1. Cryogenic fractional distillation produces liquid oxygen.
2. Pressure Swing Adsorption (PSA) and Vacuum Swing Adsorption (VSA) techniques yield oxygen in gas form.
3. Vacuum Pressure Swing Adsorption (VPSA) combines the principles of PSA and VSA to optimize oxygen concentration.

The choice of oxygen form—liquid or gas—significantly influences the design of storage, transport, and distribution systems within healthcare settings. Factors such as temperature and pressure play critical roles in determining the flow of oxygen, which can be stored in high-pressure gas cylinders, bulk tanks, cryogenic cylinders, or distributed through pipeline networks.

In healthcare environments, it is common practice to have both primary and secondary oxygen sources to ensure a reliable supply. Existing medical gas pipeline systems, if present, are integrated with these sources via pneumatic changeover systems to maintain an uninterrupted oxygen supply.

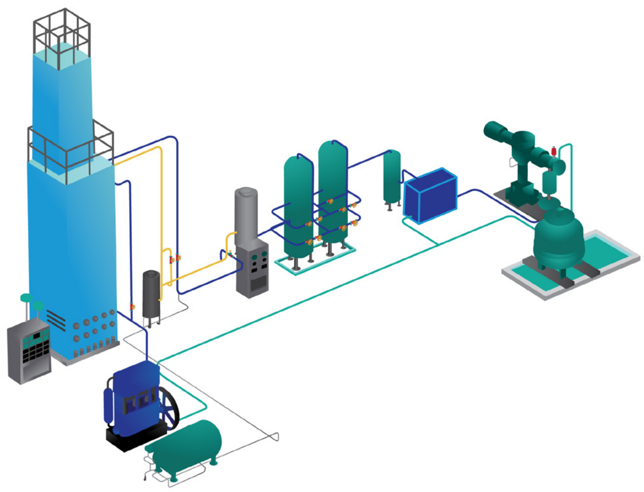
4.1.2 Oxygen production:

Air Separation Units (ASU): ASUs produce liquid oxygen (LOX), which is the gold standard for medical applications in HICs and can offer significant benefits due to compact storage, economic efficiencies, and high purity level of 99%. Cryogenic air separation is a less energy-intensive method of producing oxygen than alternatives, which means ASUs can achieve low unit costs for oxygen at high volumes.[18] In addition, transporting LOX can be efficient as one liter of LOX is equivalent to 798 litres of oxygen gas.[19] Unlike on-site generation technologies, LOX has low electricity requirements at the facility, making it a strong option for many rural areas.

18 PATH and CHAI. Business Models in Respiratory Care. October 2021. https://www.path.org/our-impact/resources/business-models-respiratory-care/ [Accessed 16 May 2024]

19 Ibid

Illustration 1: Air Separation Unit (ASU) [20]



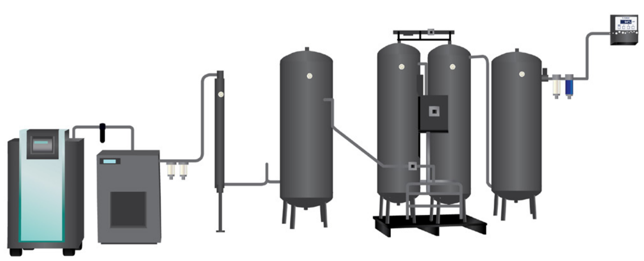
Source: WHO document: WHO. (2023). Foundations of medical oxygen systems. World Health Organization

Despite these advantages, utilizing oxygen from ASUs comes with its own set of challenges. The logistics of distributing LOX, particularly to remote or difficult-to-access facilities, can be complex and may delay deliveries. ASUs are quite large, require high initial capital investments, and are typically built for industrial purposes in LMIC contexts. These factors can limit the availability of LOX produced by ASUs in some settings.

Pressure Swing Adsorption (PSA) and Vacuum Swing Adsorption (VSA) plants: PSAs and VSAs generate oxygen by filtering nitrogen from the air. Each produces oxygen with 90-96% purity, which is suitable for medical use. PSAs and VSAs can be operated on-site and have the capability to supply oxygen directly to patients via piping systems, or to fill cylinders for distribution. PSAs and VSAs stand out as the only large-scale, on-site production option for health facilities in LMICs. Many new plants were procured, and the broken ones were repaired during the pandemic. Both products can be especially useful in areas that have electricity but are far from ASUs, making LOX difficult or impossible to obtain.

However, there are barriers to the successful deployment and sustained use of PSA and VSA plants. They are dependent on a reliable electricity supply and require regular maintenance performed by qualified professionals to prevent operational failures or the production of sub-standard oxygen. The procurement of spare parts for repairs can also pose logistical challenges. Additionally, the high up-front capital expenditures paired with ongoing energy, and maintenance costs can be prohibitive for some health facilities.

Illustration 2: Pressure Swing Adsorption (PSA) and Vacuum Swing Adsorption plants [21]



Source: WHO document: WHO. (2023). Foundations of medical oxygen systems. World Health Organization

20 US/Eu vs SSA (sub-Sahara Africa) - Institute for Transformative Technologies (ITT) and Oxygen Hub (2021)

21 US/Eu vs SSA (sub-Sahara Africa) - Institute for Transformative Technologies (ITT) and Oxygen Hub (2021)

Bedside oxygen concentrators: Oxygen concentrators employ the same foundational technology as PSA plants, but on a smaller scale. Unlike ASUs and PSAs, oxygen concentrators typically provide oxygen-enriched air directly to individual patients. By filtering nitrogen from the air, these devices can produce oxygen and are capable of delivering flow rates from 3 to 10 litres per minute (LPM), with advanced and novel models reaching up to 60 LPM. Oxygen concentrators do not carry the high up-front capital expenditures of PSAs and ASUs, can be deployed flexibly, and avoid the challenges and logistics associated with cylinder distribution.

Despite their flexibility, these devices require a reliable power source to operate effectively, and they need regular maintenance to prevent breakdowns and ensure purity. Although modifications like splitters can extend their use to more than one patient, most oxygen concentrators have historically been designed for single patient use in a non-acute, long-term care setting, and are not always suitable for large-scale oxygen delivery.

Illustration 3: Bedside concentrator [22]

Source: WHO document: WHO. (2023). Foundations of medical oxygen systems. World Health Organization

4.1.3 Oxygen storage and distribution:

Oxygen storage and distribution technologies, notably cylinders, tanks and medical gas piping systems play an important role in ensuring a consistent supply of medical oxygen to patients. Portable oxygen cylinders, refillable at centralized facilities or on-site with concentrators or PSA systems, cater to individual patient requirements and are crucial for emergency situations, such as patient transfers. Piping distribution systems provide a centralized, efficient means of delivering oxygen to multiple bedsides in medical facilities. The source of oxygen for these systems can vary, ranging from on-site PSA plants to vacuum insulated evaporators (VIEs) that store and vaporize LOX sourced from ASUs.

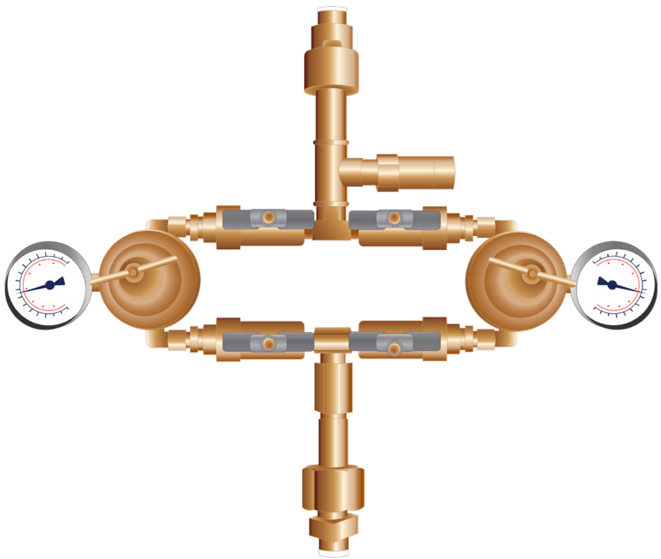
22 US/Eu vs SSA (sub-Sahara Africa) - Institute for Transformative Technologies (ITT) and Oxygen Hub (2021)

Liquid and gas oxygen storage: Gas oxygen cylinders are versatile, refillable containers designed to store oxygen under high pressure, making them adaptable for both bedside and pipeline system delivery within medical settings. Available in a range of sizes and pressures, they can meet diverse medical requirements, from individual patient care to broader hospital needs. Despite their usefulness, oxygen cylinders come with logistical and safety challenges. These include the need for regular refilling, secure transportation, and the risk of leaking and explosion of using high-pressure oxygen used at the bedside, all of which can complicate their management. Liquid oxygen storage systems can also extend the range of ASU networks to smaller facilities. However, non-bulk versions of liquid storage products are not being used widely in LMICs.

Medical gas pipeline systems (MGPS): MGPS serve as the lifeline of healthcare facilities, channeling oxygen directly from production plants or storage units to patient care areas. Typically integrated into the infrastructure of hospitals during construction or through retrofitting, MGPS ensure a seamless and continuous supply of medical oxygen to bedside outlets. In HICs, the adoption of MGPS is standard practice, enabling efficient oxygen delivery at the patient's bedside and reducing the reliance on portable cylinders.

Despite the clear advantages of MGPS, including improved safety by minimizing manual handling of cylinders and the risk of cross-contamination, the implementation of MGPS in LMICs presents substantial challenges.

Illustration 4: Medical gas pipeline systems (MGPS)



Source: WHO document: WHO. (2023). Foundations of medical oxygen systems. World Health Organization

These include a requirement for medical-grade materials, the expertise of skilled technicians for installation, the cost of retrofitting existing structures, and the challenge of maintaining hard to access systems in contexts with few maintenance resources. Consequently, while MGPS offers a robust solution for efficient oxygen delivery in hospitals, its widespread implementation, especially in resource-constrained environments, requires innovative solutions to overcome financial and technical hurdles.

4.2 Oxygen delivery technologies:

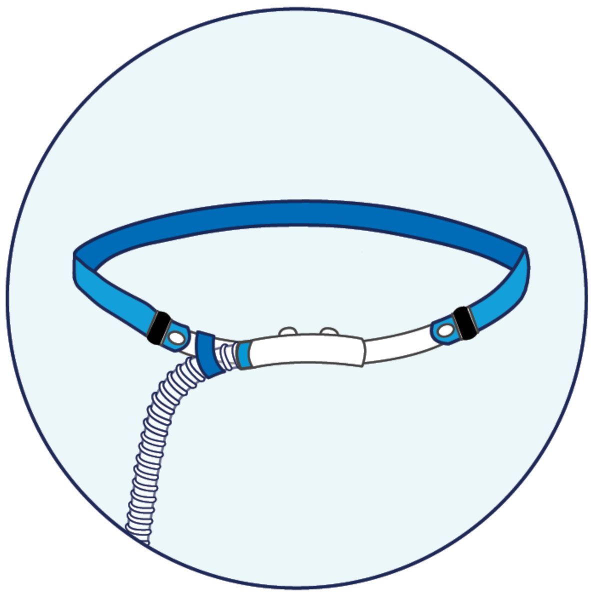
Delivery devices and equipment are essential in providing oxygen therapy to patients, serving as the critical pathway through which treatment is administered. The choice of these devices is carefully made, considering the unique healthcare requirements and specific clinical conditions of each patient to ensure the most effective treatment.

Note that this section will focus exclusively on advanced non-invasive and invasive oxygen delivery systems. It will cover advanced non-invasive options such as Continuous Positive Airway Pressure (CPAP) and bubble CPAP machines, High Flow Nasal Cannula (HFNC) therapy, and invasive ventilators, which play a crucial role in the management of critical patients suffering from hypoxemia. Importantly, this segment will not include other non-invasive oxygen delivery methods such as standard nasal cannulas, face masks, face masks with reservoir bags, and Venturi face masks, to concentrate on the advanced options that are critical for more severe cases.

4.2.1. Non-invasive respiratory support:

Heated Humidified High-flow Nasal Cannula (HFNC) Therapy: HFNC devices are designed for patients requiring respiratory support, delivering oxygen at high flow rates with added warmth and moisture. This method enhances patient comfort and improves oxygenation, which is advantageous in intensive care settings. However, the device's reliance on continuous access to electricity, its higher cost, and its demand for a high flow oxygen source for some patients, pose challenges in settings with limited resources.

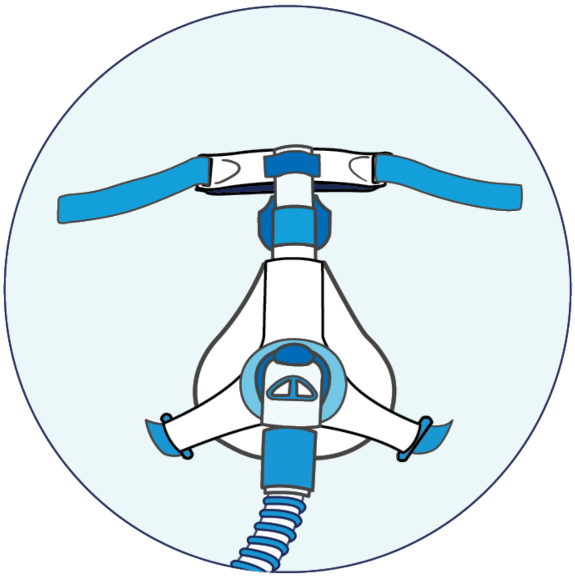
Illustration 5: High-flow cannula



Source: WHO document: WHO. (2023). Foundations of medical oxygen systems. World Health Organization

Continuous Positive Airway Pressure (CPAP) machine: CPAP machines provide non-invasive respiratory support that uses steady air pressure to help people breathe more easily. While CPAP is effective, it is often too expensive for many hospitals in LMICs. These devices also need reliable electricity and skilled healthcare workers, making them less accessible in places with limited resources.

Illustration 6: Continuous Positive Airway Pressure (CPAP) oronasal mask



Note: This is just one example of the delivery interface

Source: WHO document: WHO. (2023). Foundations of medical oxygen systems. World Health Organization

Bubble CPAP: Bubble CPAP are a subset of CPAP machines and are a non-invasive respiratory support devices particularly beneficial for infants, including preterm neonates, that deliver consistent air pressure to aid breathing. It stands out for being cost-effective and, in certain cases, surpasses traditional CPAP in efficacy, particularly for newborns due to its gentler and more stable pressure delivery. However, its adoption in LMICs has been restrained by factors such as unreliable electricity and water supply, alongside a scarcity of trained healthcare professionals—challenges common to most current solutions. This underscores the urgent need for tailored training and infrastructure to leverage bCPAP's potential in resource-limited settings.

Illustration 7: Bubble CPAP

4.2.2 Invasive respiratory support:

Ventilators: Invasive ventilators are primarily utilized in Intensive Care Units (ICUs) for critical patients that require respiratory support, necessitating skilled medical professionals for procedures such as intubation and for adjusting settings like pressure, volume, controls, and alarms. These ventilators are designed for various settings including ICUs for comprehensive ventilatory support in adult and pediatric patients, transport situations offering portable ventilatory assistance, and subacute care where they provide primarily non-invasive ventilation but can also offer invasive support in emergencies for patients unable to breathe independently or needing help to maintain ventilation. Ventilators can provide therapy with room air only, or oxygen can be added to provide up to 100% oxygen therapy. The maintenance of ventilators involves frequent calibration of gas sensors as well as other steps requiring materials and labor not commonly available in LMICs.

Illustration 8: Invasive respiratory support ventilators

Source: WHO document: WHO. (2023). Foundations of medical oxygen systems. World Health Organization

4.3 Patient oxygen monitoring

There is an array of products involved in the diagnosis and monitoring of hypoxemia. Pulse oximeters and multi-modal devices offering additional patient monitoring parameters are foundational to oxygen therapy, enabling health care workers to detect and monitor hypoxemia, and assessing patient's condition and oxygen needs.

Pulse oximeters and multi-modal devices: Pulse oximeters and multi-modal devices are essential medical diagnostics devices offering non-invasive, real-time monitoring of blood oxygen levels and other critical vital signs. This technology is necessary for the early detection of hypoxemia and continuous monitoring of oxygen levels. In recent years, the accessibility of pulse oximetry has significantly expanded, transforming it into a widely used tool across various healthcare settings.[23] This increased adoption has been instrumental in improving patient outcomes by enabling healthcare providers to make informed decisions swiftly, including for the identification and management of COVID-19 patients.

While pulse oximetry has made significant advancements, its deployment in LMICs still encounters challenges, notably due to economic and technological barriers. A specific concern is its reduced accuracy in individuals with darker skin tones, potentially leading to underdiagnosis. However, initiatives like the UCSF Open Oximetry Project supported by Unitaid, aim to address this issue by developing more inclusive technologies. Such efforts underscore the importance of innovating pulse oximetry to ensure it delivers equitable and effective healthcare across all populations.

Illustration 9: Pulse oximeters

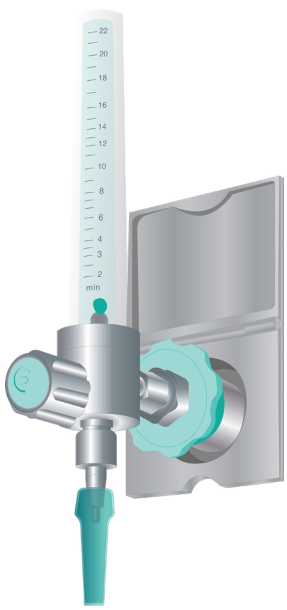
Source: WHO document: WHO. (2023). Foundations of medical oxygen systems. World Health Organization

23 Chew R, Zhang M, Chandna A, Lubell Y. The impact of pulse oximetry on diagnosis, management and outcomes of acute febrile illness in low-income and middle-income countries: a systematic review. BMJ Glob Health. 2021 Nov;6(11):e007282. doi: 10.1136/bmjgh-2021-007282. PMID: 34824136; PMCID: PMC8627405.

4.4 Oxygen conditioning, regulation and testing devices

Throughout the distribution and delivery of oxygen technologies, various devices are employed to manage the pressure, flow rate, humidity, and purity of the oxygen. These devices include pressure regulators, flowmeters, valves, flow splitters, humidifiers, and oxygen analyzers, each playing a crucial role in ensuring the oxygen is delivered safely and effectively.

Illustration 10: Oxygen outlet: conditioning and regulation using a flowmeter



Source: WHO document: WHO. (2023). Foundations of medical oxygen systems. World Health Organization

4.5 Current business models for oxygen delivery

The previous section analyzed several existing technologies essential for oxygen access. However, the efficacy of these technologies depends on the business model ecosystem that determines how oxygen and respiratory care equipment is bought, sold, supplied, and delivered to patients.
A particular technology's effectiveness in improving oxygen access can be significantly compromised if it operates through an inefficient or inappropriate business model. This section presents an overview of the existing business models for medical oxygen, focusing on their key characteristics and relative strengths and drawbacks.

4.5.1. Business Models for Oxygen Delivery

The sections below provides an overview of the operational context of business models within the oxygen ecosystem, based on previous work by PATH and CHAI "Business Models in Respiratory Care".[24] This section covers the three models that are most commonly used in medical oxygen:

- Bulk supply agreements including liquid oxygen and gas cylinders.
- Cash-and-carry filling stations including LOX and PSA plants.
- Direct equipment purchases including PSA plants and oxygen concentrators.

Bulk supply agreements for liquid oxygen and gas cylinders: This business model for LOX and gas cylinders involves consistent oxygen delivery from ASUs, PSA systems, or filling stations directly to facilities. This model primarily operates on long-term contracts between gas suppliers and facilities, ensuring a steady delivery of LOX or gas cylinders. The supply of LOX often caters to non-medical, industrial needs and depends on the availability of electricity at the ASU, and uninterrupted funding from the healthcare facility or healthcare system. It usually requires facilities equipped with specific piping systems.

This approach is streamlined such that it requires minimal labor or logistics involvement, given that all associated costs including transportation are usually covered within the supply agreement. Despite the potential cost savings of long-term contracts, facilities frequently prefer short-term agreements. The usage of gas cylinders, while logistically demanding in terms of transportation and stock management, remains a common approach. There can also be high prices for LOX, depending on the proximity of the nearest ASU, among other factors.

24 PATH and CHAI (n. 18)

Cash-and-carry filling stations LOX and PSA: Customers fill their cylinders at designated stations or plants and handle transportation themselves. The cylinders are either provided by the supplier on a rental basis to facilities, or facilities may own their own cylinders. This is typically done on an ad-hoc basis, meaning there is no predetermined schedule or regularity to these transactions. The process is labor-intensive and involves complex logistics, including managing cylinders and transportation.

This approach serves as an invaluable "supply of last resort" option, particularly when other oxygen sources face failures or become overwhelmed by demand. However, it is less feasible for facilities needing many cylinders and tends to be more expensive due to the irregular nature of purchases and higher transportation costs.

Direct equipment purchases for on-site generation PSA and oxygen concentrators: Health facilities buy PSA systems and oxygen concentrators up-front and are responsible for their maintenance and operation. Proper training is necessary to ensure regular upkeep, which is essential to prevent malfunction or impure oxygen production. These systems also require reliable electricity at the facility. This model involves high initial costs and ongoing operating expenses. PSAs also often need customization to fit specific facility needs. Such customizations are often not modular enough to allow for expansion when the needs at the hospital grow.

The business models detailed above comprise the primary mechanisms that oxygen reaches patients via respiratory care equipment in LMICs. For PSA equipment configuration, the facility typically needs to have internal piping or an additional booster compressor for cylinder filling.

Taken together with the assessment of current technologies, a few themes emerge. On-site generation of oxygen requires both maintenance and electricity, which can be expensive and threaten consistent production. Irregular electricity supply could result in spikes in electrical current which present maintenance challenges.

Further, treating oxygen like a commodity via bulk supply agreements avoids these issues, but can require significant infrastructure, distribution networks, logistics management, and consistent financing. Across technologies and business models, affordability can be a major barrier to access. In the next section, we cover emerging innovations that offer improvements on current models.

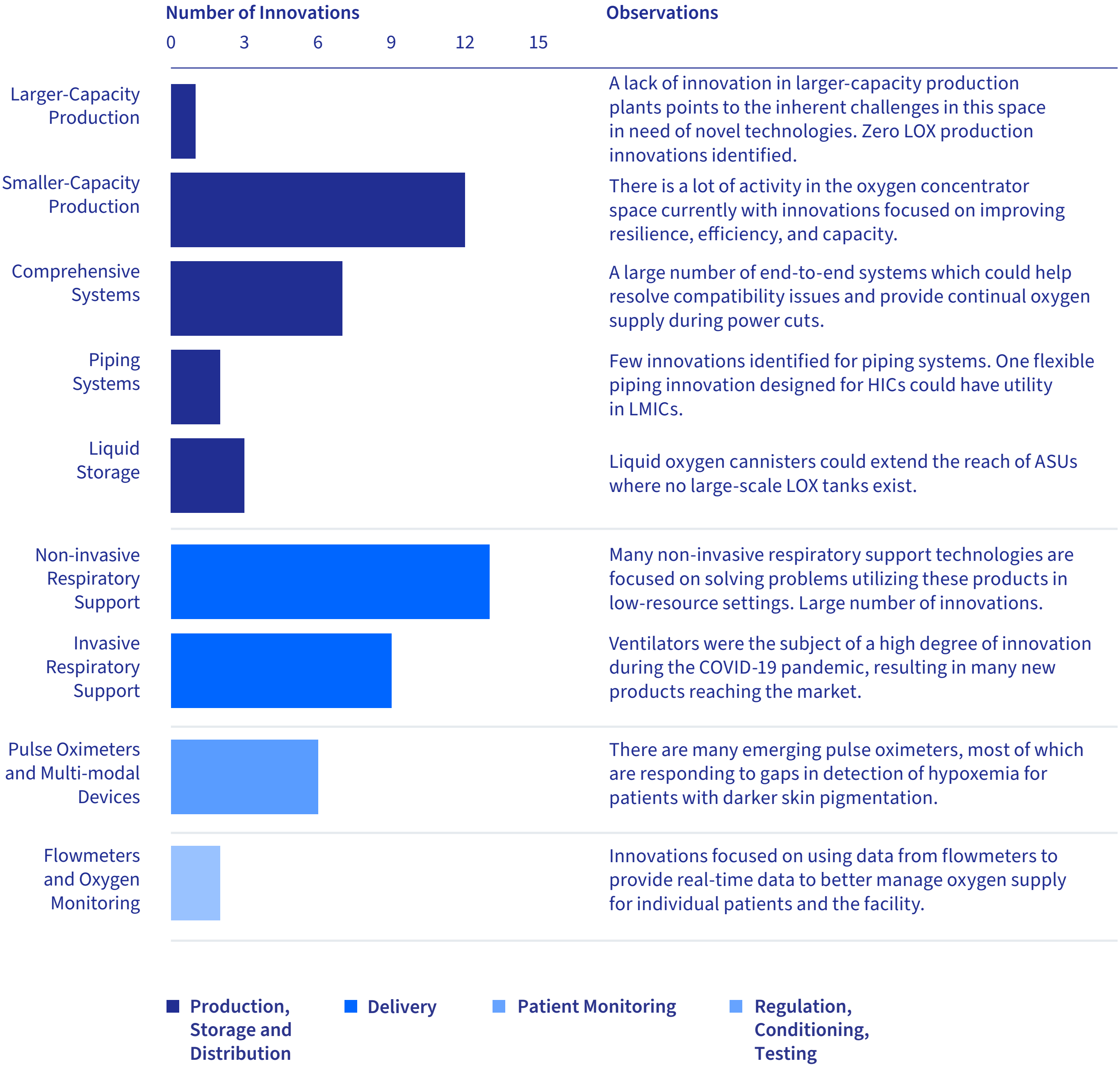
5. Emerging technologies and business models for LMICs

Over the past few decades, innovation in the oxygen space has been limited. The challenges highlighted by the COVID-19 pandemic have emphasized the shortcomings of existing technologies and business models. This heightened awareness has stimulated interest in developing new approaches to oxygen access, especially in LMICs.

This section introduces both current and emerging technologies and business models that have the potential to enhance and expand access to oxygen.

It is important to note that this compilation of innovations may not be comprehensive, and some options might not be readily available for purchase. Additionally, the inclusion of these innovations here is not meant to indicate endorsement, priority, or lead to immediate procurement without further evaluation and adherence to quality assurance processes.

Figure 6. New and near-to-market products (non-exhaustive)



5.1 Oxygen production, storage, and distribution technologies

Large Capacity Production: As previously noted, current technologies for high-capacity, on-site generation of medical oxygen have significant drawbacks. There are not many emerging technologies to fill this gap. However, one exception is the Medical-Ceramic Oxygen Generator (M-COG) system developed by NASA, which produces high-purity oxygen with almost no moving parts.[25] This represents a potential design improvement over PSA technologies, which require significant regular maintenance. This landscaping effort did not identify any significant technological innovations for liquid oxygen.

Small Capacity Production: During the COVID-19 pandemic, significant advancements were made in the development of novel oxygen concentrators. Innovations have addressed crucial challenges including, enhancing continuous operation despite unstable grid power, operational efficiency in various environmental conditions, durability, maintainability, manufacturability, and versatility for multiple use cases. Some novel oxygen concentrators were inspired by recent efforts by UNICEF and Oxygen CoLab to design more resilient products.[26] Additionally, multiple open-source projects emerged, enabling designs for more affordable concentrators to be adopted globally. Lastly, a number of alternative energy products with similar or greater production capacity to oxygen concentrators are now launching, including the solar-powered oxygen delivery system[27] and the O2Cube,[28] as examples.

Comprehensive Systems: Recent trends in oxygen technology innovation have seen end-to-end systems that combine oxygen production with storage, regulation and delivery components. For instance, the FREO2 Oxylink[29] system integrates an oxygen concentrator, cylinders, monitoring unit, and distribution system into one package. The benefits of these systems include streamlined supply chains and easily integrated products, enabling efficiencies for planning and set-up.

Oxygen Storage: Currently, gas oxygen cylinders, while versatile in size, require frequent refilling and face transportation challenges, with added complexity if refilling is restricted to specific supplier cylinders. There are some liquid oxygen storage solutions that are smaller than bulk tanks, for example Chart Industries[30] and CAIRE's[31] products. These have not been used widely in LMICs but have the potential to extend the reach of liquid oxygen distribution networks.

25 NASA. NASA Designs Tech for Oxygen on Moon, Finds Applications on Earth. December 2021. https://www.nasa.gov/centers-and-facilities/nesc/nasa-designs-tech-for-oxygen-on-moon-finds-applications-on-earth/#:~:text=With%20the%20nation%20facing%20multiple,in%20countries%20dealing%20with%20coronavirus. [Accessed 16 May 2024]

26 UNICEF and NEST360. Target Product Profile: Resilient Oxygen Concentrator. https://www.unicef.org/supply/media/12621/file/TPP-for-Oxygen-Concentrator-April-2022.pdf [Accessed 14 August 2024]

27 Hawkes MT, Conroy AL, Namasopo S, et al. Solar-Powered Oxygen Delivery in Low-Resource Settings: A Randomized Clinical Noninferiority Trial. JAMA Pediatr. 2018;172(7):694–696. doi:10.1001/jamapediatrics.2018.0228

28 LeanMed.O2Cube. https://leanmedinnovation.com/o2-cube/ [Accessed 16 May 2024]

29 FREO2 Foundation. https://freo2.org/products-innovations [Accessed 16 May 2024]

30 Dura-Cyl. https://files.chartindustries.com/14336761_DuraCyl_CasterBase.pdf [Accessed 16 May 2024]

31 Caire Niterra Group. https://www.caireinc.com/product/caire-liberator/ [Accessed 16 May 2024]

Oxygen Distribution (MGPS): As previously noted, medical gas pipeline systems, common in HICs, are challenging to implement in LMICs due to the high costs of installation in pre-existing structures, the need for medical-grade materials, and the requirement for skilled technicians, making them less feasible for widespread adoption in these regions.

There have been a small number of innovations in this space. For instance, The Omega Flex MediTrac system[32] uses a corrugated metal tubing, resulting in a flexible piping material that can be installed easier and more quickly, even in pre-existing health facilities.

More detailed examples of emerging oxygen production, storage and distribution technologies are outlined in Appendix 1.

5.2 Oxygen delivery technologies

5.2.1 Oxygen delivery - Non-invasive respiratory support:

Innovations in oxygen delivery technologies, such as CPAP, Bubble CPAP, oxygen blenders, and other advanced non-invasive respiratory aids, have made significant progress in overcoming common challenges. These innovations have been specifically engineered to ensure continuous operation in areas with unreliable power supply, maintain efficiency across diverse environmental conditions, facilitate safe usage for multiple patients simultaneously, adapt to various gas sources, and allow for ease of manufacturing. An example is the Vayu Bubble CPAP and oxygen blender system,[33] supported by Unitaid. They have been designed to operate without electricity by relying on available compressed oxygen in low-resource settings. The devices are offered at a fraction of the price in comparison to gold-standard devices, and operating costs are made more affordable through incorporating reusable components.

5.2.2 Oxygen delivery - Invasive respiratory support:

During the COVID-19 pandemic, ventilators were the subject of a high-degree of innovation, both in HICs and LMICs. As a result, there are many new products on the market that focus on filling previous technology gaps. Many of these products aim to be more affordable, easier to use, and easier to manufacture than their predecessors, while some specifically focus on design for under-resourced settings. It remains to be seen how many ventilator manufacturers the market can support now that the urgency of the COVID-19 pandemic has receded.

Innovations have addressed crucial challenges, enhancing continuous operation despite unstable grid power supply, operational efficiency in various environmental conditions, and compatibility with a variety of gas sources. For example, the Medical Technology Transfer and Services' (MTTS) Impala Ventilator[34] includes an optional reusable breathing circuit that can be safely disinfected between patients to decrease operating costs.

More detailed examples of emerging oxygen delivery technologies are outlined in Appendix 2.

32 Meditrac by OmegaFlex. https://meditrac.us/ [Accessed 16 May 2024]
33 Vayu Global Health Innovations. https://vayuinnovations.org/vayu-bcpap-system/ [Accessed 16 May 2024]
34 LifeKit by MTTS. https://www.mtts-asia.com/impala-ventilator/ [Accessed 16 May 2024]

5.3 Patient monitoring technologies

Pulse oximeters and multi-modal devices: These devices are crucial for diagnosing hypoxemia and have seen remarkable advancements aimed at enhancing implementation in LMICs, with significant contributions from initiatives like those supported by Unitaid through the AIRE, and TIMCI projects.[35] These projects focus on broadening pulse oximetry's reach within primary healthcare frameworks, particularly for managing childhood illnesses through the IMCI strategy.

Despite and increased uptake during the last couple years, efforts such as UCSF's Open Oximetry Project,[36] also backed by Unitaid, are crucial in addressing and rectifying the variability in device performance across different skin tones, laying the groundwork for equitable access. Furthermore, the emergence of multi-modal devices like the Neopenda neoGuard[37] are bridging critical healthcare delivery gaps by offering multi-parameter monitoring solutions to improve neonatal and pediatric care.

More detailed examples of emerging oxygen delivery technologies are outlined in Appendix 3.

5.4 Oxygen conditioning, regulation, and testing technologies

These tools ensure that oxygen pressure, flow, humidity, and purity are optimal for patient therapy. Essential devices like pressure regulators, flowmeters, and humidifiers are crucial for the safe and effective delivery of oxygen.

An example of a technology in this category is the Salvus ATAS O2,[38] a digital flowmeter that attaches to gas cylinders or bedside outlets, controlling the flow and offering real-time usage data to healthcare administrators. Another example is the Air Liquide Healthcare TAKEO2[39] which notifies medical staff with an alert when the oxygen level in a cylinder is low, facilitating timely refills and ensuring continuous patient care.

More detailed examples of emerging oxygen conditioning, regulation and testing technologies are outlined in Appendix 4.

35 Unitaid. Unlocking the door to oxygen access – pulse oximetry as part of a holistic approach. 23 November 2020. https://unitaid.org/news-blog/unlocking-the-door-to-oxygen-access-pulse-oximetry-as-part-of-a-holistic-approach/#en [Accessed 16 May 2024]

36 Open Oximetry. https://openoximetry.org/about/ [Accessed 16 May 2024]

37 Neopenda. https://neopenda.com/neoguard/ [Accessed 16 May 2024]

38 Salvus. https://www.salvus.me/en-us/real-time-monitoring-of-medical-oxygen [Accessed 16 May 2024]

39 Air Liquide Healthcare (n. 31)

5.5 Technology Pipeline

The following provides a landscape that outlines a pipeline of technologies reviewed per stages of development and the type of technology.

Figure 7: Technology Pipeline (non-exhaustive)

Legend:

Technology Type:				
	Patient Monitoring	Non-Invasive Respiratory Support	Ventilators	Liquid Oxygen Storage
	Comprehensive Systems	Small Capacity Production	Other	

Stage of Development:	R&D	Pre-approval testing in LMICs	Commercially available, no deployment in LMIC Healthcare Facilities	Commercially available, some deployment in LMIC Healthcare Facilities	Unknown
Comprehensive		**Air2O2** - GCE Healthcare, UK	**Moves SLC** - Thornhill Medical, Canada	**O2 Cube** - LeanMed LLC, US	
		Low-Pressure Oxygen System (LPOS) - FREO2, Australia	**VOCSN** - Ventec Life Systems, US	**Oxygen Reservoir Filling System** - Diamedica, UK	
			Oxylink System - FREO2, Australia	**POGS** - O2N2 Site Gas Systems, US	
Diagnosis, Monitoring & Delivery	**Advanced Integrated Circuit and Systems Lab Pulse Oximeter** - Tufts Univ, US	**ATAS O2 [gas monitoring and regulation]** - Salvus, Brazil		**TAKEO2 [gas monitoring]** - Air Liquide Healthcare, France	
	EquinOx Pulse Oximeter - Johns Hopkins Univ, US			**Lifebox-Smile Train AH-M1 Pulse Oximeter** - Lifebox, US/UK	
	HEAL Pulse Oximeter - Olin College, US			**neoGuard** - neopenda, US	
	PROBE Lab Pulse Oximeter - Brown Univ, US			**Bubble CPAP System** - Vayu Global Health Innovations, US	
	Delivery Room Portable CPAP with Resuscitation - Diamedica, Ltd, UK	**SAANS Neonatal CPAP** - InnAccel, India		**Dolphin Bubble CPAP** - MTTS, Vietnam	
	OxERA - Umova and Gabler Medical, S. Africa/UK			**Oxygen Concentrator CPAPs 10 and 20** - Diamedica, Ltd, UK	
	Oxygen Blender System - Vayu Global Health Innovations, US			**Portable Baby CPAP** - Diamedica, Ltd, UK	
	Suzy Phoenix Hood - SouthMed, NZ			**Pumani Bubble CPAP** - Hadleigh Health Technologies, US	
	Breathe Ventilator - Breathe Ventilator Project, Switzerland			**Rescue AB FIDO** - MIROLA, Sweden	
	HEV and HPLV Ventilators - CERN, Switzerland			**Seattle PAP** - Draeger, Germany	

Figure 7: Technology Pipeline (continued)

Legend:				
Technology Type:	Patient Monitoring	Non-Invasive Respiratory Support	Ventilators	Liquid Oxygen Storage
	Comprehensive Systems	Small Capacity Production	Other	

Stage of Development:	R&D	Pre-approval testing in LMICs	Commercially available, no deployment in LMIC Healthcare Facilities	Commercially available, some deployment in LMIC Healthcare Facilities	Unknown
Diagnosis, Monitoring & Delivery	**Mechanical Ventilator Milano -** Vexos, US			**Suzy Hood -** SouthMed, NZ	
	One Breathe Ventilator - OneBreath, Inc, US			**Gradian ICV -** Gradian Health Systems, US	
	VitaCaeli G1 Ventilator - Ligand Global, Canada			**Impala Ventilator -** MTTS, Vietnam	
	Vitality Ventilator - Spiritus & NASA, US				
	WorldVent - World Ventilator Foundation, US				
Distribution & Storage	**Next Generation Portable Therapeutic Liquid Oxygen System (NPTLOX) -** Essex Industries, US		**MediTrac [medical gas piping system] -** Omega Flex, US	**Dura-Cyl -** Chart Industries, US	**IOT Gateway [medical gas piping monitoring system] -** Limelight IT Solutions, India
				Liberator Reservoirs - CAIRE, Inc., US	
Production	**Global O2 Concentrator -** EPFL Essential Tech Center, Switzerland	**Open Source Oxygen Concentrators -** Multiple		**PulmO2 10L Oxygen Concentrator -** Drive DeVilbiss and Sanrai International, US	
	Novel Oxygen Concentrator - U. of Iowa, US	**Oxylink-5 Concentrator -** FREO2 and Kröber, Australia/ Germany		**Solar-Powered Oxygen Delivery (SPO2) -** U. of British Columbia, Canada	
	OVSI Concentrator - U. of Cambridge, UK	**Siphon -** FREO2, Australia			
	R-O2 Concentrator - CREATIVenergie, UK				
	Resilient Oxygen Concentrator - ArdenMed, US and NZ				
	SentOx Concentrator - Sentient Bionics, South Africa/ Australia				
	M-COG [Ceramic, solid state oxygen generator technology] - NASA & America Oxygen LLC, US				

5.6 Emerging Business Model Elements

As outlined in Section 4.2.1, "Business Models for Oxygen Delivery," the prevailing business models for oxygen delivery are marked by significant shortcomings, contributing to oxygen access gaps in many LMICs. The COVID-19 pandemic has prompted a reassessment of these models. While some of the alternative approaches mentioned below have been piloted, others have yet to be tested and are still in planning or conception phases.

The concept of Oxygen as a Service (OaaS) dates to a report authored by PATH in 2020.[40] Generally, OaaS refers to the provision of end-to-end medical oxygen services by private-sector companies, much of which has been carried out by under-resourced government entities, historically. For example, a Subscription Model could enable a health facility to engage a private company to provide oxygen deliveries for a flat rate, enabling a level of predictability for both buyers and suppliers. The Oxygen CoLab – an FCDO-funded initiative – is currently piloting a number of OaaS approaches, often in combination.

While OaaS approaches represent an important potential solution for end-to-end oxygen provision, in isolation, they are less focused on existing equipment that is already sitting at health facilities. This is significant, as the COVID-19 pandemic sparked a wave of investment in respiratory care equipment. In Figure 8 "Emerging Business Models Overview" below, the landscape report differentiates between models well-positioned to sustain existing investments versus those better positioned to improve access to oxygen where no production capacity exists. For instance, countries could employ Umbrella Management Agreements that enable a single firm to manage multiple existing production technologies across a given geography.

It is crucial to note that business models can be combined in various ways to meet the specific needs of both the community and healthcare facilities. For example, different Oxygen as a Service (OaaS) approaches, such as Subscription Models and Equipment/Service Bundles, are often used together. Moreover, business models designed to protect existing investments can also be integrated with OaaS strategies. For instance, Healthcare Industry Verticals, which focus on oxygen needs, can be paired with Umbrella Management Agreements. The decision to use these combinations depends on the unique challenges each business model addresses, as shown in Figure 8, thereby enabling complementary solutions.

40 PATH. Oxygen as a Utility: An Innovative Model for Increasing Access to Oxygen in Low- and Middle-Income Countries. Seattle: PATH; 2019.

Figure 8: Emerging Business Models Overview

Business Model	Oxygen as a Service Approaches	Supports Existing (COVID-19) Investments	Relieves up-front capital constraints	Smooths operational expenses	Fills human resource gaps	Improves logistics	Enables flexible/ customized approaches
Subscription Plans	■		■	■	■		
Equipment and Service Bundling	■			■	■	■	
Healthcare Industry Vertical	■						■
Leasing and Rental Models	■		■		■		■
Franchising	■		■		■	■	■
Umbrella Management Agreements		■		■	■	■	
Sale or Lease-back Programs		■		■	■	■	

Subscription Plans:

Subscription plans allow customers to pay a recurring fee to access a product or service without owning the underlying assets. In the case of medical oxygen, this model is most effective for regularly needed products or commodities. For example, oxygen could be provided on a subscription basis and delivered to the health facility, as could consumables which are needed regularly.

Example:
HealthPort is a health-tech company based in Nigeria that is focused on using digital solutions to improve medical oxygen treatment. The company is experimenting with subscription-based provision of oxygen utilizing a hub and spoke model. Oxygen is produced centrally with LeanMed's O2 Cube product and then distributed to a network of facilities. As part of this effort, HealthPort is learning more about the financial model for medical oxygen subscriptions, including willingness and ability to pay.

Advantages Compared to Legacy Models:
Subscription plans enable buyers to substitute up-front major capital outlays for small, recurring expenses. All costs are integrated (in the case of oxygen as a commodity), are predictable and give companies the benefit of financial planning and forecasting. Vendors retain ownership of products and responsibility for equipment selection and maintenance, relieving the customer of these burdens.

Equipment and Services Bundling

Equipment and Service bundling involves packaging multiple required inputs which are normally sold separately into a single, comprehensive solution for customers. For instance, a supplier could offer an oxygen production technology bundled with a service package to ensure that the technology is regularly maintained for a specific duration.

Example:
Sanrai International is a medical device distribution company with offices in Latin America, Africa, the Middle East, and Asia. Sanrai is offering equipment and services bundling as part of its work piloting novel oxygen provision models in two Indian states. Oxygen concentrators and diagnostic tools are packaged with routine maintenance services and clinical training for health facilities. This model enables Sanrai to explore different payment approaches through government procurement systems and to explore payment models for service.

Advantages Compared to Legacy Models:
Bundling can consolidate all inputs required for reliable oxygen delivery and to actually increase usage of oxygen which is often a separate challenge to simply making equipment available into a single commercial offering, streamlining purchasing for the customer. It also ensures compatibility between equipment, consumables, and training, simplifying procurement and maintenance and ensuring oxygen is used more consistently.

Healthcare Industry Vertical

Typically, bulk oxygen – and particularly LOX – is provided by the industrial sector, which is often not incentivized to prioritize healthcare needs. The Healthcare Industry-Vertical model tailors production, distribution, and support services to the needs and realities of health facilities.

Example:
Hewatele Operates a "Milkman Model" where they produce oxygen at an affordable price (compared to the market standard) and deliver it exclusively to the healthcare sector, optimizing for the location and needs of health facilities, rather than industry. The lower cost of oxygen supplied by Hewatele is a result of the strategic placements of their oxygen plants which reduces transportation distance and cost. Additionally, Hewatele provides maintenance and training services to partner facilities to enable efficient use of oxygen, from diagnosis to its implementation.

Advantages Compared to Legacy Models:
Healthcare industry verticals enable products and services customized to the needs of the health sector. This creates incentives for companies to create healthcare sector payment structures, bundle products, and locate production near facilities.

Leasing and Rental Models

Health facilities can lease or rent respiratory care equipment rather than purchase it outright. The vendor retains ownership, provides maintenance services and potentially consumables as well.

Example:
There are few existing examples of leasing and rental models to expand oxygen access; however a number of organizations are considering including this offering in the future.

Advantages Compared to Legacy Models:
These models avoid high up-front costs associated with purchasing equipment. They also enable flexibility to respond to changing oxygen demand. Health facilities can access the latest equipment and technology without the long-term commitment. Lastly, the burden of maintenance is transferred from the facility to the private sector as written in the lease agreement. Lease-end options could provide opportunities for facilities to own durable and well-maintained but value-depreciated equipment at low prices.

Franchising

A franchisor provides blended financing, product, and global management practices to a local entrepreneur (franchisee) who manages distribution and day-to-day operations. This model is similar to fast-food operations and other common types of franchises.

Example:
The Oxygen Hub supports entrepreneurs in Kenya, Ethiopia, and Nigeria with financing, equipment leasing, and management support. This follows a hub and spoke model with an anchor hospital that distributes to outlying facilities in peri-urban and small/midsize towns. Franchisees start with a turnkey solution set provided by the franchisor. Over time, those franchisees who demonstrate consistent success have the opportunity to take ownership of the assets.

Advantages Compared to Legacy Models:
Entrepreneur franchisees benefit from a validated product development effort, improved financing terms, global management practices, and established anchor demand, allowing them to expand faster. Entrepreneurs bring local market knowledge and relationships to generate additional demand. Additionally, franchise networks also benefit from collective purchasing power. Through centralizing procurement, franchisors can negotiate better rates with suppliers. This in turn enhances profitability for the franchisor and the franchisee.

Umbrella Management Agreements

A single firm is selected to operate and maintain existing respiratory care equipment across a region or country via an umbrella agreement. An umbrella agreement between the supplier and a dispersed group of clients outlines the terms and conditions for operation and maintenance, which could include pay-for-performances incentives.

Example:
No known examples of this type of agreement exist yet. However, there are a number of service-oriented medical equipment solutions companies that cover broad regions of sub-Saharan Africa, for example, and would be well-positioned to pilot such an agreement. Models could include one firm that operates and maintains multiple PSAs. Contracts may involve performance incentives based on the amount of uptime for each product.

Advantages Compared to Legacy Models:
This model may be particularly applicable for countries that procured large volumes of products during the COVID-19 pandemic, volumes that may be difficult to operate and maintain either via existing human resources or on an individual contract basis. A selected firm may find efficiencies ordering spare parts in bulk, for instance, or synchronizing service schedules across dispersed equipment.

Sale or Lease-back Programs

Governments sell or lease large-scale equipment to private companies and provide a guaranteed public offtake of a specific volume of oxygen they will buy regularly. Under this model, the government is liquidating assets that may be difficult to operate or maintain and providing guaranteed oxygen demand to the buyer.

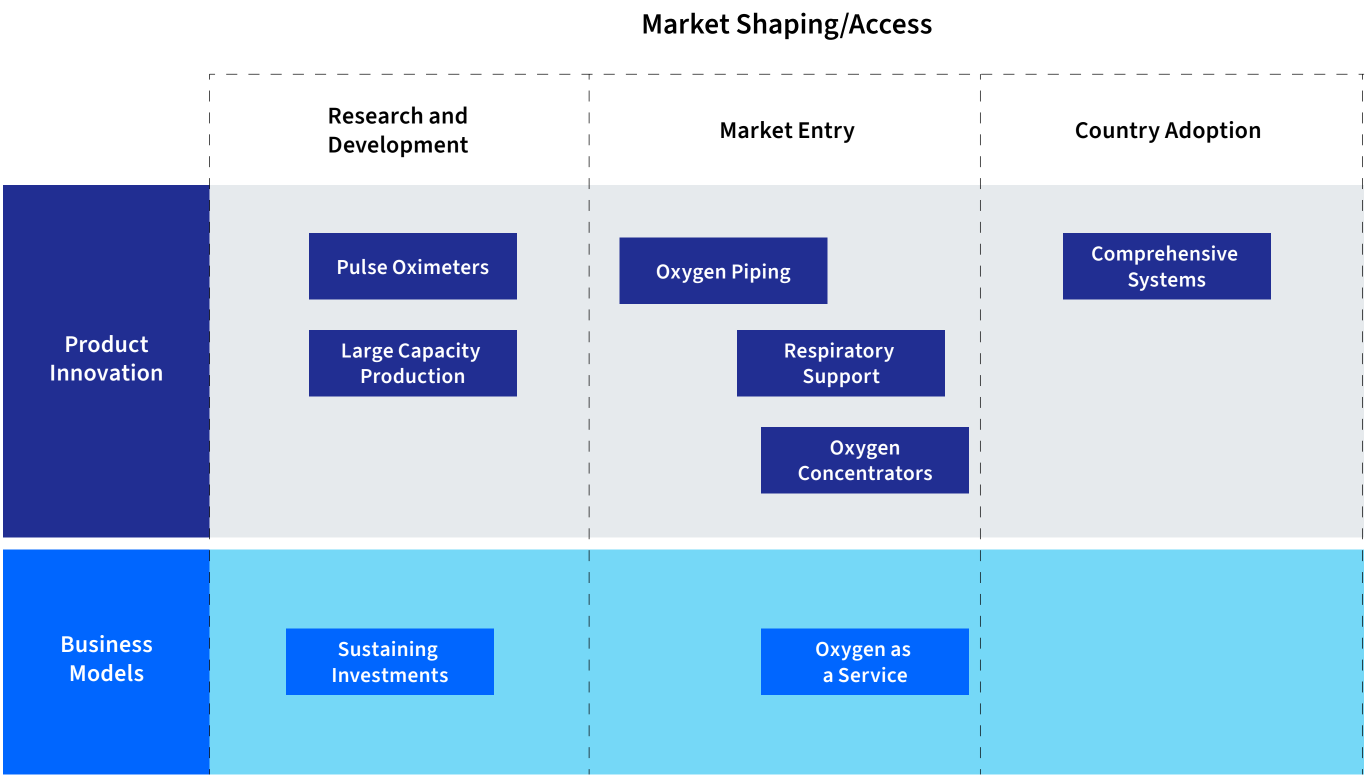
Example:
No known examples exist yet. This type of program may be most suitable for PSAs or large-scale production equipment. Governments could use proceeds from sale or lease to fund oxygen purchases. Private companies could sell excess oxygen produced for profit.

Advantages Compared to Legacy Models:
This approach may be an attractive option to governments who have large numbers of PSA plants from COVID-19 procurements. The private sector becomes responsible for maintaining and operating equipment, while the government can offload responsibilities and generate income to purchase oxygen. Lastly, it creates guaranteed demand, which could be used to lower prices.

6. Potential opportunities

Across the range of innovations and solutions presented in this landscape, there are numerous investment areas to advance the accessibility of oxygen in LMICs. The section below highlights several opportunities that exist to accelerate oxygen access efforts, summarized in Figure 9 below. These opportunities are not comprehensive, nor specific to Unitaid's mandate and operational framework, but instead represent a range of interventions that could be undertaken by different global health actors and stakeholders across the value chain of medical oxygen.

Figure 9: Opportunities to accelerate development and introduction of new products and business models for medical oxygen (illustrative and non-exhaustive)



6.1 Research and Development Stage:

Product Innovation

- **Large Capacity On-site Production:** In response to the design drawbacks of current large-capacity on-site production, there are promising innovations in the pipeline that may require far less maintenance, a key challenge of existing generation technologies. Investments piloting these products in LMICs are key to understanding their potential. Additionally, opportunities to combine these products with alternative energy sources, such as solar power, could solve multiple access challenges.
- **More Accurate Pulse Oximeters:** Following studies indicating that pulse oximeters are less accurate for individuals with darker skin pigmentation, numerous efforts are underway to assess and develop more precise pulse oximeters. As these projects advance, there will be opportunities to introduce improved products into LMIC markets.

Business Models

- **Sustaining Current Investments:** There is a pressing need to articulate novel business models to protect COVID-19-era investments that enabled respiratory care equipment deployment. Investments in this space could pilot concept models that bundle service level agreements or shift equipment management to the private sector, for example. The specific business models highlighted in Figure 8 that could be well-positioned to sustain current oxygen therapy investments include Umbrella Management Agreements and Sale or Lease-Back Programs, which could be deployed in conjunction with Oxygen as a Service approaches.

6.2 Market Entry Stage:

Product Innovation

- Innovative Medical Gas Piping: Flexible piping products that have been used in HICs could solve significant challenges retrofitting hospitals in many low-resource settings. Initial product introduction efforts could be expanded upon to better understand effective models when adapting this product to LMICs.
- Respiratory Support Products Designed for LMICs: Recent developments in respiratory support technologies for LMICs highlight a focused approach towards making these essential medical devices more accessible, efficient, and adaptable to settings with limited resources. These innovations, ranging from simple bubble CPAP systems to versatile ventilators, share key features: they are designed for environments with minimal access to electricity and infrastructure, prioritize ease of use, durability, and affordability, and cater to a wide range of patient needs, from neonatal to adult care.
- Next Generation Oxygen Concentrators: Improved oxygen concentrators meant to be more efficient and resilient are starting to reach the market. Opportunities to assess the acceptability and cost-effectiveness of these products will likely help drive their adoption.

Business Models

- Oxygen as a Service: Responding to the challenges of traditional business models, OaaS pilots are underway in several countries. Oxygen as a Service (OaaS) approaches may be combinations of multiple business models listed in Figure 8 to provide end-to-end medical oxygen services. Expanding models that prove particularly effective will be a critical investment to ensure uptake across countries and regions. Additionally, opportunities exist to incorporate elements of OaaS in earlier-stage models focused on sustaining current investments.

6.3 Country Adoption Stage:

Product Innovation

- Comprehensive Systems: At least one system that packages multiple elements of oxygen production, storage, and delivery is already commercially available and in-use in several LMIC healthcare contexts. There are several additional commercially available comprehensive systems, but they are not designed for use in LMIC healthcare facilities, so their features and price may or may not be well-suited. Investment could support bringing additional beneficial comprehensive systems to market and incorporating improved elements that expand their use in low-resource settings, such as next generation oxygen concentrators.

7. Conclusion

This landscape report highlights a broad spectrum of solutions to enhance medical oxygen access, which is crucial for universal healthcare coverage and preparedness for future pandemics. It emphasizes technology innovations in large-scale production, oxygen distribution, and energy-efficient product development. The report also underscores the importance of expanding successful initiatives and exploring novel business models to leverage pandemic-era investments.

Future efforts should build upon and amplify the impact of existing investments in medical oxygen, ensuring a cohesive, sector-wide approach to improving healthcare delivery in LMICs. By addressing both immediate needs and long-term sustainability, these efforts can significantly enhance health outcomes and resilience in LMICs.

However, it is important to recognize the limitations of this landscape report. While it provides an overview of current and emerging technologies, business models, and potential opportunities, it is not exhaustive. Rapid advancements in technology and evolving healthcare needs mean that new solutions and innovations will continue to emerge.

Moreover, the success of these initiatives relies heavily on coordinated global efforts, adequate funding, and robust implementation strategies. Stakeholders, including governments, international organizations and private sector partners must work together to address the systemic challenges and barriers to oxygen access.

In conclusion, while this report outlines significant advancements and potential pathways to improve medical oxygen access, ongoing evaluation, adaptation and innovation are essential. Further developments in this space are anticipated, which will continue to enhance access to medical oxygen and ultimately improve global health outcomes. This dynamic and evolving landscape requires continuous investment, commitment and collaboration to ensure that all individuals, regardless of location, have access to this life-saving resource.

Appendix

Appendix 1: Oxygen production, storage, and distribution technologies

This is not exhaustive, it is a dynamic space and is subject to change

Large Capacity Production

Technology: Medical Ceramic Oxygen Generator (M-COG)
Organization: American Oxygen and NASA
Description: A ceramic, solid state oxygen generator technology with no moving parts to generate 99.95% pure oxygen. The M-COG uses ceramic wafers that, when heated, pull oxygen out of the surrounding air. In addition to durability, M-COG systems are designed to be more energy efficient. M-COG systems can accommodate a large or small capacity based on a modular design.

Small Capacity Production

Technology: Global O2 Concentrator
Organization: EPFL Essential Tech Center
Description: An oxygen concentrator designed for LMIC healthcare settings. Product is designed to withstand harsh conditions, enable remote monitoring, offer improved energy efficiency and is easy to maintain.

Technology: Novel Oxygen Concentrator
Organization: University of Iowa
Description: An oxygen concentrator with a simplified design for easier manufacture and maintenance.

Technology: O2 Cube
Organization: LeanMed, LLC
Description: The O2 Cube is a solar-powered medical oxygen production system that fills oxygen cylinders of all sizes at 10lpm to 2,000psi to serve small and mid-sized healthcare facilities in LMICs and globally. It can operate unattended and perform real time data collection.

Technology: Open Source Oxygen Concentrators
Organization: Multiple
Description: There are a number of efforts both complete and underway to develop open-source oxygen concentrator plans and innovations. Examples include Open O2 and OxiKit.

Technology: OVSI Concentrator
Organization: University of Cambridge
Description: An oxygen concentrator that can produce 10 LPM of >85% pure oxygen in challenging environmental conditions and power fluctuations. It is also designed to be easily maintained.

Technology: PulmO2 10L Oxygen Concentrator
Organization: Drive DeVilbiss Healthcare and Sanrai
Description: An energy-efficient oxygen concentrator providing up to 10 LPM. Designed as a fit-for-purpose solution according to UNICEF's target product profile, it is intended to be resilient in hot, humid, and high-altitude environments, energy efficient, more user friendly and long lasting with minimal maintenance.

Technology: Oxylink-5 Concentrator
Organization: FREO2 and Kröber
Description: The Oxylink-5 oxygen concentrator can provide up to 5 LPM oxygen and is designed for use in low-resource health clinics. It is designed to be resilient in dusty environments and easier to maintain. It can be used with the Oxylink System to provide continuous oxygen therapy during frequent power outages.

Technology: R-0_2 Concentrator
Organization: CREATIVenergie
Description: A portable oxygen concentrator designed specifically for low resource settings that is more durable and energy efficient, and can be powered by renewables as well as grid power.

Technology: Resilient Oxygen Concentrator
Organization: ArdenMed
Description: Designed to be a more energy efficient oxygen concentrator that can be powered via solar panels and car batteries. Device is designed to be more robust in harsh environmental conditions and provide information to ease troubleshooting

Technology: SentOx Concentrator
Organization: Sentient Bionics
Description: SentOx is an oxygen concentrator that is designed to be portable, robust, and affordable, with particular emphasis on easier local manufacturing and maintenance.

Technology: Siphon
Organization: FREO2
Description: Oxygen concentrator designed to be durable, easy to maintain, affordable and electricity-free. The system harnesses energy from a small amount of running water to separate oxygen from the surrounding air.

Technology: Solar-Powered Oxygen Delivery (SPO2)
Organization: University of British Columbia (UBC)
Description: The solar-powered oxygen delivery system consists of a commercially available oxygen concentrator, charge controller, battery bank, and solar panels to provide medical-grade oxygen from ambient air without the need for reliable grid access.

Comprehensive Systems

Technology: Air2O_2
Organization: GCE Healthcare
Description: Air2O_2 comprises a filling station and multiple tanks. The filling station uses an oxygen concentrator, compressor, control system, and user interface to fill the tanks with 15 bar oxygen. The low-pressure oxygen tank has two flow selectors to simultaneously serve two patients.

Technology: Low-Pressure Oxygen System (LPOS)
Organization: FREO2
Description: LPOS is designed to provide a continuous flow of oxygen to patients during power outages by filling a low-pressure reservoir with excess oxygen while the power is on, then using the reservoir for oxygen therapy when the power is not available.

Technology: Moves SLC
Organization: Thornhill Medical
Description: Designed for austere environments with limited infrastructure, MOVES SLC is a life support system which combines an O2 concentrator, an O2-conserving ventilator, suction, and vital signs monitoring into one portable, battery-operated device.

Technology: Oxygen Reservoir Filling System
Organization: Diamedica, Ltd.
Description: A system of 20L or 100L low-pressure oxygen reservoirs and a 12V battery-powered compressor that can be used to fill the vessels from an oxygen concentrator. Reservoirs can be filled while there is electricity; vessels continue to provide oxygen during power failures.

Technology: Oxylink System
Organization: FREO2
Description: The Oxylink System is an end-to-end solution with an Oxylink concentrator and interlinking storage and delivery products designed to provide a continuous flow of oxygen, even during power outages.

Technology: Portable Oxygen Generator System (POGS)
Organization: O_2N_2 Site Gas Systems
Description: Portable oxygen generator system (pressure swing adsorption) designed for the battlefield. It is rugged, portable by a single person, and requires only simple maintenance. Smaller models provide 10 LPM and larger models go up to 33 LPM. POGS can be used to provide customized oxygen therapy for up to four patients, or it can fill cylinders to provide oxygen therapy.

Technology: VOCSN
Organization: Ventec Life Systems
Description: Designed for home and long-term care settings, a portable, battery-powered respiratory system that combines five separate medical devices — a ventilator, oxygen concentrator, cough assist system, suction, and nebulizer.

Medical Gas Piping Systems (MGPS)

Technology: IOT Gateway
Organization: Limelight IT Solutions
Description: An IOT enabled solution which serves as an industrial gateway to monitor oxygen lines of hospitals to perform audits and detect and send warnings of leakages.

Technology: MediTrac
Organization: Omega Flex, Inc.
Description: A flexible, corrugated, medical gas piping system designed to convey medical gases and vacuum to patient care areas throughout a facility with decreased installation time and total installed cost.

Liquid Oxygen Storage

Technology: Dura-Cyl
Organization: Chart Industries
Description: Dura-Cyl is a 240L liquid oxygen reservoir that can replace the weight and volume of approximately twenty of the largest-sized high-pressure cylinders. It includes a liquid cylinder control manifold regulator to enable filling high-pressure cylinders.

Technology: Liberator Reservoirs
Organization: CAIRE
Description: The CAIRE liquid oxygen reservoir is designed to be used in a long-term oxygen user's home environment. One 60 liter-sized reservoir replaces the weight and volume of approximately nine of the largest-sized high-pressure cylinders.

Technology: Next Generation Portable Therapeutic Liquid Oxygen System (NPTLOX)
Organization: Essex Industries
Description: The Next Generation Portable Therapeutic Liquid Oxygen System (NPTLOX) is a low pressure, portable, 10-liter, liquid oxygen storage and gaseous delivery system designed for battlefield use.

Appendix 2: Oxygen delivery technologies

This is not exhaustive, it is a dynamic space and is subject to change

Non-invasive respiratory support

Technology: Bubble CPAP System
Organization: Vayu Global Health Innovations
Description: The Vayu bubble CPAP system is a low-cost device designed for under-resourced environments globally. It does not require electricity, medical compressed air, or manual power for operation.

Technology: OxERA Oxygen Device
Organization: Umoya and Gabler Medical
Description: OxERA is designed to fill the product gap between a reservoir mask and positive pressure therapies like high flow nasal cannula and CPAP. It is designed to deliver consistently high levels of oxygen and positive expiratory pressure.

Technology: Delivery Room Portable CPAP with Resuscitation
Organization: Diamedica, Ltd
Description: Delivery Room CPAP is designed to enable the earliest possible use of CPAP. The machine delivers a source of continuous pressurized room air, which can be supplemented with oxygen from an oxygen concentrator or cylinder, if required. The device also has a manually controlled resuscitation function to use in the event of newborn apnea.

Technology: Dolphin Bubble CPAP
Organization: MTTS
Description: The Dolphin is a bubble CPAP with its own air blower designed for use in LMICs. It is designed to have an easy-to-use interface and built-in battery for two hours of backup power (excluding heat and humidity). There is a breathing circuit option that can be safely disinfected and reused between patients to decrease operating costs. The device also has an integrated pulse oximeter compatible with reusable sensors.

Technology: Oxygen Blender System
Organization: Vayu Global Health Innovations
Description: The Vayu oxygen blender system supplies blended low flow oxygen to infants and children up to age five. Designed for under-resourced environments in many global contexts, it does not require electricity or compressed air.

Technology: Oxygen Concentrator CPAP 10 and 20
Organization: Diamedica, Ltd
Description: The Oxygen Concentrator CPAP 10 and the Oxygen Concentrator CPAP 20 both require no external gas supplies as it generates continuous oxygen and room air at 5 or 10 litres per minute each, with a total flow 10 or 20 litres per minute. The blended, warmed and humidified gases are delivered through a patient cannula interface with direct pressure control for CPAP.

Technology: Portable Baby CPAP
Organization: Diamedica, Ltd
Description: The machine delivers a source of continuous pressurized room air, which can be supplemented with oxygen from an oxygen concentrator or cylinder, if required. The blended, pressurized flow is delivered through a patient cannula interface.

Technology: Pumani bubble CPAP
Organization: Hadleigh Health Technologies
Description: Designed for under-resourced environments, Pumani aims to provide the standard theraputic pressure of CPAPs for a lower cost. The device is designed for quick set-up and minimal maintenance.

Technology: Rescue AB FIDO
Organization: MIROLA
Description: Rescue AB FIDO is a portable rebreathing system compatible with compressed oxygen tanks that removes CO_2 from the patient's outbreath and feeds the remaining oxygen back to the patient. This technology extends the time a single patient can receive oxygen therapy with a particular volume of oxygen.

Technology: Saans Neonatal CPAP
Organization: InnAccel
Description: Portable, infrastructure-independent, neonatal CPAP for short-term breathing support designed for low-resource settings. There are multiple therapy modes (CPAP, Bubble CPAP, HFNC, Resuscitation) in a single device.

Technology: Seattle PAP
Organization: Draeger
Description: The product is designed to provide effects similar to high frequency oscillatory ventilation for improving gas exchange and to offer more efficient respiratory support compared to other methods of non-invasive respiratory support.

Technology: Suzy Hood
Organization: SouthMed
Description: The Suzy hood is a clear hood that is placed over the patient's head to provide non-invasive ventilation. The hood allows the patient to speak, wear glasses, cough and even sip water, aiming to provide greater overall comfort and higher tolerability of treatment.

Technology: Suzy Phoenix Hood
Organization: SouthMed
Description: The Suzy Phoenix Hood aims to reduce oxygen demand below that of a mask while maintaining a high fraction of inspired oxygen (FiO_2) and achieving the high positive-end expiratory pressure (PEEP) characteristic of a non-invasive ventilation hood. This is accomplished through the addition of a reservoir and nasal cannula to a hood.

Invasive respiratory support (ventilators)

Technology: breathe ventilator
Organization: breathe ventilator project
Description: A ventilator designed for under-resourced settings that aims to be affordable, easy to use and maintain, and to improve durability.

Product name: Gradian ICV
Description: The Gradian Intensive Care Ventilator (ICV) is designed to provide care to infant, pediatric, and adult patients in healthcare facilities and during transport.

Technology: HEV and HPLV Ventilators
Organization: CERN
Description: The HEV and HPLV ventilators are designed to be a high-quality, low-cost ventilator originally used for the COVID-19 pandemic. Intended to use easily-sourced, inexpensive components.

Technology: Impala Ventilator
Organization: MTTS
Description: The Impala is a mechanical ventilator designed for use in LMICs. It includes eight operating modes and built-in battery for four hours of backup power. There is a breathing circuit option that can be safely disinfected and reused between patients to decrease operating costs.

Technology: Mechanical Ventilator Milano (MVM)
Organization: Vexos
Description: The MVM was designed for rapid, large-scale, low-cost production for the COVID-19 pandemic. It is free of moving mechanical parts and requiring only a source of compressed oxygen and medical air to operate.

Technology: OneBreath Ventilator
Organization: OneBreath, Inc.
Description: OneBreath aims to address the need for continuous ventilation in the absence of compressed gas or electricity, instead providing a range of settings utilizing portable oxygen concentrators as a source of oxygen.

Technology: VitaCaeli G1
Organization: Ligand Global
Description: The VitaCaeli G1 is designed for use in developing countries. It uses a resuscitator bag traditionally used for manual ventilation and instead automates the process by inserting it into a device that can perform repetitive breaths.

Technology: Vitality Ventilator
Organization: Spiritus and NASA
Description: The NASA-designed Vitality is a cost-efficient ventilator for hospital and field use designed for up to 90% of patients needing ventilatory support. The efficient NASA design uses 1/7th the number of parts used in a typical ventilator and is designed to be easily serviced.

Technology: WorldVent
Organization: World Ventilator Foundation
Description: WorldVent is designed to be an affordable innovation for under-resourced settings. It has few moving parts and is designed to prevent wasting oxygen.

Appendix 3: Patient monitoring technologies

This is not exhaustive, it is a dynamic space and is subject to change

Pulse oximeters and multi-parameter monitoring devices

Technology: Advanced Integrated Circuit and Systems Lab Pulse Oximeter
Organization: Tufts University
Description: The pulse oximeter leverages semiconductor technology and artificial intelligence (AI) signal processing to deliver a bias-free oxygen saturation reading for all populations.

Technology: EquinOx Pulse Oximeter
Organization: Johns Hopkins University
Description: The EquinOx is designed to better estimate blood oxygen saturation in darker skin tones using novel hardware and a novel algorithm to correct for skin tone.

Technology: Lifebox-Smile Train Pulse AH-M1 Pulse Oximeter
Organization: Lifebox
Description: A pulse oximeter developed for low-resource settings with robust construction, rechargeable batteries, and reusable patient monitoring probes for adults, children, and neonates.

Technology: neoGuard
Organization: neopenda
Description: A low-cost, body-worn, multiparameter, battery-powered, continuous patient monitoring device for neonates to adults. It measures pulse, respiration rate, SpO2, and temperature. This product is designed specifically for use in under-resourced settings.

Technology: HEAL Pulse Oximeter
Organization: Olin College of Engineering
Description: The HEAL pulse oximeter includes an algorithm to account for the relationship between oxygen saturation and red-to-infrared ratio within different skin pigmentation to provide more accurate readings across skin pigmentation.

Technology: PROBE Lab Pulse Oximeter
Organization: Brown University
Description: A pulse oximeter that leverages advanced optics to estimate peripheral blood oxygen saturation accurately for all skin tones.

Appendix 4: Oxygen regulation, conditioning and testing technologies

This is not exhaustive, it is a dynamic space and is subject to change

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Technology: ATAS O2
Organization: Salvus
Description: ATAS O2 is an online digital flowmeter which can be used on a compressed gas cylinder or coupled with medical bedside outlets, regulating flow and providing hospital administration with real-time data on oxygen consumption.

Technology: TAKEO2
Organization: Air Liquide Healthcare
Description: TAKEO2 is designed to let medical staff know how much oxygen is left in a cylinder. The device emits a warning sound when oxygen level is low.

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