Oxygen as a Utility

An Innovative Model for Increasing Access to Oxygen in Low- and Middle-Income Countries

PATH

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Abbreviations

ARI	acute respiratory infection
CAPEX	capital expenditures
DALY	disability adjusted life year
DES	discrete event simulation
DRC	Democratic Republic of the Congo
IBRD	International Bank for Reconstruction and Development
IDA	International Development Association
IFC	International Finance Corporation
IMCI	integrated management of childhood illness
LMICs	low- and middle-income countries
LPM	liters per minute
MOH	ministry of health
NCD	noncommunicable disease
NGO	nongovernmental organization
O_2	oxygen
O_2aaU	Oxygen as a Utility
OPEX	operating expenditures
P	probability of patients receiving the oxygen they need
PSA	pressure swing adsorption
RFP	request for proposals
TCO	total cost of ownership
TIMCI	Tools for Integrated Management of Childhood Illness
WHO	World Health Organization

Executive summary

PATH, in collaboration with the Bill & Melinda Gates Foundation and Philips Healthcare, led the development of an implementation plan to increase access to medical oxygen services in response to the unmet and growing need for medical-grade oxygen in low- and middle-income countries (LMICs). Despite urgent calls for action, progress to date has not kept pace with the growing need for oxygen. The challenges limiting oxygen access stem from trends, including population growth and epidemiological shifts, increased reliance on limited domestic resources, and more horizontal as opposed to vertical (disease-specific) programming. The plan described here, to provide oxygen services as a utility, is a potential new way forward, developed to address many of the issues that limit oxygen access.

The rationale for an innovative solution: what is the core of the problem? Diseases requiring oxygen for treatment are accounting for a larger share of the burden of disease than a decade ago. During this epidemiological shift, LMICs will need to maintain longstanding disease prevention efforts while adding more access to integrated health products and services, including oxygen. To accomplish this with constrained resources, a more efficient, low-cost system for oxygen production and distribution is increasingly needed; however, unique challenges exist in the oxygen market, which must be addressed.

Key issues include delayed payments, insufficient training, supply chain inefficiencies, and a lack of ownership. Addressing these challenges can reduce the per-patient cost of oxygen and maximize the degree of access attainable with limited financial resources. The new model proposed here seeks to accomplish this by simultaneously addressing multiple challenges that both firms and countries face as they attempt to meet the need for oxygen services.

Several global efforts are underway to address some of these issues, but none address a broad set of challenges at once. One large new initiative at PATH seeks to increase access to devices that detect the need for oxygen, pulse oximeters; however, it does not expand access to oxygen—the essential medicine required by these devices to improve health outcomes by treating hypoxemia (low oxygen in the blood). Examples of existing models that do seek to increase access to medical oxygen for patients at public health facilities include (1) new social enterprises and (2) public-private partnerships. These existing programs generate new competition with incumbent oxygen suppliers, but do not seek to change the underlying structure of the market for oxygen. Furthermore, broader trends in health, including improved referral linkages from primary to tertiary care, superior detection of severe disease, and increased care-seeking, will all cause the need for oxygen to swell even further. Said another way, many otherwise successful efforts to improve health will be hampered unless the oxygen issue is addressed. And while efforts are underway to address the situation by purchasing oxygen concentrators, developing and amending policies, and establishing new social enterprises, these programs all work on the margins of the issue without confronting the core challenge of generating long term incentives for firms to produce increasingly reliable and less expensive service delivery.

Oxygen is a high-impact investment that requires new thinking to disrupt the status quo of limited access. To accomplish this, we propose Oxygen as a Utility (O_2aaU), an end-to-end program through which national health systems contract firms to provide oxygen from production to patient at fixed rates for a fixed time period. This new market-based intervention should be trialed in countries in which observable factors predict that take-up of this program is most likely and health returns will be large. Deploying oxygen as a utility requires involvement from firms that produce oxygen and the products to deliver it, financiers such as development banks, and donors. In the model, these actors will work together to develop an operating model that results in qualified firms delivering oxygen services to patients at fair market rates. While much is unknown about the feasibility of O_2aaU, and potential health and economic impact cannot be measured given lack of data, a unique opportunity exists for PATH to conduct a pilot of O_2aaU, alongside a large multi-country impact evaluation, to refine the concept, learn more, and move it forward, pending favorable findings. As part of the implementation plan, we describe an impact model that requires data from a pilot, which would contribute instrumental data to the oxygen field even if O_2aaU is not implemented further.

What is Oxygen as a Utility and how can it overcome key challenges in oxygen access? Addressing the growing need for oxygen requires a solution that fundamentally changes how oxygen is generated, distributed, and paid for. O_2aaU is a concept for generating, delivering, and billing oxygen services as a public utility, designed to make these fundamental changes possible in order to increase sustainable access to affordable medical oxygen for people in LMICs. O_2aaU is based on observations of seamless markets for oxygen services in single-payer health systems of high-income countries and proven methods to attract private investment in infrastructure such as electricity and communication. O_2aaU seeks to simultaneously address a series of challenges that limit oxygen access through a program of market-based interventions.

The O_2aaU approach brings the essential players—health systems, oxygen suppliers, manufacturers and/or distributors, and financial partners—into a unified system to ensure reliable service provision that is driven by increased public-private investment. Through this model, an increased number of oxygen suppliers would compete through auctions designed to drive down cost. Governments would receive a lower fixed price in exchange for offering a firm commitment to purchase a pre-established amount of oxygen, services, and equipment to provide oxygen over a long time horizon. Financial partners guarantee the value of these commitments to reduce the risk that countries will default on their payments, seeking to encourage the increased competition that turns the wheels of this new mechanism

O_2aaU is a novel, innovative approach that relies on a bank guarantee (a practice common among large infrastructure investments such as clean water and electricity) to unlock private investment to increase access to oxygen. A guarantee, combined with other essential components of the O_2aaU operating model, may be a powerful tool to address the underlying market failures that have long prevented firms from adequately supplying oxygen in LMIC markets. The O_2aaU approach is unique in that it combines equal parts public health and economic development to overcome the range of challenges that limit investment in this market.

Our proposed approach integrates most aspects of oxygen delivery, from production to distribution of both the gas and the devices that dispense it, to training of staff on when to administer oxygen and how to use this equipment, and equipment maintenance; herein we refer to this entire end-to-end solution as “oxygen” or “oxygen services.” The concept provides incentives for suppliers to provide oxygen services by de-risking investment through financial guarantees and ensuring an agreed-upon rate to be paid for these services over multiple years. Existing interventions have not adequately addressed the challenges of providing equitable oxygen access, whether it be policy, training, infrastructure, credit constraints, or combinations thereof. The O_2aaU approach addresses those factors through an operating model that is designed to be adapted to the unique policy and market conditions present in a given setting.

Country selection

To identify countries in which it may be beneficial to implement O_2aaU, PATH reviewed 82 LMIC profiles and weighed them against key criteria to identify those with the highest potential for both health and economic impact. Examples of key criteria in the selection tool include the burden of acute respiratory infections, population size, and the country’s expenditure on health. The criteria used were equally weighted and the results were standardized to simplify comparison across countries. To identify countries in which PATH’s presence and work might contribute to the ease of an O_2aaU pilot, the list was then filtered based on the presence of a PATH country program and possibility of piloting O_2aaU alongside an upcoming, related investment focused on increasing access to pulse oximetry at the primary care level.

Partner identification

The identification and selection of financial partners that could guarantee timely payments for products and services provided, and of suppliers capable of and willing to making large investments will be critical to the introduction, adoption, and scale-up of O_2aaU. Partners could include stakeholders from financial, manufacturing, private, multilateral, and governmental sectors. PATH has developed criteria to support the selection of financial partners and oxygen suppliers in a given country so that they support the unique customization of the operating model for that country. Key requirements for suppliers include (1) the ability to provide medical-grade oxygen end to end, including generation, distribution, training, and maintenance; (2) demonstrated success in implementing and scaling oxygen solutions; (3) an ability to operate globally; and (4) experience working in LMICs. Beyond these high-level criteria, selection will be dependent on factors such as existing presence in a region and pre-existing relationships with in-country partners. The criteria outlined here may be used to pre-screen suppliers that are eligible to bid on supplying the oxygen for a market.

Operating model

The essential actors will be brought together in a framework that we call the operating model. The goal of the model is to generate oxygen service markets that are complete, to ensure universal oxygen coverage and to increase competition to drive down prices. The O_2aaU operating model comprises four sequential activities: (1) evaluation of the amount of oxygen, equipment, training, and maintenance needed for a given market; (2) determination of market segment boundaries, and partitioning as necessary so that no one market is too large, keeping in mind that in a single market, prices are lower but risk is higher and prices are higher and risks lower in a partitioned market; (3) establishment of the price for providing a set of products and services for oxygen in this market through an auction-based tender among suppliers; and, finally, (4) implementation, when suppliers deliver products and services in exchange for payment terms that are agreed upon in advance.

Financial investment model

PATH created a tool that estimates the financial investment that would be required in a country if O_2aaU were implemented. The tool estimates the need for oxygen using a set of user inputs about a given region, calculates the total cost to meet the need, and analyzes the revenue required to justify the investment. To better understand potential financial mechanisms underpinning guaranteed private-sector investments, PATH conducted a landscape of the World Bank Group's investments. This analysis identified the project-based guarantee and the grant-loan combination as likely pathways, as well as the key stakeholders that could participate.

Health impact model

PATH worked with a researcher from the University of Washington to try to determine a health impact model that could be created using existing knowledge. We had hoped to find estimates that we could use as proxies for at least some of the assumptions regarding process indicators at each stage; however, the literature is sparse and a model developed today would rely on many uncertain assumptions. These uncertainties are due to limited evidence on the health impact of reliable access to oxygen and lack of implementation data, as the O_2aaU model is only at the concept development stage. Therefore, we recommend waiting until we have more trustworthy data on which to base the assumptions—from in-country qualitative research and actual data from a pilot. These data could then be used in a discrete event simulation model that could predict health outcomes resulting from increased access to oxygen. The results would still come with a set of limitations, but they would be far more compelling.

Piloting Oxygen as a Utility: Implementation plan

O_2aaU may realize large health and economic benefits as well as produce unintended consequences for health and the economy. Implementing a pilot of O_2aaU is an essential next step to more deeply understand and study these potential unknown effects as well as the expected impact of O_2aaU. Piloting O_2aaU in a single country or a region within a country is an essential step toward evaluating the theory of change and gathering data to model potential impact in other contexts. The pilot should be designed to mirror a full-scale implementation of O_2aaU as closely as possible.

PATH developed a three-phased approach to implement O_2aaU in order to move this model from a concept to implementation at scale. Phase 1 covers customization of the general operating model to a select geography, which takes into account factors such as existing capacity, total need, regulatory environment, and infrastructure. Phase 2 is a small-scale pilot to evaluate and refine the customized operating model within a given context. Learnings from the pilot will inform future adaptations of the operating model in other regions or countries. Phase 3 takes the refined operating model to scale within a select geography or geographies based on learning and evidence from the pilot.

1. Background

In Gorakhpur, India, late in the summer of 2017, following the rainy season, 60 children died at the Baba Raghav Das Medical College. Most were suffering from infections of Japanese encephalitis—some in the later stages of the disease—and their families had placed them in the care of the region's most admired medical facility: a modern, 1,000-bed public care center to which patients traveled hundreds of miles to receive treatment. Although autopsies were not performed, the common denominator among the deceased was that they all succumbed to their condition during a period when the hospital had run out of oxygen.

Medical oxygen may not share the spotlight with the marquee priorities of global health, but it is no less in need of the same serious attention and consideration. While for vaccines, funded breakthroughs have been made, condition-specific solutions have been identified, and supply chains have been optimized for delivery, oxygen is often overlooked as a perfunctory treatment, useful but not glamorous, and widely assumed to be a commodity that is readily available. As has been witnessed, though, both in the type of catastrophe that transpired in Gorakhpur as well as in the countless, preventable tragedies that patients in low-income settings face daily in the absence of medical oxygen, such assumptions are entrained by death. Thus, a new paradigm must be established, one whereby well-engineered market mechanisms ensure that oxygen is produced in volumes to meet demand, where it is delivered dependably by suppliers to the health facilities that need it, where it is paid for on-time at a reasonable rate, and where all stakeholders are properly incentivized to ensure that the user—whether a suffering child or otherwise—is guaranteed access to the treatment they need to take healthy breaths.

Oxygen is a cost-effective and essential lifesaving medicine. It is one of 30 priority lifesaving medicines for women and children included in the World Health Organization's (WHO) Model List of Essential Medicines. At approximately US$50 per disability adjusted life year (DALY) averted, oxygen is highly cost effective. For comparison, oxygen is nearly twice as cost-effective as pneumococcal conjugate vaccine (estimated at $100/DALY). Oxygen is used across age groups to manage a wide range of conditions, including severe pneumonia, birth asphyxia, sepsis, malaria, asthma, and cardiac obstructive pulmonary disease. Oxygen is also essential for safe surgery, anesthesia, and obstetric and emergency care. Despite its cost-effectiveness and status as an essential medicine, nearly half of hospitals in LMICs have inconsistent or no supply of oxygen, and only half have working pulse oximeters. Further, the equipment and training needed to appropriately administer oxygen to patients are commonly lacking.[1]

Increasing access to oxygen can lead to improved health outcomes across many disease areas. As diagnosis of severe disease continues to improve at the primary care level and as referral linkages from primary to secondary and tertiary care strengthen, health systems will treat more patients seeking advanced care and oxygen will become an increasingly important commodity in the treatment of a wide range of indications.

2. Rationale and need for an innovative solution

2.1. A static system facing growing demand

Recently, medical devices to detect and treat diseases requiring oxygen have recently received large investments, however,[2,3,4] none of these investments have included sustainable oxygen solutions. Vaccine coverage, antibiotics, and antimalarials have all benefited from substantial financial investments—in the products themselves, the supporting systems for delivery and appropriate administration to patients—which have increased reliable access. However, access to medical oxygen, an essential drug for the treatment of pneumonia and myriad other indications, remains limited in many LMICs. Three broad transitions underway in LMICs suggest that the need for oxygen services will only increase with time[5]:

1. Epidemiological and demographic shifts are resulting in more children with diseases that are difficult to prevent and must be treated.
2. Funding for health systems, particularly within middle-income countries, is shifting to an increased reliance on domestic resources.
3. The rise of single-payer health systems results in more horizontal, as opposed to vertical (disease-specific), programming.

The first trend is driven by population growth and epidemiological shifts in the burden of disease in LMICs. The world population is expected to grow from 7.6 billion today to 8.5 billion in 2030 and 9.8 billion in 2050. Half of this growth is predicted to be focused in nine countries: India, Nigeria, the Democratic Republic of the Congo, Pakistan, Ethiopia, Tanzania, the United States, Uganda, and Indonesia.[6] In 2050, the majority of the population over the age of 60 years will be living in LMICs.[7] The number of children is rapidly growing in Africa. By 2055, it is predicted that almost 40 per cent of the world's total children will be in Africa. This number is expected to increase to 50 per cent by the end of the century.[8]

All countries are faced with major challenges to ensure their health and social systems are ready to address this demographic shift. At a global level, noncommunicable diseases (NCDs) were estimated to be the cause of death for 71 per cent of the world's 56.9 million deaths in 2016.[9] While LMICs currently face the double burden of disease, a decrease in communicable diseases is projected, which will be replaced by an increase in NCDs.[10]

The second trend—more reliance on domestic resources—is concerning for oxygen access, because countries will increasingly prioritize allocation of their limited resources. Prior to this transition, donors were paying a larger share of total health system costs. Going forward, country governments will increasingly self-finance many costs previously supported by donors.[5] As a result, they will increasingly face a tighter budget constraint on all health expenditure and funds may need to be spent more efficiently or service availability, including oxygen, may be reduced. Access to oxygen services amplifies the effectiveness of treatment for many treatment indications. As such, it is likely a good investment for countries to prioritize even in a shifting financial landscape.

Finally, the third trend—the rise of single-payer health systems—has the potential to promote an increased focus on and broader scale-up of oxygen, as it is an imperative treatment for many indications. As countries shift priorities to meet changing health needs, the use of oxygen in the treatment of multiple indications could justify further investment and scale-up efforts from both an epidemiologic and an economic perspective. However, to equitably increase access, the per-patient cost of providing oxygen will need to be reduced or more expenditure allocated to the health system.

2.2. Market challenges for oxygen are broad and affect many disease areas

Broad investments in a country's health system have been demonstrated to be an important driver of macroeconomic growth. The WHO's policy brief *Making the economic case for investing in health systems* notes that there is strong evidence that spending on health systems – including essential medicines and therapeutics – contributes to not only improved health outcomes but can serve as a primary determinant of a productive workforce. At a higher level, the report acknowledges that, “Greater health leads to improved consumption opportunities, and also greater opportunity to pass on the benefits of education and other endowments to future generations. Better health intrinsically enhances quality of life, reduces expenditure on health services, and also improves the capacity to contribute to society.”[11] A common example – the distribution and use of bed nets to reduce malaria transmission – illustrates how investment in a straightforward solution can engender a tidal shift for a public health burden and improve the overall health of a society.[12]

Investments in oxygen enhance the utility of health expenditure in myriad disease areas. If oxygen access continues to be deficient, there is risk of reducing the effectiveness of many other investments. However, quantitative evidence does not exist to precisely identify the value-add of oxygen services. As such, this section makes the case for O_2aaU as a novel approach to overcome the range of challenges in oxygen service provision. For each challenge, we identify indicators that can allow for measurement of change for each factor. This section does not describe in great detail the interventions needed to achieve the anticipated changes or the risks that may be associated with pursuing these interventions. It is meant to highlight the breadth of issues in the current state and the comprehensive nature of the solution that is needed. Section 6 discusses how these challenges could be addressed and Section 8 provides a blueprint for piloting and testing potential solutions through O_2aaU.

The causes of inadequate oxygen access include insufficient maintenance, poor infrastructure, and credit constraints; insufficient and irregular supply from producers; and lack of equipment and training among providers to adequately identify patients who need oxygen and dispense oxygen effectively.

O_2aaU is designed to improve equitable access to reliable medical oxygen supply by addressing key challenges that countries face: collective action problems; supply chain inefficiencies; insufficient training on oxygen use; delayed payment/nonpayment of oxygen suppliers; rapid deterioration and failure of capital equipment; non-optimal level of competition; and inequitable access in remote areas. Rather than require a detailed understanding of which challenge is causing lack of access, O_2aaU was designed as a solution that addresses all seven challenges concurrently, limiting the likelihood that gaps will remain. Components of the proposed intervention model are summarized in Table 1; each challenge is outlined in further detail thereafter. Challenges will manifest in different ways across markets and ultimately require a customized solution under this intervention approach. This customization process is described in further detail in Section 6.4.

Implementing O_2aaU to generate the expected future states in Table 1 will come with significant barriers and risks. A risk matrix in Appendix F attempts to list and categorize these risks by likelihood of occurrence and their impact. In seeking to induce the expected future states, unintended results both positive and negative may occur. Implementing and testing the O_2aaU model through a pilot in a real-world setting will allow for better understanding, planning around potential unintended results and amplification of the desired future states.

Collective action problems: Oxygen gas, equipment for dispensing oxygen, training to appropriately use and maintain the equipment, and functional procurement mechanisms are required to provide uninterrupted supply. However, oxygen faces a collective action problem: there is rarely a responsible party to ensure supply.[a] Oxygen is always a part of pediatric, mother and child, emergency, and acute care, among other departments, but is infrequently planned for as a standalone factor that impacts health care outcomes. With the predominance of vertical disease programs and suboptimal medical device management across the health system, oxygen supply is frequently

[a] For a thorough treatment of collective action problems see Mancur Olson, The Logic of Collective Action (1971).

TABLE 1. **Challenges that limit equitable access in oxygen markets.**

EXISTING CHALLENGE	METRIC-MEASURABLE INDICATOR(S)	CURRENT STATE	ANTICIPATED CHANGE(S) O_2AAU SEEKS TO INDUCE	EXPECTED FUTURE STATE
Collective action problems	• Number of buyers of oxygen.	• Health facilities decentralized. • Various departments purchasing their own oxygen.	• Aggregate planning/ responsibility and reduce organization costs	• Reduced number of buyers
Supply chain inefficiencies	• Supply stockouts.	• Not tracked.	• Required common service provisions enforced.	• Reduced stockouts.
	• Supply pipeline inventory/ leadtime.	• Not tracked.	• Auction to most efficient supplier in area.	• Unknown.
Insufficient training on oxygen use	• Diagnosis of need for oxygen. • Number of providers trained. • Adherence to clinical guidelines.	• Not tracked.	• Training bundled with common service provision.	• Increased diagnosis of patients needing oxygen. • Increased adherence to guidelines.
Delayed payment/ nonpayment of oxygen suppliers	• Days bill outstanding.	• Delayed.	• Financial backing and contracted promise to pay.	• Reduction in outstanding bills.
Rapid deterioration and failure of capital equipment	• Device failure rate. • Number of days of up-time. • Total failure frequency.	• Poor.	• Companies internalize maintenance and optimally maintain equipment.	• Increased up-time. • Reduced equipment failure.
Non-optimal level of competition	• Price. • Quality (supply chain efficiency).	• Unregulated monopolies and over-fragmented demand.	• Auction with single or multiple partitions. • Guarantee of recruiting new entrants.	• Reduced price for oxygen services. • Increased quality.
Inequitable access in remote areas	• Coverage rates. • Quality (supply chain efficiency). • Price.	• Remote areas lack reliable access.	• Demand and auctioning packaged together. • Subsidy if cost remains too high. • Long term contracts.	• Increased coverage of oxygen services. • Increased quality. • Lower prices. • Supply optimization.

overlooked despite its cross-cutting uses. By negotiating a monetary fee for each department's oxygen needs, and then contracting its end-to-end provision as a collective service, the responsibility of any one department to organize a facility's oxygen supply is removed. O_2aaU can define the range of products and services needed for effective oxygen delivery and determine an appropriate price that can then be charged across multiple divisions of a country's ministry of health (MOH).

Supply chain inefficiencies: Supply chain optimization, both in production and distribution, in combination with a well-designed auction process, is needed to increase reliability and drive prices down. Although it may be in the interest of government to optimize oxygen market efficiency and equity, specialized skills in and knowledge of oxygen production and distribution systems, and, potentially, large capital investments to establish optimal generation and distribution networks, are necessary. O_2aaU would contract suppliers with established technical expertise to provide oxygen reliably while also supporting government-led monitoring of service performance. The industry has the capability to aggregate several small retail markets to create a wholesale market with much bigger supply capability at a much lower price. Increased long-term accountability against performance standards may prevent or address price variations and supply disruptions.

Production of high-quality medical-grade oxygen is a complex process to regulate. Distribution to patients is difficult; shipping, installing, and distributing medical oxygen safely are specialized activities that require a high degree of precision for quality and safety. Explosion of oxygen cylinders is a danger in transit. With some oversight, industrial gas suppliers are best positioned to safely control production and management of supply distribution for a competitive and cost-efficient price. The risk and complexity of governments owning these processes have frequently led to the breakdown of systems and lack of access to oxygen. Under the proposed O_2aaU model, industry would manage the risks of ensuring quality and safe distribution of supply, while governments would oversee quality control.

Insufficient training on oxygen use: Improved diagnosis of patients who are hypoxic through pulse oximetry has been shown to increase oxygen use. However, training to identify hypoxemia and deliver oxygen safely is limited and often does not address the range of indications for which effective delivery is required. Further, oxygen administration requires adequate training and incentives; if administered improperly, oxygen can be an ineffective treatment and/or cause harm to patients and sometimes death, particularly in vulnerable patients such as neonates.[13,14] Including training as part of an end-to-end solution improves patient safety and removes the burden from the MOH and relies on the contracted firms to help health care workers to better understand when to use oxygen and how to safely deliver it. Firms that produce oxygen and equipment to administer oxygen often develop training materials and methods. O_2aaU will explicit select and contract firms able to provide these training services.

Delayed payment/nonpayment of oxygen suppliers: Firms that produce oxygen lack leverage to demand payment for their products. In the worst circumstances, they have had to stop supplying oxygen to motivate customers to pay, which threatens the lives of patients. Delayed payment or nonpayment is a common problem for many suppliers. O_2aaU seeks to create a credit product to ensure suppliers receive regular payments. O_2aaU allows governments to coordinate service across users, spread out service payments over a longer period of time, and, in some cases, lower transaction costs by managing fewer contracts with suppliers. At the same time, coordinating service across users will increase volumes and reduce costs from the economies of scale. This may make it possible to provide oxygen to a larger number of patients without additional financing. In cases in which the cost of providing oxygen is in excess of what a government is able to afford, the O_2aaU model includes capital investments from donors or impact investors to subsidize the financing gap until a country's income increases and payments can be made reliably without external support.

Deterioration and failure of capital equipment: Preventative and corrective maintenance is frequently overlooked or ineffectively provided for medical equipment. For oxygen delivery equipment, it can be difficult to identify that a cylinder is leaking or an oxygen concentrator is generating supply at a lower purity level without appropriate product procurement and systematic checks for functionality once installed. O_2aaU addresses both challenges. First, aggregating and organizing procurement across health facilities will support better selection of products and reduce the number of equipment brands and models for which training and spare parts would be required. Second, industry contracts will include detailed specifications for the routine and corrective maintenance expected within the proposed end-to-end service agreement. Regular performance monitoring will ensure expectations are met.

Non-optimal level of competition: The number of firms providing oxygen is often too many or too few, creating over-fragmented demand or a monopoly, respectively. In overly-fragmented markets where the number of firms is too high, such as in Uttar Pradesh India, many suppliers are in robust competition to sell oxygen cylinders to health facilities. This competition keeps the prices of cylinders low, however, the market is locked in a sub-optimal equilibrium; each producer controls only a small share of the market and likely does not have the capital or market share to invest in more efficient technologies such as cryogenic production. In other markets, characterized by one or two firms dominating production, health facilities are often price-takers with no alternative. In this monopolistic situation, firms may seek higher prices for oxygen services, limiting the amount that health facilities and patients can consume. To be sure, O_2aaU will itself generate monopoly-like conditions after offering a service contract to a single supplier. The key difference is that the price for this new contract is decided ex-ante through a competitive process, rather than the status quo in which health systems are often price-takers from monopolistic firms. Extensive monitoring will be essential to maintain the quality of services to be provided through the contract.

Inequitable access in remote areas: It is often more costly to supply oxygen services to remote areas than to health facilities easily accessible by good road networks. Under the status quo, these areas experience either higher prices or a lack of supply; both resulting in underconsumption of oxygen, which results in worse patient outcomes. In structuring the market, two main options exist. First, create heterogeneous markets where high-cost remote areas are subsidized by low-cost dense and accessible areas. Second, create homogenous markets in which remote areas are segmented and priced separately. If prices remain higher than the budget for these facilities, a subsidy should be put in place to enable equitable oxygen consumption.

Supplying to remote areas may also require infrastructure and supply chain investments to bring down costs in the long term. Investments by firms rely on an expectation that they will be able to make a profit in the future. O_2aaU relies on a bank guarantee and long-term contracts to increase the level of certainty in future profit generation.

3. Oxygen as a Utility: Defining a new solution

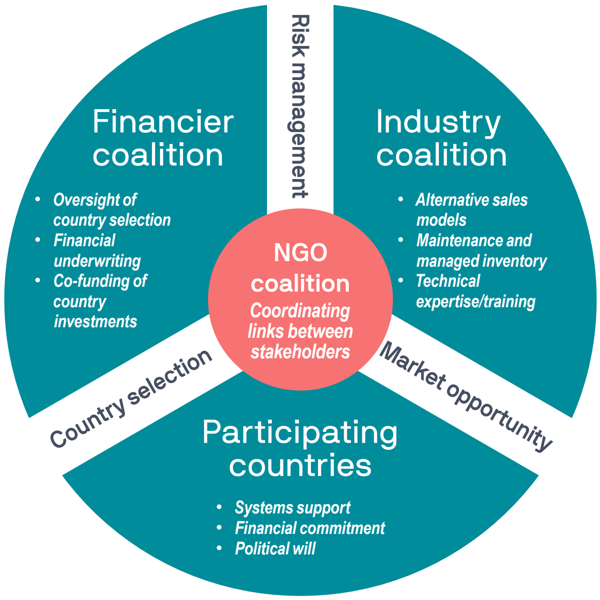
The Oxygen as a Utility concept seeks to address the range of issues that limit oxygen access through a single, powerful consortium of partners and agreements. O_2aaU brings together representatives from LMIC, private industry, and financial institutions to provide end-to-end medical oxygen services, from production to administration to patients by a health provider. O_2aaU provides oxygen and all related services by contracting private-sector companies at fair market prices identified through an auction-based tender. Countries pay rates for an agreed-upon length of time for this service. Because large investments in LMICs can be risky due to increased probability of late payment and/or default, financial institutions will be recruited to provide guarantees to limit the risk to suppliers. Nongovernmental organizations (NGOs) will act as intermediaries between countries and the other parties to facilitate the intervention. A separate third party will be responsible for monitoring the effectiveness of the program.

Implementing the program begins with identifying potential early-adopter countries using the selection criteria defined in the following section. Once identified, an NGO partner may conduct an in-depth assessment of the selected countries to understand the current availability of oxygen and the status of the necessary components, as described in Section 6. Based on this assessment, a feasibility analysis would be conducted and cost estimates developed. Final country selection will be based on the feasibility, estimated costs, and projected ability to impact health outcomes.

Once a country has been selected, O_2aaU is implemented using the operating model described in Section 6. Examples of areas that may need to be strengthened prior to implementation include medical device policies, procurement practices, oxygen policies, and regulatory practices. Similarly, during the pre-service delivery stage, contracted suppliers will develop any oxygen-specific infrastructure needed. This could include piping systems for hospitals, oxygen distribution centers, or even oxygen production facilities if they do not currently exist in country. Pre-implementation infrastructure will vary based on existing oxygen infrastructure in a given setting. Suppliers will also be responsible for developing and conducting clinical training and setting up maintenance protocols that ensure appropriate use and timely, thorough maintenance of oxygen equipment. To be sure, some of these factors may not be modifiable in a short time-frame needed in for a pilot. Pre-selecting countries based on the presence of or ability to modify these factors will therefore be important.

The goal of O_2aaU is to address a suite of challenges countries face when attempting to deliver oxygen services all at once. At a later time, it may be possible to examine this market intervention when more is known about the most effective levers. However, until that time, O_2aaU is designed to broadly address a range of challenges simultaneously. Under the status quo, a large number of complicated processes that consume a tremendous amount of a health system's skills and financial resources are dedicated to the provision of a single drug, oxygen. O_2aaU suggests contracting this work to a supplier with a comparative advantage, and appropriate incentives to provide superior services for less money.

FIGURE 1. **Oxygen as a Utility stakeholders.**



Abbreviation: NGO, nongovernmental organization.

The price to a country for O_2aaU will incorporate the costs to deliver oxygen and consumables, as well as the costs for infrastructure investments, training, and ongoing maintenance. It will be structured so that industry partners realize a positive net present value within the period of the contract. For the purposes of this report, a ten-year time horizon is used to model costs of a hypothetical pilot in Uttar Pradesh, India (Section 8.1.2). Further analysis is required to understand what level of financial guarantee will be required to sufficiently reduce the discount rate suppliers use in their net present value assessments to justify the investment.

To explore the concept and assess the feasibility of an operating model that provides oxygen as a utility, PATH investigated the following research questions:

- In which countries is this operating model likely to be most appropriate and feasible?
- What financial model is applicable?
- What stakeholders are required for implementation?
- How much would this cost for a country and the financial guarantors?
- What is the potential health impact?

4. Country selection

The goal of the country selection process is to identify potential early-adopter countries where O_2aaU would be appropriate and could be successfully implemented. Success here is defined as implementing a solution that is financially and logistically sustainable while achieving health impact and producing financial returns for firms and the economy as a whole. The country selection process uses key measurable factors to select countries that meet these criteria.

The PATH team began with 82 LMICs, selected because oxygen access is unreliable in many of these countries. In addition, there is a higher potential for health and economic impact in many LMICs due to high mortality rates of children under 5 years. Data were then compiled for each of the factors outlined in Table 2 and ranked relative to each other. A Tableau tool was created to visualize and to assess the influence of specific factors. While the method for selecting the criteria for country ranking is not comprehensive, the purpose of this exercise was to reduce the potential focal countries to a number that could be feasibly reviewed in more detail.

To determine a country's score, each country was ranked from highest to lowest for each criterion. The rankings were then translated into proportions based on the number of countries with information for each indicator. For example, the country with the lowest rates of mortality from acute respiratory infection (ARI) was given a ranked proportion of 0.01 (1/82) and the country with the highest ARI mortality rates was given a ranked proportion of 1 (82/82). Qualitative indicators were translated into 0 or 1. For example, a country was given a 1 if it had adopted WHO's guidelines for integrated management of childhood illness and a 0 if it had not. All criteria were weighted equally for the results we report; however, the Tableau tool allowed weights to be adjusted. Raw scores were then standardized from 0 to 100 to simplify comparison across countries. A score of 0 represented a country for which all indicators were ranked the lowest, and a score of 100 represented a country for which all indicators were ranked the highest. The only exception to this methodology is that the world population ranks were adjusted, given that India was an outlier.[b]

[b] After examining histograms of each indicator, all were approximately normally distributed except for proportion of world population, with India as a significant outlier. The original method provided India with a ranked proportion of 1 and the second largest country a proportion of 0.99 (81/82), yet this did not sufficiently account for the larger population in India relative to other countries (approximately 30%). Therefore, the distribution of the ranked proportions was artificially shifted so that the second-largest country was given a proportion of 0.7 and subsequent countries given a ranked proportion relative to the new scale.

TABLE 2. **Country selection criteria and rationale.**

CRITERIA	RATIONALE
Percentage of the world's population residing in LMICs	Potential health impact and market for medical oxygen.
Percentage of deaths among children under 5 years due to ARI, 2016	Burden of pneumonia disease and potential for health impact in children under 5 years are often key metrics for global health investors.
Percentage of children with ARI for whom advice or treatment was sought from a health facility or provider	A measure of care-seeking at a health facility—a secondary indicator of potential health impact, as this determines how many children present at health facilities.
Implementation of IMCI	Country buy-in and health care worker training in IMCI.
Current health expenditure per capita (in US dollars), 2016	Funding the government is willing and able to dedicate to health care.
Ease of doing business score	Composite measure of the ability to set up and operate a business in each country.

Abbreviations: ARI, acute respiratory infection; IMCI, integrated management of childhood illness; LMICs, low- and middle-income countries.

The result of this initial screen is a ranked list of countries in which O_2aaU may be more or less feasible and/or impactful. A higher adjusted score indicates a country in which implementing O_2aaU is more feasible and the health need is higher than in other countries, whereas a low score indicates lower feasibility. The top ten countries when all indicators are equally weighted are listed in Table 3.

The final stage of the selection process will involve in-depth work in each of the potential implementation countries. The two high-level factors that will be gauged in the next stage are below.

- **Government commitment:** Gauging country interest and commitment requires a deep understanding of how decisions are made in a specific country, how key decision-maker positions shift, and the frequency at which they switch. In-person discussions and, ideally, engagement in a technical working group or other official body will aid in understanding a country's political processes and the likelihood for O_2aaU to be implemented. Further, depending on the governance structure in a given country, engagement may be required at both the national and subnational levels.
- **Existing oxygen solutions:** A suitable O_2aaU country must have the interest and desire to dedicate resources and implement a solution, but also must be early enough in the process to implement an end-to-end solution without disrupting ongoing programs. As such, it will be integral to understand the degree to which oxygen solutions are already implemented. For example, in Senegal the Ministry of Health and Social Action has installed 38 oxygen generation plants in their hospitals and they are in the process of installing plants in 25 health centers. The government is clearly motivated to improve access to oxygen; however, they may be too far along in their own strategy

TABLE 3. **The top ten countries when all feasibility and impact criteria are equally weighted.**

COUNTRY	SCORE
Indonesia	77.4
Moldova	76.9
Philippines	74.4
India	74.0
Vietnam	72.7
Morocco	69.7
Solomon Islands	68.4
Guatemala	67.7
Nepal	66.8
El Salvador	66.7

5. Financing

Addressing core challenges the oxygen market faces may require reducing the financial risk that private firms supplying oxygen are exposed to. To mitigate risks that may inhibit investment, namely delayed and non-repayment for oxygen services, among others summarized in Table 1, the PATH team reviewed common financing mechanisms that are used to support large infrastructure investments in LMICs to determine appropriate and feasible funding models for O_2aaU implementation. The team determined that a project-based guarantee, such as those offered by the World Bank Group's Guarantees Program or a grant-loan combination, would ensure the project's bankability, scalability, and replicability. As such, both mechanisms are described in further detail below.

5.1. Financing with a guarantee

PATH studied the World Bank Group Guarantees Program to better understand the use of this financial mechanism to support public, private, project and policy infrastructure investments. The landscape included reviewing 30 case studies from 23 countries and defined the context and need of the borrower's environment, stakeholder types, basic contracting mechanisms, guarantee structures, and benefits to the guarantee based on the desired outcome of the project or policy. Two common World Bank Group guarantee types were identified through this work: project-based guarantees and policy-based guarantees (summarized in Table 4).

While both guarantee types can be used for similar purposes, each is flexible and adaptable to multiple contractual structures and has to be designed for the context in which it will be applied. Guarantee loans have ranged from $3.5 million to $1.6 billion and tenure can extend up to 35 years. Key considerations in the design of a guarantee structure include estimated cost of the infrastructure project, risk allocation between the government and private-sector investors, agreement types, and private-sector investor interest.

TABLE 4. **Overview of World Bank guarantee types.**

FINANCIAL MECHANISM	PURPOSE	BENEFITS	EXAMPLE
Project-based guarantee (includes loan and payment guarantees)	Applied to specific project investments whereby governments seek to attract private investment.	• Mitigates risk in the event of financial/performance default. • Reduces cost of financing for a project. • Attracts private-sector investment. • Provides a model for scalability and replicability.	Scaling Solar program:[15] This program provides a bundled package of World Bank Group services to help countries establish a sustainable market for solar power. The program "aims to make privately funded grid-connected solar projects operational within two years and at competitive tariffs." (See box in Section 8.3 for more detail.)
Policy-based guarantee	Applied to country programs that seek to develop or adopt policy to promote economic growth/poverty reduction; sovereign-level financing.	• Enhances credit quality of the government. • Supports country's fiscal and macroeconomic framework. • Provides a long-term solution to economic challenges due to socioeconomic or political crisis.	Ghana Macroeconomic Stability for Competitiveness and Growth Credit: Ghana was able to raise $1 billion through a sovereign bond issuance supported by the World Bank Group in order to meet refinancing deadlines, extend debt maturities, and smooth out its debt service profile.

5.2. Financing with a grant-loan combination

The PATH team landscaped infrastructure projects in LMICs that were financed through a grant-loan combination to better understand the use of this financing mechanism to support public, private, project and policy infrastructure investments. To inform O_2aaU concept design, this landscape drew parallels from a review of utility infrastructure projects in the digital, energy, transportation, and water sectors. The grant-loan combination is summarized in Table 5.

Grant-loan combinations are commonly used for global infrastructure investments; therefore, they are not country or project specific and do not have a standardized structure. However, in LMICs, grant-loan combinations are used to facilitate private-sector investment when commercial or political risks are too high to attract private capital through standard market function and/or when there is opportunity to accelerate positive development and economic impact in a given country. Grant-loan combinations can include loans, loan guarantees, and equity investments.

TABLE 4. **Overview of World Bank guarantee types.**

FINANCING MECHANISM	PURPOSE	BENEFITS
Grant-loan combination	Applied to specific project investments whereby there is interest in engaging (or potential to engage) government in cost-sharing and there is interest in seeking local/global private investment.	• Provides low-interest loans and/or interest-free credits (depending on financing partner). • Engages domestic/global private investment. • Stimulates domestic economy. • Engages diverse funding base.

5.3. Financial partner identification

Potential financial investors in O_2aaU include global development banks, regional or national development banks, and multinational private-sector companies. Based on the analysis above, the World Bank is a leading potential investor given their broad geographic reach, appropriate financial mechanisms, and the potential alignment of O_2aaU with their strategy. However, additional development banks could be approached. Table 6 lists six additional development banks that were selected for their relevant strategy and geographic focus, which could be approached depending on the country selected for O_2aaU implementation.

TABLE 6. **Strategic and geographic focus of pertinent development banks**

	RELEVANT STRATEGIC FOCUS	RELEVANT GEOGRAPHIC FOCUS
African Development Bank	Gender; private-sector development	Africa
Asian Development Bank	Infrastructure	Asia
Development Bank of Latin America	Infrastructure	Latin America
European Bank for Reconstruction and Development	Strategy agnostic	North Africa
German Investment Corporation	Growth strategies	Frontier markets in Africa and South and Southeast Asia
International Finance Corporation	Infrastructure	Africa, Asia, Latin America

Adapted from Michelitsch R, Soriano A, Cuestas E, et al. *Comparative Study of Equity Investing in Development Finance Institutions (DFI)*. Washington, DC: Inter-American Development Bank; 2017. https://publications.iadb.org/en/comparative-study-equity-investing-development-finance-institutions.

Below is a more in-depth assessment of the considerations for working with the World Bank, the African Development Bank, and/or multinational companies in the implementation of O_2aaU. Further to this assessment, financial partners should be selected based on the proposed investment size. An example cost analysis for the state of Uttar Pradesh, India, is included in Section 8.1.2.

5.3.1. International: The World Bank

Providing oxygen as a utility with financing through the World Bank Group Guarantees Program depends on meeting the program's criteria for eligibility. Key criteria include the need for government support/interest, defined development impact (that contributes to the economic development of the member state), demonstrable long-term viability, and need for and/or interest in mobilizing private investment (or mitigating government payment risk). A project is eligible for a World Bank Group guarantee if it is a private project that is a direct beneficiary of an obligation from the government (which includes a sovereign-owned entity). For the project to qualify for a loan guarantee, the debt must be extended by commercial entities. If eligible, key considerations in the design of a guarantee structure for O_2aaU include estimated cost of infrastructure project, risk allocation between government and private-sector

WORLD BANK FINANCIAL INSTRUMENTS

Senior debt

- International Bank for Reconstruction and Development (IBRD) loans (middle-income countries); to commercial entity or to host country
- International Development Association (IDA) loans (low-income countries)
- International Finance Corporation (IFC) loans; typically 7 to 12 years to companies, intermediary banks, and other financial institutions

Guarantees

- Partial risk; protects lenders against payment defaults arising from breaches of sovereign contractual undertakings
- Partial credit; covers certain debt service payments against all risks

Equity

- IBRD/IDA loans to a host country can finance the host country's equity investment
- IFC can make equity or quasi-equity investments, typically between 5% and 20%

Others

- Global Partnership on Results-Based Approaches: results-based financing and impact bonds
- Public – Private Infrastructure Advisory Facility: catalyzes public-private partnerships

investors, agreement types, and private-sector investor interest.

5.3.2. Regional: African Development Bank

The African Development Bank has six flagship programs to support industrialization in its member states. A national oxygen scheme could qualify for funding under three: flagships two (attract and channel funding into infrastructure and industry projects); four (promote and drive enterprise development); and six (develop efficient industry clusters across the continent). To qualify, the enterprise created by the project must be majority owned by private-sector investors or be publicly owned; for greenfield projects, the maximum in which the bank may participate is 33% of total project costs. The bank participation percentage can be higher for projects that expand on existing facilities, which, in the instance of the O_2aaU operating model, would apply to pre-established oxygen generation and delivery infrastructure.

5.3.3. Commercial: Industrial gas multinationals

Many industrial gas multinationals provide financing options to prospective clients. For example, Linde provides engineering, procurement, and construction packages that leverage their operational expertise and financing capacity to create "customized, bankable financing structures."[16] Often, these involve letters of credit, different types of export credits, and other forms of project financing. By contrast, Air Liquide's robust credit lines allow them to

AFRICAN DEVELOPMENT BANK FINANCIAL INSTRUMENTS

Senior debt

- Up to 15 years (with five-year grace period)

Guarantees

- Partial risk, partial credit (long tenures)
- For specific credit or commercial bank small- to medium- sized enterprise programs; risk priced

Subordinated debt

- Subordinated loans or bonds
- Local currency possible; maximum 15 years (10 + 5); risk priced

Equity

- Direct investment in banks, development financial institutions, microfinance institutions, and others
- Up to 25% with or without board seat; planned exit; commercial returns

rapidly engage in new opportunities for growth.

5.3.4. Trade-offs

In addition to providing the capital necessary to execute the project, potential pathways for financing O_2aaU should ultimately serve to incentivize stakeholders to ensure supply meets the true need for oxygen. The capacity and breadth of experience the World Bank Group leverages make it an ideal candidate for supporting the project. A regional development bank may be capable of providing localized expertise and will have charter values that align with the project, should supplementary funding or guarantees be necessary. Depending on the structure the model takes, commercial investment may prove an efficient mechanism for funding. When executed adroitly and with the proper guarantees, the financing should reduce risk for all non-guarantor participants; provide liquidity for capital and operational expenditures; and foment trust among the consortium of suppliers, health facilities, and government agencies that will serve to make the O_2aaU operating model a success.

5.4. Required investment

A process was established to estimate the costs associated with implementing O_2aaU in a region, with region-specific inputs (e.g., type of oxygen generation source, number of inpatient hospital beds, and number of years in the proposed contract). The PATH team developed a tool to calculate the total cost of ownership (TCO) for various tools that deliver oxygen. The tool calculates both the capital expenditures (CAPEX) and operating costs (OPEX) associated with providing oxygen to a single facility or an entire region over a specified number of years. The components included in the CAPEX and OPEX estimates generated by PATH are shown in Figure 2. CAPEX may also include land purchase, construction, and equipment costs for oxygen generation facilities, however estimates for these costs are highly variable across the regions included in the TCO tool and were excluded from the estimate.

INDUSTRIAL GAS MULTINATIONALS FINANCIAL INSTRUMENTS

Senior debt

- Bond issues through Euro Medium-Term Notes Program

Short-term debt

- Negotiable European Commercial Paper
- US Commercial Paper

Letters of credit

Export credits

- Single-source and multisource
- Structured

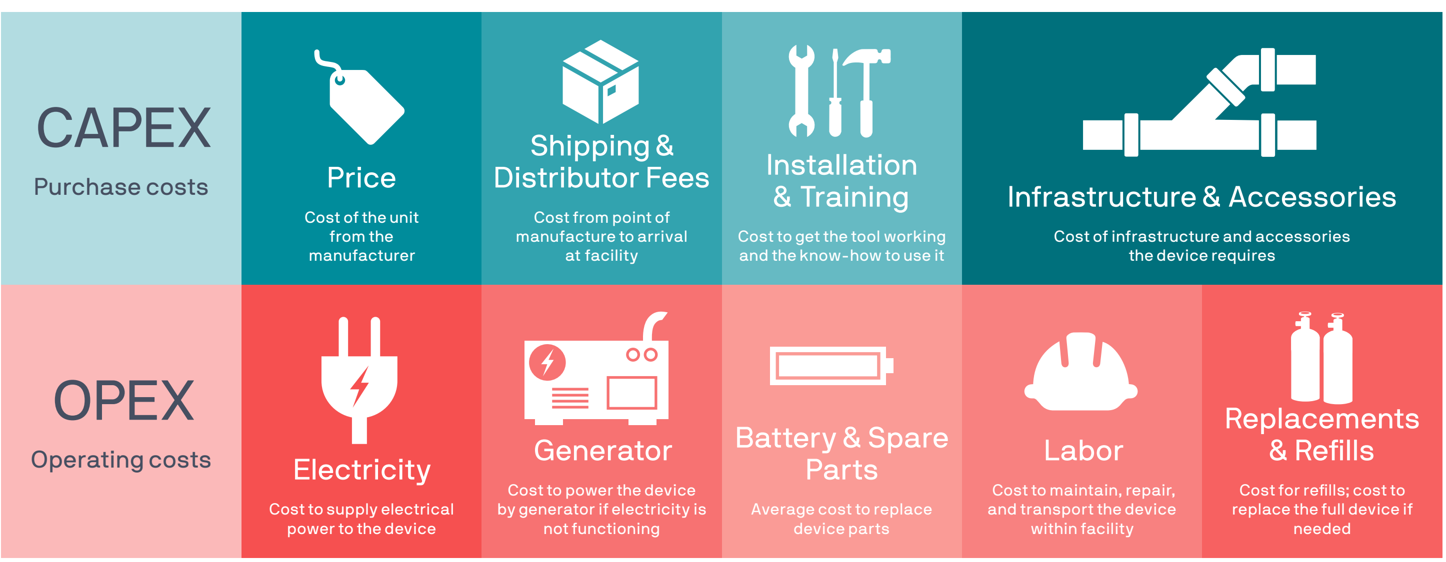
Syndicated credit facility

- €2 billion, five-year with 2 one-year extension options (Air Liquide)

Bilateral credit facility

- €1.6 billion committed credit lines, undrawn (Air Liquide)

FIGURE 2. **Components of the total cost of ownership tool.**



Abbreviations: CAPEX, capital expenditures; OPEX, operating expenditures.

The TCO tool functions by calculating the total oxygen required to meet the need of the facility or facilities and then calculating the cost to meet that need (methods are described in the sidebar below). Users enter data about the facility or facilities in their region, including the number of facilities, the types of beds in each facility, the hours of operation, availability of electricity, and if each facility is rural or urban. Where available, costs such as cylinder refills, electricity, and labor are estimated using data specific to each country. The tool then provides estimates of the costs to meet the calculated need using a single type of oxygen delivery device (e.g., cylinders) or a mix of devices (e.g., cylinders, oxygen concentrators, PSA plants). Device costs are estimated using an average across a number of sources to include a range of high- and low-cost devices and to better represent the category of products.

QUANTIFYING OXYGEN NEED

The quantity of oxygen is calculated using an industry-accepted approach, which is to determine the peak oxygen flow requirements for a facility using the following equation:

Peak flow = (number of critical care beds x 10 liters per minute of oxygen) + (number of general beds x 0.75 liters per minute of oxygen)

This peak flow is the key factor in determination of the quantity and type of oxygen generation equipment a facility should purchase, because a health facility must be able to supply peak demand.

5.4.1. Estimating required financing

To provide an estimate of the funding required to implement O_2aaU at scale, costs are estimated for providing oxygen to the entire public health systems in Tanzania and the state of Uttar Pradesh in India. Costs are estimated for periods of five and ten years. The total oxygen need for oxygen was calculated using the number of facilities and beds in each region and the formula described in the Quantifying Oxygen Need call out box in section 5.4 above. To be sure, these estimates only account for costs related to the provision of oxygen gas only and omits additional products and services that would be contracted as part of O_2aaU. The range of additional items to include and their costs vary widely by country, hence here the estimate is oxygen gas only. To estimate the costs, we assumed a mix of cylinders, oxygen concentrators, and PSA plants would be used to meet the need. Because the amount of the need that is currently being met is unknown, this model estimates what would be required to meet the total need.

A series of additional assumptions were required to run this initial estimate, which are detailed in Appendix B. While some of the assumptions are educated conjectures based on information available online, they are adequate for the illustrative purposes of this model. If O_2aaU were to be implemented in a country or region, primary research would be conducted to provide inputs that would more accurately estimate the actual costs. These would then be vetted with stakeholders in the private and public sectors. In addition, it would be necessary to estimate the feasibility given the existing infrastructure, distance to oxygen providers (for cylinder delivery), and required maintenance. The results of our analyses are summarized below.

5.4.1.1. India

The PATH team used the Indian Public Health Standards[17] to determine the average number of beds in each of the three types of facilities: primary health centers, community health centers, and district hospitals. Table 7 shows the type of facility and the total number of each type of facility in Uttar Pradesh. Using the quantification calculation, the total oxygen need is estimated to be 7.6 billion liters per year. The product mix modeled to meet this need is as follows:

- Primary Health Centers: 10 LPM oxygen concentrators and cylinders
- Community Health Centers: Oxygen cylinders
- District Hospitals: One 500 LPM Oxygen plant per hospital

TABLE 7. **Number of beds in each facility and total number of each type of facility in Uttar Pradesh, India.**

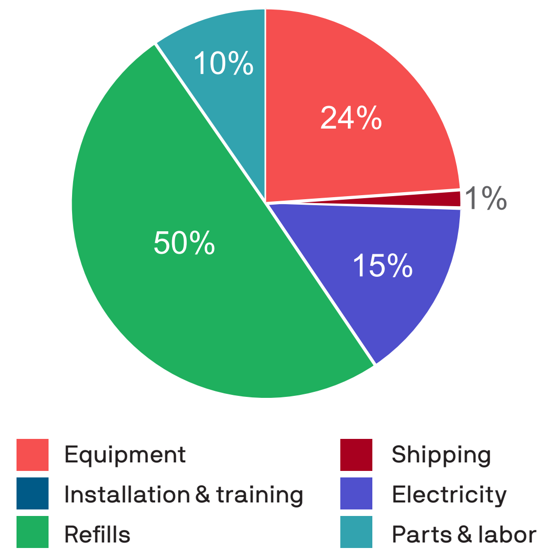
	PRIMARY HEALTH CENTERS	COMMUNITY HEALTH CENTERS	DISTRICT HOSPITALS	TOTAL
Number of facilities by facility level*	3,621	822	106	4,549
Average number of general inpatient beds per facility†	5	27	270	302
Average number of critical care beds per facility†	1	3	30	34
Total estimated oxygen need (liters per year)	26.1 billion	21.7 billion	27.9 billion	75.9 billion

*Source: Discussion with government of Uttar Pradesh, India.

† Source: National Health Mission, Government of India website. Indian Public Health Standards page. http://164.100.154.238/nhm/nrhm/guidelines/indian-public-health-standards.html. Accessed June 2019.

The TCO model estimates a cost of $239 million to provide oxygen to Uttar Pradesh for ten years under this scenario. This includes capital expenditures including equipment, shipping and installation equal to $61 million or 25% of the total. Equipment purchase costs are the majority of that. Operating expenditures are the remaining 75% of the costs with electricity to run the oxygen plants and concentrators and parts and labor making up 15% and 10% of the total respectively. Cylinder refills comprises the greatest percentage at 50% of the total cost. (See Figure 3.) Additional factors that need to be considered when implementing a solution like this include the costs to install piping systems in the facilities, availability and reliability of electricity, maintenance capacity, potential additional training required to operate new oxygen delivery devices, and delivery of these devices. If the timeline is reduced to five years, the total cost is then $144 million. Under this scenario, capital expenditures are 38% of the total while operating expenses are 62%.

FIGURE 3. **India product mix 10 years ($239 million).**



5.4.1.2. Tanzania

For Tanzania, the PATH team used staffing level guidelines to determine the average number of beds in four types of facilities: health centers, district hospitals, regional hospitals, and specialized hospitals.[18] Table 8 shows the number of general and critical care beds in each facility and the total number of each type of facility. The total oxygen need in Tanzania was calculated using the same methods as in the example for Uttar Pradesh. The need for oxygen is met using a combination of sources: cylinders for the health centers; a combination of cylinders and 10 LPM oxygen concentrators for district hospitals; two 500 LPM PSA plants in each regional hospital; and three 1,000 LPM PSA plants in each specialized hospital. The rationale for using multiple PSA oxygen plants in the hospitals is to create redundancies and to accommodate for facilities with multiple buildings. The assumptions listed in Appendix B were also used in the Tanzania example.

The first important comparison is that Tanzania would require roughly half as much oxygen as Uttar Pradesh due to its smaller population and fewer facilities. However, as shown in the examples below, despite requiring half the amount of oxygen as Uttar Pradesh, the cost to provide that oxygen using cylinders would be higher in Tanzania. This is because the cost of oxygen cylinders in India ($0.0003 per liter) is a fraction of the cost in Tanzania ($0.001 per liter). If O_2aaU were implemented in Tanzania, it may be possible to reduce this cost through negotiation. It should be noted that these costs do not account for the cost of oxygen piping in the regional and specialized hospitals. The results of both scenarios are summarized below.

The TCO model estimates a cost of $255 million to provide oxygen to Tanzania for ten years under this scenario. Interesetingly, this is ~$15 million more than the estimated cost to provide oxygen to Uttar Pradesh. This is mainly

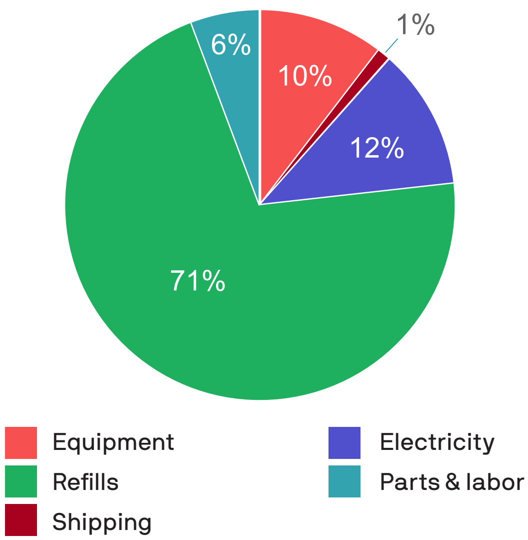
TABLE 8. **Number of beds in each facility and total number of each type of facility in Tanzania.**

	HEALTH CENTERS	DISTRICT HOSPITALS	REGIONAL HOSPITALS	SPECIALIZED HOSPITALS	TOTAL
Number of facilities by facility level*	509	65	22	7	603
Average number of general inpatient beds per facility†	24	175	450	1,500	2,149
Average number of critical care beds per facility†	1	18	45	150	214
Total estimated oxygen need (liters per year)	7.5 billion	10.5 billion	9.1 billion	9.7 billion	36.7 billion

* Source: United Republic of Tanzania Ministry of Health, Community Development, Gender, Elderly and Children website. Health Facility Registry page. https://www.jica.go.jp/project/tanzania/006/materials/ku57pq00001x6jyl-att/REVIEW_STAFFING_LEVEL_2014-01.pdf. Accessed April 2017.

† Assumes one critical care bed for health centers. In all other facilities, assumes max number of beds per standards and assumes 10% of beds are critical care.

FIGURE 3. **Scenario B: Product mix ($255 million).**



because the cost to refill cylinders in Tanzania is three times higher than in India. In this scenario, Operating expenditures account for 88% of the total with the cost of cylinder refills making up 71% of the total cost. Additional operating expenditures include the cost of electricity (12%) and parts and labor (6%) to run the oxygen plants and concentrators. Up-front capital expenditures make up only 11% (Figure 4). If spread over five years, the total cost of the implementation would drop to $141 million and capital expenditures would increase in proportion from 11% to 20%.

5.4.2. Financing analysis application to O_2aaU

Both scenarios modeled above provide useful insight into the potential rollout of a state-level intervention in Uttar Pradesh and a national-level intervention in Tanzania. By extension, lessons can be applied to other countries under consideration for the O_2aaU operating model.

These analyses can inform a price per liter estimate by providing an idea of costs a private-sector company or consortium of companies would incur. From this starting point, acknowledging there are limitations in the model, we can begin to explore pricing models. Additional considerations will include if only the public health system should be considered in the model or if the private health sector and industrial markets should be added. If the model were to include estimates of the potential demand from the private health and industrial sectors, it could reduce the government's payments. However, depending on the certainty of the estimates for these other market segments, this could increase the risk to the consortium. However, it could also remove some risk if there is a chance the government could not cover the full payment.

Many of the decisions related to delivery and pricing will depend on the context of the implementation country. Further, it should be noted that the cost figures for both scenarios are in nominal and not real terms. If the totals accounted for the time value of money and were discounted to be set in real dollars, the figures would be lower. The discount rates used in a net present value analysis will depend on each supplier's unique situation and the nature of guarantee provisions and will weigh into their decision to participate. More work is required to understand the degree to which de-risking this investment through financial backing could reduce the discount rate to make this a more inviting investment.

Additional consideration include population growth as that will likely correlate strongly with demand for oxygen services. For example, the Indian census is performed decennially on the first year of the new decade (e.g., 2001, 2011, 2021). The last census found that Uttar Pradesh's population growth was greater than 20% during the last decade, exceeding the national average. The magnitude of this growth—and whether it has plateaued in the last eight years or has continued unabated—will heavily influence oxygen demand forecasting. Improving the reliability of these figures will help refine the cost model.

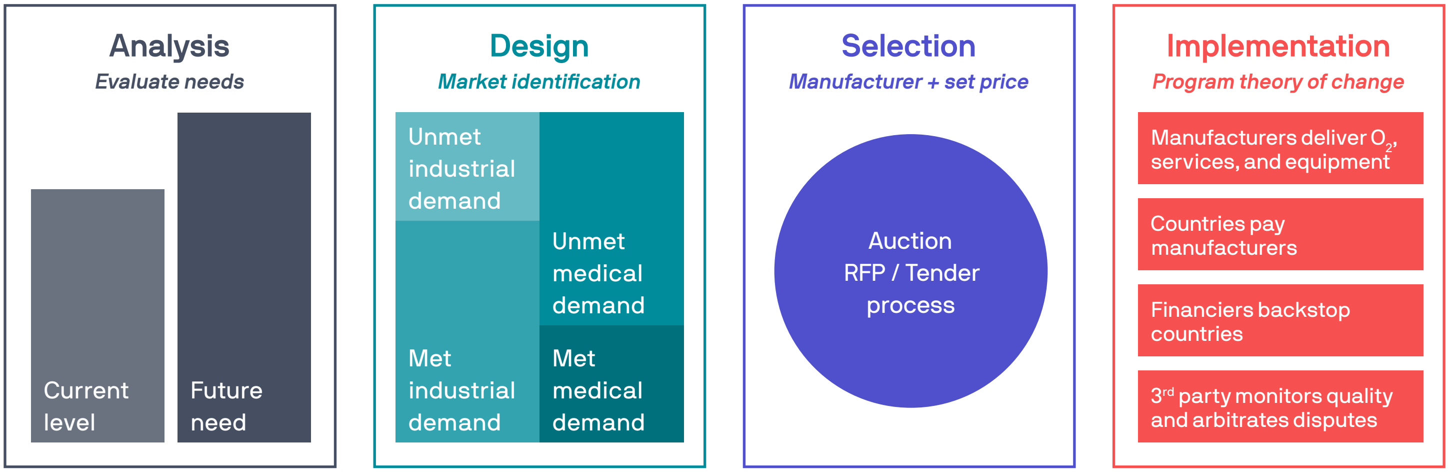
To be sure, the assumptions used in the TCO significantly influence both the total cost and types of costs, which highlights why an in-depth in-country assessment should be conducted prior to making any final recommendations.

6. Operating model

The O_2aaU operating model brings the players together—health care decision-makers, oxygen suppliers, and financial partners—into a system that ensures reliable medical oxygen service provision through increased private-sector investment. The operating model described below is a generalized structure that is meant to be modified to enable the provision of sufficient oxygen services, payment for oxygen at fair market prices, and monitoring of service quality. First, the entire model is described and then the role of each stakeholder group is highlighted within each of the four phases of the model.

The goal of the model is to generate oxygen service markets that are complete, to ensure no one is left out and to increase competition to drive down prices. Suppliers tend to favor more valuable and lower-cost markets, such as cities instead of rural areas. The proposed operating model therefore seeks to generate conditions that incentivize suppliers to enter new markets and pursue economies of scale. Long-term contracts aim to spur innovation and improve service reliability while reducing cost—in part by carefully structuring more heterogeneous markets than currently exist. Varied or heterogeneous markets that group more and less profitable market segments together allow the more profitable areas, such as cities, to cross-subsidize less profitable rural areas; this is an essential feature of O_2aaU. This grouping increases equity rather than just the number of people accessing oxygen.

Figure 4 illustrates the operating model, which comprises four sequential activities. An analysis is conducted to determine the need for oxygen in the market (left panel). Next, the geographic boundaries and the current composition of the market are identified by the group of stakeholders overseeing model implementation. Then, the suppliers bid on or submit a competitive offer to supply the market (third panel). Finally, suppliers deliver products and services in exchange for payment terms that are agreed upon in advance (right panel).



6.1. Analysis: Evaluation of needs

The current rate of medical oxygen use in LMICs is estimated to be only 10% of the need.[19] Consumption is constrained by inadequate supply, inefficient delivery methods, poor training, limited equipment to dispense oxygen, and insufficient access to credit. A thorough quantitative analysis is needed to determine the:

- **Current level of functional oxygen availability.** The amount of oxygen that is currently used, products used to dispense it, and number of properly trained providers must be determined. The needs assessment should be done early in the process and will likely require data collection, unless sufficiently accurate and granular administrative data sources already exist.
- **Future need.** To estimate future need, ideal consumption must be estimated. This estimate will be based on (1) ongoing data collection; and (2) observations from partners, such as Assist International, which has observed marked increases in oxygen use when access and cost barriers are not in place. This estimate, in conjunction with anticipated growth rates, can then be used to determine the size of the market.

The needs assessment is a critical step for (1) identifying the size and composition of the market and (2) selecting the suppliers. The factors evaluated within the needs assessment must be detailed to be able to understand gaps in oxygen access. Effectively identifying current gaps will enable appropriate market design and pre-screening of suppliers for their ability to work within a given context. Examples of factors that could be included in the needs assessment are shown in Table 9. This assessment would be completed a third-party coalition of NGOs, working with the government.

TABLE 9. **Factors to include in needs assessment.**

	PURPOSE OF INCLUDING DATA TYPE IN NEEDS ASSESSMENT.
Training	Training of health care workers to properly identify and test (by using a pulse oximeter) patients to determine oxygen requirement.
	Training of health care workers to safely and effectively provide oxygen.
	Training of facility staff to maintain equipment.
Infrastructure	Current oxygen production capacity.
	Availability and reliability of electricity (to enable concentrator use).
	Existence and quality of oxygen piping for centralized systems.
	Road quality and access (distance and time to current supply).
Current equipment availability	Availability of equipment to dispense oxygen, including nasal cannulas, tubing, continuous positive airway pressure devices, ventilators.
	Availability of pulse oximeters for diagnosis of hypoxemia and monitoring of patients.
Current oxygen consumption rates	Average consumption of oxygen by health facility.
Regulatory and policy environment	Evaluation to determine if: • Regulatory systems are adequate to ensure high-quality products are delivered. • Regulatory processes are clear and transparent. • Health policies include oxygen and support its safe and effective use.

6.2. Design: Market identification

The first step in the design phase is to segment the markets in the target country or determine if market segmentation is needed. To begin, the potential geographic boundaries and customers in the market must be identified. For example, will the program seek to serve only hospitals, or does the government have adequate financial resources to serve lower-level facilities as well? To generate a lower-risk oxygen market, it may be possible to broaden the market to a more diverse portfolio of industrial gases, containing both industrial and medical customers.[c] Next, a census of existing suppliers must be conducted to estimate the number of high-quality suppliers that may enter into an auction. The amount of competition will dictate the future price.

After gathering these data, two decisions must be made. First, should the market be segmented at all? Second, if segmented, should the segments be heterogeneous or homogeneous? Table 10 summarizes the trade-offs of each option.

The key determination is at what point a single market becomes too large and it is advisable to partition. This partition point will need to be studied using local data collected by the government and an NGO partner with the expertise of an auction theory expert. The assumptions on effects due to change in market size are hypotheses that need to be evaluated. Determining the appropriate market size through a network model may be an effective way to evaluate the ideal market size. There are many benefits to a single market; however, as the size becomes large, risks increase and the number of firms that can deliver in such a large market is reduced. In general, a single market has lower prices and increased risk. A partitioned market will have higher prices and lower risks. During the design phase, auction experts, policymakers, and firms will be essential to stakeholders in negotiating and determining the appropriate decision on partitioning or having a single market.

Two options exist for optimally determining the market segments, each of which has trade-offs:

1. **Heterogeneous markets:** Higher profit margins in dense urban areas will subsidize losses in rural sectors. However, this may lead to poor service provision in the rural regions where distribution is more challenging.
2. **Homogenous markets:** Areas with high profit margins are grouped together, and areas with lower profit margins are grouped together. Firms will demand more compensation for less profitable, challenging markets, but they may be able to specialize and deliver higher quality. More competition to win access to desirable high-profit-margin areas may drive down the total price.

Health and economic development are natural strategic and complementary partners. Medical oxygen is a unique commodity in that it has both medical and industrial applications. In most cases, the purity required for medical oxygen is sufficient for use in industrial applications and therefore the gas can be used in either application. However, some production methods for oxygen for industrial applications use oil, which renders the gas unusable for medical purposes. One key difference is that medical gas requires a more carefully managed supply chain to ensure that contaminants do not enter the cylinder and contaminate the oxygen, which could harm patients. Industrial gas does not require the same quality controls. Considering the economic aspects of both the medical and industrial markets is appropriate because health and economic development are complementarities that amplify one another's respective impact. For O_2aaU, economic development projects that explicitly increase the use of industrial gas[d] may help

TABLE 10. **Market segmentation pros and cons.**

	PROS	CONS
Single market	• Economies of scale • Lowest price in winner-take-all auction • Supply increased to remote areas • Simplifies monitoring	• Supply risk • Incumbent power: lock-in effect • High future switching costs • Few large suppliers exist
Supply partitioning (segmenting)	• Matching of sales volume to firms' capabilities • Risk reduction with multiple suppliers • Reduces lock-in effect • Higher-quality operations • Supply increased to remote areas	• Higher prices • More complex to monitor • More complex to design and negotiate
Status quo	• Most choices for individual facilities	• Higher prices • Complex to monitor • Lower-quality logistics • Remote area coverage poor

c. Medical oxygen is a minor component of an industrial gas company's product portfolio, often representing less than 10% of total oxygen production.[7]

d. Air Liquide has implemented such projects in Morocco, which seek to improve the businesses of small-holder welders.

FIGURE 5. **Required supplier capabilities and characteristics.**

Required capabilities

Medical-grade oxygen production

Manufacturers must be able to support production of medical-grade oxygen

Distribution and delivery

Manufacturers must have effective distribution and delivery networks to guarantee sustainable oxygen use in health facilities

Training, service, and maintenance

In order to ensure sustainable adoption of oxygen as a utility, support service capacity is necessary

Required characteristics

Demonstrated success

Manufacturers will have demonstrated evidence of delivery, growth, and competency to meet scale-up and implementation challenges

Multinational operational capacity

Manufacturers should have global operational capacity and experience to address challenges and ensure adequate supply

LMIC engagement

A track record of engagement, interaction, or pro-social mission for oxygen in LMICs

Abbreviation: LMICs, low- and middle-income countries.

to generate more stable, less costly medical oxygen. Investments to create new industrial customers could make otherwise low-value areas more attractive to oxygen suppliers. In effect, an economic development project strategically paired with or situated within an O_2aaU market could make both programs more successful while generating health externalities for an economic development program.

Additionally, existing medical oxygen contracts must be evaluated to determine the feasibility of replacing existing suppliers. For new suppliers to expand business and drive down prices, areas cannot be locked into contracts with existing industrial suppliers.

6.3. Select: Supplier identification

6.3.1. Pre-screening capabilities and characteristics for suppliers

Primary supplier selection criteria must be met in order to mobilize suppliers that can effectively meet the needs of end users and comprehensively address the manifold challenges that inhibit broad adoption of O_2aaU in LMICs (Figure 5).

Since the target countries for the O_2aaU operating model will have differing levels of oxygen services, the common capabilities necessary for the sustainable and effective delivery of oxygen must be that producers (or devices) generate medical-grade oxygen; distribute and deliver throughout a large geographic region; and provide training, service, and maintenance on all components necessary for the oxygen delivery ecosystem. Ideal characteristics for the members of a consortium of suppliers are (1) a clear history of success in the industry; (2) a global capacity from which they can leverage their operational expertise; and (3) a commitment or demonstrable level of engagement with LMICs.

Once a pool of candidate firms has been established based on capabilities and characteristics, guidelines for down-selection will be necessary. Consortium membership should reflect a diverse coalition of partners, with representation across geographic regions to ensure buy-in from country stakeholders.

Given the diversity of countries the O_2aaU project could serve, the consortium should be able to leverage pre-existing relationships with regional or in-country partners and/or contractors. A localized understanding of challenges faced in oxygen delivery may support the identification of solutions. A representative fraction of consortium partners should have either a footprint in the country; subsidiaries or partner relationships; or at the very least, operations in countries adjacent to a target country. Additional consortium partners should also capture the diversity of oxygen supply solutions available, as an idealized one-size-fits-all approach will fail to meet the total oxygen needs for a given country. The work of pre-screening would be completed by the government procurement agencies, potentially with NGO support.

6.3.2. Supplier selection

Selecting suppliers that are capable of delivering the diverse array of products and services in difficult environments will be a challenging task. The operating model will rely on a customized auction or tender[e] to identify the appropriate supplier(s) and price. Governments with large public health

e. The terms auction is used in this document for simplicity, however, an extensive body of literature beyond the scope of this report addresses the appropriate competitive market institutions for various situations such as double auctions, sealed bid-offers, and competitive sealed tenders. Here, we simply identify some of the key tradeoffs and encourage that a thorough review of the local context, based on policy and regulatory constraints, be conducted and an appropriate competitive bidding process be identified using evidence, expert advice, and government guidance.

systems have begun to rely on private firms with extensive specialized experience in oxygen service provision to deliver oxygen products effectively. Setting the price of delivering the diverse array of products and services needed to supply medical oxygen is a difficult and expensive process for public health systems. The auction could be designed by experts contracted by the facilitating third party or NGO coalition alongside the implementing government to determine the appropriate form.

An auction may be employed to reveal the most competitive price.[20,21] A key factor of a successful auction is ensuring that enough companies bid on the service contract; the number of companies bidding should be at least five. This is the point at which different components of O_2aaU begin to come together. The financial guarantee described in Section 5 must be credibly in place to encourage entry of new firms to participate in the auction. If no additional firms enter and participation is low, the price identified will be too high, and the auction will fail to reveal the equilibrium price.

The precise structure of the auction will depend on factors defined during the customization phase; this includes the number of firms bidding, and the length, value, and services provided under the contract. An auction theory expert will need to be employed during implementation to design a customized auction that maximizes service coverage, supplier performance, and price reductions for reliable oxygen supply.

In general, there are two possible structures for an auction: price only and mixed feature. Price-only auctions are used for public governments as mixed-feature auctions are not easily legally enforceable. In addition, mixed-feature auctions rely on firms to self-report on the quality of the services they offer, adding additional risk. To promote fairness and transparency, reduce risk, and increase likelihood of implementation, we suggest a price-only auction with minimum service requirements that will be closely tracked. The steps for implementing this type of auction are as follows:

- All candidates entering the auction must be pre-screened using criteria identified in Section 6.3. This is a costly process as all potential entrants must be screened.
- Minimum service requirements defined before the auction will define the minimum requirements on which the selected firms must be able to deliver if they have the winning bid.
- Firms bid for the market based on the price they would need to be paid. The lowest bid wins the auction.
- Key risks: this auction may screen out companies offering high-quality services that cost more. Ensuring future competition is essential. Designing the process to limit lock-in effects and regulating the winning company during the contracting period

At the conclusion of the competitive process, contracts will be generated that commit the supplier to supplying agreed-upon products and services at the auctioned price over the specified period of time. To reduce the price of this contract, risk of government default will be removed by guaranteeing their payments through a development bank.

6.4. Implementation

Delivering the promised products and services on time and at pre-agreed prices relies on effective contracting to ensure all stakeholders agree on the terms and monitoring procedures in place to ensure all stakeholders are held accountable for their commitments. Implementation is the responsibility of the contracted firms.

- **Contracting:** Contracts must contain incentives against and penalties for delayed or failed deliveries by suppliers, as well as clear requirements in terms of what is sufficient quality for their products and services. Similarly, contracts need to include explicit commitments from countries about payment terms (e.g., the minimum amount of oxygen they will purchase over the time period and the minimum number of medical devices that will be dispensed), as well as the consequences if they fail to order or pay for the agreed-upon quantity. Contracting could be facilitated by an NGO.
- **Monitoring:** Asymmetric reporting incentives for each party demand that a third party conduct supply audits at regular intervals to evaluate the quality of oxygen provided and services delivered.

Financial guarantees are put in place to reduce risk and bring down the initial contracted price. If the guarantee must be disbursed, financiers will step in to ensure timely payments per contract terms and maintain the flow of oxygen. To prevent complete market failure, countries will be put on remediation plans and subject to financial penalties or withholding of other loans. The complete cascade of possible events needed to implement the model successfully are identified in the theory of change in Appendix A.

7. Measuring the potential impact of Oxygen as a Utility

A key argument for justifying O_2aaU is its potential for health impact. However, given that no similar interventions exist, health impact estimates were not developed. Instead, two modeling approaches were identified, and a single is recommended for future development. Shan Liu, PhD, of the department of Industrial & Systems Engineering at the University of Washington, supported the project team in identifying and examining (1) a model using existing evidence with a number of key assumptions and (2) a model post-pilot implementation that would use new data in a discrete event simulation (DES) model.

To lay the foundation for either modeling approach, the first step was to identify a list of factors from the theory of change that might predict increases in functional oxygen availability. Existing or new data were then identified to measure each factor. While data exist for a short list of factors, a number of gaps in information were identified, including:

- **Estimates of the oxygen gap in each country.** Gaps are calculated by subtracting the current oxygen supply (which was available for only some sub-Saharan African countries or from proxy measures based on number of beds within facilities across the health system) from the oxygen need (which was easier to estimate using the burden of disease).
- **Estimates of the relative increases in intermediate quality measures for the O_2aaU project.** Since this is a new project, there are no data about its effectiveness. One study shed light on the impact of increased oxygen on pneumonia-related mortality,[6] and a few small, country-specific, qualitative research studies describe the impact of increased oxygen availability.[22–24] At a minimum, proxy measures are required for all process indicators to estimate anticipated changes.

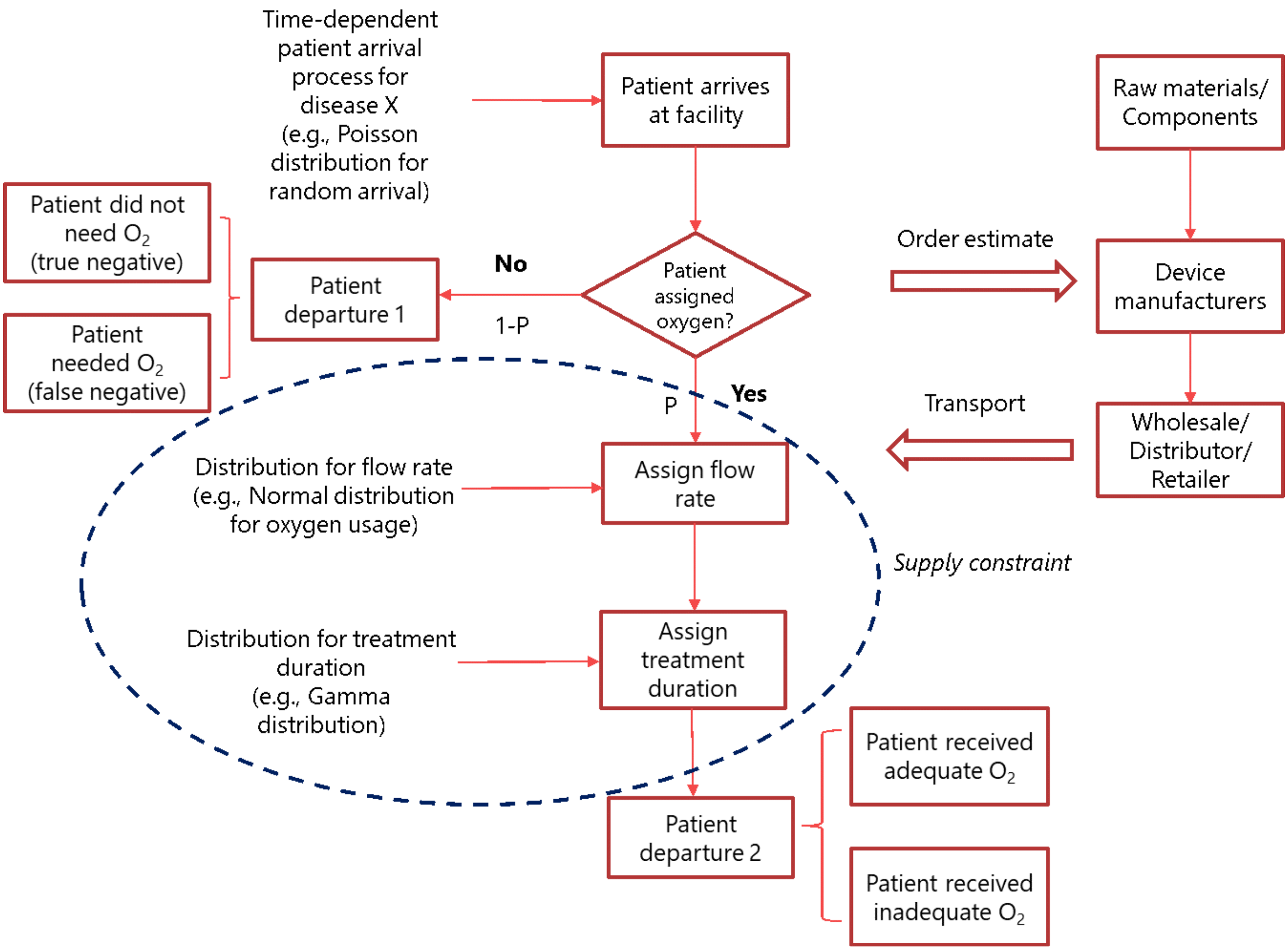
A model using existing data could be developed by first estimating increases in oxygen use if supply is brought to 100%. However, this model would be based on a series of broad assumptions, including that the supply chain is perfectly effective, so it would not be reasonably trustworthy. The alternative model proposed is a DES model, which is commonly used in engineering disciplines as a flexible modeling technique. The key benefits of this approach are:

- It is practical and actionable (it uses real data from a pilot as much as possible) and flexible (certain aspects can be expanded and others left simple, depending on the level of effort desired).
- The model itself and the results are relatively easy to explain regardless of a person's technical ability (e.g., to government ministry officials and funders, among others).
- The model enables the capture of variance or uncertainty in the care process, which can be used to conduct various scenario analyses that are costly to test out in practice.

An example DES, which expands on ideas presented in Bradley et al.,[25] is shown in Figure 6. On the left side of this figure, facility-level demand is characterized for the O_2aaU program. The right side of the figure shows the basic structure of supply and how it feeds into "Supply constraint." Before and after O_2aaU pilot implementation, data may be collected on the facility-level workflow, disease caseload (e.g., pneumonia, surgery, neonatal ward), patient arrival process, hypoxemia prevalence, flow rate, treatment duration, staff training, and oxygen supply capacity. Based on the data, the model could simulate the total demand and the supply gap, and their variabilities for any time-scale of interest, as outputs.

To estimate the probability of patients receiving the oxygen they need ("P" in Figure 6), the model could be expanded to include a cascade analysis that characterizes the sequential steps before a patient receives oxygen. This type of analysis would show how patients drop out as they move through the treatment pathway: from arrival at a health facility, to identification by a health care worker as needing oxygen, to consumption of functional oxygen and completion of appropriate treatment. Simulated limitations in health care worker training or oxygen availability result in patient dropout at each step in the treatment pathway. Alternatively, P could be estimated using facility-level data and linear regression to predict compliance given various facility, patient, and health worker attributes as covariates. Both approaches might provide similar results, but the regression approach might not show patient dropout as clearly.

FIGURE 6. **Discrete event simulation model.**



Abbreviations: O_2, oxygen; P, probability of patients receiving the oxygen they need.

Adapted from Bradley BD, Howie SRC, Chan TCY, Cheng Y-L. Estimating oxygen needs for childhood pneumonia in developing country health systems: a new model for expecting the unexpected. *PLOS ONE*. 2014;9(2):e89872. https://doi.org/10.1371/journal.pone.0089872.

8. Piloting Oxygen as a Utility: Implementation plan

Transitioning O_2aaU from the conceptual framework described in this report to a scalable oxygen access solution will require an initial pilot. Through the pilot, it will be possible to refine the theory of change, determine failures in the proposed theory, and collect data to enable modeling of the program's impact. In this way, the pilot will test if the solution identified above is able to address the problems in the oxygen market. If it does not address them sufficiently, it is designed to enable learning and adaptation for the development of a refined version of O_2aaU.

To develop the pilot, an implementation plan for the O_2aaU model is needed. The pilot implementation plan proposed involves a three-phased approach (Figure 7) to move this model from concept to implemented scale. After the initial step of selecting a country, phase 1 covers customization of the operating model to a select geography. Phase 2 is a small-scale pilot to evaluate and refine the customized operating model in practice. Phase 3 takes the refined implementation model to scale within a select geography or geographies.

8.1. Phase 1: Customization

During the customization phase of the implementation pilot, the operating model will be adapted to fit the local market and existing capacity for oxygen delivery. As such, an in-depth assessment of potential pilot countries is needed to select a setting in which potential feasibility and opportunities for learning are high.

Once a pilot setting is selected, a detailed understanding of the existing oxygen capacity, total oxygen need, regulatory environment, and other key considerations will enable customization of the operating model so that it is locally appropriate. Examples of customization efforts include research to:

- Accurately measure the market segment requiring new or improved functional oxygen access within the pilot region.
- Assess the relative contribution of different factors in the specific geography to the lack of sufficient access to oxygen. For example, to what extent is there a lack of

FIGURE 7. **Three-phase pilot implementation plan.**

Phase 1: Customization

Determine how to customize the operating model in a given country by assessing:

- Existing industrial and non-industrial oxygen capacity
- Population size/oxygen need
- Level of existing health care worker training
- Governmental efficiency

Phase 2: Pilot

Implement operating model at a small scale to evaluate feasibility:

- Conduct a process evaluation of the intervention model
- Assess the health and economic impact of intervantion components
- Determine the cost effectiveness

Phase 3: Scale-up

- Disseminate and prepare for countrywide scale-up with key stakeholders and decision-makers
- Align with other efforts seeking to expand oxygen access

enough oxygen generation capacity versus inadequate or unreliable distribution of oxygen?

- Understand the regulatory and procurement policy landscape for medical oxygen to ascertain which facets of the operating model will be implementable and which will require significant policy change.
- Estimate the required funds for a scaled model relative to the current budget of the health system in the selected country. If shortfalls in domestic financing are expected, the level of external financing required will also need to be estimated.

Further, while the current approach was designed to maximize feasibility of implementation, every market has a unique risk profile for which mitigation strategies will be required; for example, available data may be inaccurate or insufficient, limiting the ability to make decisions and fully understand current and future oxygen needs. To mitigate this risk, we will plan on implementing a flexible contracting arrangement that will allow for changes in response to new data or observations. We will ensure that a contracting expert is hired for the development of these complex contracts. We will also investigate a phased implementation plan that refines the model in a limited number of facilities.

8.1.1. Pilot country selection

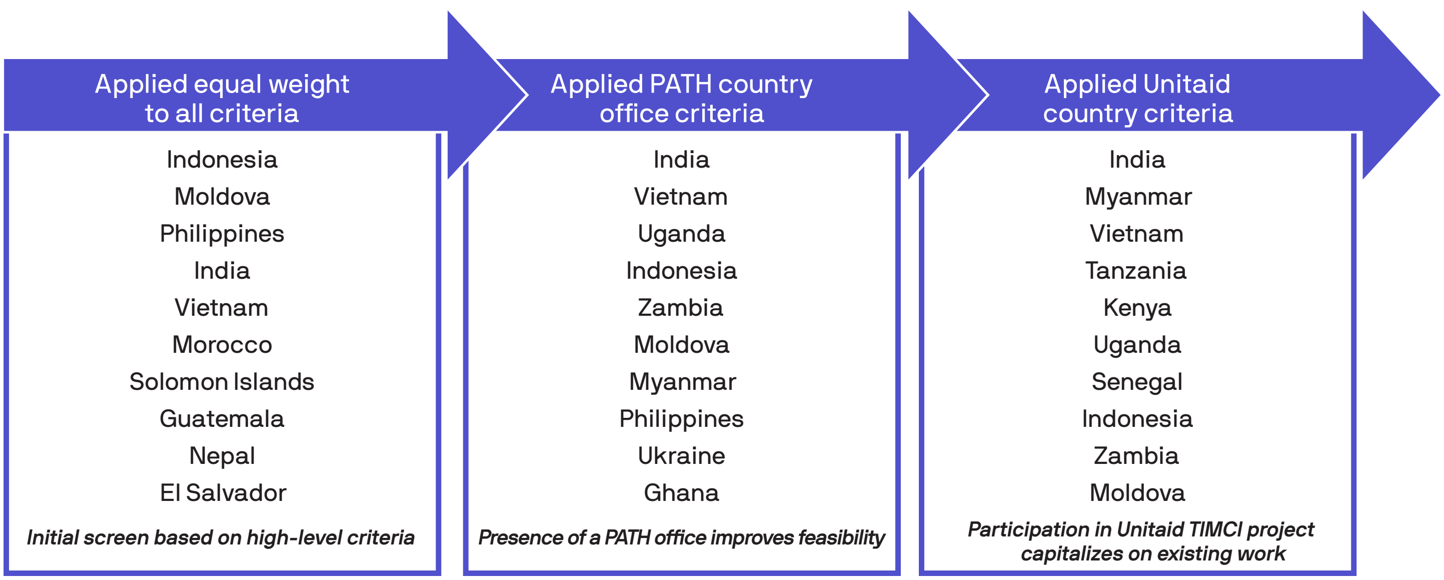
PATH developed profiles for nine countries identified as likely candidates for a successful initial pilot (using the selection criteria outlined in Section 4). We compared quantitative information across countries and added qualitative information gathered from our research and interviews with oxygen industry representatives. The profiles, found in Appendix A, can serve as a reference tool for site selection, and we recommend applying the following filters in making the final choice:

- Presence of a PATH country program: This filter ensures the country has in-country PATH staff who can support the proposed pilot.
- Unitaid investment focus country: There is an opportunity to leverage work that will be done under the Unitaid Tools for Integrated Management of Childhood Illness (TIMCI) project, which seeks to increase access to pulse oximetry. This project will operate in five countries: India, Kenya, Myanmar, Senegal, and Tanzania. PATH added this second filter to capture the potential complementarities between TIMCI and O_2aaU and cost savings leveraging another project's infrastructure. The anticipated complementarities include regular engagement with the same group of key decision-makers, the same counterfactual in data collection, and a single investment in the required fixed costs for data collection (e.g., contracting with partners, conducting trainings, institutional review board submissions).

With the exception of three countries, the countries included in Appendix A correspond to the list of countries identified for a potential pilot as described in Section 8. Moldova was excluded due to its small population (approximately 3 million) and resulting limited market size; (2) the Democratic Republic of the Congo was included as an example of a country with a large population (approximately 81 million) and resulting market size and potential for health impact; and (3) Indonesia was excluded due to the lack of a PATH country program and thus possible difficulty implementing a pilot.

The top ten countries before application of these two criteria (left column), after application of the first criterion (middle column), and after both additional criteria were applied (right column) are shown in Figure 8. While the application of these two criteria significantly alters the initial results, these are important considerations for a pilot because the presence of a PATH country program increases the feasibility of a successful implementation and the link with Unitaid indicates that an oxygen solution will be required. If PATH were involved, the presence of a country program and the Unitaid, TIMCI project apparatus may also be beneficial in facilitating a full post-pilot

FIGURE 8. **Final country selection process.**



Abbreviation: TIMCI, Tools for Integrated Management of Childhood Illness.

FIGURE 9. **Figure 9. Link between our problem statement, barriers, interventions and the proposed pilot.**

PROBLEM	BARRIERS	INTERVENTION	PILOT	IMPACT
PROBLEM STATEMENT: **Lack of reliable access to oxygen**	Demand for oxygen is unclear, disorganized, and small	Aggregate purchasing	Examine how to incentivize industry and maximize cost reductions	**PILOT OUTCOME:** **Empirically demonstrate feasibility and optimal approach for O_2aaU**
	Insufficient incentive to provide equitable access	Establish mechanism to ensure equitable access to supply	Trial auction oxygen through procurement	
	Payment delays create constraints and risks	Establish payment fund backed by guarantee	Trial accountability mechanisms	
	Insufficient country financing available	Infuse donor capital to finance gap	Identify donor dependency and subsidy transition plans	
	Short-term country planning and budgeting	Integrate after sales services	Trial performance-based payment approaches	
	Limited awareness of appropriate oxygen use	Train when and how to provide oxygen	Test different training approaches	

Abbreviation: O_2aaU, Oxygen as a Utility.

implementation; however, if PATH were not a key implementing partner, an initial assessment would be more useful for predicting the countries most likely to scale effectively.

We focus on India in this report, specifically the state of Uttar Pradesh, because the feasibility of a successful pilot is high in this area. This is based on three factors: (1) the government of Uttar Pradesh is actively seeking to increase access to oxygen in their public health system; (2) PATH has an office in Uttar Pradesh, with strong ties to the government; and (3) the TIMCI project will be introducing pulse oximetry at the primary care level is being introduced in early 2020.

8.1.2. Estimating pilot financing

To estimate the cost to conduct a pilot we used the TCO tool to estimate the costs for a limited set of facilities. The example being a set of facilities in a district in Uttar Pradesh, India. On average, a district in UP has 48 PHC's, 11 CHC's and two District Hospitals. Using these as a basis for our estimate, we calculate that the cost of oxygen for a 5 year period would be $2.1 million. For 10 years, the cost would be $3.4 million. Capital costs would be $824k for 5 years and $905K for 10 years. The difference is due to the need to replace the oxygen concentrators after the 5 years. Operating expenditures would be $1.3 million and $2.5 for five and ten years respectively.

For comparison, we ran the model using costs in Tanzania for the same number and type of facilities. Under this scenario total costs for five years were $4 million and for 10 years they were $7.4 million. Capital expenditures are estimated to be $763k for five years and $845k for 10. The difference is from the oxygen concentrator replacement costs. The large difference in oxygen cylinder costs between Tanzania and India are evident in the operating expenditures, which are estimated to be $3.3 million and $6.5 million for five and 10 years respectively. We assume that the capital costs for a pilot would be borne by the supplier who would recoup those costs over time via the negotiated supply price.

To be sure, the pilot could be made smaller or larger than the examples above. These estimates are shown to illustrate the approximate costs in relation to a fixed and relatively small number of facilities.

8.2. Phase 2: Pilot

With country-specific nuances in mind and customization identified, a pilot is needed to test the assumptions and validate the theory of change for O_2aaU. The pilot should be designed to estimate the potential health and economic impact of O_2aaU. Based on the pilot country's unique circumstances, certain elements of the operating model may be more or less feasible or impactful in providing O_2aaU. As noted in Figure 9, there are a number of operating model elements to vary and pilot. Designing a pilot to examine all possible combinations is infeasible, as this would be prohibitively expensive and require an overly complex study design. Instead, the proposed approach is to select a country for piloting and determine which factors are most relevant for testing to maximize efficacy in that setting.

For example, evidence suggests that demand for oxygen is often unclear and/or fragmented across many purchasers[26] therefore, a core component of the proposed approach is to aggregate purchasing. However, country procurement regulations may limit the options for volume aggregation. In some countries, aggregation may be limited to a single scenario; whereas in other settings, piloting two or three different thresholds of volume aggregation in different regions or states could expand existing understanding of what constitutes a sufficient business incentive for industry to engage. To illustrate contextual variance further, case studies are outlined below for India and Tanzania.

The pilot will require a third-party evaluation to provide understanding of which facets of the proposed approach contribute most effectively to increased reliable access to oxygen. Collectively, the results will enable us to refine the theory of change and provide evidence regarding whether the program should be scaled. In preparation for the proposed pilot, each component of the operating model is broken down by market barriers, intervention

CASE STUDY: INDIA

Current circumstances: There are more than 30 licensed suppliers of medical oxygen in Uttar Pradesh; however, supply is unreliable and suboptimally organized. These suppliers are contracted by individual health facilities and/or by district hospitals, which manage supply on behalf of a set of facilities. Transaction costs across the state are high; payment delays are frequent; accountability to ensure reliable supply is limited; and fragmented demand limits the incentive to perform. Further, various areas where distribution is difficult are often neglected.

Proposed pilot approach: Given that health care decision-making is devolved to the states in India, the proposed customization of O_2aaU would examine variations in managing competitive supply auctions, with procurement led by the state procurement corporation in one state and by a third-party firm in another. In either scenario, applying O_2aaU in this way would reduce the number of service contracts to a manageable number of firms. The state or third-party firm would then be able to more effectively negotiate for equitable and reliable supply to urban and rural regions, as well as ensure efficient performance and payment.

CASE STUDY: TANZANIA

Current circumstances: In Tanzania, the majority of oxygen supply is provided by a single dominant firm. In addition, the market is underdeveloped and the potential for growth is modest; the business case is unclear and may not be large enough to attract many new entrants. While transaction costs are primarily limited to a single firm, the security of medical oxygen supply would be at risk if something were to happen to this firm. Further, it is unclear if the threat of new market entrants is sufficient to prevent the incumbent supplier from asserting monopoly-like power.

Proposed pilot approach: Given that the Medical Stores Department plays a central role in public-sector health commodity supply, the proposed customization of O_2aaU for Tanzania would be to aggregate and apportion volumes at the national level. As in the case of India, the proposed pilot would auction volumes to multiple suppliers, thereby diversifying supply risks with a consortium of reliable firms. In doing so, the pilot could introduce further complexity in contracting, payment, and accountability. However, it would expand access to previously unserved or underserved regions in the country.

mechanism, and factors to pilot in the framework in Figure 12 above. As outlined in Section 7, a post-pilot DES model is recommended to demonstrate impact size. Rather than rely on very limited data and a number of assumptions to model potential impact before the pilot, a post-pilot DES model would use new data to simulate the intervention at scale in a given setting compared to the status quo in order to predict the change in oxygen access and economic opportunity. An investment in a pilot will substantially increase the validity and reliability of impact estimates.

8.3. Phase 3: Scale-up

Modifications to the operating model may be made based on the pilot evaluation. If successful, evidence, lessons, and political capital from the pilot will be extracted to support broader scale. If results do not support scale-up, it may be appropriate to return to the customization phase, pilot again, and re-evaluate. Once modifications are in place, the oxygen model should be aligned with other efforts to expand access to oxygen and may be introduced at scale. Contingencies for scale include, but are not limited to:

- Expanded understanding of gaps in functional access to oxygen across additional geographies.
- Feasibility of further customization to accommodate the unique requirements of additional regions/geographies.
- Renewed or broader political commitment from key decision-makers in-country.
- Continued, and potentially increased, investments of domestic resources and/or external financing.
- Supplier capacity and capability to scale services.

The World Bank Group's Scaling Solar initiative is a practical example of how an infrastructure development program can be structured to produce scale, especially one requiring large-scale international financing and coordination. The O_2aaU program will mimic the Scaling Solar initiative in guaranteeing that countries have all the tools needed to contract for oxygen as a utility.

Scalability for O_2aaU will also rely on successfully proving the effectiveness of the approach through robust measurement. It will be essential to demonstrate whether O_2aaU can have a direct impact on health outcomes through improved access to oxygen. Further, future work to estimate economic growth resulting from the introduction of this concept will make it much easier to make a case for scale and adoption across settings.

Finally, sustainability will be best ensured if all stakeholders are well connected. Government decision-makers, local implementing partners, and (where applicable) PATH in-country staff should be intimately involved in all key activities and decisions of the program. PATH will leverage our long-standing relationships with suppliers, consulting them when applicable to design feasible program strategies, and develop relationships with additional players in the international finance community.

SCALING SOLAR PROGRAM

The goal of the Scaling Solar program is to take advantage of sub-Saharan Africa's solar resources to generate clean, renewable energy for the continent. At the outset, the World Bank wanted to create a way for countries to scale solar via a comprehensive service package. This package was designed to include advisory services, contracts, pre-approved financing, guarantees, and political risk insurance from the World Bank, International Finance Corporation, and Multilateral Investment Guarantee Agency. This one-stop-shop approach, as well as a competitive tender process (which attracted 48 developers), resulted in a successful outcome in Zambia and led to more Scaling Solar programs. These programs are currently being implemented in several countries in sub-Saharan Africa, including Ethiopia, Madagascar, and Senegal, and are being considered in other regions.

9. Additional activities and areas for investigation

In the course of developing this concept, we identified two additional areas for further exploration. These areas were not originally considered in the proposed O_2aaU concept; however, they have potential to improve the feasibility and/or impact of the proposed approach.

- **Potential for economic development:** Explicitly seeking to promote economic development and increased health care access as part of the O_2aaU model would be strategically beneficial as it could attract funding and political support from stakeholders invested in both economic development and health impact. It is likely that investment in infrastructure (e.g., plants, facility improvements); required services to provide the oxygen (e.g., truck drivers, maintenance personnel); and increased productivity from improved health outcomes for patients receiving oxygen therapy when needed would have benefit to the economy. However, estimating changes in economic development is complex and would require additional consideration, data collection, and modeling.

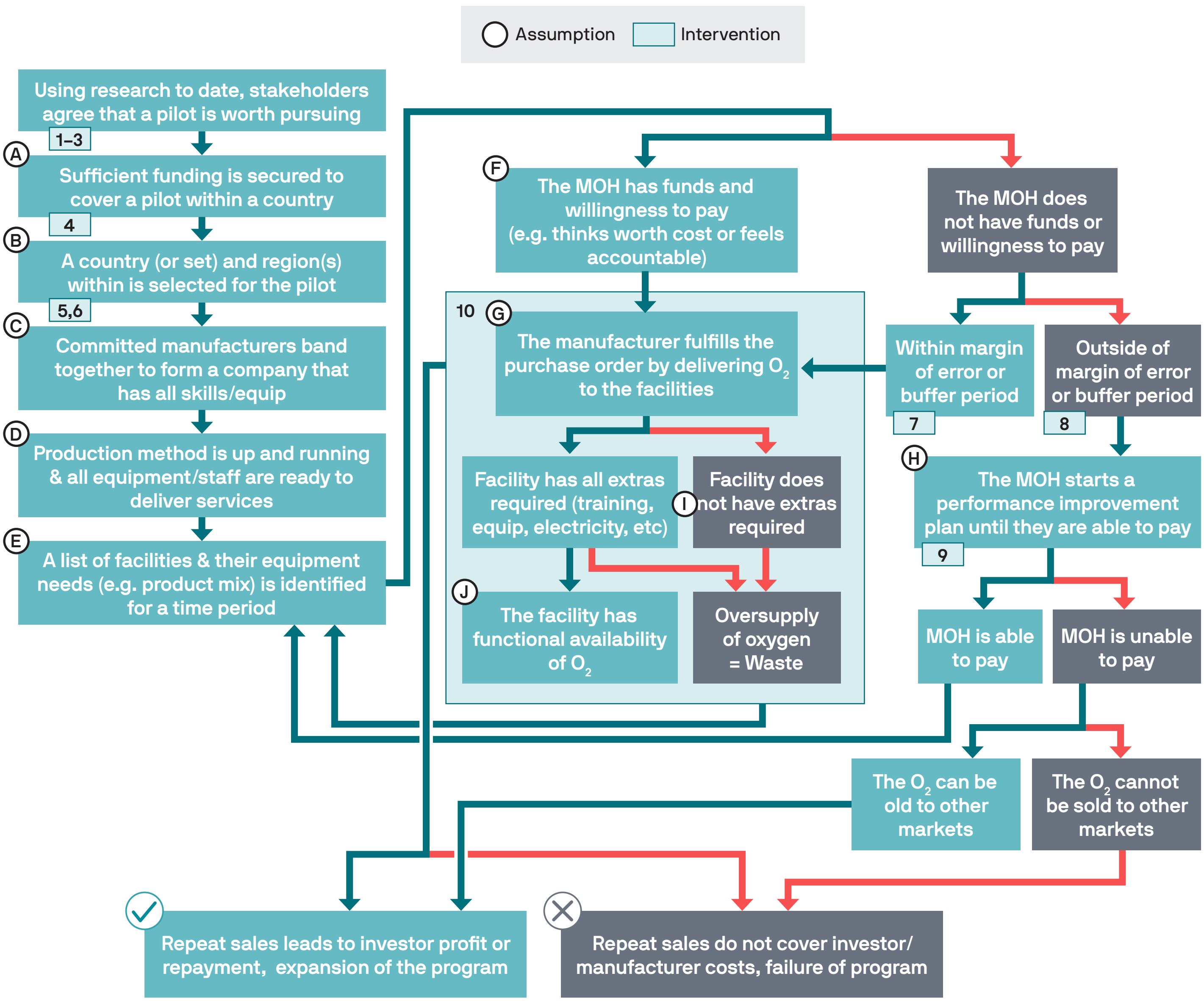
  Economic returns on health have been estimated and are generally positive.[27] The cleanest identification is found in Thomas et al. (2004). However, this and other estimates are from the nutrition field and may be possible only due to the large number of people these interventions reached. It may be valuable to estimate the economic returns on a large-scale oxygen program, given the vast number of disease areas with which oxygen interacts.

- **Potential for building medical oxygen and industrial oxygen market segments:** This exploratory work revealed that the medical oxygen market is often only a small portion of the overall oxygen market in a given country. Industrial oxygen uses need to be further researched to understand the potential value in combining medical and industrial oxygen demand to ensure a reliable supply and obtain lower prices. Industrial applications could include the manufacturing sector, mining sector, and small- or medium-sized enterprises for welding or repair services.

Beyond opportunities to improve the operating model, further work is needed to estimate the precise costs to implement a pilot in a given geography. These costs would include not only the costs to implement the O_2aaU concept, but also the costs to collect and analyze the data to assess the impact. This often requires building the research infrastructure and capacity in the implementation area, unless an existing project is underway that can be leveraged. Next steps would be to select a potential site for a pilot, customize the intervention, estimate the costs, and finance this specific effort.

10. Appendices

10.1. Appendix A. Theory of Change



Abbreviations: equip, equipment; MOH, ministry of health; O_2, oxygen.

10.1.1. Interventions: PATH and investors

1. The team narrows the country list down to a few potential countries, and estimates the range of price points and expected supply required given the expected demand.
2. PATH does field work in the countries to validate the key assumptions in the calculations and to better understand the gap (e.g., product mix, available equipment, etc.). The calculations are updated to reflect improved information.
3. Using estimates, the team collects a pool of funds from a group of investors that would cover the most expensive country—in the event that the country is unable to pay.
4. The team pitches the idea to the country (e.g., if a manufacturer produces the units, then the ministry of health (MOH) would commit to purchasing X units at X price for X years) and outlines the requirements of the contract. The requirements include aspects such as: the MOH will enforce regulations, provide a firm commitment, agree to the penalty/payment structure, add oxygen to the essential medicines list, and so on.
    - Variations: (1) The team pitches a range of price and quantity targets (e.g., X units at Y price, or X + 1 units at Y + .75); (2) the MOH puts "skin in the game" and covers some of the up-front costs; (3) a fixed monthly fee covers a portion of the costs—rather than having all costs be covered in the cost of the oxygen "unit."
    - Key unknowns: (1) Is this a credit problem, an information problem, or both? (2) At what point will the MOH revert resources from needier causes—creating unintended consequences? (3) Depending on the role the MOH plays in maintenance/training/procurement, what existing systems/processes are in place that could be altered with the least disruption?
5. The team scans the landscape for possible manufacturers that fulfill fixed criteria based on country needs (e.g., the product mix, reputable, sufficient capacity) and finds a prime that is a good fit. Their role includes that they (1) find subcontractors that collectively fulfill all manufacturing needs; (2) produce everything for end-to-end solution (from tubes to training); (3) deliver the equipment/services (training, supply chain, trucks, etc.); and (4) then recover those costs from the purchase of the oxygen units.
6. Legally binding "bullet proof" contracts are prepared between:
    - The MOH and the investors, stating that the MOH will purchase X units at X cost over X years.

      Key unknown: What can be learned from Gavi, the Vaccine Alliance's incentive/accountability structure to help ensure countries pay?
    - The investors and the manufacturers, stating that the investors will back the purchase if the MOH does not pay.
    - The MOH and the manufacturers, outlining their working relationship.
7. The investors act as a credit company and pay on the MOH's behalf.
8. The investors find buyers at the given price point.
    - Key unknown: Like banks owning homes, investors do not want to own oxygen. How can stakeholders ensure that there are other markets (e.g., from private sector, another country) to cover this scenario? And who actually does the selling—local agents?
9. The investors provide capacity-building or technical support to help get the MOH back on track.
10. The investors audit for unintended consequences:
    - Manufacturers: Are they skimping on quality across the board?
    - Government: Are they upholding contractual obligations? Forcing oversupply?

      Key unknown: What if the model estimates were drastically wrong and the MOH is now committed to purchasing way too many units or units at way too high a price point? Who is the judge?

10.1.2. Assumptions: Investors, government, manufacturers

- The **investors** believe that government will either (1) pay the manufacturers on time or (2) pay back the investors in a timely manner. Some might also expect to earn a reasonable profit.
- The **government** is compelled, knows they will have the money to commit (or thinks they will not be held accountable for paying), and commits.
- The **manufacturers** trust that the other manufacturers will be good partners, believe that the per-unit costs will cover the fixed startup/equipment costs and routine services, believe that they will get paid on time by either the MOH or by the investors, and have a large source of funds up-front to pay for all of the startup costs.
- The **manufacturer** is able to form an effective governance structure for partnership, procure all necessary supplies, pay taxes/fees, hire and train staff, build or expand existing production method, and uphold all prior commitments.
- The **government** knows what the forecasted gap is at each facility (e.g., assessment or through facility requests) AND they have a procurement system that continually tracks the occurrence/fulfillment of gaps (stockouts).
    - Key unknowns: (1) Is the manufacturer involved at this step? If they are, they will have a perverse incentive to order more units/services than they need. (2) If the MOH's procurement system functions poorly, whose role is it to improve it?
- The **government** is scared about what will happen if they do not pay.
- The **manufacturer** replenishes all products needed (oxygen, trucks, staff, equipment) smoothly to be able to meet demand, AND they have the desire/ability to complete the order.
- There are other markets to sell to (e.g., demand from private health sector, other industries, or other countries), AND the oxygen has not expired, AND it is possible to

transport the oxygen to these markets, AND those buyers have ability/desire to pay at the right price.

- The manufacturer oversees quality control, including continual management of the equipment and ongoing training.
  - Variation: The government takes on a portion of the end-to-end solution.
  - Key unknown: Where does the line for the responsibility of the oxygen system lie between the government and the manufacturer? Options include:
    - The manufacturers deliver the oxygen alone. If so, there is a need to ensure electromedical engineers are trained for maintenance, clinicians are trained on use, and that there is a functioning procurement system for medical supplies.
    - The manufacturers ensure all equipment/training/consumables are ready to use continually. If so, who bears the cost when an MOH-owned piece of equipment fails? How can it be ensured that manufacturers do not skimp on quality and that they can estimate the costs of maintenance?
- Medical devices are in place, have required consumables and other equipment, and are used by trained health care workers (e.g. "functional availability"); there is support from leadership and patients behave as expected. See Table A1 for more details.

10.1.2.1. Assumptions that underpin "functional availability"

TABLE A1. **Assumptions that underpin "functional availability."**

CATEGORY	ASSUMPTIONS
Medical devices	**Medical devices are in place (access/location)** • Oxygen equipment is installed in appropriate wards/locations within the hospital, and there is a way to ensure equipment stays in those areas. • Ward environment and culture facilitate good oxygen therapy practices (adequate space, patient-centered care, good interdisciplinary relationships). **Medical devices are operating properly (maintenance)** • Appropriate wards are included in hospital generator grid, if needed. • Functional maintenance system is in place with the ability to meet the additional needs of oxygen equipment.
Overall system	• There is stakeholder buy-in at the facility level (hospital manager and clinicians recognize the need). • There is appropriate monitoring of oxygen use both for procurement and evaluating the effectiveness of the program.
Patient behavior	• Patients seek treatment at hospital/primary care facility. • The costs of oxygen therapy to patients are minimized.

10.1.2.2. Indicators for pilot model[f]

TABLE A2. **Indicators for pilot model.**

WHAT IS THE INDEPENDENT VARIABLE BEFORE AND AFTER?	INDICATOR	COLLECTED IN UNITAID?
Capacity (human & equipment) & supply	Equipment: Average maximum liters per month per facility	
	Equipment: Summary of product mix that is "functional" (with clear definition) per facility	
	Equipment: Summary of consumables that are "functional" (with clear definition) per facility	
	Equipment: Average hours per month of electricity per facility	
	Equipment: Average # of maintenance visits per facility	
	Oxygen: Average liters per month ordered per facility	
	Oxygen: Average liters per month delivered per facility	
	Human capital: Scores from knowledge tests of health workers, per facility	
	Human capital: # of nurses, providers, administrative staff per facility	
	Human capital: # of average yearly oversight checks to ensure regulations are being followed and quality upheld	
	Functional availability: # and % of facilities assessed to have "functional availability" of oxygen at the time of oversight visit (or score from an assessment as an alternative)	
	Functional availability: Score from functional availability assessment (based on this section) per facility	
Costs	MOH: Average monthly cost per liter of oxygen paid by the government, broken down by equipment/oxygen/maintenance/training/transportation/oversight (amortized over the entire time period, as needed)	
	Manufacturers: Average monthly cost per liter of oxygen paid by all manufacturers for that facility broken down by equipment/O_2/maintenance/training/transportation/oversight (amortized over the entire time period, as needed)	
Demand	# children who present with cough or difficulty in breathing at the facility	X
	Average # of monthly patients who come to the facility, disaggregated by symptom and disease	
	# and % of children who receive POX measurement as per guidelines	X
	# and proportion of children with correct classification of severe disease using POX	X
Use	% and # of children that receive oxygen	
	Average length of time these children are on oxygen treatment	
	Proportion of children that develop severe complications after assessment at facility	X
	# and % of target facilities in the project that meet full criteria for effective POX implementation (trained HCW and functional POX)	X
	% of observed HCWs who adhere to country-appropriate use of POX as per intervention guidelines (appropriate guidelines TBD)	X
Unintended consequences	Difference between oxygen delivered and oxygen used to gauge oversupply	

Abbreviations: HCW, health care worker; POX, pulse oximeter; TBD, to be determined.

[f] We will need to consider context-specific factors that can influence the indicators for demand, including seasonality, epidemics, etc.

10.1.3. Discrete event simulation model limitations

Limitations of the discrete event simulation model and its results include:

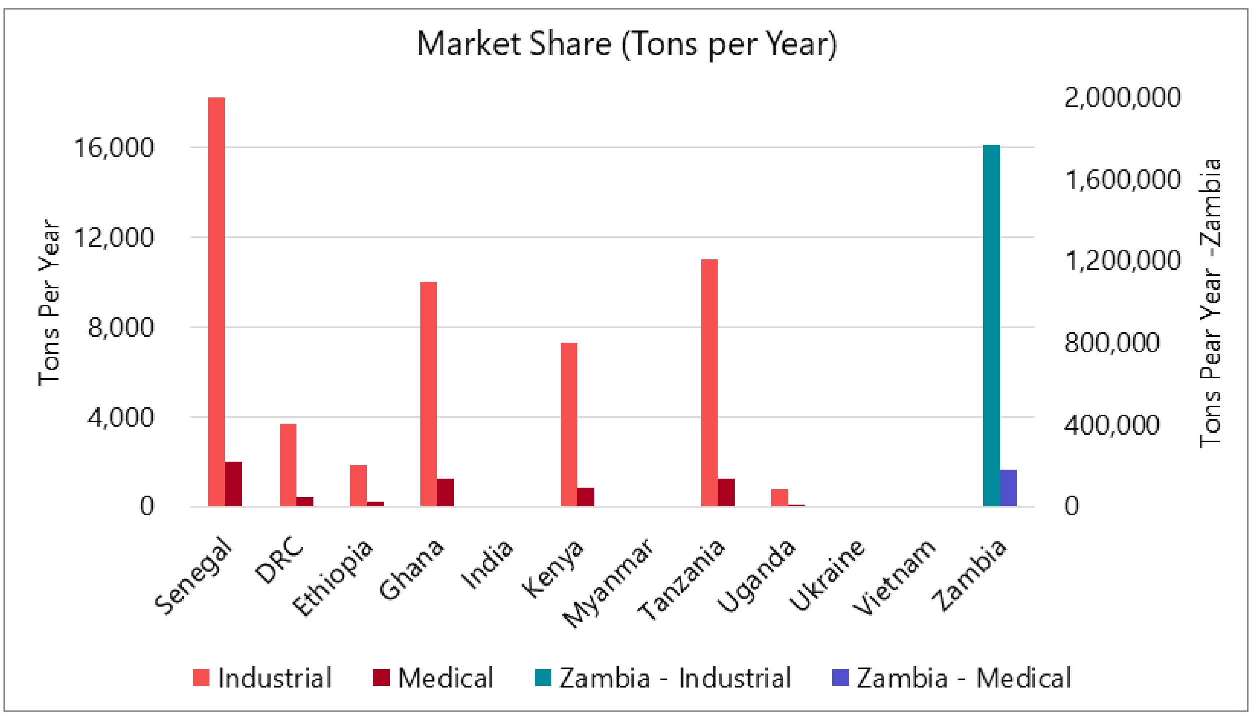
- Detailed data collection requirements. As with any model, the estimates will only be as useful as the underlying data are accurate. We can right-size the data collection given available resources, but collecting the indicators in Table A18 for a series of facilities will increase confidence in the results.
- Assumptions regarding the distribution of patient arrival and oxygen usage. Figure 5 proposes distributions common within health care. That said, if enough data are collected in the pilot, the pilot data themselves could be used as opposed to a standard distribution.
- Generalizability. Aggregating facility-level models from a sample that is not representative of the regional/national level or beyond will rely on a series of assumptions, and there are likely to be concerning confounders. We can mitigate this risk by purposefully selecting pilot facilities and pursuing a more rigorous study in the future, should the results of this work prove promising.

Alternative approaches could include mathematical programming models, supply chain optimization, econometric models, game theory, and other statistical-based methods. However, we recommend discrete event simulation because it is practical as opposed to theoretical, and could be as simple/complex as dictated by available resources.

10.2. Appendix B: Country profiles

The purpose of the following section is to summarize information about the health status and oxygen supply/demand in low- and middle-income countries (LMICs) that have a PATH country program and are most able to pilot O_2aaU. The section below includes a table that summarizes quantitative data that can be compared across countries followed by qualitative information per country that was gathered from three sources: online, using the methodology outlined in the Appendix; PATH documents; and an expert from the oxygen industry.

10.2.1. Figure A1. Market share of oxygen per country.



Abbreviation: DRC, Democratic Republic of the Congo.

10.2.2. Summary of quantitative indicators per country

TABLE A3. **Summary of quantitative indicators per country.**

TYPE	INDICATOR & SOURCE	SENEGAL	DRC	ETHIOPIA	GHANA	INDIA	KENYA	MYANMAR	TANZANIA	UGANDA	UKRAINE	VIETNAM	ZAMBIA
ARI burden	WHO/DHS (% of children with ARI for whom advice or treatment was sought)	48	42	31	56	73	66	58	55	80	92	81	70
ARI mortality	WHO (% of U5 deaths due to ARI)	15	16	16	12	15	14	18	15	16	8	12	14
Age distribution	World Bank (% of population < 14 years old)	42.88	46.28	40.55	38.52	27.78	40.47	26.83	44.91	47.71	15.49	23.06	44.78
Population	World Bank (% of world population)	0.42	2.15	2.8	0.77	36.15	1.32	1.44	1.52	1.13	1.23	2.58	0.45
Leading causes of death	IHME GBD (Top 3 2017)	1. CVD	1. Respiratory Infections/ TB	1. Respiratory Infections/ TB	1. CVD	1. CVD	1. HIV/AIDS & STIs	1. CVD	1. Respiratory Infections/ TB	1. HIV/AIDS & STIs	1. CVD	1. CVD	1. HIV/AIDS & STIs
		2. Respiratory Infections/ TB	2. NTDs/ Malaria	2. Maternal and neonatal disorders	2. Respiratory Infections/ TB	2. Chronic Respiratory	2. Respiratory Infections/ TB	2. Neoplasms	2. CVD	2. Respiratory Infections/ TB	2. Neoplasms	2. Neoplasms	2. Respiratory Infections/ TB
		3. Maternal and neonatal disorders	3. CVD	3. Enteric Infections	3. NTDs/ Malaria	3. Respiratory Infections/ TB	3. CVD	3. Chronic Respiratory	3. Maternal and neonatal disorders	3. Maternal and neonatal disorders	3. Neurological Disorders	3. Diabetes & CKD	3. CVD
Oxygen equity and gaps	SPA (% of govt hospitals with any oxygen)	74%	16%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	SARA (Avg: % of facilities with oxygen)	N/A	12%	N/A	N/A	N/A	23%	N/A	72%	N/A	N/A	N/A	6%
	ABCE (Avg: % of hospitals with oxygen)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	57%
EODB score	World Bank	54	37	49	59	67	70	45	54	57	68	68	65
Health expenditures	World Bank	53	21	28	68	63	66	62	35	38	141	123	57
Unitaid country	PATH	Yes				Yes	Yes	Yes	Yes				

Abbreviations: ABCE, ; Avg, average; EODB, ease of doing business; ARI, acute respiratory infection; CKD, chronic kidney disease; CVD, cardio vascular disease ; DHS, Demographic and Health Surveys; DRC, Democratic Republic of the Congo; GBD, Global Burden of Disease; govt, government; IHME, Institute for Health Metrics and Evaluation; N/A, not applicable; NTD, neglected tropical disease ; SARA, Service Availability and Readiness Assessment; SPA, Service Provision Assessment; STI, sexually transmitted infection; TB, tuberculosis; U5, under 5 years old; WHO, World Health Organization.

10.2.3. Country-specific summaries

Below is a summary of what was found. Each section contains the following subsections:

- Health need—Summarizes the acute respiratory infection (ARI) burden, ARI mortality, leading causes of death, and demographics such as the age distribution and population of the country. The health burden for diseases that require oxygen, other than ARI, are not included in this report due to the variety of syndromes. The primary data sources are the same as those from the indicators in Table A3 [the World Health Organization (WHO)/ Demographic and Health Surveys, UNICEF, the Institute for Health Metrics and Evaluation, and the World Bank].
- Oxygen availability—Summarizes estimates for the proportion of clinics/hospitals with any functioning oxygen availability or related information that helps portray current status. Arguably, the most reliable estimates are from the two surveys below, though these are only available from five countries in the selected list:
    - Service Provision Assessment (SPA)—The SPA survey is performed by the Demographic and Health Surveys Program and funded by the US Agency for International Development. The three questions about oxygen are part of a lengthy survey that covers aspects such as inventory of basic supplies in various facility types and wards. Data are collected from 400 to 700 facilities, which are selected from a comprehensive list of health facilities. Sampled facilities are chosen to adequately represent different facility types and managing authorities.
    - Service Availability and Readiness Assessment (SARA)—The SARA surveys are conducted by the country's ministry of health. The methodology was developed by WHO and US Agency for International Development to measure and track progress in health systems strengthening. Similar to the SPA survey, the lengthy SARA survey assesses the availability and functionality of various items in a health facility. Facilities are sampled to represent different wards and managing authorities.
- Oxygen supply—Summarizes information about where a country's oxygen is manufactured (in country versus imported), the oxygen market (industry versus health system), and how much oxygen is produced by each facility. The primary source of this information is an oxygen expert who serves as a consultant to PATH.
- Policy attributes—Summarizes what could be found about the health policy landscape. The primary data sources are our online search and summary documents from PATH.

In terms of methodology, the steps we followed below were not exhaustive; rather, they were intended to constitute an 80/20 approach, rapidly assessing a small amount of the available information to make larger predictions. For each country, we used the following search terms:

"oxygen concentrators" AND country

"oxygen cylinders" AND country

"liquid oxygen" AND country

"oxygen delivery" AND country

For each set of results, we reviewed each result on the first three pages and noted any relevant/interesting information. Next, we searched for the term "oxygen" on the ministry of health website for each country. Finally, we conducted a PubMed search for each country (country AND oxygen).

Senegal

Health need

In Senegal, the top three causes of death were cardiovascular disease, respiratory infections/tuberculosis (TB), and maternal and neonatal disorders.[28] Regarding the ARI burden, results from nationally representative surveys showed that an estimated 48% of children with ARI sought treatment in a health facility and 15% of deaths among all children were due to ARI.[29] Two studies in Senegal documented that around 30% of children with ARI were hypoxemic.[30,31] Senegal accounted for an estimated 0.4% of the LMIC population; 43% of the country's population was aged < 14 years old.[32,33]

Oxygen availability

The results from an SPA conducted in Senegal in 2017 are shown below.[34]

Additional information about the oxygen availability in this country: An oxygen concentrator was installed at Ndioum Hospital, a rural hospital in Senegal, to assess the feasibility and cost of using concentrators to supply oxygen.[35] The Senegal study was small, but an increase in oxygen availability was documented. However, the intervention was limited by challenges with training nurses on oxygen treatment, a lack of confidence of the families using oxygen therapy, and ineffective maintenance and repair due to poor technical training. The study also noted power outages, which limited the use of the concentrator.

Oxygen supply

The following table summarizes what is known at this time.

In addition, in 2017, Air Liquide opened an oxygen house, or end-to-end oxygen service, which provides equipment, training, maintenance, and technology assistance for treatment and medical record documentation.[36]

Policy attributes

Oxygen is indicated for anesthesia and other procedures in the Senegal Essential Medicines List.

TABLE A4. **Results from a Service Provision Assessment conducted in Senegal, 2017.**

COUNTRY	TYPE OF FACILITY	OWNERSHIP	TOTAL FACILITIES (N)	OXYGEN AVAILABILITY	PULSE OXIMETERS	TYPE OF EQUIPMENT		
				FACILITIES WITH ANY OXYGEN (%)	FACILITIES WITH PULSE OXIMETER (%)	FACILITIES WITH OXYGEN CYLINDER (%)	FACILITIES WITH OXYGEN CONCENTRATOR (%)	FACILITIES WITH OXYGEN DISTRIBUTION SYSTEM (%)
Senegal (2017)	Hospitals	Government/public	19	74%	74%	74%	68%	68%
		NGO/Nonprofit	-	-	-	-	-	-
		Private for profit	18	67%	56%	67%	67%	50%
		Mission/faith-based	-	-	-	-	-	-
	Health clinics	Government/public	687	3%	2%	2%	1%	1%
		NGO/Nonprofit	32	9%	13%	9%	3%	0%
		Private for profit	38	8%	8%	5%	5%	5%
		Mission/faith-based	-	-	-	-	-	-
	All facilities	Government/public	706	5%	4%	4%	3%	2%
		NGO/Nonprofit	50	30%	8%	6%	2%	0%
		Private for profit	38	8%	34%	37%	37%	29%
		Mission/faith-based	-	-	-	-	-	-

Abbreviations: NGO, nongovernmental organization.

TABLE A5. **Oxygen supply in Senegal.**

IMPORTED OXYGEN	No data available.
DOMESTIC BULK OXYGEN PRODUCTION	Air Liquide (Dakar and Richard Toll) (1929): 5 tpd
PSA PLANTS	Randgold (Massawa): 2 x 20 tpd PSA plants
MARKET SHARE	**Industrial:** 90% There is an estimated 18,250 tpy. The primary consumers include agricultural and fish processing, phosphate mining, fertilizer production, petroleum refining, zircon and gold mining, construction materials, and ship construction and repair. **Medical:** 10%, 2,000 tpy

Abbreviations: PSA, pressure swing adsorption; tpd, tons per day; tpy; tons per year.

Democratic Republic of the Congo

Health need

In the Democratic Republic of the Congo (DRC), the top three causes of death were respiratory infections/TB, neglected tropical diseases/malaria, and cardiovascular disease.[28] Regarding the ARI burden, results from nationally representative surveys showed that an estimated 42% of children with ARI sought treatment in a health facility and 15% of deaths among all children were due to ARI.[29] The DRC accounted for about 2% of the LMIC population; 46% of the country's population was aged < 14 years old.[32,33]

Oxygen availability

Results from an SPA conducted in 2017 are shown below.[34]

Additional information about the oxygen availability in this country:

- A SARA survey conducted in 2014 showed 12% of facilities with cardiovascular wards and 12% of facilities with chronic respiratory wards had any oxygen available.[37] Details on the type, quantity, and quality of the oxygen in those facilities were not noted.
- During an assessment of the availability of emergency and essential surgical care in a sample of 12 district hospitals, 6 hospitals did not have an oxygen supply and 8 hospital lacked consistent access to mask and tubing to connect to an oxygen source.[38]

TABLE A6. **Results from a Service Provision Assessment conducted in Democratic Republic of the Congo, 2017.**

COUNTRY	TYPE OF FACILITY	OWNERSHIP	TOTAL FACILITIES (N)	OXYGEN AVAILABILITY	PULSE OXIMETERS	TYPE OF EQUIPMENT		
				FACILITIES WITH ANY OXYGEN (%)	FACILITIES WITH PULSE OXIMETER (%)	FACILITIES WITH OXYGEN CYLINDER (%)	FACILITIES WITH OXYGEN CONCENTRATOR (%)	FACILITIES WITH OXYGEN DISTRIBUTION SYSTEM (%)
Senegal (2017)	Hospitals	Government/public	328	16%	9%	7%	12%	11%
		NGO/Nonprofit	33	39%	15%	33%	27%	33%
		Private for profit	71	25%	14%	14%	18%	15%
		Mission/faith-based	213	27%	13%	13%	19%	18%
	Health clinics	Government/public	527	2%	1%	1%	1%	1%
		NGO/Nonprofit	10	0%	0%	0%	0%	0%
		Private for profit	93	5%	6%	3%	2%	4%
		Mission/faith-based	136	7%	4%	1%	2%	4%
	All facilities	Government/public	855	7%	4%	3%	5%	5%
		NGO/Nonprofit	43	30%	12%	26%	21%	26%
		Private for profit	164	14%	10%	8%	9%	9%
		Mission/faith-based	349	19%	9%	8%	13%	13%

Abbreviations: DRC, Democratic Republic of the Congo; NGO, nongovernmental organization.

Oxygen supply

The following table summarizes what is known at this time.

TABLE A7. **Oxygen supply in the Democratic Republic of the Congo.**

IMPORTED OXYGEN	Hezer Gases (Lubumbashi), Import bulk liquid O_2 (15-ton tank) (fill industrial and medical oxygen cylinders)
DOMESTIC BULK OXYGEN PRODUCTION	Gecamines (Lubumbashi), Air Products: 350 tpd Captive (GOX) (captive) Gecamines/EGMF (Likasie), Air Products: 350 tpd Captive (GOX) (captive) Sotrafer S.p.r.l. (Lubumbashi) O_2 production: 1 tpd (steel manufacturing company)
PSA PLANTS	Randgold (Kolwezi), Air Liquide: 30 tpd; Sodimico (Lubumbashi), Indian: 5 tpd; Alan Beelen (Lubumbashi), Indian: 7 tpd; SNCC (Lubumbashi), Linde: 10 tpd, Sotrafer Sprl (Lubumbashi), Sanghi: 3, 4 tpd; Congo Steel Mills SPRL (Lubumbashi), Sanghi: 6,9 tpd; Safricas (Kinshasa), Sanghi: 3, 4 tpd; Intakatech (Panzi Hospital): 15 tpd; Randgold (Kibali): 20 tpd
MARKET SHARE	**Industrial:** 90%, 3,650 tpy [mining (copper, cobalt, gold, diamonds, zinc, tin, tungsten), mineral processing, (metal products, lumber, cement, commercial ship repair)] **Medical:** 10%, 400 tpy

Abbreviations: O_2, oxygen; PSA, pressure swing adsorption; tpd, tons per day; tpy; tons per year.

Additional information about the oxygen supply in this country:

- In 2016, after a decade of Doctors Without Borders supporting health facilities in southern DRC, the Ministry of Health took over the project, including designing a health system with appropriate oxygen availability.[39] Large solar panels were installed to provide electricity to oxygen concentrators.
- In 2013, a donation from Belgium provided for a medical oxygen production unit at a hospital focusing on victims of sexual violence.[40]
- In 2011, the Pierre Fabre Foundation pledged to provide two years of support for a sickle cell treatment unit at the Monkole hospital facility in the DRC, including 18 oxygen concentrators.[41]

Policy attributes

Oxygen is indicated only for anesthesia in the DRC Essential Medicines List.

Ethiopia

Health need

In Ethiopia, the top three causes of death were respiratory infections/TB, maternal and neonatal disorders, and enteric infections.[28] Regarding the ARI burden, results from nationally representative surveys showed that an estimated 31% of children with ARI sought treatment in a health facility and 16% of deaths among all children were due to ARI.[29] Ethiopia accounted for about 3% of the LMIC population; 41% of the country's population was aged < 14 years old.[32,33]

Oxygen availability

The availability and utilization of medical devices were assessed among three hospitals in Jimma Zone in 2013.[42] One hospital had four nonfunctioning oxygen concentrators, and two hospitals had one functioning concentrator each. All hospitals reported overall issues in training and maintenance for medical devices.

According to Clinton Health Access Initiative reports, only 2% of health centers had a fully functioning oxygen delivery device and 0% had functional pulse oximeters.[43] Among hospitals, 64% had fully functioning oxygen delivery devices and 45% had pulse oximeters in their inpatient pediatric wards. Only 41% of hospitals had biomedical engineers and technicians to maintain oxygen equipment.

Policy attributes

Oxygen is indicated only for anesthesia in the Ethiopia Essential Medicines List.

In 2015, the Federal Ministry of Health developed a strategy to prevent deaths in children < 5 years of age.[43] One component was advocating for new policy on oxygen scale-up and management. The Clinton Health Access Initiative and local officials are working on a national road map for oxygen and pulse oximetry scale-up, including a target for comprehensive implementation of pulse oximetry and oxygen access and management in more than 3,500 health centers and 800 hospitals by the end of 2020.

Oxygen supply

TABLE A8. **Oxygen supply in Ethiopia.**

IMPORTED OXYGEN	No data available.
DOMESTIC BULK OXYGEN PRODUCTION	Universal Gas (at Ecclesia Memorial Hospital), O_2, N2 filling plant in Adama (Nazareth, 100 km E of Addis Ababa in Oromia Regional State); Gab Ethiopia Oxygen and Acetylene Production Plc (Duken, 32 km from Addis Ababa): 10 tpd ASU (2009) • Sanghi, supplies high-purity medical O_2 (99.7%) and high-purity industrial O_2 (99.7%) • Gab Ethiopia Oxygen and Acetylene Production Plc (50%)
PSA PLANTS	Oxygen Centre (Bahir Dar, Amhara Region): 3 tpd (2019)
MARKET SHARE	**Industrial:** 85%, 1,825 tpy (textiles, leather, chemicals, metals processing, cement) **Medical:** 15%, 220 tpy

Abbreviations: N2 Dinitrogen, ; O_2, oxygen; PSA, pressure swing adsorption; tpd, tons per day; tpy; tons per year.

Ghana

Health need

In Ghana, the top three causes of death were cardiovascular disease, respiratory infections/TB, and neglected tropical diseases/malaria.[28] Regarding the ARI burden, results from nationally representative surveys showed that an estimated 56% of children with ARI sought treatment in a health facility and 12% of deaths among all children were due to ARI.[29] Ghana accounted for about 0.8% of the LMIC population; 39% of the country's population was aged < 14 years old.[32,33]

Oxygen availability

In 2015, the Rikair Company Limited, an oxygen storage and generating company, donated an oxygen concentrator and associated consumables to the Ghana Police Hospital as part of its corporate social responsibility.[44]

Ghana plans to implement the WHO Package of Essential Noncommunicable Disease Interventions, a risk management package for noncommunicable diseases, to facilitate risk factor assessment and treatment.[45] As part of a baseline survey of the capacity of health facilities in 2013, district and regional hospitals had two to three functioning oxygen cylinders, but these were extremely limited at lower-level health centers.

Twelve nurses from the Korle-Bu Teaching Hospital in Ghana were interviewed to understand perspective on clinical administration of oxygen within the emergency and post-operative wards.[46] Some nurses noted limited education on oxygen treatments and a lack of protocols on oxygen therapy. Cost and availability of consumables were also challenges.

Policy attributes

Oxygen is indicated only for anesthesia in the Ghana Essential Medicines List.

Oxygen supply

TABLE A9. **Oxygen supply in Ghana.**

IMPORTED OXYGEN	No data available.
DOMESTIC BULK OXYGEN PRODUCTION	Air Liquide (Tema): 20 tpd; Takoradi Gas (Takoradi): 8 tpd • Air Liquide (40%), Takoradi Gas (20%)
PSA PLANTS	Goldfields Damang Mine, Damang, Air Liquide: 10 tpd; AngloGold Ashanti (Obuasi), Air Liquide: 10 tpd; Kastena (Kumasi), Sanghi: 2 tpd; Jokumak (Ghana), Sanghi: 2 tpd; Rikair (Kaso), Sanghi: 1 tpd; EcoAir (Accra), Sanghi: 2 tpd; Frank Air (Accra), Sanghi: 1 tpd; Des Air (Accra), Sanghi: 1 tpd; Oxy Air (Accra), Sanghi: 1 tpd; Oxy Supply (Accra), Sanghi: 1 tpd; Kumoxy Gen (Accra), Sanghi: 1 tpd; Tema Steel Ltd. (Tema), Sanghi: 7 tpd; Intrinsic Resources (Tema), Sanghi: 1 tpd
MARKET SHARE	**Industrial:** 80%, 10,000 tpy (hydrocarbon production, crude oil production and refining, industrial mineral mining, lumber, light manufacturing, aluminum smelting, cement, electricity generation) **Medical:** 10%, 1,200 tpy

Abbreviations: PSA, pressure swing adsorption; tpd, tons per day; tpy; tons per year.

India

Health need

In India, the top three causes of death were cardiovascular diseases, chronic respiratory diseases, and respiratory infections/TB.[28] Regarding the ARI burden, results from nationally representative surveys showed that an estimated 48% of children with ARI sought treatment in a health facility and 15% of deaths among all children were due to ARI.[29] India accounted for about 36% of the LMIC population, and 28% of the country's population was aged < 14 years.[32,33]

Oxygen availability

See the PATH report titled *Landscape Assessment and Recommendations to Increase Access to Oxygen and Pulse Oximetry in India*, which summarizes the availability in detail.[47]

Oxygen supply

See the PATH report for more information about supply.[Ibid.]

Policy attributes

Oxygen is indicated only for anesthesia in the India Essential Medicines List.

TABLE A10. **Oxygen supply in India.**

IMPORTED OXYGEN	No data available.
DOMESTIC BULK OXYGEN PRODUCTION	No data available.
PSA PLANTS	No data available.
MARKET SHARE	**Industrial:** No data available. **Medical:** No data available.

Abbreviations: PSA, pressure swing adsorption.

Kenya

Health need

In Kenya, the top three causes of death were HIV/AIDS and other sexually transmitted infections, respiratory infections/TB, and cardiovascular diseases.[28] Regarding the ARI burden, results from nationally representative surveys showed that an estimated 66% of children with ARI sought treatment in a health facility and 14% of deaths among all children were due to ARI.[29] Kenya accounted for about 1.3% of the LMIC population, and 40% of the country's population was aged < 14 years old.[32,33]

Oxygen availability

A SARA survey conducted in 2013 showed that 13% of surgery wards and 33% of obstetric wards had any oxygen. Details on the type, quantity, and quality of the oxygen in those facilities were not noted. See the PATH report titled *Assessment and Recommendations to Increase Access to Oxygen and Pulse Oximetry in Kenya*, which summarizes the availability in more detail (available upon request).

Oxygen supply

In addition to the following table, see the PATH report for more information about supply (available upon request).

Policy attributes

Oxygen is noted for only anesthesia in the Kenya Essential Medicines List.

TABLE A10. **Oxygen supply in India.**

IMPORTED OXYGEN	Noble Gases, 100% local, PSA & imported bulk, imports: 4 tpd; LOX in isotainers from Dubai and lands these isotainers (liquid) at US$0.43/kg, and gas in cylinders, aggressively low prices, direct presence in Nairobi, Kisumu, and Mombasa, approximate volume sold is 5 tpd, 80% imported bulk and 20% local production, Synergy, based in Mombasa and has resellers in key areas e.g. Nairobi, local production using a 5 tpd PSA plant (offers cylinder supply)
DOMESTIC BULK OXYGEN PRODUCTION	BOC Kenya (Nairobi), BOC Cryoplants P600: 17 tpd; Weldgas (Nairobi): 3 tpd (1996) • BOC Kenya (70%), Noble Gases (10%)
PSA PLANTS	Welgas (Nairobi), Sanghi: 7 tpd; Noble Gases (Nairobi), Sanghi: 3 tpd; Devi Ruiru (Nairobi), Sanghi: 1 tpd; Steel makers (Mombasa), Sanghi: 5 tpd; Kusco (Mombasa), Sanghi: 5 tpd; Steel Makers Limited (Nairobi), Sanghi: 3 tpd; Devki Steel Mills (Nairobi), Sanghi: 7 tpd; Welding Alloys Ltd (Nairobi), Sanghi: 3 tpd; Corner Garage Group (Mombasa)
MARKET SHARE	**Industrial:** 90%, 7,300 tpy (small-scale consumer goods, agricultural products, horticulture, oil refining; aluminum, steel, lead; cement, commercial ship repair) **Medical:** 10%, 800 tpy

Abbreviations: LOX,Liquid oxygen ; PSA, pressure swing adsorption; tpd, tons per day; tpy; tons per year.

Myanmar

Health need

In Myanmar, the top three causes of death are cardiovascular disease, neoplasms (cancer), and chronic respiratory infections.[28] Regarding the ARI burden, results from nationally representative surveys showed that an estimated 58% of children with ARI sought treatment in a health facility and 18% of deaths among all children were due to ARI.[29] Myanmar accounted for about 1.4% of the LMIC population, and 27% of the country's population was aged < 14 years old.[32,33]

Oxygen availability

No information is available at this time.

Additional information about the oxygen supply in this country:

- In January 2019, Japan's largest industrial gas producer, Taiyo Nippon Sanso Corp., opened its first gas manufacturing plant in Myanmar.[48] The plant has a production capacity of 1,000 tons of nitrogen and oxygen per month. The company is among the top five industrial gas suppliers in the world, with many plants in Southeast Asia.
- At the end of 2019, a new medical oxygen filling plant will open in Myanmar. It was built by Kitajima Sanso, another Japanese gas company[49] as requested by the Ministry of Health and Sports, there is a standard for medical gases. The company is also conducting activities and seminars with hospitals to reduce accidents related to cylinders for medical use.

Policy attributes

The Myanmar Essential Medicines List was not available for review. However, the collaboration between the Ministry of Health and Sports and Kitajima Sanso (outlined above) indicates some buy-in by the government.

Oxygen supply

TABLE A12. **Oxygen supply in Myanmar.**

IMPORTED OXYGEN	No data available.
DOMESTIC BULK OXYGEN PRODUCTION	No data available.
PSA PLANTS	No data available.
MARKET SHARE	**Industrial:** No data available. **Medical:** No data available.

Abbreviations: PSA, pressure swing adsorption.

Tanzania

Health need

In Tanzania, the top three causes of death were respiratory infections/TB, cardiovascular disease, and maternal and neonatal disorders.[28] Regarding the ARI burden, results from nationally representative surveys showed that an estimated 55% of children with ARI sought treatment in a health facility and 15% of deaths among all children were due to ARI.[29] Tanzania accounted for about 1.5% of the LMIC population, and 45% of the country's population was aged < 14 years.[32,33]

In a prospective cohort study of 165 patients < 18 years of age in Tanzania with respiratory compromise, 87% required oxygen therapy.[50] Almost 50% of patients were hypoxic; of those, 28% died.

Oxygen availability

A SARA survey conducted in 2012 showed that 77% of facilities with cardiovascular wards, 75% of facilities with chronic respiratory wards, and 63% of facilities with surgery wards had any oxygen available. Details on the type, quantity, and quality of the oxygen in those facilities were not noted.

A detailed analysis of an SPA survey conducted in 2014 noted that one-tenth of facilities had a high readiness to manage chronic respiratory disease.[51] Less than 10% of facilities had any oxygen available.

In 2009, the Tanzanian Ministry of Health conducted a comprehensive assessment to measure health facilities' capacity to perform basic surgical interventions.[52] Of the 48 facilities surveyed, only 42% had consistent access to oxygen and most relied on oxygen concentrators. There was also a lack of oxygen tubing, pulse oximeters, and pediatric airway equipment.

In 2016, Tanzania issued a directive for the creation of a National Surgical, Obstetric, and Anesthesia Plan.[53]

In addition, Oxymat, a pressure swing adsorption oxygen manufacturer, donated an oxygen generator with Pulse Healthcare Limited to Tumbi Regional Referral Hospital in the Kibaha district.[54] Tumbi is a public hospital for the Coastal region of Tanzania.

Policy attributes

Oxygen is indicated for both anesthesia and other procedures in the Tanzania Essential Medicines List.

Oxygen supply

TABLE A13. **Oxygen supply in Tanzania.**

IMPORTED OXYGEN	No data available.
DOMESTIC BULK OXYGEN PRODUCTION	Tanzania Oxygen Ltd (Dar es Salaam), Cosmodyne Aspen 1000: 30 tpd LOX/LIN • BOC Tanzania (10%), Tanzania Oxygen Limited (TOL) (40%)
PSA PLANTS	Industrial Gas & Chemical (Mwanza), Sanghi: 3 tpd; Iron & Steel (Dar es Salaam), Sanghi: 3 tpd; Kamal Steel (Dar es Salaam), Sanghi: 5 tpd; Sas gas (Morogoro), Sanghi: 1 tpd; M. M. Integrated Steel Mills Ltd, Subhash Patel Group (Dar es Salaam), Sanghi: 7 tpd
MARKET SHARE	**Industrial:** 90%, 11,000 tpy (agricultural processing mining) **Medical:** 10%, 1,250 tpy

Abbreviations: LIN, liquified nitrogen ; LOX, Liquid oxygen ; PSA, pressure swing adsorption; tpd, tons per day; tpy; tons per year.

Uganda

Health need

In Uganda, the top three causes of death were HIV/AIDS and other sexually transmitted infections, respiratory infections/TB, and maternal and neonatal disorders.[28] Regarding the ARI burden, results from nationally representative surveys showed that an estimated 80% of children with ARI sought treatment in a health facility and 16% of deaths among all children were due to ARI.[29] Uganda accounted for about 1.1% of the LMIC population, and 48% of the country's population was aged < 14 years old.[32,33]

Oxygen availability

There is no information at this time.

Policy attributes

Oxygen is indicated only for anesthesia in the Uganda Essential Medicines List.

Oxygen supply

TABLE A14. **Oxygen supply in Uganda.**

IMPORTED OXYGEN	No data available.
DOMESTIC BULK OXYGEN PRODUCTION	Uganda Oxygen Limited (UOL) (Kampala): 3 tpd • Uganda Oxygen Limited (50%)
PSA PLANTS	Hans Metal (Urusha), Sanghi: 1 tpd Uganda Oxygen Ltd (Kampala), Sanghi: 7 tpd; Oxygas Uganda (Kampala), Sanghi: 3 tpd; Tembo Steel (Jinja), Sanghi: 8 tpd; Steel Corp of East Africa, Sanghi: 0.5 tpd; Steel Enterprises (Jinja), Sanghi: 1 tpd; Oxygas Ltd (Alam Group) (Kampala), Sanghi: 7 tpd; BHL Healthcare OxyExpress (10+, 15+ PSA plants at Mulago Hospital, Kiruddu Referral Hospital, Kawempe Referral Hospital, International Hospital Kampala, Meng Hospital)
MARKET SHARE	**Industrial:** 95%, 730 tpy **Medical:** 5%, 80 tpy

Abbreviations: PSA, pressure swing adsorption; tpd, tons per day; tpy; tons per year.

Ukraine

Health need

In Ukraine, the top three causes of death were cardiovascular diseases, neoplasms (cancer), and neurological disorders.[28] Regarding the ARI burden, results from nationally representative surveys showed that an estimated 92% of children with ARI sought treatment in a health facility and 8% of deaths among all children were due to ARI.[29] Ukraine accounted for about 1.2% of the LMIC population, and 15% of the country's population was aged < 14 years old.[32,33]

Oxygen availability

There is no information at this time.

Policy attributes

The Ukraine Essential Medicines List was not available in English.

Oxygen supply

TABLE A15. **Oxygen supply in Ukraine.**

IMPORTED OXYGEN	No data available.
DOMESTIC BULK OXYGEN PRODUCTION	No data available.
PSA PLANTS	No data available.
MARKET SHARE	**Industrial:** No data available. **Medical:** No data available.

Abbreviations: PSA, pressure swing adsorption.

Vietnam

Health need

In Vietnam, the top three causes of death were cardiovascular diseases, neoplasms (cancer), and diabetes/chronic kidney disease.[28] Regarding the ARI burden, results from nationally representative surveys showed that an estimated 81% of children with ARI sought treatment in a health facility and 12% of deaths among all children were due to ARI.[29] Vietnam accounted for about 2.6% of the LMIC population, and 23% of the country's population was aged < 14 years old.[32,33]

Oxygen availability

There is no information at this time.

Oxygen supply

Table A16. Oxygen supply in Vietnam.

Policy attributes

Oxygen is indicated for both anesthesia and other procedures in the Vietnam Essential Medicines List.

Oxygen supply

TABLE A16. **Oxygen supply in Vietnam.**

IMPORTED OXYGEN	No data available.
DOMESTIC BULK OXYGEN PRODUCTION	No data available.
PSA PLANTS	No data available.
MARKET SHARE	**Industrial:** No data available. **Medical:** No data available.

Abbreviations: PSA, pressure swing adsorption.

Zambia

Health need

In Zambia, the top three causes of death were HIV/AIDS and other sexually transmitted diseases, respiratory infections/TB, and cardiovascular disease.[28] Regarding the ARI burden, results from nationally representative surveys showed that an estimated 70% of children with ARI sought treatment in a health facility and 14% of deaths among all children were due to ARI.[29] Zambia accounted for about 0.4% of the LMIC population, and 45% of the country's population was aged < 14 years old.[32,33]

Oxygen availability

Results from the Access, Bottlenecks, Costs, and Equity (ABCE) project are reported in *Health Service Provision in Zambia: Assessing Facility Capacity, Costs of Care, and Patient Perspectives (ABCE)* and shown below. The project was conducted by the Institute for Health Metrics and Evaluation in 2014.

In addition, a SARA survey conducted in 2010 showed that 6% of facilities with surgery wards had any oxygen available. Details on the type, quantity, and quality of the oxygen in those facilities were not noted.

Policy attributes

Oxygen is indicated for both anesthesia and other procedures in the Zambia Essential Medicines List.

TABLE A17. **Results from the Institute for Health Metrics and Evaluation's Access, Bottlenecks, Costs, and Equity (ABCE) project.**

COUNTRY	TYPE OF FACILITY	URBAN/RURAL	OWNERSHIP	PERCENTAGE OF FACILITIES WITH OXYGEN	TOTAL HOSPITALS (N)
Zambia	Hospitals	Urban	Private	75%	60
			Public	36%	55
		Rural	Private	75%	40
			Public	40%	25
	Health clinics	Urban	Private	92%	60
			Public	44%	169
		Rural	Private	0%	10
			Public	6%	353
	All facilities	Urban	Private	83%	120
			Public	42%	224
		Rural	Private	60%	50
				8%	378

Oxygen supply

TABLE A18. **Oxygen supply in Zambia.**

IMPORTED OXYGEN	No data available.
DOMESTIC BULK OXYGEN PRODUCTION	Chambishi Metals (Chambishi), Air Products: 100 tpd Konkola Copper Mine (KCM; Vedanta Resources UK) (51%), ZCI Bermuda (28.4%), ZCCM Zambia (Nchanga) (20.6%), Air Products: 2 x 350 tpd Kansanshi Copper Mine (First Quantum Minerals) (Solwezi), Air Products: 2 x 750 tpd Kansanshi Copper Mine (First Quantum Minerals) (Kitwe), Air Liquide: 650 tpd Kansanshi Copper Mine (First Quantum Minerals) (Nkana), Air Products: 60 tpd Mopani Copper Mines (MCM; Glencore) (73.1%), First Quantum Minerals (16.9%), Zambia Consolidated Copper Mines (ZCCM; Kitwe) (10%), Air Products: 60 tpd Mopani Copper Mines (MCM) (Mufulira; Zambia), Air Products: 850 tpd NCZ (Lusaka), Eastern: 350 tpd First Quantum Minerals (Kansanshi Deslime Project) (Kolwezi), Air Products: 750 tpd Afrox Zambia (Ndola), BOC Cryoplants P600: 17 tpd; Afrox Zambia (60%)
PSA PLANTS	IGL (Kitwe), Sanghi: 4 tpd; Scaw Metals (Kitwe), Sanghi: 2 tpd: GNC (Kitwe), Sanghi: 3 tpd: Oxyzam (Lusaka), Sanghi: 3 tpd; NCZ (Lusaka), Sanghi: 3 tpd; UTH (Lusaka), Sanghi: 3 tpd; ZAF (Lusaka), Sanghi: 3 tpd; Tazara (Mpika), Chinese: 3 tpd: ZAF (Lusaka), Eastern: 3 tpd; GNC (Kitwe), Indian: 3 tpd; Oxyzam (Lusaka), Indian: 3 tpd; UTH (Lusaka), Indian: 3 tpd; Powerflex (Kitwe): 1 tpd; Chingases (Lusaka): 6 tpd
MARKET SHARE	**Industrial: 99%, 1,765,000 tpy (copper mining and processing, construction, chemicals, textiles, fertilizer, horticulture)** **Medical: 1%, 178,000 tpy**

Abbreviations: PSA, pressure swing adsorption; tpd, tons per day; tpy; tons per year.

10.3. Appendix C: Total cost of ownership assumptions

- Critical care beds = 10% of total facility beds.
- All facilities are open 24 hours/7 days a week.
- Power source = Electricity (Mains).
- % urban/% periurban = 50%/50% primary health centers; 65%/45% community health centers; 80%/20% district hospitals.
- Does not account for reserve supplies.
- Assumes Oxygen as a Utility program would replace any existing oxygen sources, so total oxygen provided = total oxygen need.

	BASELINE DATA	SOURCE OR ASSUMPTION FOR BASELINE INPUT
Oxygen consumption per general bed (LPM)	0.75	PATH assumption
Oxygen consumption per critical care bed (LPM)	10.00	PATH assumption
Percent markup on device cost for shipping to urban areas	15%	PATH assumption
Percent markup on device cost for shipping to rural areas	25%	PATH assumption
Percent markup on device cost for distributor fee	15%	PATH assumption
Cost of electricity (per kWh)	0.08	https://www.globalpetrolprices.com (Data from June 2018. Accessed February 2019)
Cost of diesel fuel for generators (per L)	0.96	https://www.globalpetrolprices.com (Data from February 2019. Accessed February 2019.)
Amount of diesel fuel used in generators (L per kWh)	0.10	https://deepresource.wordpress.com/2012/04/23/energy-related-conversion-factors (Accessed February 2019.)
Cost of highly skilled labor (per person per hour)	US$3.60	https://tradingeconomics.com/countries (Data from December 2019. Accessed February 2019.)
Number of technical people trained per device	5	PATH assumption
Cylinder refill cost (7.0 m3 /7,000 L cylinder)	US$2.00	Balrampur district hospital records
Cylinder transport cost (7.0 m3/7,000 L cylinder)	US$0.37	Balrampur district hospital records
Average growth rate per year	5.1%	PATH assumption
Inflationary growth	5.24%	https://www.inflation.eu/inflation-rates/india/historic-inflation/cpi-inflation-india-2018.aspx
Discount rate	15%	PATH assumption
Cylinder costs (each)	US$100.00	PATH assumption

Abbreviations: LPM, liters per minute.

10.4. Appendix D: Estimated total cost of ownership

10.4.1. Uttar Pradesh Scenario A annual costs (US$ in 1,000s)

(December 2017 to December 2018 year-on-year inflation was 5.24%, per inflation.eu.)

	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	YEAR 7	YEAR 8	YEAR 9	YEAR 10	TOTAL
Operating Expenditures											
Cylinder refills	$25,681	$27,027	$28,443	$29,934	$31,502	$33,153	$34,890	$36,719	$38,643	$40,667	$326,660
Parts & labor	$188	$197	$208	$219	$230	$242	$255	$268	$282	$297	$2,386
Total OPEX	$25,869	$27,225	$28,651	$30,152	$31,732	$33,395	$35,145	$36,987	$38,925	$40,965	$329,046
Capital Expenditures											
Equipment	$75,042										$75,042
Shipping	$77										$77
Installation & training	$375										$375
Total CAPEX	$75,494										$75,494
Total costs	**$101,363**	**$27,225**	**$28,651**	**$30,152**	**$31,732**	**$33,395**	**$35,145**	**$36,987**	**$38,925**	**$40,965**	**$404,540**

Abbreviations: CAPEX, capital expenditures; OPEX, operating expenditures.

10.4.2. Uttar Pradesh Scenario B annual costs (US$ in 1,000s)

	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	YEAR 7	YEAR 8	YEAR 9	YEAR 10	TOTAL
Operating Expenditures											
Concentrators											
Electricity	$1,497	$1,575	$1,658	$1,745	$1,836	$1,933	$2,034	$2,140	$2,253	$2,371	$19,041
Parts & labor	$498	$524	$552	$581	$611	$643	$677	$712	$750	$789	$6,338
Cylinders, 7 K											
Refill	$15,037	$15,825	$16,655	$17,527	$18,446	$19,412	$20,430	$21,500	$22,627	$23,812	$191,272
Parts & labor	$73	$77	$81	$85	$90	$95	$99	$105	$110	$116	$931
PSA plant, 500 LPM											
Electricity	$2,099	$2,209	$2,324	$2,446	$2,574	$2,709	$2,851	$3,000	$3,158	$3,323	$26,693
Parts & labor	$1,736	$1,827	$1,923	$2,024	$2,130	$2,241	$2,359	$2,482	$2,612	$2,749	$22,084
Total OPEX	$20,941	$22,038	$23,193	$24,408	$25,687	$27,033	$28,450	$29,940	$31,509	$33,160	$266,359
Capital Expenditures											
Equipment											
Concentrators	$3,958				$3,958				$3,958		$11,875
Cylinders	$29,293										$29,293
PSA plant, 500 LPM	$15,969										$15,969
Shipping											
Concentrators	$194				$194				$194		$583
Cylinders	$45										$45
PSA plant, 500 LPM	$2,948										$2,948
Installation & training											
Concentrators	$7				$7				$7		$20
Cylinders	$146										$146
PSA plant, 500 LPM	$248										$248
Total CAPEX	$52,809				$4,159				$4,159		$61,127
Total Costs	**$73,750**	**$22,038**	**$23,193**	**$24,408**	**$29,846**	**$27,033**	**$28,450**	**$29,940**	**$35,668**	**$33,160**	**$327,486**

Abbreviations: CAPEX, capital expenditures; LPM, liters per minute; OPEX, operating expenditures; PSA, pressure swing adsorption.

10.5. Appendix E: Countries used in selection tool

NUMBER	ABBREVIATION	COUNTRY/AREA NAME
1	AFG	Afghanistan
2	AGO	Angola
3	ARM	Armenia
4	BGD	Bangladesh
5	BEN	Benin
6	BTN	Bhutan
7	BOL	Bolivia
8	BFA	Burkina Faso
9	BDI	Burundi
10	CPV	Cabo Verde
11	KHM	Cambodia
12	CMR	Cameroon
13	CAF	Central African Republic
14	TCD	Chad
15	COM	Comoros
16	COD	Congo, Dem. Rep.
17	COG	Congo, Rep.
18	CIV	Côte d'Ivoire
19	DJI	Djibouti
20	EGY	Egypt
21	SLV	El Salvador
22	ERI	Eritrea
23	ETH	Ethiopia
24	GMB	Gambia
25	GEO	Georgia
26	GHA	Ghana
27	GTM	Guatemala
28	GIN	Guinea
29	GNB	Guinea-Bissau
30	HTI	Haiti
31	HND	Honduras

10.5. Appendix E: Countries used in selection tool, continued

NUMBER	ABBREVIATION	COUNTRY/AREA NAME
32	IND	India
33	IDN	Indonesia
34	JOR	Jordan
35	KEN	Kenya
36	KIR	Kiribati
37	PRK	Korea, Dem. People's Rep.
38	KGZ	Kyrgyzstan
39	LAO	Lao People's Democratic Republic
40	LSO	Lesotho
41	LBR	Liberia
42	MDG	Madagascar
43	MWI	Malawi
44	MLI	Mali
45	MRT	Mauritania
46	FSM	Micronesia (Federated States of)
47	MDA	Moldova
48	MNG	Mongolia
49	MAR	Morocco
50	MOZ	Mozambique
51	MMR	Myanmar
52	NPL	Nepal
53	NIC	Nicaragua
54	NER	Niger
55	NGA	Nigeria
56	PAK	Pakistan
57	PNG	Papua New Guinea
58	PHL	Philippines
59	RWA	Rwanda
60	STP	São Tomé and Principe
61	SEN	Senegal
62	SLE	Sierra Leone

10.5. Appendix E: Countries used in selection tool, continued

NUMBER	ABBREVIATION	COUNTRY/AREA NAME
63	SLB	Solomon Islands
64	SOM	Somalia
65	SSD	South Sudan
66	LKA	Sri Lanka
67	SDN	Sudan
68	SWZ	Swaziland
69	SYR	Syrian Arab Republic
70	TJK	Tajikistan
71	TZA	Tanzania
72	TLS	Timor-Leste
73	TGO	Togo
74	TUN	Tunisia
75	UGA	Uganda
76	UKR	Ukraine
77	UZB	Uzbekistan
78	VUT	Vanuatu
79	VNM	Vietnam
80	YEM	Yemen, Rep.
81	ZMB	Zambia
82	ZWE	Zimbabwe

10.6. Appendix F: Risks

Risk matrix

PATH assessed the risks associated with the implementation of the O_2aaU operating model. The risk matrix (outlined below in Table A10.6) seeks to summarize each risk, level of risk, and risk mitigation plan. The level of risk was defined by considering the likelihood of occurrence against the significance of impact. The risks with a high likelihood of occurrence have been written into implementation plan as they will require to be planned for from the start of implementation. The risk matrix will continue to serve as an important management tool and assist with the planning, decision-making, and implementation of the operating model.

TABLE A10.6. **Summary of risks specific to the implementation of the oxygen-as-a-utility operating model.**

DESCRIPTION OF RISK	LIKELIHOOD OF OCCURRENCE	SIGNIFICANCE OF IMPACT	DESCRIPTION OF IMPACT	DESCRIPTION OF RISK MITIGATION
Data available is inaccurate or insufficient to make informed current and future needs assessment.	High	Moderate	Under/over/incomplete estimation of amount of oxygen and other services required.	Flexible contracting arrangement that allows for changes in response to new data or observations. Contracting expert required for design Phased implementation plan that refines the model in a limited number of facilities
Current supply is too low to meet forecasted demand.	Low	Moderate	It is not possible to purchase enough oxygen to meet the forecasted demand	Select manufacturers capable of generating or importing additional supply of oxygen
Low guarantee to meet entire forecasted future need/demand.	Low	Low	Future growth outpaces forecasted future growth leading to inadequate future supply due to current underinvestment.	Forecasting of increasing future demand to be added to operating model
Country is unwilling or uninterested in participating in implementing this model.	High	High	Implementation does not occur in this country.	Country selection will include early and in-depth conversation around this model. Their equal ownership and investment would be a requirement.
Decentralization policies prohibit central governments from entering into large centralized contracts	Moderate	High	Ability to create large markets and achieve scale is reduced	Seek exceptions to these policies given value for health gained or work in countries more willing to aggregate demand.
Market size is too small (insufficient) to attract market entry or investment.	High	High	Manufacturers will not participate if there is not sufficient incentive	Identifying additional buyers and market segments to increase potential.
Market size is too large in volume or value, which creates computational and planning challenges.	High	High	Difficult to estimate requirements to meet the need	Determining what level of pooling is best. Enough business incentive, but not too large to centrally manage. Divide overly large market into smaller parts.

TABLE A10.6. **Summary of risks specific to the implementation of the oxygen-as-a-utility operating model, continued**

DESCRIPTION OF RISK	LIKELIHOOD OF OCCURRENCE	SIGNIFICANCE OF IMPACT	DESCRIPTION OF IMPACT	DESCRIPTION OF RISK MITIGATION
Market size is geographically challenging, which creates logistical challenges in transportation and delivery.	High	High	Manufacturers are not willing to participate due to potential costs and risk of not being able to deliver.	Design solutions that are not dependent on supply chains or transportation and delivery
Industrial market is limited or nonexistent, which reduces the overall potential upside and increases risk if countries default.	High	Med	Manufacturers and financiers may not be willing to participate if there is not a secondary market	Include potential industrial markets as a criteria in country selection
Banks are not willing to back this model as the risk is too high and/or they do not see value.	High	High	Without the backing of financial institutions, manufacturers may not be willing to take on the risk associated with investing in LMIC	Partner with banks or other institutions early on to understand and meeting their needs ensure buy in prior to implementing
Forecast of health and/or economic impact insufficient to attract investment by private/public sector.	Low	High	Without economic and/or health impact, it may be that resources are better allocated in other ways	Collect necessary data and speak with a wide range of experts to develop credible models.
Market design is influenced by incumbents and contains only low-value or challenging areas.	Moderate	Moderate	Catalyzing change in the market will be difficult if incumbents are overly influential and the market there are no areas where delivery is lower cost to offset the higher cost areas.	Include potential market size as country selection criteria. Include influence of incumbent companies as a criteria. Include additional incentives if market only low-value
Corrupt motives prohibit change to market, which limits uptake.	Moderate	Low	Change will not be effective if buyers do not participate in the plan	Put third party monitoring in place. Design payment methods and tracking to prevent corruption
Facilities do not comply, causing the intervention to not be taken up.	Moderate	Moderate	Change will not be effective if buyers do not change habits and contracts to procure oxygen through the new system	Ensure buy in at all levels through information campaigns, avoid countries where change is resisted, decision making is overly decentralized and it's not feasible to centralize ordering and payments
Manufacturers do not see value as volume is insufficient for business incentive and do not apply/bid in auction.	Low	High	Inefficient uncompetitive market	Encourage new entrants by making guarantees sufficiently sized. Ensuring volumes are pooled to create sufficient business case.
Equilibrium price too low/high for manufacturer ability/interest.	Moderate	Moderate	Company is unable to deliver on bid.	High transparency and accountability on performance in contracting terms (penalty).

DESCRIPTION OF RISK	LIKELIHOOD OF OCCURRENCE	SIGNIFICANCE OF IMPACT	DESCRIPTION OF IMPACT	DESCRIPTION OF RISK MITIGATION
Country uses low-price finding mechanism versus high-quality mechanism.	High	Moderate	Thus, auction results in low-quality entrants and selection.	In bid/auction evaluation, you must have balanced criteria that check for technical appropriateness and price competitiveness. Must have pre-defined evaluation criteria.
Country cannot or will not allocate more funding (or any funding) for procurement.	Low	High	Keeps country using suboptimal quantities of oxygen.	Country selection to find countries willing to spend and/or subsidies to support spending.
New market entrants disrupt/undercut price after contracting period.	Low	Moderate	Country bound by expensive and/or less efficient contract when superior options or terms exist with other firms.	Enforceable and flexible contracting terms that allow for integration of new technology and/or efficient distribution mechanisms.
Design of auction is non-transparent and/or unfair due to industrial interests or political motivations.	Moderate	High	Suboptimal organizations contracted or price for market is above the market rate.	Co-design auction with auction theory experts and policy makers using a sound political strategy.

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