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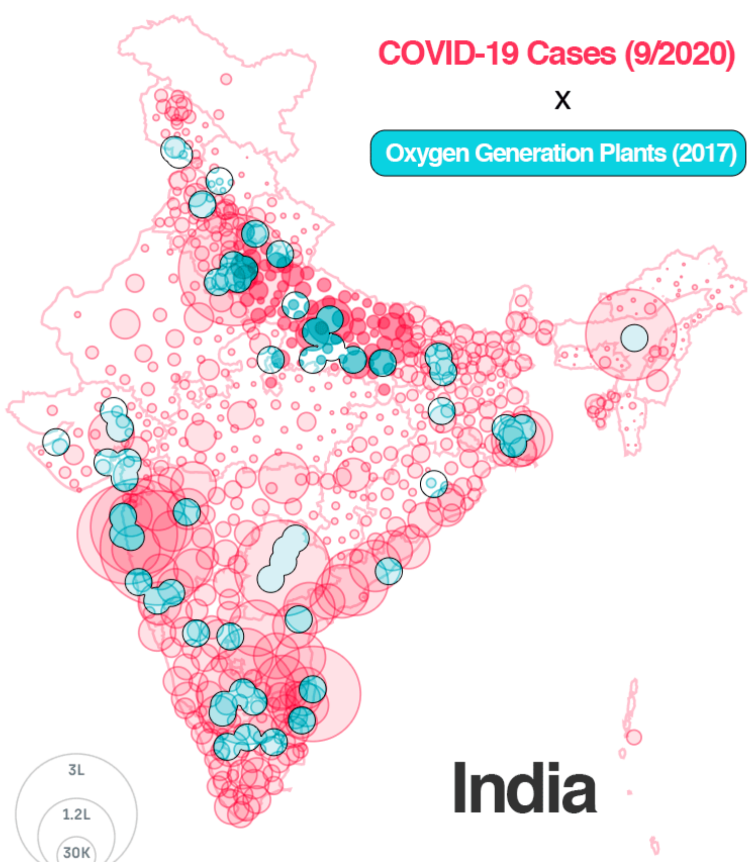
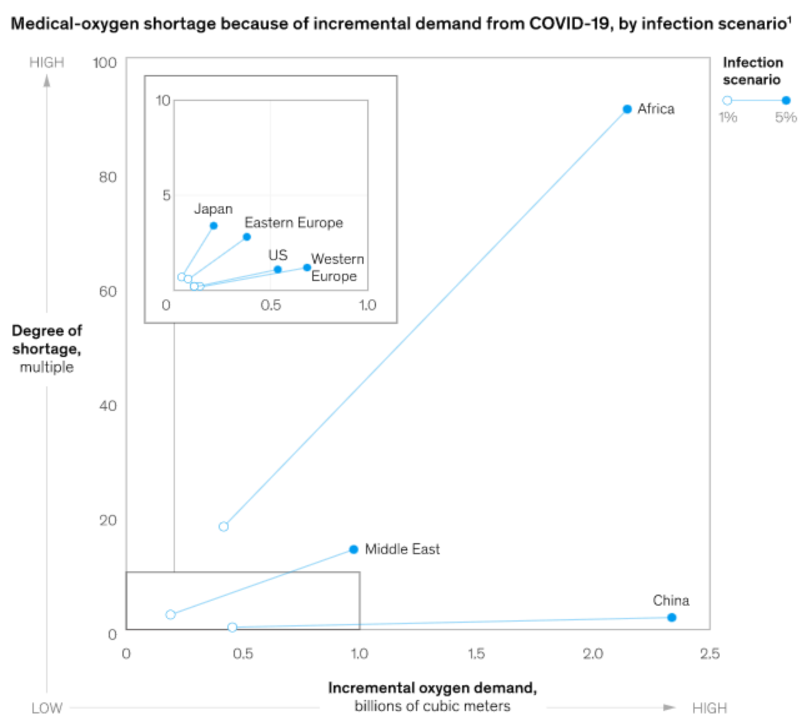
Oxygen Generation During COVID-19

The Problem

- According to the WHO, with 1 million new cases of COVID each week **the world needs an additional 620,000 cubic meters of medical oxygen gas each day**, equivalent of 88,000 large 5ft long cylinder tanks, to fight the virus. [Source: U. of Minnesota / WHO, June 6]
- **One cylinder tank treats about one adult per day**; the **daily price** of a "J" cylinder of oxygen **ranges from $112 in Guinea, (including transport), to $23 in Kenya.** COVID has further created price-gouging and black markets - in Peru, a **tank now costs 10x more than in 2019**.
- Degrees of shortage and actual need volume vary massively around the world, with China needing the most volume and Africa being under-supplied. [Source: McKinsey , August 25]
- Expanding capability is costly - *"170,000 concentrators can be made available over the next 6 months, with a value of US$100 million dollars"*. That wholesale price tag is $588 per concentrator, well below the usual market value of $1,500+. [Source: WHO]





Executive Summary

The current problem of Oxygen availability is multi-fold; generation is at the base of the issue (not enough plants and concentrators), followed by distribution and efficiency in medical usage. The global optimal need of concentrated medical O2 was estimated at 10 Billion L per day; the likely real usage was closer to 2 Billion Liters O_2, pre-COVID. Source: PATH / OSMS Estimate

A COVID patient requires 10L of Oxygen per minute in the severe stage, and 30L of Oxygen per minute in the critical stage (usually at the stage of invasive ventilation). Extrapolating the June 6 WHO estimate based on 1 million infections per day, **COVID creates an added demand of 620 million liters** of Medical Oxygen gas per day, or **an added 30+% load on the system**.

Most **large, efficient hospital systems use delivered liquid oxygen** that can be stored in large tanks on-site, but this requires a developed industry. Here is a **cost comparison** of existing solutions:

Type	Philipps M10	HVO 120	180 LOx Delivery	Peruvian 25m3 PSA
Liters per Day	14,400L[1]	172,800L[2]	154,980L[3]	600,000L[4]
Purchase Price	$1,500	$45,000	$175 per delivery[5]	$300,000
Cost to produce 100 M Liters O2 in 200 days[6]	**$52,083**	**$130,208**	**$112,917**	**$250,000**

Personal concentrators surprisingly offer the best price per Liter of Oxygen generated. They are in hospital emergency use already, but it remains to be seen how efficient these machines will be in a real-world environment with many patients needing oxygen simultaneously.
The WHO warns that personal concentrators have maintenance and output issues.
The currently most promising low cost solution is **OxiKit, a DIY Open Source Oxygen Concentrator** that can potentially generate 15L/minute. Testing and replication is underway by multiple groups.
A secondary solution is to **encourage diversion of 5-10% of industrial LOX production** with the help of local government partners.

[1] 10L per minute, *60*24=14,400
[2] 120L per minute, *60*24=172,800
[3] assuming one 180L LOx Dewar can be refilled per day; the expansion factor of Oxygen is 861, so 180*861=154,980L of Oxygen gas.
[4] 25m3 per hour = 25,000L per hour, *24 = 600,000L per day
[5] Average U.S. price, not known for particular other countries
[6] Discounted or multiplied depending on output, meaning you'd need 34 M10s running in parallel, 3 HVO 120s, only 80% of the plant etc.

Crisis Zones

South America

Guatemala

[research in progress]

Ecuador

[research in progress]

Bolivia

- There's been a monopoly on liquid oxygen since 10 years, and due to an extremely high purity standard set by the Bolivian government, nobody can compete with them. During COVID, the company has since quadrupled (!) the price of liquid oxygen. The **sole location of liquid oxygen in Bolivia is Santa Cruz**, as shown on the map
- A single trucking convoy shipment of 66 tons of LOx was mentioned in transit to the capital (likely, 2 trucks); political clashes allegedly delayed the shipment. Source: Washington Post, August 13
- A hospital purchased their own PSA Plant with enough production for 10 ICU and 5 emergency care units, so approx. 6-8m3/hr. Source: El Deber, July 16
- Quillacollo said they're building an oxygen plant but nothing has been accomplished so far
- Another plant is planned to be opened in mid-October.
- University in Ururu, UTO, is creating a local oxygen plant since they have good funding but don't have a schedule of setup yet.
- Another industrial plant that made oxygen for metal-mending is now diverting its oxygen production towards medical purposes. The medical team contacted the Ministry of Public Works, and the ministry is now trying to repurpose the engine, but COVID has slowed that work a lot, and it is not complete.
- All government agencies are experiencing a huge shortage of funding; some hospital workers have not been paid for 5 months despite 12-14 hour days.

- Road blockades caused around 40 people dead due to the lack of supply of Oxygen
- IBNORCA is the standards agency; testing concentrators and certification is extremely difficult usually. The press picked up the issue, and demand for change is strong, so the ministry is now cooperating on making access to regulatory testing easier.

Peru

- A flourishing black market of Oxygen is happening in Peru, with private citizens buying for home use. Source: CNN, June 5

- People buy a tank for nearly $1,500 (a 1000% price increase above normal) on the black market, and then get refills for $26/day - a fortune for many people in Peru. Source: Washington Post, June 18
- The biggest issue is price gouging, and people trying to buy their own oxygen tanks. Source: Yahoo News Australia, August 10
- Small Oxygen plants are being built; the materials weigh about 3 tons and cost $300,000; with that scale plant they can produce around 25m3/hour, which fills around 50-70 bottles of oxygen per day and supplies 35-40 ICU beds on an ongoing basis. [which is barely a small hospital at best]
The effort was spearheaded by the

local government. On the right is the main concentrator machine after being unloaded from a military cargo plane. [Source: Government of Peru, Sept 1]

- Another plant was installed in Arequipa; it took 2 months to construct.
- Peru seems to buy PSA plants that can only do around 25m3/hour for slightly more remote regions, such as the POC 8400 model. [Source: Inmatec]

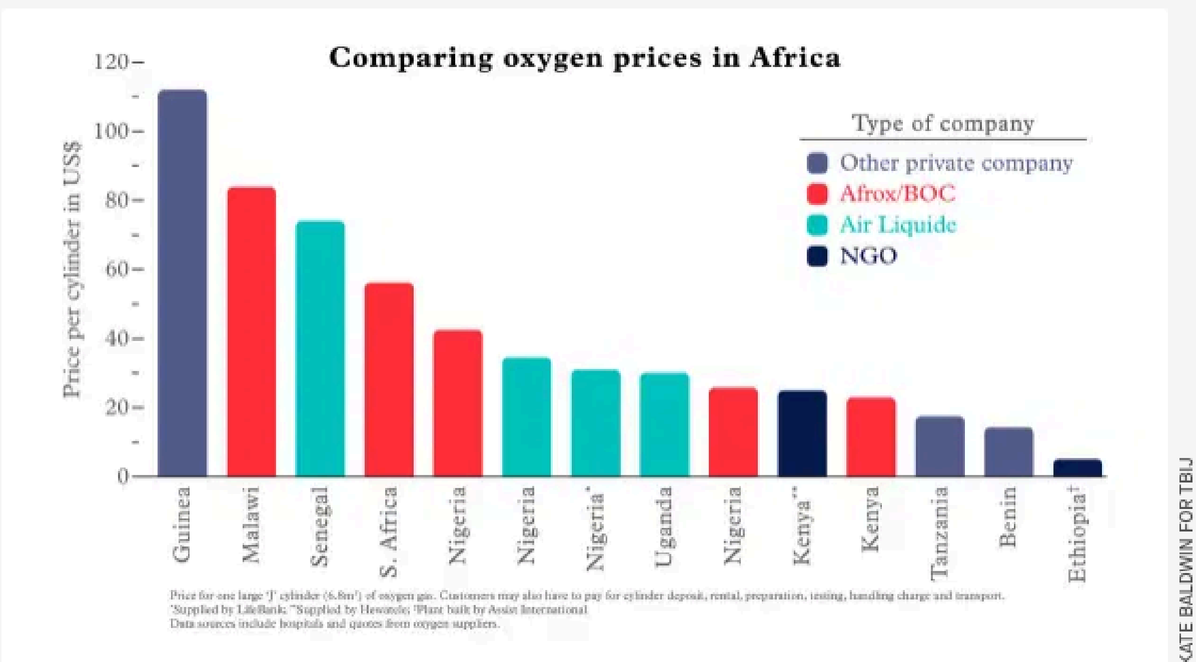
- The Peruvian government announced a plan of nearly $25 million to purchase oxygen [we assume this is liquid oxygen] and $3.2 million to develop plants and generators. [Source: Associated Press, June 5]

- Oxygen plants seem to be along most of Peru, with the main hotspot being Lima, the nation's capital and housing 1/3rd of the population. It also looks obvious that the plants only go up in the Andes, but there seems to be no plant in the Amazon basin (which still houses 25% or so of the country's population).

Africa

Africa has some of the biggest problems with Oxygen globally in fighting the pandemic.

- Much of the problem is the oxygen supply in Africa is dominated by two multinational gas suppliers who dominate the market for oxygen cylinders. They are **being accused of charging unaffordable high prices**; the two companies are
    - **Air Liquide**
    - **Linde Group**
        - Accused specifically of making it difficult for clinics to switch to cheaper systems by trying reduce competition.
        - Before 2013, Linde Group's Kenyan subsidiary, BOC Kenya had a near monopoly on oxygen and **was charging $58 per J cylinder**, **plus additional fees for transport and a cylinder deposit and leasing fee**.



There are a number of ongoing solutions and efforts on a large scale that happened pre-COVID:

- **Independent Oxygen Plants**
    - Dr. Steve Adudans and Dr. Bernard Olayo, of **Kenya's Center for Public Health and Development, acquired funding and built their own oxygen plants** under the name Hewatele, and installed 3 plants between 2014 and 2018. They created a system of drop off and pick up of cylinders directly from hospitals and clinics for free (the

"milkman model"), and provided rural areas with oxygen for the first time. They charged $25 for a J cylinder, and within a year BOC reduced its prices in order to compete which boosted the overall supply in the market.

- **Oxygen Concentrators**
  - Professor Roger Reasool, a physicist at the University of Melbourne, has developed the FREO2 concentrators in2017 that can run on solar or river power and have a "bladder" which stores oxygen and continues supplying patients when the power goes off.
  - In a trial at Mbarara hospital in Uganda, the machines eliminated oxygen shortages and cut the number of cylinders used in three months from 77 down to 2.

Source: QZ, August 11

Source: AP News

Rwanda

[research in progress]

Guinea

- In Guinea, **not a single hospital bed has a direct oxygen supply**, and the daily deliveries of cylinders are taking their toll on budgets, with each one costing $115.
-

Congo

- Only 2% of healthcare facilities have oxygen on hand

Tanzania

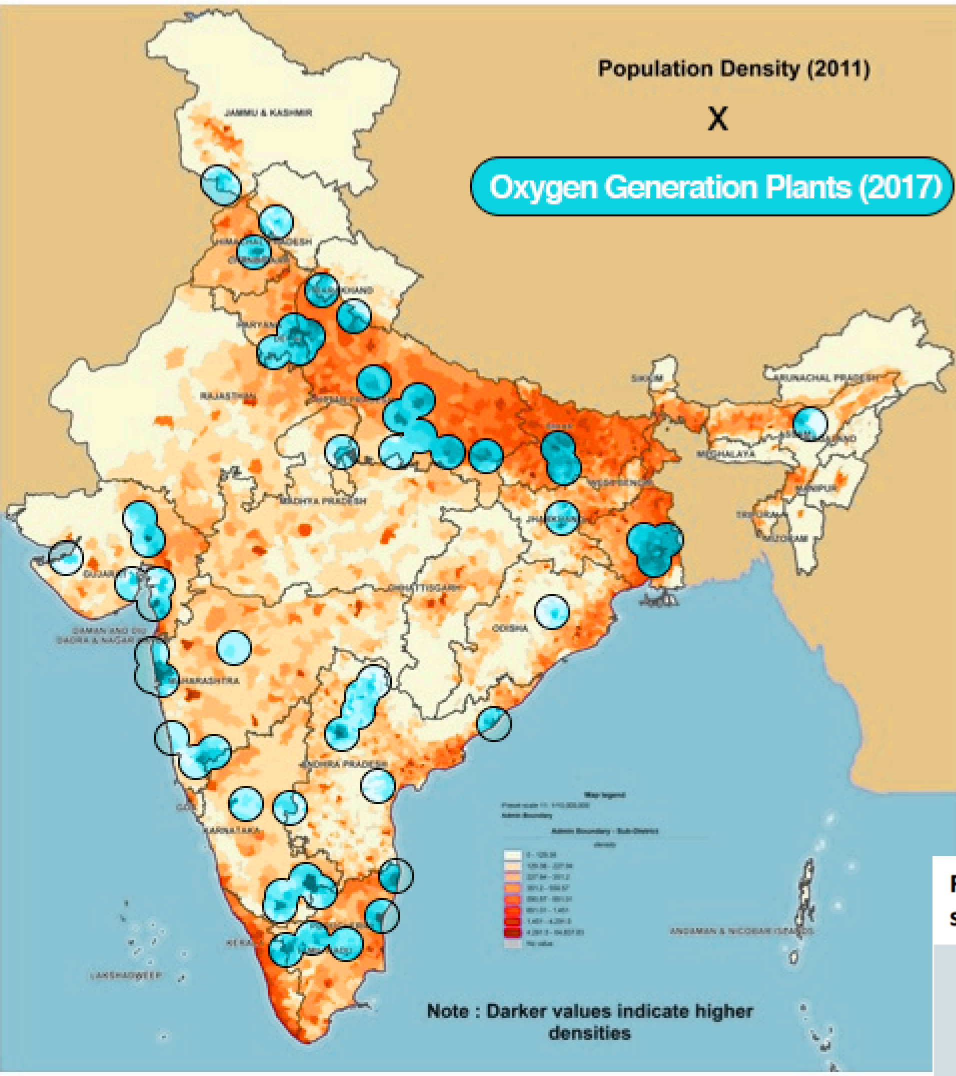
- Only 8% of healthcare facilities have oxygen

South Asia

Bangladesh

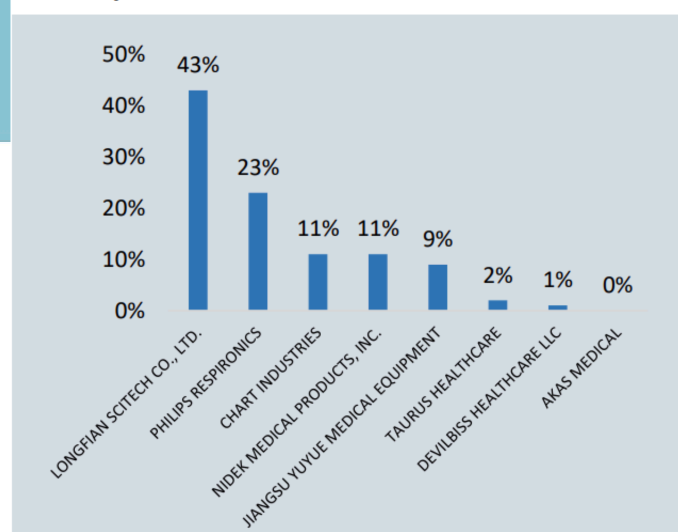
- Only 7% of healthcare facilities have oxygen. Source: AP News

India



- **Demand has tripled** in certain parts of India due to rising case numbers. Source: [Al Jazeera, September 16]
- Assessment by the PATH team in 2017 located 30 providers operating LOX (liquid oxygen) and PSA (compressed gas oxygen) plants around India. The blue circles indicate a 50km radius around each plant, which serve as a distribution threshold. If a hospital outside of this 50km radius requests a delivery, the supplier either charges a surplus, or does not deliver - ergo, **geographic location plays a huge part in the availability of oxygen**. Source: PATH, 2017 / India Census 2011 / OSMS Data Visualization / Covid19India

Figure 6. India oxygen concentrator public-sector market share by manufacturer, when known.



- Air Products, a smaller manufacturer, reported more than a 100% increase in demand. **Some Indian hospitals are partially reporting a tripling and even quadrupling in demand and usage.** Patients had to be moved to other hospitals due to oxygen shortages. Their consumption is approx. 24L per bed per day. Some plants had to shut down, which created further shortages and required the import of oxygen from other states. Source: Deccan Herald, August 19
- A dedicated, detailed report on access was made for India by PATH in 2017. Link to Report

- Indian industry is at least partially retooling and diverting LOX production to medical applications, which is being commissioned in turn by local governments. Source: Air Products India, May 2020
- 66% of the oxygen generation market in India is controlled by two companies. Source: PATH, 2017

Problem Analysis & Solutions

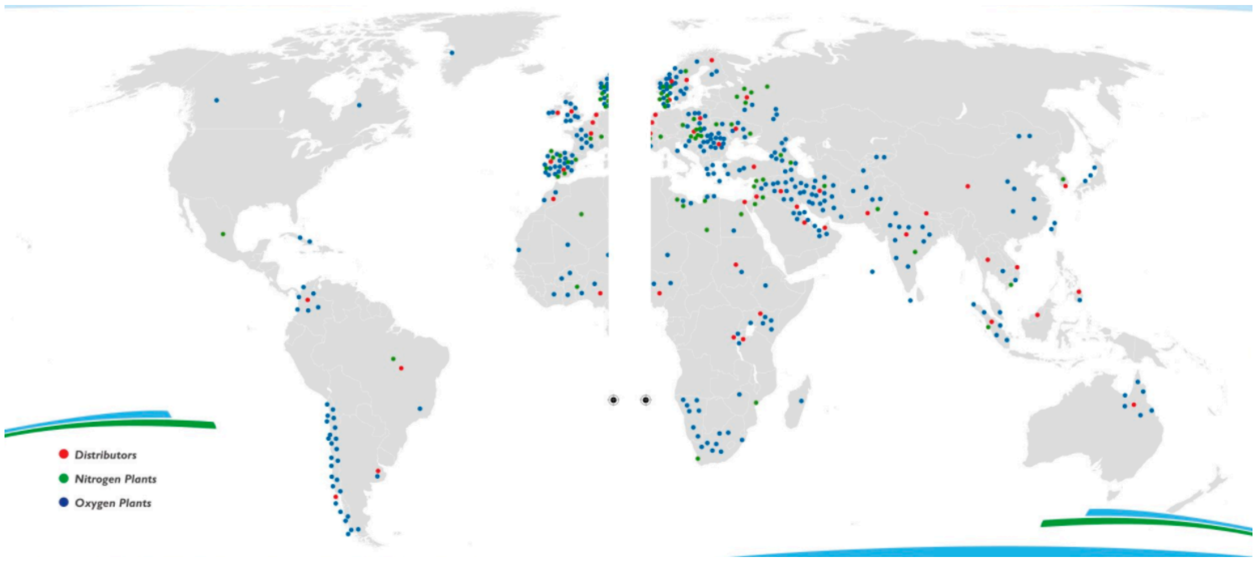
Global & Local Production Estimation

It's very difficult to evaluate actual Medical Oxygen production capability around the world, as countries do not publish this sort of data in a uniform way, and some LOX plants are meant for industrial use only and won't show up in medical literature or research Pre-COVID.

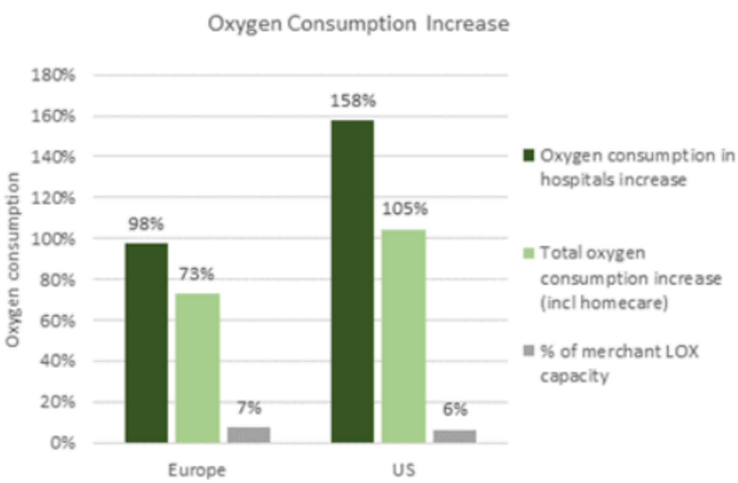
It is important to note that oxygen shortage is not just a "developing world issue, according to the CEO of Novair: *"We are seeing that oxygen supply is becoming a matter of general concern. In developed countries, **despite the large existing capacities, the system for delivering liquid oxygen and bottles has reached its limits**. We are informed that there is a lack of medical oxygen in some places, and we are requested to supply oxygen generators to hospitals to support the existing oxygen source."*

One potential way of getting the big picture is to use recent trade association reports of the manufacturers: The **global oxygen market was worth $37.93 billion in 2019**. It is expected to grow at a compound annual growth rate (CAGR) of 11% and reach $59.17 billion by 2023.

We can also look at individual manufacturers' publications, such as OxyMat's Map which has decent distribution in the west coast of South America, for example:

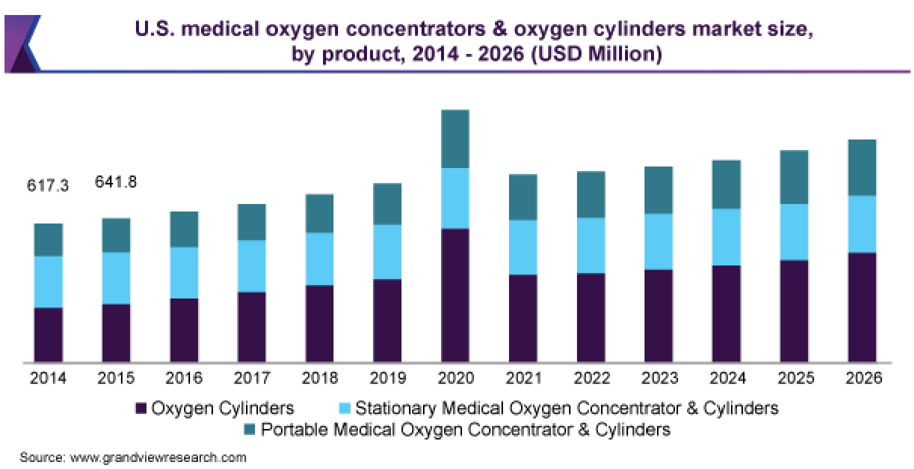


Pre-COVID, the global demand for medical oxygen was largely driven by Pneumonia-induced Hypoxemia, with **around 1.5-2.7 million patients** needing oxygen therapy for that condition. [Source: NIH, 2010]



Medical Oxygen consumption has since gone up by 100-150% in Europe and the US due to COVID. [Source: Center for Global Development]

There's an industry expectation that oxygen consumption will decrease back to base growth rate in 2021. [Source: Grandview Research, May 2020]



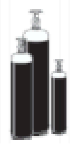
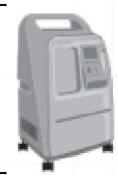
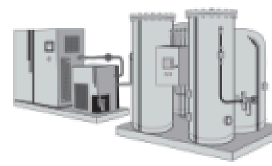
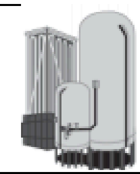
As of 2019, **35% of the world's medical oxygen generation market was in personal concentrators**, and **nearly 60% of applications were in home use** (!). Due to COVID, the non-homecare applications have increased significantly, but include repurposing of personal concentrators in wall-mounted hospital applications. As of 2019, **32% of the world's oxygen generation revenue was from North America.** Source: Grandview Research

The Gates Foundation financed a speculative model of Oxygen as a utility in 2019.

Another dimension we can look at is the actual consumption of atmospheric oxygen, which might have some correlation. Currently, the planet consumes 32.8 Gigatonnes of atmospheric O2 per year. Source: ScienceDirect, 2018

Oxygen Sources & Storage via WHO

Table 2: Description and comparison of oxygen sources and storage[1]

	Cylinders	Concentrators (PSA)	Oxygen plant (PSA)	Liquid oxygen
General characteristic				
Image				
Description	A refillable cylindrical storage vessel used to store and transport oxygen in compressed gas form. Cylinders are refilled at a gas generating plant and thus require transportation to and from the plant	A self-contained, electrically powered medical device designed to concentrate oxygen from ambient air, using PSA technology.	An onsite oxygen generating system using PSA technology, which supplies high-pressure oxygen throughout a facility via a central pipeline system, or via cylinders refilled by the plant.	Bulk liquid oxygen generated off-site and stored in a large tank and supplied throughout a health facility pipeline system. Tank requires refilling by liquid oxygen supplier.
Clinical application and/or use case	Can be used for all oxygen needs, including high-pressure supply and in facilities where power supply is intermittent or unreliable. Also used for ambulatory service or patient transport. Used as a backup for other systems.	Used to deliver oxygen at the bedside or within close proximity to patient areas. A single concentrator can service several beds with the use of a flowmeter stand to split output flow.	Can be used for all oxygen needs, including high-pressure supply.	Can be used for all oxygen needs, including high- pressure supply and in facilities where power supply is intermittent or unreliable.
Distribution mechanism	Connected to manifold of central/sub-central pipeline distribution system, or directly connected to patient with flowmeter and tubing.	Direct to patient with tubing or through a flowmeter stand.	Central/ sub-central pipeline distribution system, or can be used to refill cylinders that can be connected to manifold systems in the facility.	Central pipeline distribution system.
Electricity requirement	No	Yes	Yes	No
Maintenance requirement	Limited maintenance required by trained technicians.	Moderate maintenance required by trained technicians, who could be in-house.	Significant maintenance of system and piping required by highly trained technicians and engineers, can be provided as part of contract.	Significant maintenance of system and piping required by highly trained technicians and engineers, can be provided as part of contract.
User care	Moderate; regular checks of fittings and connections, regular checks of oxygen levels, cleaning exterior.	Moderate; cleaning of filters and device exterior.	Minimal; at terminal unit only.	Minimal; at terminal unit only.
Merits	– No power source.	– Continuous oxygen supply (if power available) at low running cost. – Output flow can be split among multiple patients.	– Can be cost-effective for large facilities. – Continuous oxygen supply.	– 99% oxygen obtained. – High oxygen output for small space requirement.
Drawbacks	– Requires transport/ supply chain. – Exhaustible supply. – Highly reliant upon supplier. – Risk of gas leakage. – Risk of unwanted relocation.	– Low pressure output, usually not suitable for CPAP or ventilators. – Requires uninterrupted power. – Requires backup cylinder supply. – Requires maintenance.	– High capital investments. – Requires uninterrupted power. Needs adequate infrastructure. – High maintenance for piping. – Requires backup cylinder supply. – Risk of gas leakage from piping system.	– Requires transport/ supply chain. – Exhaustible supply. – High maintenance for piping. – Needs adequate infrastructure. – Requires backup cylinder supply. – Risk of gas leakage from piping system.

3 pathways to Oxygen Generation:

- **Industrial scale, requiring tank transport or piping**

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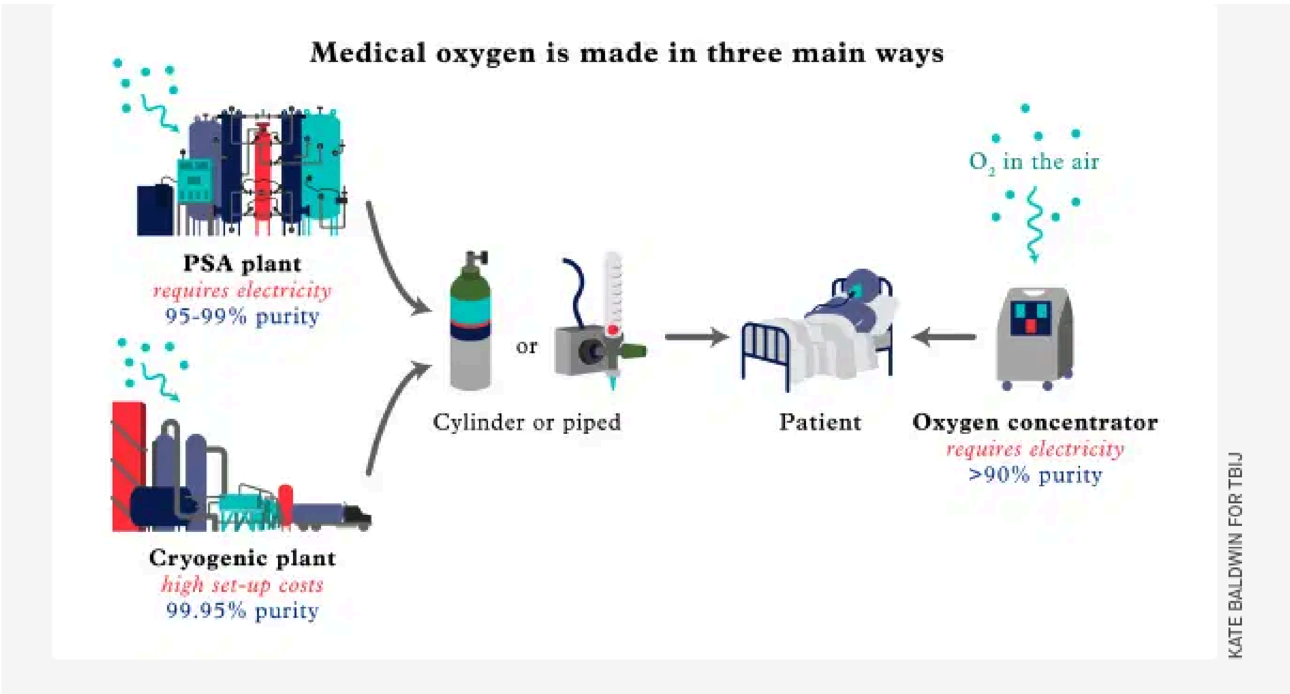
- PSA Plant (end result: compressed oxygen gas, most efficient at smaller volumes)
- Cryogenic Plant (transient result: liquid oxygen, most efficient at large volumes)
- **Personal scale, 1 machine per patient**
    - Oxygen concentrator (directly delivered to a breathing patient)

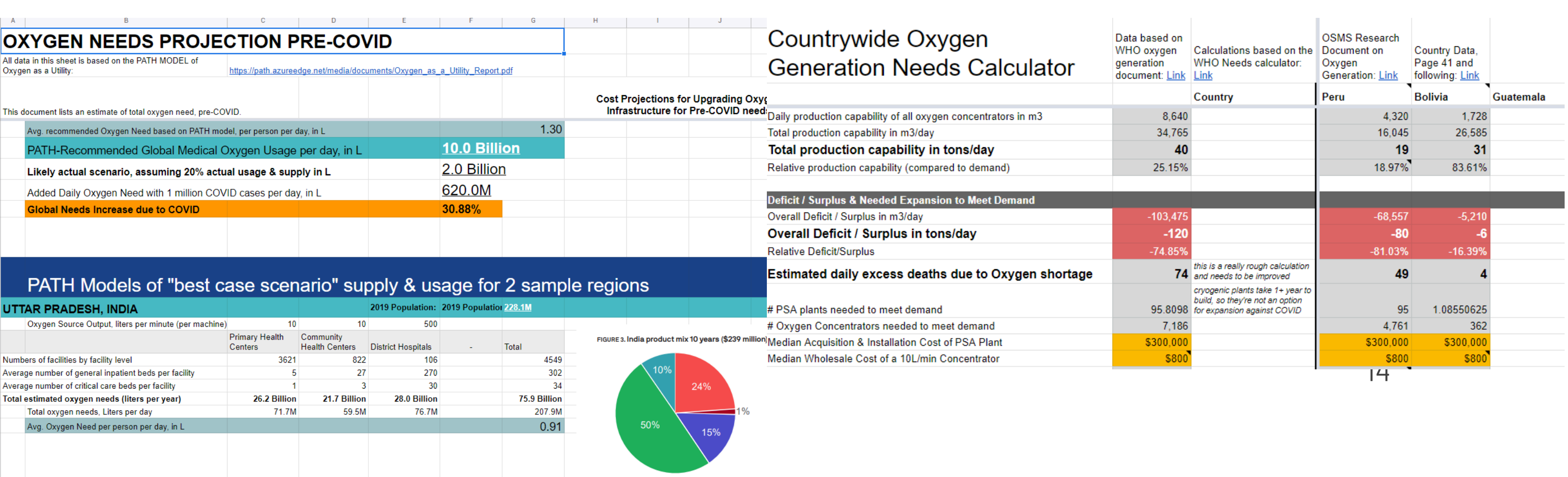


https://en.wikipedia.org/wiki/Oxygen_therapy#Storage_and_sources

OSMS Oxygen Demand & Shortage Modeling / Calculator

OSMS has put together a rudimentary calculator and modeling tool that we can apply to different countries and different COVID scenarios. It's a *simplified amalgamate version* of the UNICEF Oxygen Systems Planning Tool and the WHO Essential Supplies Forecasting tool, combined with market research and PATH's oxygen demand modeling.

>>Link to Calculator<<



Gaseous Oxygen Math & Daily Need per Patient

A severe COVID patient needs a base line of around 10 liters of gaseous oxygen per minute (specifically, 5-15L/min, 10 is the median most orgs use). [Source: Partners in Health, April 21]

Table 1: Sample oxygen flow planning per 100 bed facility

Hypothetical 100 bed COVID-19 treatment facility				
Disease severity	Avg. O_2 flow rate		Size of solutions of scale*	
	per patient	Total	PSA Plant	Bulk liquid
Severe 75 patients	10 L/min	75 * 10 * 60 = 45,000 L/hr	= 45 m^3/hr	= 1.25 m^3/day
Critical 25 patients	30 L/min	25 x 30 x 60 = 45,000 L/hr	= 45 m^3/hr	= 1.25 m^3/day
			= 90 m^3/hr	= 2.5 m^3/day

However, as the disease worsens, **critical patients need 30L/min** as displayed in the table on the right. **A hospital with 100 average COVID patients needs about 2,160m3 of oxygen gas (or 2.7m3 of liquid oxygen, each weighing about 3.1 tonnes) per day.**
[Source: WHO, April 4]

Now to the math: 1,000 L of uncompressed Oxygen gas is contained in one Cubic Meter, m^3. When **inside a tank, the gas is compressed around 161 times** - so a 5ft tall cylinder (a "J" cylinder, or "M265") only has 46.4L of "water volume" but holds around 7500L of gas compressed to the cylinder. This can be confusing when trying to compare methods and numbers, so be mindful that **in an oxygen context, Liters are used for volume, not weight.**

MEDICAL OXYGEN TANK SPECIFICATIONS

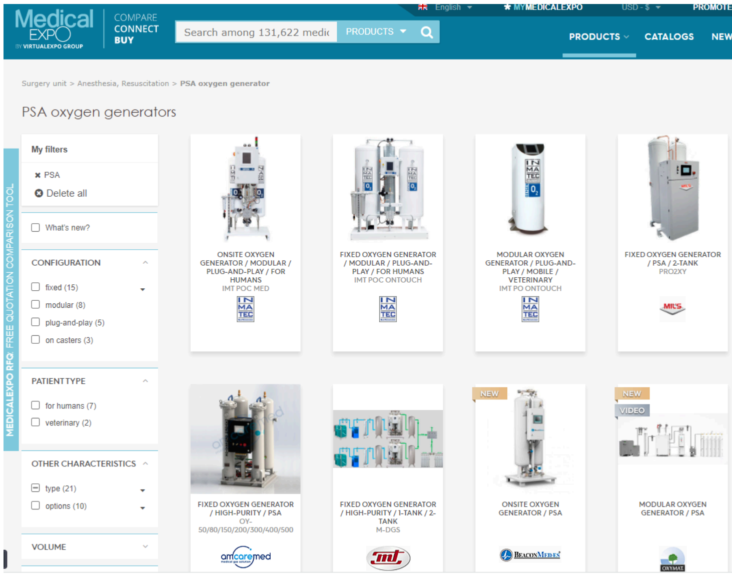
PART #	SERVICE PRESSURE psi	SERVICE PRESSURE bar	WATER CAPACITY lbs	WATER CAPACITY liters	DIAMETER in	DIAMETER mm	LENGTH in	LENGTH mm	CYLINDER WEIGHT lbs	CYLINDER WEIGHT kgs	OXYGEN cu ft	OXYGEN liters
M265	2216	153	102.2	46.4	9.80	248.9	51.7	1313	84.7	38.4	265	7503
M150	2015	139	63.7	28.9	8.00	203.2	47.2	1198	49.2	22.3	150	4248
M122	2216	153	47.1	21.4	8.00	203.2	36.2	919	40.3	17.9	122	3455
M90	2216	153	34.7	15.7	7.25	184.2	32.7	830	30.4	13.7	90	2549
M60	2216	153	23.2	10.5	7.25	184.2	23.1	587	22.3	10.1	60	1699

Oxygen gas can be produced by personal oxygen concentrators, or so-called Pressure Swing Absorption plants utilizing Zeolites that separate Oxygen and Nitrogen inside a compressor. Power needs and effectiveness vary from plant to plant, but here's a mid-size plant as an example for resources required:

O2 output	Compressor Power	Chiller Power	Power Cost	Foot Print
400 m3/day	400 HP or 276 kW	150 HP or 80 kW	0.75 kW/ m3	190 m2

One PSA plant produces between 2-190m3 of oxygen per hour (that is, 48-4,500m3/day) Source: Oxymat.com and weigh about 1.5-20 tons each. Source: AirSep
Example: A Peruvian PSA plant purchased to fight the COVID shortage produced 25m3/hour, and cost approx. $300,000 for purchase and installation. Source: Peruvian Government
This means it produces around 25,000L of Oxygen per hour, enough to fill 80 "J" cylinders in a day if the plant runs at a 24 hour shift. The Peruvian government claimed around 50-70 cylinders per day so we can assume this plant runs around 18 hours per day.

Relatively large, deployable Oxygen Concentrator Systems (DOCS) machines produce 50-200 Liters per minute. Source: PCI Gases



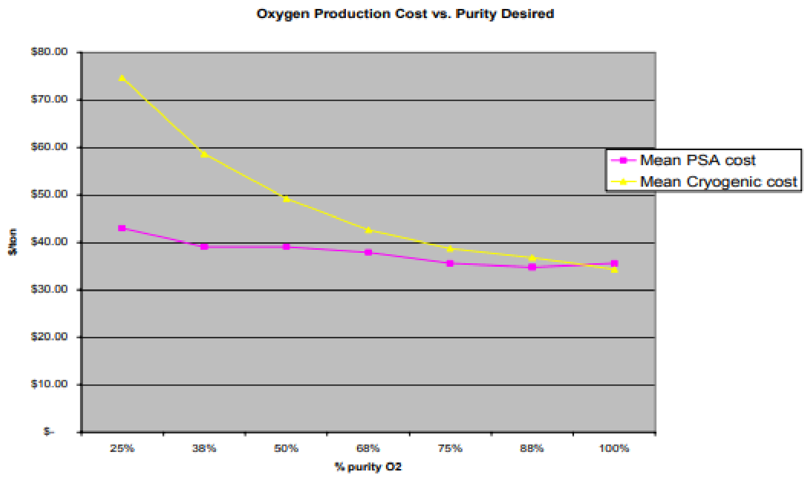
Further yet, smaller HVO (High Volume Oxygen) machines cost, for example, $45,000 per unit, $450/month in power and maintenance, and can produce 120 Liters per Minute. Source: High Volume Oxygen

There is an international marketplace for medical oxygen generation and PSA plants which could be utilized by larger non-profits and governments, called MedicalExpo .

Market studies might give deeper insight in the overall market, but are expensive to obtain. Source: Marketwatch, May 2020

Installation lead time for a skid-mounted PSA is now down to close to 2 weeks in the developed world, according to the CEO of Novair.

Figure 3: Oxygen Production Cost vs. Purity Desired



Source: Tuson 1994

Liquid Oxygen Math

With advanced technology, it is possible to generate liquid oxygen at -183°C, which allows for much faster transport but sharply increases maintenance needs and requirements for highly trained engineers, as well as cooling infrastructure.

At scale though, and for the purity required in medical oxygen, the generation cost of PSA systems and cryogenic systems is very similar (graphic on the right).

The expansion ratio for LOx is: **1 L of liquid oxygen turns into 861 L uncompressed oxygen gas**. This is a formula of volume, so weight remains constant but volume changes.

When liquid oxygen is transported, the transport capability is usually measured in metric tonnes, which is a weight unit. **1L of liquid oxygen weighs about 1.14kg**. So 1 metric ton of liquid Oxygen = 1000kg of liquid oxygen = 876L of liquid oxygen = 0.876m3 of liquid oxygen.
When this liquid Oxygen is converted into its gaseous, uncompressed form, it expands 861 times, so 876L of LOx expands to 754,236L or 754m3 of uncompressed Oxygen gas.
That means, **1 metric ton of liquid oxygen delivers as much oxygen gas as 100 "J" cylinders** (each of which has a capacity of 7500L of uncompressed Oxygen gas).

Liquid oxygen is transported in large cryogenic tanker trucks (above), or in large barrels (on the right).

An average tanker trailer has about 7,700 Gallons / 29,147L capacity, about 33 metric tonnes of liquid oxygen. Source: Bulktransporter

A typical cryogenic liquid oxygen dewar (vacuum-encased barrel) is 5.2ft tall and has a volume of 180L. When empty, it weighs around 118kg and is then filled with 186kg of liquid oxygen - so **the barrel weighs about 304kg (672lbs) when full**. Source: AirProducts.
One of these 180L liquid oxygen barrels delivers as much oxygen as 21 "J" Cylinders: 154,980L of uncompressed oxygen gas.

Refilling one of the barrels costs $100-200 in the United States.
Source: Highvolumeoxygen

To receive LOX at a hospital, it needs to install a $20,000+ tank to store it for consumption.

Liquid Oxygen plants can be massive - the **largest in the world** is in South Africa, took 3 years and around $300 Million to build, houses the largest compressor ever built, employs 800 people and **produces 5,000 tons (!!) of liquid oxygen per day**. Source: AirLiquide
While this LOx is meant for industrial purposes, its high level of purity makes it likely to be useable in a medical context; many industrial LOx plants around the world have committed to **reserve 10-30% of output for COVID** fighting purposes. Source: AirProducts
In terms of large-scale international aid, one method could be to buy LOx in bulk and ship it across Africa and even overseas, as absurd as this sounds.

Current projections are that Merchant/**Industrial LOX production has been pivoted by 6-7% towards supplying healthcare facilities fighting COVID**. Source: Center for Global Development, May 2020

You can also use this converter to calculate oxygen volume and weight in its different forms.

Unit Conversion Data for Oxygen

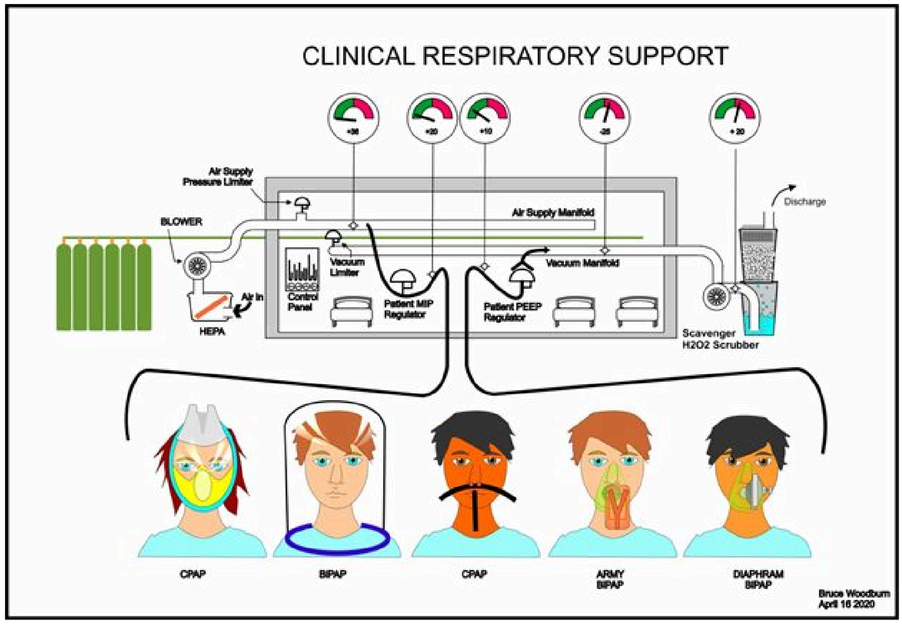
	Weight		Gas		Liquid	
	pounds (lb)	kilograms (kg)	cubic feet (scf)	cu meters (Nm^3)	gallons (gal)	liters (l)
1 pound	1.0	0.4536	12.076	0.3174	0.105	0.3977
1 kilogram	2.205	1.0	26.62	0.6998	0.2316	0.8767
1 scf gas	0.08281	0.03756	1.0	0.02628	0.008691	0.0329
1 Nm^3 gas	3.151	1.4291	38.04	1.0	0.3310	1.2528
1 gallon liquid	9.527	4.322	115.1	3.025	1.0	3.785
1 liter liquid	2.517	1.1417	30.38	0.7983	0.2642	1.0
1 short ton	2000	907.2	24160	635	209.9	794.5

Scf (standard cubic foot) gas measured at 1 atmosphere and 70°F.
Nm3 (normal cubic meter) gas measured at 1 atmosphere and 0°C.
Liquid measured at 1 atmosphere and boiling temperature.

Now, generating this liquid oxygen requires a dedicated plant. So-called Cryogenic Air Separation Units (ASU) are large plants based on a 130-year-old process of separating gases through their liquid boiling points at extremely low temperatures (around -300°F). They are more efficient than PSAs or concentrators, but only when large volumes of oxygen are required, approx. 10 metric tons per day per plant or more. A medium-size cryogenic plant can cost $60 million to set up. [Source: Aceee.org, 2007]

Oxygen Distribution within Facilities

[COSMIC assembled an open source oxygen delivery setup for non-critical patients] (i.e. for non-invasive ventilation, NIV), which is referred to as a **CRS**, Clinical Respiratory Support.



Commercially Available Personal Concentrators

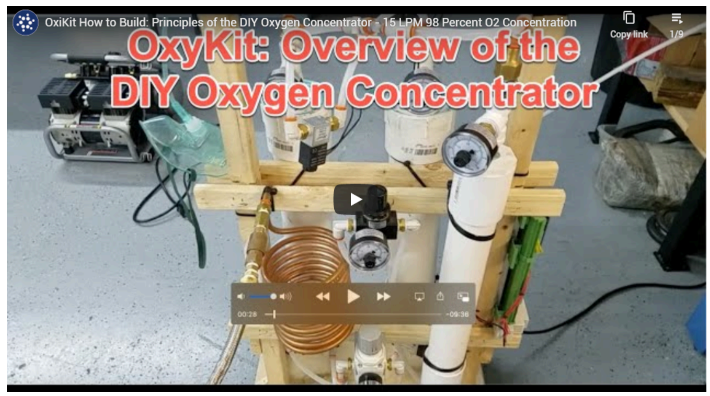
- As a reference point, a **[$1,500 M10 oxygen concentrator]** [from Philipps] **produces around 10 liters of 92% pure oxygen per minute (14,400L per day)**, weighs 53lbs/ 26kg and needs 600W / 6 Amps of power.

  At least 10 liters per minute is required for a non-critical COVID patient; for critical patients, 30 liters per minute are required - so 3 of these machines would have to work in parallel.

- Maintenance issues of the machines are known, so the [WHO recommends that they should only be used with a backup] in place.

Most Promising Grassroots Solution: OxiKit

- www.oxikit.com
- A personal oxygen concentrator allegedly producing 15 liters per minute, at 98% concentration. Very promising design and versatile deployability especially to middle-income countries.
- **The import of Zeolite (the substance used to bind nitrogen) can create delays.** In some countries, there's no domestic production, so foreign shipping is required.
- Finding a strong, oil-free, efficient and reliable compressor can take time in some markets.



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Zeolite

Zeolite is the key component and import bottleneck in building a pressure swing absorption (PSA) oxygen concentrator, and is used as a molecular sieve. There are many types of Zeolites, and research is advised to buy the correct type. Sodium Zeolite was previously used until Lithium Zeolite showed to have better absorption, but is harder to obtain. Source: Taylor and Francis
Li-X Zeolite is the latest and most effective version of Lithium Zeolite. Source: MedicalXPress

- "The most common type of commercial zeolite for oxygen concentration process is zeolite 13X due to its outstanding nitrogen to oxygen adsorption selectivity. However, 13X zeolite modified with Li+ exchange method exhibits a higher nitrogen adsorption capacity at the active cation sites of the zeolite framework [5,6,7]. JLOX-101 LiX zeolite provided by LUOYANG JIANLONG Chemical is designed specifically for a PVSA process with high oxygen selectivity [8]." Source: NIH
- OxiKit's team specifically recommends *"zeolite - Sodium - 13x - 0.5mm Pellet size; order from us by emailing zeo@oxikit.com"*

Pricing of 13X molecular sieve Sodium Zeolite: Zeolite goes from $25 for 1lb up to $400 for 100lbs.
Online Buying Sources 13x Sodium: 1) Brownell, 2) Moistureboss, 3) Deltaadsorbents
Online Buying Source Lithium-X: 1) Jalon 2) Alibaba Catalyst 3) MoistureBoss

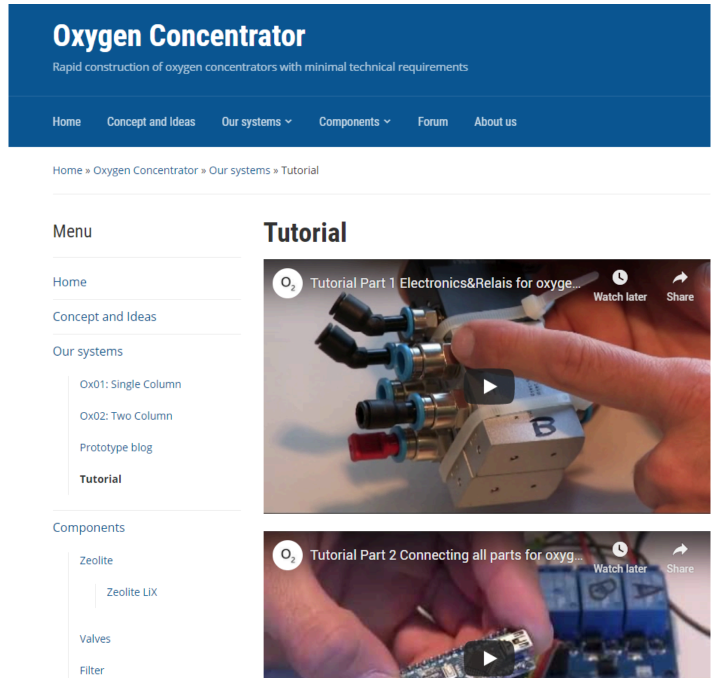
The Potential Role of OSMS in solving the Oxygen Generation Issue

Time is of the essence here; people are dying in real-time due to a lack of medical oxygen and it's primarily an engineering, distribution and economic problem. While requiring cooperation of many stakeholders to successfully solve it, we can do things on our side to move the needle.

Primarily, we can connect the right kinds of stakeholders to each other, filter successful designs and encourage international cooperation among our network.

Action Items [internal document]

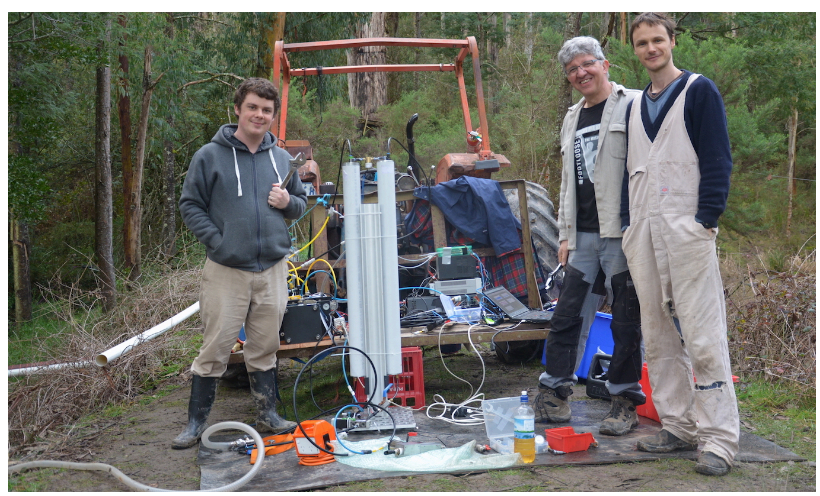
Candidate 2: ETH Zurich Open Source Concentrator



- http://oxygenator.geprojects.tech/
- Detailed tutorials for duplication, detailed instructions on code and materials
- Active community developing and testing since April, but has slowed down on the developer side it seems
- Zeolite guide, but with limited info
- Press coverage happened early on but has slowed down since. Source: MedicalXPress, April 9
- Being developed at ETH Zurich

[Old / just for reference]: FREO2

- www.freo2.org
- Produces about 1.2l/minute, purity unknown.
- Australian foundation that produced an off-the-grid Oxygen Concentrator.
- Originally designed to fight pneumonia
- Runs on solar power primarily, hence useful for extremely rural application, but TBD practicability of transport and installation.
- Flow of 1.2 L/min was continuously maintained to a simulated patient during 30 d on grid power, despite power failures totaling 2.9% of the total time, with durations of 1–176 min.



[Old / Just for Reference]: RepRap Oxygen Concentrator (Open Source)

- https://github.com/RepRapLtd/Oxygen-concentrator
- In preliminary testing phases and doesn't have a functional "in-house" design yet, but an open community of developers
- Volume and purity, as well as practical application, unknown.