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# BLUEPRINT FOR A NATIONAL MEDICAL OXYGEN GRID IN INDIA

October 2022

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# Dedication

This work is dedicated to the many who suffer without access to medical oxygen every day and to the tens of thousands of kind individuals who generously supported India's fight for oxygen during the COVID-19 pandemic.

# Foreword

Although medical oxygen is one of the oldest known therapeutic innovations in medicine, the importance of this intervention has been in sharp focus during the COVID-19 pandemic. Patients with severe COVID-19, which often causes acute respiratory distress syndrome (ARDS), require immediate, high-purity oxygen without which their damaged lungs are unable to maintain blood oxygen levels.  Patients with COVID-related ARDS around the world have died because oxygen supplies were late getting to them or were not of high enough quality.

This report by Laxminarayan, Bhushan, and colleagues describes ways to ensure that the attention that medical oxygen has received can be leveraged to create a broader network – a grid of oxygen resources – that would not only protect against a future pandemic-related oxygen crisis but also prevent tens of thousands of deaths related to childbirth, pneumonia in infants and small children, trauma, cardiovascular disease, and chronic pulmonary disease that are because of a lack of oxygen.  The idea of a national or regional grid could work much like a blood bank that ensures that life-saving blood reaches everywhere.  But to get there we need to both educate health care providers on the value of using medical oxygen to save lives, as well as organize health systems to ensure that a steady and reliable supply of high-quality oxygen is available in all corners of the world.

India is a large country with a diverse geography and population, enormous logistical and public health challenges, and an incredible capability for innovation.  Getting healthcare providers to responsibly use oxygen is an important task. Building a modern information technology platform to then ensure that their demand is visible to suppliers is equally critical.

In recent years, innovations from India in the public health domain have resonated globally.  The Evin platform that was developed and deployed to track vaccines in India is now used beyond India's borders.

It is my hope that no Indian, and indeed, no citizen of any country, dies because of a lack of medical oxygen, and for that reason, having an expansive vision of the future of medical oxygen is important to lay out, as has been done in this report.  I encourage public health policymakers everywhere to treat the issue of expanding access to medical oxygen with the urgency it deserves.

Soumya Swaminathan
Chief Scientist, World Health Organization

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# List of Abbreviations

| S No. | Abbreviation | Expansion |
|---|---|---|
| 1 | AIIMS | All India Institute of Medical Sciences |
| 2 | ASU | air separation unit |
| 3 | BAU | business as usual |
| 4 | CDDEP | Center for Disease Dynamics, Economics and Policy |
| 5 | COPD | chronic obstructive pulmonary disease |
| 6 | COVID-19 | coronavirus disease 2019 |
| 7 | Cr | crore |
| 8 | FMCG | fast-moving consumer goods |
| 9 | GDP | gross domestic product |
| 10 | GPU | gas processing unit |
| 11 | GRAP | graded response action plan |
| 12 | HPCL | Hindustan Petroleum Corporation Limited |
| 13 | HQ | headquarter |
| 14 | ICU | Intensive care unit |
| 15 | INR | Indian rupee |
| 16 | IOCL | Indian Oil Corporation Limited |
| 17 | ISO | International Organization for Standardization |
| 18 | IT | information technology |
| 19 | JSW | Jindal South West |
| 20 | kL | kiloliters |
| 21 | LMO | liquid medical oxygen |
| 22 | LOX | liquid oxygen |
| 23 | LPG | liquified petroleum gas |
| 24 | LPM | liters per minute |

# List of Abbreviations (contd.)

| S No. | Abbreviation | Full Form |
|---|---|---|
| 25 | MT | metric tons |
| 26 | MTPD | metric tons per day |
| 27 | NMOG | national medical oxygen grid |
| 28 | NSSO | National Sample Survey Office |
| 29 | ODAS | oxygen demand aggregation system |
| 30 | ODTS | oxygen digital tracking system |
| 31 | PESO | Petroleum and Explosives Safety Organization |
| 32 | PHC | primary health center |
| 33 | PIB | Press Information Bureau |
| 34 | PM—CARES | Prime Minister's Citizen Assistance and Relief in Emergency Situations |
| 35 | PSA | pressure swing adsorption |
| 36 | PSU | public sector undertaking |
| 37 | PwC | PricewaterhouseCoopers |
| 38 | SME | small and midsized enterprises |
| 39 | WHO | World Health Organization |

# 1. Background

The COVID-19 pandemic is arguably the most far reaching global crisis of the 21st century till date. According to the World Health Organization, 15 million people died and there were billions of cases caused by the deadly virus.

The crisis had multiple facets, including a shortage of medical professionals and limited access to medicines, hospital beds, and monitoring mechanisms, but perhaps the most glaring aspect was the shortage of medical oxygen, especially in low- and middle-income (LMIC) countries, resulting in colossal tragedy and loss of life.

The World Health Organization (WHO) has recognized medical oxygen as a lifesaving essential medicine with no substitution. It has potentially saved of millions of lives, including children and newborns, during pneumonia, malaria, and other ailments.[1]

However, access to medical oxygen is often limited by infrastructure and supply chain challenges. Hospitals typically cannot manufacture it by themselves and are dependent on refillers and liquid medical oxygen (LMO) suppliers. Furthermore, usage is not typically tracked, and systems worldwide are not equipped to handle any needs. This has resulted in the loss of lives that could have otherwise been saved.

Various initiatives have been taken recently to address this medical oxygen crisis. A significant focus area has been on expanding production capacity. This is a laudable and much-needed effort, but a related yet underexplored area has been identifying alternative mechanisms to supply oxygen in a crisis.

Similar mechanisms have been deployed in other sectors, notably electricity; they allow transfer of resources from surplus (production) areas to resource-deficit areas almost seamlessly, using a grid. Most of the supply chain,

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[1] https://www.thelancet.com/action/showPdf?pii=S0140-6736 percent2821 percent2900561-4

logistics, and distribution mechanisms in diverse areas, such as oil and gas, fast-moving consumer goods (FMCG), telecom, and liquefied petroleum gas (LPG), are structured using a grid-like mechanism.

This report builds on this idea and explores the concept of national medical oxygen grids (NMOGs), which can ensure a supply of high-quality oxygen to all parts of a country and smooth out fluctuations in demand. In addition to catering to needs in an emergency, they can also help ensure availability in a nonpandemic/business-as-usual (BAU) scenario and manage childhood illnesses, such as pneumonia.

The report is divided into multiple sections. It begins by offering an in-depth understanding of the supply and demand infrastructure and identifies the magnitude of the need gap. Next, it lists best practices in creating a grid and potential implications for an NMOG. The next section details the concept of NMOG, including its technical design, operating model, governance framework, and information technology (IT) design. It also identifies quality parameters to gauge grid performance. The report concludes by highlighting major recommendations from this study. The report was prepared by analyzing public domain data and consulting industry experts and stakeholders. The data used in some places are specifically from India, but the recommendations are meant for all LMIC countries, aspiring to strengthen their health systems from a medical oxygen availability and usage perspective.

# 2. Executive Summary

## "Oxygen gives life to life"

Medical oxygen is considered a lifesaving essential medicine with no substitute.[2] Typically prepared by liquification followed by fractional distillation of atmospheric air, which has 21 percent oxygen, medical oxygen is highly pure (99.5 percent pure in liquid form), stored and transported in specialized containers, and delivered to patients via a host of gas pipeline systems and medical equipment.

Since its earliest usage, in the late eighteenth century (Grainge 2024), medical oxygen has treated multiple pulmonary and nonpulmonary conditions, such as pneumonia, sepsis, malaria, trauma, and cardiovascular diseases (Stein et al. 2020).

The lifesaving importance of oxygen has been well documented in the medical literature, but the dependence of entire healthcare systems on robust supply lines may have been highlighted best by the COVID-19 pandemic.

### 2.1. COVID 19 Wave 1

In December 2019, the pandemic commenced in China. WHO declared a public health emergency of international concern on January 30, 2020 and a pandemic on March 11, 2020.[3] In its most common form, the disease manifested as a mild to moderate respiratory illness, especially in those with underlying medical conditions, such as cardiovascular disease, diabetes, chronic respiratory disease, or cancer.

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[2] WHO (https://www.who.int/health-topics/oxygen#tab=tab_1)

[3] Time (https://time.com/5791661/who-coronavirus-pandemic-declaration/)

The first case of COVID-19 in India was reported on January 30, 2020. The wave peaked in September 2020, with a seven-day average of daily cases of 93,617 on September 16 and 10,17,705 active cases as the highest for the year. Many strict protocols and measures were enforced, such as social distancing, strict lockdowns, active case detection, isolation, contact tracing, and quarantine.

Considering the novel nature of the infection, the focus was on ramping up testing capacities and medical infrastructure, such as beds, ICUs, and ventilators. The peak oxygen need during Wave 1 in India was estimated to be ~3,095 metric tons (MT) per day.

## 2.2. COVID-19 Wave 2

Wave 2 was much more devastating. India became a pandemic epicenter, second only to the United States. By late April 2021, India had passed 2.5 million active cases and averaged 3,00,000 new cases daily. On April 30, 2021, India reported 400,000 new cases in a single day.[4] On May 9, 2021, India had 4,03,738 new cases and a seven-day average of 3,91,008 cases.

Led by the Delta variant, the wave was characterized by shortages of medical oxygen in almost all parts of the country[5], with reports of long lines of patients waiting for refills and hospital distress calls for oxygen tankers. As per official estimates, production was significantly enhanced, from ~5,700 metric tons per day (MTPD) (August 2020) to ~9,500 MTPD (May 6, 2021). The corresponding sales were almost 9,000 MT on May 6, 2020.[6]

Along with enhanced capacity, other innovative measures were undertaken in both the public and private sectors to meet this increased demand, including adopting the oxygen nurse concept (Maharashtra), using smaller portable LMO cylinders in smaller health facilities (Gujarat), and transporting with special oxygen trains.

The air force and navy increased efforts to assist the civil administration to expedite distribution within the country and worldwide.[7] Oxygen availability was improved by increasing production and imports, adding pressure swing adsorption (PSA) plants, procuring oxygen concentrators, converting nitrogen and argon tankers, and setting up an oxygen digital tracking system for real-time monitoring.[8]

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[4] https://edition.cnn.com/world/live-news/coronavirus-pandemic-vaccine-updates-05-01-1/h_cdd6ab036620523ad156b8347c47448f

[5] https://www.newindianexpress.com/nation/2021/apr/12/covid-19-india-overtakes-brazil-with-second-highest-number-of-cases-2289126.html

[6] Press Information Bureau (PIB) May 10, 2021, Ministry of Commerce and Industry, Center undertakes multiple initiatives to enhance oxygen availability, distribution, and storage infrastructure; availability improved through increasing production and imports, adding PSA plants, and procuring oxygen concentrators; oxygen tanker availability strengthened by conversion of nitrogen and argon tankers, import, domestic manufacturing, and rail and air transportation; oxygen digital tracking system set up for real-time monitoring; last-mile infrastructure strengthened by increasing the number and capacity of cryogenic tankers at hospitals and procuring medical oxygen; General Financial Rules relaxed to fast-track the procurement of critical supplies.

[7] https://www.indiatoday.in/coronavirus-outbreak/story/indian-air-force-navy-step-up-efforts-to-ferry-oxygen-and-medical-supplies-1800056-2021-05-08

[8] https://pib.gov.in/PressReleseDetailm.aspx?PRID=1717459

## 2.3. Wave 2 Aftermath and Measures Undertaken

Considering the limited oxygen infrastructure in the country, a multitude of short- and long-term policy measures were undertaken to prevent a repeat of this crisis.

- **Installing PSA Plants Across the Country**
  Through July 2021, ~1,452 PSA plants were approved by the government for major hospitals nationwide.[9] With support from various state governments and other organizations, around 3,277 were installed by December 2021. To promote installation in private-sector hospitals, the regulations governing establishing medical oxygen facilities on the hospital premises were relaxed and subsidies extended to reduce the capital expenditure required.[10]

- **Increasing Production Capacity for Medical Oxygen**
  LMO production capacity was increased from 5,700 MTPD in August 2020 to 9,690 MTPD in May 2021. This was done by enhancing production in steel and other ASU plants. By December 2021, capacity was 18,860 MTPD.[11]

- **Developing Digital Platforms to Track Demand and Supply**
  Online digital solutions viz. Oxygen Demand Aggregation system (ODAS) and Oxygen Digital Tracking System (ODTS) were developed to ascertain the demand for medical oxygen from all medical facilities and to track their transportation.

- **Importing and Distributing Oxygen Concentrators**
  The central government provided states with ~1,14,000 oxygen concentrators through December 2021; 100,000 were provided through the PM-CARES fund and the remainder provisioned in the Emergency COVID Response Package (ECRP)-II.

- **Improving the Hospital-Level Oxygen Infrastructure**
  Under ECRP-II, approved in July 2021, funds were sanctioned to the states to install 958 LMO storage tanks and medical gas pipeline systems in 1,374 hospitals. In a massive ninefold increase, the central government decided to increase oxygen-supported beds from 50,583 to 4,35,077 via the ECRP-II.

- **Importing and Distributing Oxygen Cylinders/Cryogenic Tankers**
  To augment the number of cryogenic tankers needed to transport LMO, additional tankers were airlifted from abroad, and tankers used for liquid argon and nitrogen were converted. As the majority of smaller health facilities depended on oxygen cylinders, around 1,02,400 cylinders were procured in April and May 2020 and distributed to states. Orders for an additional 1,27,000 cylinders were placed in April 2021 (54,000 jumbo cylinders [D-type] and 73,000 regular cylinders [B-type][12]).

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[9] Secretary, ministry of health and family welfare letter dated 06-07-2021 to all states/UTs

[10] https://blogs.worldbank.org/endpovertyinsouthasia/india-gearing-next-oxygen-emergency-and-improving-health-services

[11] https://www.financialexpress.com/healthcare/covid-19/government-scales-up-oxygen-production-at-18-836-metric-tonnes-towards-preparedness-of-impending-covid-19-wave/2390933/

[12] Press Information Bureau, Government of India

## 2.4. Important Learnings

Wave 2 events highlighted the importance of building robust medical oxygen infrastructure to meet similar emergencies. From a passive supply–demand side equilibrium, the focus shifted to obtaining a detailed understanding of the landscape and supply lines, with various processes and steps initiated to strengthen the supply network. Some of the key learnings included the following:

- Demand is largely unpredictable, as oxygen is a lifesaving product; the country needs to be ready for an oxygen emergency.
- Production is largely concentrated in a few regions, rendering prompt transportation and supply a bottleneck during a demand surge.
- The private sector dominates production, distribution, and consumption, but considering the consequences of a shortage, the government must become a stakeholder to ensure public interest during a crisis.
- In a crisis, industrial oxygen was diverted for medical use, but this comes at an opportunity cost to industries dependent on oxygen. A separate medical oxygen source/reserve should be available for contingencies, so that industrial production is not affected.
- As the cost of setting up their own plants is much higher, hospitals are dependent on suppliers.
- Accurate forecasting of demand and monitoring consumption are crucial levers to enable a swift response during any potential surges. Digitalization of the supply chain network and use of modern technologies, such as artificial intelligence, should be leveraged to forecast demand based on consumption patterns.

## 2.5. International Experience

The events leading to the oxygen crisis in India were not unique; other countries also faced similar if less severe challenges. Oxygen containers were stolen in Mexico, families lamented the deaths of their loved ones in Brazil, prices were inflated on the black market in Peru, and patients' families waited under surveillance for refills. Even in the developed world, such as in the United Kingdom, supplies were rationed (Bonnet et al. 2021).

Malawi took one of the most innovative measures. Its oxygen systems typically do not meet its needs, resulting in excess morbidity and mortality from a variety of otherwise treatable illnesses and conditions. Oxygen therapy can treat pneumonia, one of the largest causes of death in children under five, but it is not available for many children in need. Surges in demand due to COVID-19 further emphasized shortfalls in production capacity, equipment, and supplies and the inability of the mechanism to quickly source oxygen from suppliers.

Malawi is now evaluating options for strategic oxygen-production source placement and development of an oxygen-distribution network. The government prepared a national medical oxygen road map that recommends certain steps to ensure adequate availability for the health system; these include emphasis on production modalities and infrastructure,  including bulk liquid oxygen (LOX) storage at key secondary and tertiary health facilities, cylinder manifolds, and direct-to-bedside piping systems.

Other structural support systems include development of policies, standards, and guidelines governing medical oxygen; strengthened advocacy, communications, and partnerships; a system for building the capacity of health workers to safely use medical oxygen, pulse oximetry, and oxygen accessories; strengthened monitoring and evaluation systems for oxygen-access programs and policies; establishment of a protocol for maintenance of production and delivery equipment and supply of spare parts; and capacity-building of biomedical engineers and technicians to manage and maintain respiratory care equipment.

## 2.6. Rationale and Need for NMOG

In the post-COVID-19 world, always ensuring the availability of oxygen in adequate quantity regardless of demand fluctuations has become very important. This becomes even more critical in a densely populated country, such as India, where the health system is in a rapid development phase and still quite fragmented. This means that the institutional oxygen need may grow rapidly, and a crisis may lead to sudden widespread surge in demand that the randomly distributed supply network is unable to meet.

Many of these challenges are not unique to the medical oxygen sector. Other sectors, such as electricity, FMCG, and oil and gas, also have very different points of production and consumption and significantly fluctuating demand. A typical way to mitigate these challenges is by setting up interconnected grids.

A grid is an interconnected network of producers and consumers to facilitate efficient and timely delivery of a product. An NMOG will connect all the manufacturers and distributors and all the base consumption units and ensure efficient and timely availability of oxygen at all places at all times.

The grid is based on following four principles: a) preference for creating large storage reservoir capacity to meet any future exigency needs, b) preference for creating an interconnected network allowing seamless flow from surplus to deficit areas (rather than independent self-sufficient centers), c) preference for public–private partnership models, and d) acting as a means to achieving oxygen self-sufficiency rather than an end goal.

The major feature of the proposed grid is a reliance on oxygen storage, which can be deployed much faster in a crisis. It is also much cheaper than conventional way of increasing production capacities, which may be unused in a BAU scenario. This storage capacity must be in the right amount (which has the highest possibility of warding off a crisis), right form (both liquid and gas), and right location (strategically identified locations).

The storage was estimated using a Monte Carlo methodology, which gave a probabilistic distribution of likely demand in future events. The liquid form was the preferred storage option to minimize the evaporation losses and optimize inventory space. The additional storage capacity will be created at the level of refillers and with some of the large government hospitals, which act as healthcare hubs for a large segment of population.

This storage will work in tandem and sequentially with other sources of oxygen (routine supply, plus new PSA capacities created) (Graded Response Action Plan).

The mechanism is enabled by a robust IT platform, which includes both traditional manual data inputs and technology and IOT devices automatic data collection. The technology layer uses specific sensors, such as for pressure, quality, level, and flow rate, and adopts other inputs, such as GPS coordination, to overcome the challenges associated with manual data entry. The IT platform ensures coordination between different stakeholders and helps in routine monitoring and resource prioritization and allocation during crisis.

Emphasis is placed on a robust monitoring and governance matrix, with capabilities well defined at different levels to monitor the grid functioning. A three-level governance framework is imagined at the local (divisional level), state, and national levels consisting of members from both public and private institutions.

To ensure grid viability, innovative financial resources are envisaged, including social impact bonds, to make it self-sustainable. Specific performance indicators are being defined for quality and compliance. To ensure greater stakeholder participation, policy design using a mix of regulatory and financial incentives to garner higher adoption is emphasized.

Some of the ways in which this grid will help are the following:

- Ensure that oxygen is always available everywhere and, during any spurt in demand, divert from production to consumption points while keeping the other points completely untouched.

- Forecast changes in demand based on patterns of consumption so that it can alter the production or initiate supply procedure and ensure availability as soon as demand is made.

- Ensure that the majority of fluctuations in demand can be met through the existing production volume of medical oxygen and a storage reserve. Dependence on industrial oxygen should be rare.

# 3. Medical Oxygen Demand and Supply Assessment

## 3.1 Demand-Side Assessment

### 3.1.1. Goals of Oxygenation Therapy and Suboptimal Prescription

A literature review reveals that the intent of oxygenation therapy is to ensure that all organs are properly oxygenated. This is usually achieved at an SPO2 level of 94+ percent, which is the treatment goal (British Thoracic Society). To achieve this, different flow rates have been defined by patient condition (Figure 1).

**The goal of oxygen therapy is to avoid the negative consequences associated with tissue hypoxia**

**Targets** Oxygen should be prescribed to achieve a target saturation of 94–98% for most acutely ill patients or 88–92% for patient-specific target range for those at risk of hypercapnic respiratory failure

| Condition | COPD and other conditions requiring controlled or low-dose oxygen therapy | Conditions for which oxygen is required only if hypoxemic | Serious illnesses requiring moderate levels of supplemental oxygen | Critical illnesses requiring high levels of supplemental oxygen |
|---|---|---|---|---|
| Oxygen Flow rate | **1-3 L/Min** | **1-6 L/ min** with nasal cannula<br>**5-10 L/min** with face mask | **1-6 L/ min** with nasal cannula<br>**5-10 L /min** with face mask<br>**15 L /min** if saturation below 85% | **15 L/min** |

Source: British Thoracic Society Guideline for oxygen use in adults in healthcare and emergency settings

*Figure 1. Oxygen Flow Rates*

No precise estimates are available on the compliance with such guidelines, but some evidence suggests suboptimal usage linked to either delayed or no oxygen therapy, low flow rates, or premature discontinuation. This is especially true of conditions where hyperbaric oxygen is indicated as an efficacious primary and/or adjunctive therapy (Kane et al. 2013)[13], such as air or gas embolism, gas gangrene, crush injury, compartment syndrome, acute peripheral ischemia, decompression sickness, enhanced healing in selected wounds.

exceptional blood loss anemia, necrotizing soft tissue infections, osteomyelitis, delayed radiation injury (soft tissue and bony necrosis), compromised skin grafts and flaps, and carbon monoxide poisoning.

However, with poor-quality protocols and compliance mechanisms, patients continue treatment on surgical therapies and broad-spectrum antibiotics only.

Similarly, in chronic obstructive pulmonary diseases (COPDs; such as bronchitis, emphysema, and bronchiectasis), asthma, and tuberculosis, long-term supplemental oxygen has been shown to improve survival outcomes (Stoller et al 2010). However, COPD patients are suboptimally prescribed medical oxygen as a supplemental therapy.

### 3.1.2. Dependance on Accessibility and Financial Affordability

Other than the adequacy of medical prescription, overall healthcare accessibility and affordability also guides medical oxygen usage. This is especially true for LMIC countries, which have a shortage of medical and paramedical staff, such as doctors (who are required to diagnose and prescribe medical oxygen), and physical infrastructure, such as hospitals and hospital beds, where a majority of oxygen is delivered.[14]

At a granular level, accessibility challenges arise in terms of gender, age, social caste, race, etc., which limits access to healthcare and therefore overall usage for different socioeconomic and demographic risk cohorts.

Many LMIC countries have low healthcare affordability, as characterized by high out-of-pocket expenditures, high incidence of catastrophic expenditures, and no social health insurance schemes; this limits access to oxygen, even if the patient has been prescribed it.

### 3.1.3. The Medical Oxygen Demand Assessment Framework

Combining the factors highlighted in the previous two sections, a demand assessment framework illustrates the relative maturity of different health systems in ensuring optimal usage (Figure 2).

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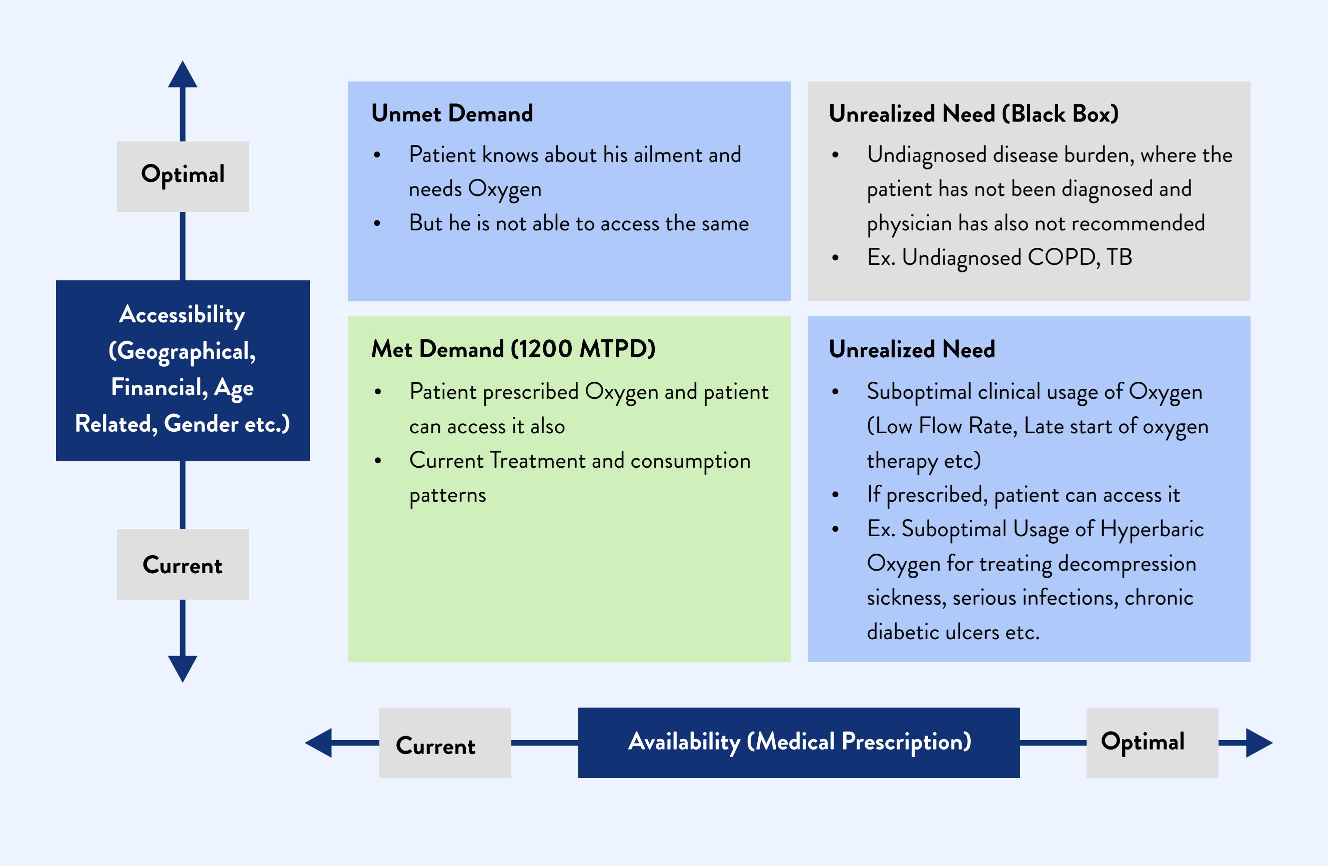
[13] https://uihc.org/health-topics/indications-hyperbaric-oxygen-therapy

[14] A majority of medical oxygen is delivered in an institutional setting, such as a hospital. The number of hospital beds is therefore a good proxy for the relative medical oxygen usage in an area.



**Unmet Demand**

- Patient knows about his ailment and needs Oxygen
- But he is not able to access the same

**Unrealized Need (Black Box)**

- Undiagnosed disease burden, where the patient has not been diagnosed and physician has also not recommended
- Ex. Undiagnosed COPD, TB

**Met Demand (1200 MTPD)**

- Patient prescribed Oxygen and patient can access it also
- Current Treatment and consumption patterns

**Unrealized Need**

- Suboptimal clinical usage of Oxygen (Low Flow Rate, Late start of oxygen therapy etc)
- If prescribed, patient can access it
- Ex. Suboptimal Usage of Hyperbaric Oxygen for treating decompression sickness, serious infections, chronic diabetic ulcers etc.

*Figure 2. Oxygen demand assessment framework*

**3.1.3.1. Lower Left Quadrant (Met Demand):** This segment represents patients who can both access and afford medical oxygen as prescribed. This segment represents the current treatment and consumption patterns. Any estimates of current usage refer to this segment only. This is the most manifested demand, and current supply patterns are oriented to meet it only.

**3.1.3.2. Lower Right Quadrant (Unrealized Need):** This segment represents situations where prescription patterns are suboptimal, despite a medical condition warranting more medical oxygen. This is prevalent in both rural areas, due to lack of trained specialists, and urban areas, where doctors may prefer other therapies, such as surgery or prolonged antibiotic use. This emphasizes the need for standard guidelines or protocols and training health professionals about medical oxygen therapy.

**3.1.3.3. Upper Left Quadrant (Unmet Demand):** This segment represents the patients who could have been prescribed medical oxygen but are unable to access it due to low healthcare accessibility and affordability. This is a significant portion of unmet demand, especially in LMIC countries. It often leads to high disease burden, resulting in preventable deaths. In many cases, the patient is aware of the medical condition and but cannot pay for the prescription. Sometimes, the patient may have been referred to a higher-order medical facility with the physical infrastructure for medical oxygen but is unable to travel for socioeconomic reasons, such as loss of daily wages.

**3.1.3.4. Unrealized Need (Black Box):** This segment represents the undiagnosed disease burden. The patient has neither been diagnosed nor prescribed oxygen, such as for COPD or tuberculosis. This reflects a significant health system constraint that requires a multipronged approach, including larger health system reforms.

**3.1.3.5.** The relative proportion of size of these boxes can indicate the maturity of health systems from a medical oxygen delivery and usage perspective. For example, in India, the oxygen consumption is estimated to be ~1,200 MTPD (non-COVID scenario). However, India has a bed density of ~1.3[15] (versus the world average of 2.5). Furthermore, as per a recent Lancet study (GBD 2016 Healthcare Access and Quality Collaborators), India ranks 145 out of 195 countries in terms of healthcare access and quality. It has one the highest undiagnosed disease burdens.[16] All of these factors indicate that the true need of medical oxygen is expected to be significantly higher than the current consumption of 1,200 MTPD. As the health system matures[17], overall healthcare accessibility and affordability[18] improve, and medical standards evolve with standard treatment protocols for medical oxygen, India will need a significantly higher amount than is currently supplied and consumed.[19] The relative proportion of Met Demand is expected to significantly increase in the future (Figure 3).

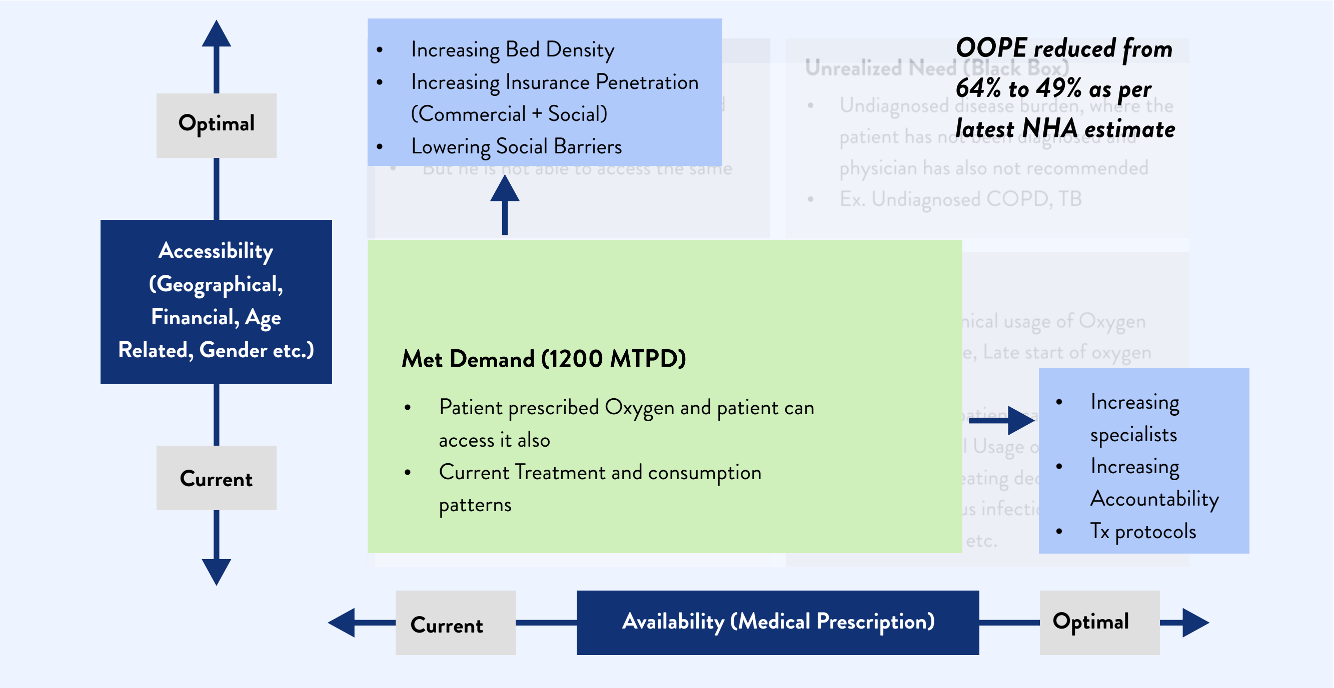


*Figure 3. Future Evolution in Oxygen Consumption Patterns (Shown in Oxygen Demand Assessment)*

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[15] India has ~1,900,000 hospital beds (CDDEP Study). https://cddep.org/wp-content/uploads/2020/04/state-wise-estimates-of-current-beds-and-ventilators_24Apr2020.pdf

[16] Over half a million TB cases are not registered in India. https://idronline.org/indias-missing-tuberculosis-cases/

[17] Illustrative Health Reforms: To provide comprehensive primary healthcare, the government of India launched the Ayushman Bharat Scheme in 2018; 150,000 Ayushman Bharat-Health and Wellness Centers are being set up nationwide by upgrading Sub-Health Centers, Primary Health Centers (PHCs), and Urban PHCs, which provide preventive healthcare and health promotion at the community level, with a continuous care approach. Through other schemes, such as the Pradhan Mantri Swasthya Suraksha Yojana (PMSSY) and Human Resources for Health and Medical Education, efforts are being taken to improve the overall health sector. PMSSY aims at setting up new AIIMS-like institutions and upgrading existing government medical colleges, improving access to tertiary care in underserved areas via HRH-ME, and increasing the availability of health professionals.

[18] OOPE in India has reduced significantly in recent years, highlighting improved financial affordability.

[19] A minority of medical oxygen may be used for patients where it is not indicated. This may not result in a shortfall for other patients, but from a system perspective, it wastes medical resources and should be avoided.

## 3.1.4. Variations in Medical Oxygen Consumption

### 3.1.4.1. By Type and Size of Facility

Oxygen can be used in both institutional (such as hospital, clinic, or nursing home) and noninstitutional or ambulatory (such as home) settings.[20] However, a significant amount is used in the hospital setting. Patients requiring medical oxygen are generally treated as serious and admitted.

Within a hospital, although oxygen is used in multiple areas, such as operation theaters, emergency rooms, ambulances, and wards, a majority is in critical care areas (such as ICUs, CCUs, HDUs, ICCUs). These beds typically constitute ~5 percent of the total hospital bed strength in India.

A bottom-up and top-down approach was attempted to assess the relative medical oxygen usage in different hospitals. However, they do not track oxygen usage at the bed, department, or even unit level. The best available data is the total payment made to medical gas suppliers and corresponding number of oxygen cylinders and liters of LMO received in a defined period. This facility-level consumption data was hence used in a top-down calculation approach to assess the variation in medical oxygen usage by type of facility (Figure 4).

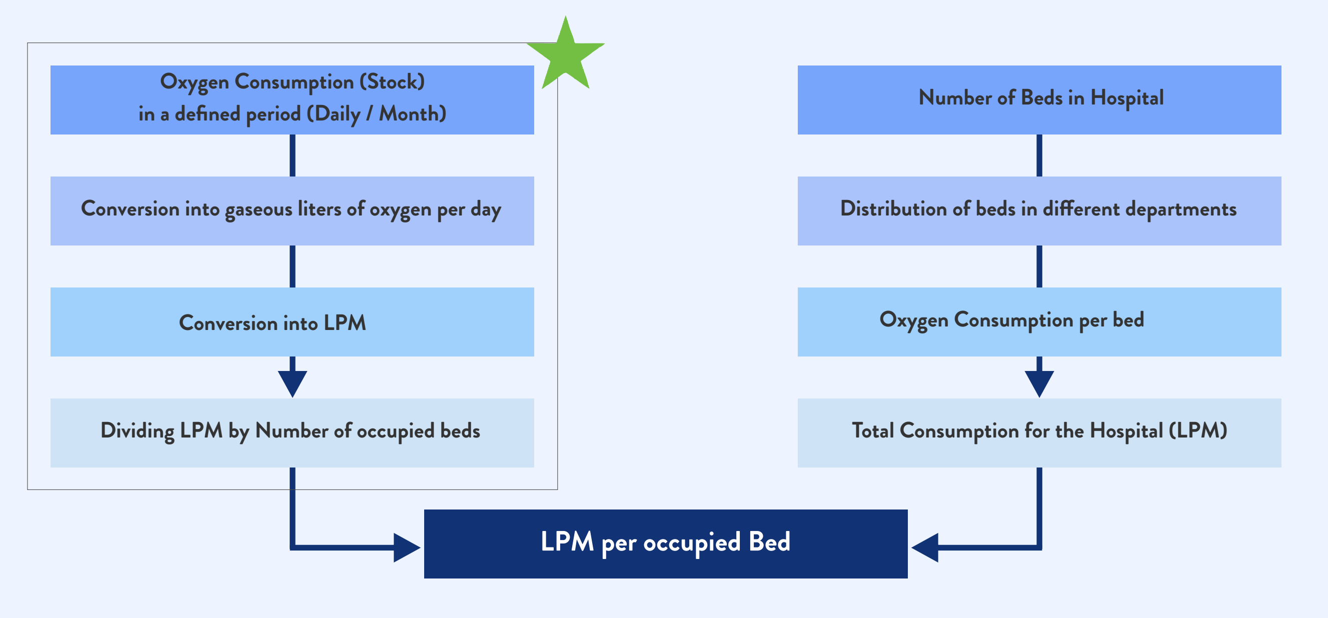

*Figure 4. Consumption calculations approach*

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[20] Ambulances use a small quantity of oxygen; every ambulance except those transporting dead bodies usually have an attached oxygen cylinder, typically a 10-liter or B-type cylinder. For personal use, mostly B-type and sometimes D-type cylinders are used by very few patients under home care. During the pandemic first and second waves, many people used these cylinders for home-isolated patients. These cylinders are refilled directly or through dealers that collect the empty cylinders and transport them to and from refillers.

Based on this approach, it is estimated that most medium to large hospitals consume medical oxygen at ~0.8–1.3 liters per minute (LPM) per occupied bed. The range is higher for hospitals with a higher percentage of critical care beds (Figure 5).

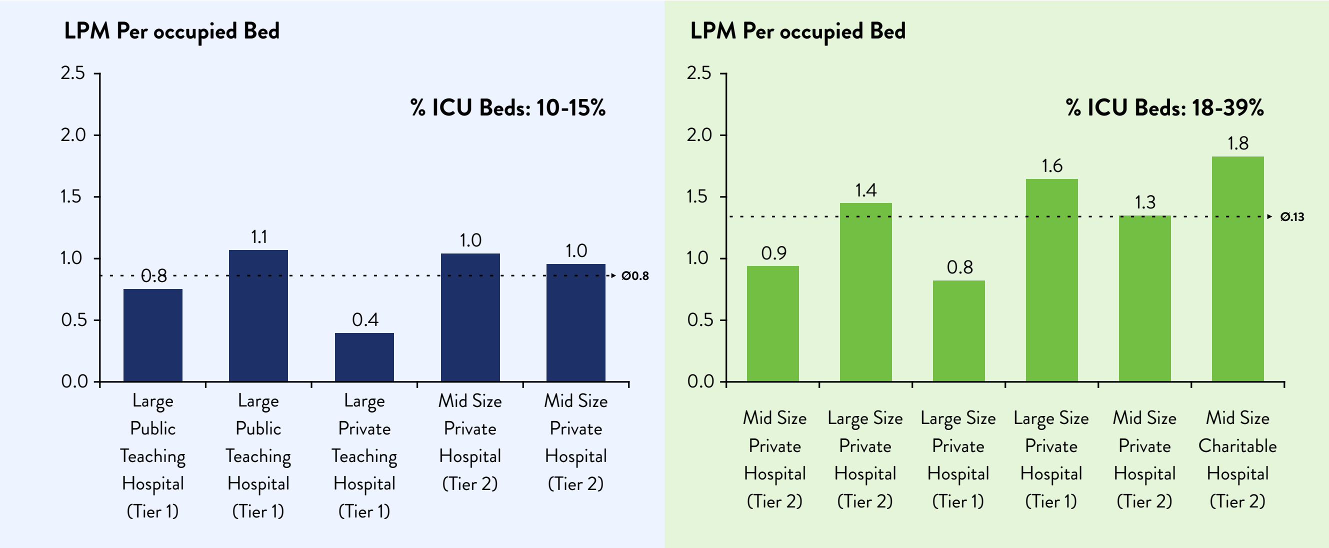


*Figure 5. Oxygen consumption per occupied bed*

At a country level, however, the oxygen consumption is estimated to be much lower (~0.5 LPM per occupied bed). This is due to significant number of small hospitals having an average of 15–30 beds, where infrastructure for critical care beds and higher oxygen delivery may not be available. These data are significant as, in the absence of any other known data, they can act as an approximate indicator of oxygen consumption in an area (if the numbers of beds are known).

### 3.1.4.2. By Medical Specialty

Variations can be expected in medical oxygen consumption by type of medical specialty and associated disease burden, but the associated data are too limited to drive any meaningful analysis. However, a significant amount of consumption is in critical care beds because a significantly higher percentage of patients admitted to these beds are given oxygen (70–100 percent) compared to other patients (5–20 percent). Furthermore, the oxygen flow rate is significantly higher in critical care beds (10–20 LPM) compared to other beds (2–5 LPM).

**Oxygen Consumption is not tracked by hospitals at Unit level (Bed, Department etc.)**

| Type of Bed | % of patients who are on oxygen support | Rate of Oxygen |
|---|---|---|
| ICU Beds (Critical Care Beds) | 70-100% | 10-20 LPM |
| General Beds<br>• Medical Beds (Internal Medicine and pulmonology)<br>• Surgical Beds (Surgery, Orthopedics, Gynecology, ENT, Ophthalmology etc.) | Medical Beds: 10-20%<br>Surgical Beds: <5% | ~2-5 LPM |

**Significant consumption happens in critical care beds (~50% - 70% of total Oxygen Consumption)**

*Figure 6. Oxygen consumption by hospital*

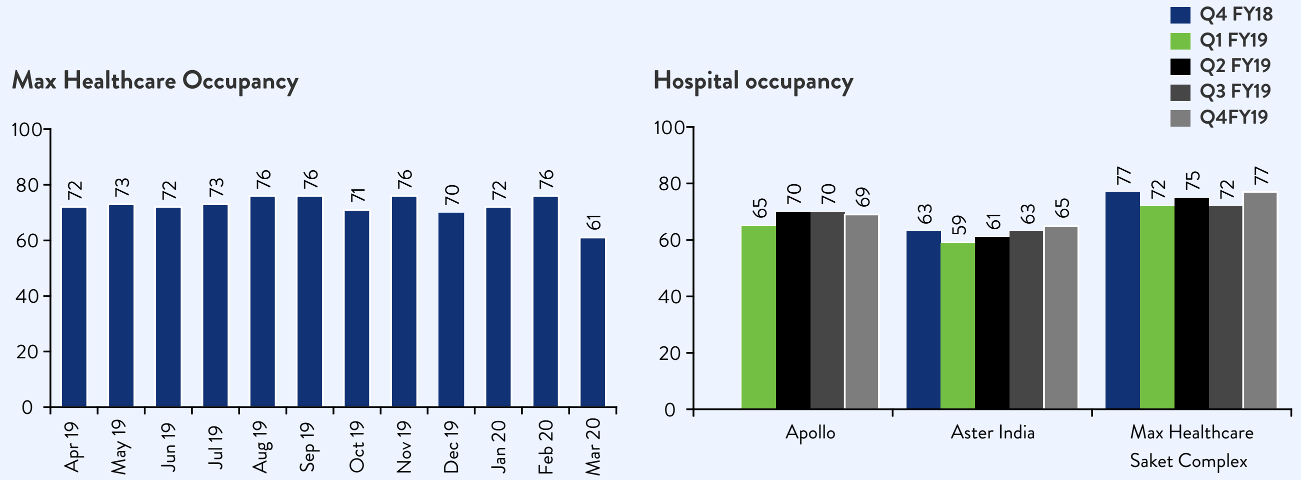
### 3.1.4.3. By Pricing and Contract Agreements

Medical oxygen is considered a low-cost input commodity, with a disproportionately high transportation and logistics cost. Hospitals pay for both oxygen delivered to the premises and the loading/unloading of refilled cylinders or LMO tanks. Most hospitals enter a long-term pricing contracts with suppliers (refillers and LMO providers), implying no or minimal seasonal price fluctuations. This trend was found across the country.

The input price was low, but hospitals charge a significant premium (up to 100fold in certain cases) for delivery to patients. The hospital typically bills patients a flat rate per unit of consumption (regardless of flow rate).

### 3.1.4.4. By Time of Year (Seasonal Variation)

Consumption records were studied for different hospitals over a two-year time frame, and minimal seasonal variation was noted. This is due to near consistent hospital occupancy levels in different times of year (Figure 7). Additionally, despite a seasonal spike of respiratory diseases, they constitute < 5 percent of total hospital admissions[21] (Figure 8) and do not necessarily represent increased consumption.



* **Source: Investor presentations, Industry Discussions**

*Figure 7. Hospital occupancy by month*

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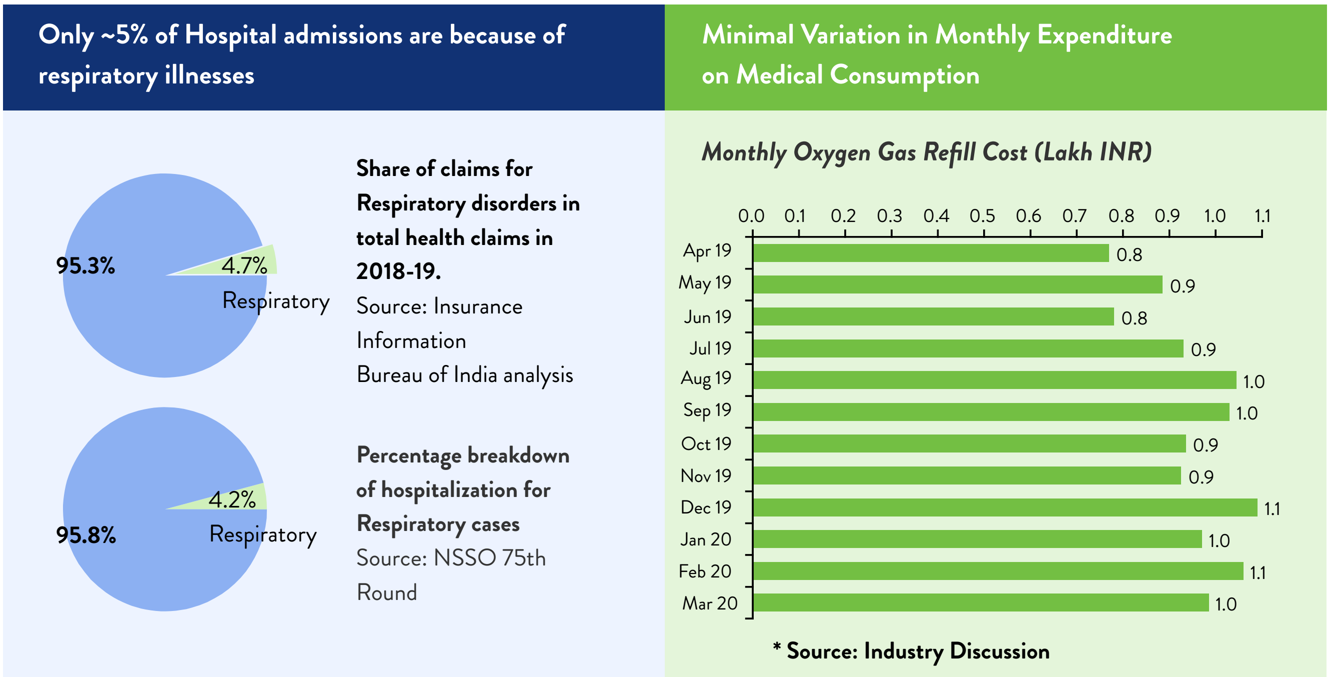
[21] National Sample Survey Office 75th round data and Insurance Information Bureau data



**Only ~5% of Hospital admissions are because of respiratory illnesses**

**Share of claims for Respiratory disorders in total health claims in 2018-19.**
Source: Insurance Information
Bureau of India analysis

**Percentage breakdown of hospitalization for Respiratory cases**
Source: NSSO 75th Round

**Minimal Variation in Monthly Expenditure on Medical Consumption**

*Monthly Oxygen Gas Refill Cost (Lakh INR)*

*** Source: Industry Discussion**

*Figure 8. Hospital admission broken down by respiratory illness (left) and Total spending on medical gas procurement by a large hospital in Delhi*

Consumption can therefore be assumed to be largely stable, permitting long-term forecasts and supply-side arrangements from a grid perspective.

### 3.1.4.5. By Form of Oxygen

A significant challenge seen in hospitals was the existing gas manifold infrastructure (specifically the caliber of the gas pipeline), which was designed to deliver only a certain flow rate of oxygen. This proved to be barrier when increased flow rates were required in COVID, and many hospitals resorted to increasing the size of this gas pipeline.Medical oxygen is given to patients in gaseous form. However, hospitals differ in how it is sourced and administered. It may be sourced from cylinders, which are either connected to oxygen gas manifolds or administered directly, or derived from LMO tanks, wherein it is converted via decompressing and passing through a chamber and then supplied to patients via gas manifold.

A significant challenge seen in hospitals was also the existing laid out Gas Manifold infrastructure (Specifically the caliber of the gas pipeline) which was designed to deliver only a certain flow rate of oxygen. This proved to be barrier when increased flow rates were required in COVID and many of the hospitals resorted to increasing the size of this gas pipeline to enable delivery of medical oxygen gas

Usage of oxygen cylinders in some form or capacity is ubiquitous in all hospitals. Smaller hospitals may be predominantly dependent on them for the majority of their needs. Medium to large hospitals may use them for ambulances, patient transportation within the hospital, backup, or emergency rooms and will have a relatively larger portion of oxygen from LMO tanks.

The LMO tank is stored on the premises, and hospitals bear the initial capital expenditure and maintenance costs. However, for significant usage, the LMO providers or refillers may operate on a rental model, where the cost is borne by the company and the hospital pays only for the oxygen consumed.

### 3.1.5. Key Learnings

**3.1.5.1.** Consumption of medical oxygen is driven by adequacy of health infrastructure, enabling accessibility and affordability, and optimal prescription patterns.

**3.1.5.2.** In LMIC countries, consumption is considered suboptimal. As the health systems mature in these countries, hitherto hidden or latent demand will need to be met, necessitating significant expansion and organization of medical oxygen ecosystems.

**3.1.5.3.** Consumption patterns remain stable, with minimal seasonal variations.

**3.1.5.4.** A significant amount of medical oxygen is delivered in hospitals. Average consumption patterns vary depending on the specialty, infrastructure, and disease burden. As a broad rule, consumption can be extrapolated using 0.5 LPM per occupied bed in different areas.

## 3.2 Supply-Side Assessment

### 3.2.1. Brief Overview

The medical oxygen supply is largely composed of two main types plants (LMO and PSA); both vary by production, supply chain, and consumption dynamics. Less production is via oxygen concentrators. A brief overview is given in Tables 1–3; the following sections provide more details.

*Table 1. Methods of oxygen production*

| Ways to Produce Medical Oxygen[22] | | |
|---|---|---|
| **ASU Plants (LMO)** | **PSA Plants (Gaseous)** | **Oxygen concentrators (Gaseous )[23]** |
| • Cool air to about −112°C until it is liquified, when the oxygen can be separated using fractional distillation to obtain liquid medical oxygen (LMO) that is 99+ percent pure.<br>• Mostly co-located with large industrial units. | • Use an adsorbent material (mostly power-intensive sodium zeolite rather than power-efficient lithium zeolite due to availability issues) to adsorb oxygen and nitrogen at different rates as the air pressure changes.<br>• Oxygen is 90–95 percent pure.<br>• Generally, co-located with hospitals. | • Small units function on the same principle as PSA but service one or a few patients at a time.<br>• Mainly deliver oxygen that is 85–90 percent pure.<br>• Attached to an oxygen bed. |

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[22] Medical practitioners and leading oxygen manufacturing plant operators as primary sources

[23] Play a limited role in supplying overall medical oxygen needs of a country and are hence not considered for further analysis

*Table 2. Methods of oxygen transportation*

| Ways to Transport Liquid Medical Oxygen (LMO) | | |
|---|---|---|
| **Cryogenic tanker trucks – Road & RoRo** | **Rail—ISO Tank containers** | **Small trucks carrying cylinders** |
| • Dedicated trucks fixed with cryogenic tanks carry oxygen over large distances.<br>• They handle the entire demand for transporting over longer distance (~400 km) and direct delivery to large hospitals and refillers.<br>• Rail-based roll-on/roll-off service: In COVID-19 Wave 2, oxygen trucks were loaded onto freight cars to speed up deliveries over long distances. | • Standardized ISO containers measuring 20 ft or rarely 40 ft long transport large quantities of cryogenic oxygen over long distances.<br>• Their movement is via both rail and road trailer trucks.<br>• ISO containers have a capacity of 20–40 MT. | • Demand for hospitals in hard-to-reach terrain and medium and small-scale hospitals is met by carrying small cylinders in vans/small trucks.<br>• Generally, each small truck can carry 50–100 cylinders equal to ~2 MT LMO. |

*Table 3. Methods of oxygen storage*

| Ways to store medical oxygen[24] | |
|---|---|
| **Oxygen cylinders** | **Large liquid storage tanks** |
| • Gaseous: Type-B (capacity: ~7 liters) and type-D (capacity: ~47 liters) cylinders are the most common.<br>• Liquid cylinders are used in emergency situations and hospitals that lack a piped oxygen-delivery system. | • Large LMO storage tanks are located at oxygen producers' facilities, large hospitals, and refillers.<br>• These tanks can hold up to 100 MT, sufficient to service demand for several days for a large hospital or small and medium hospitals across the entire district. |

The supply chain has multiple infrastructure challenges, some of which are highlighted in Figure 9 and explained in subsequent sections.

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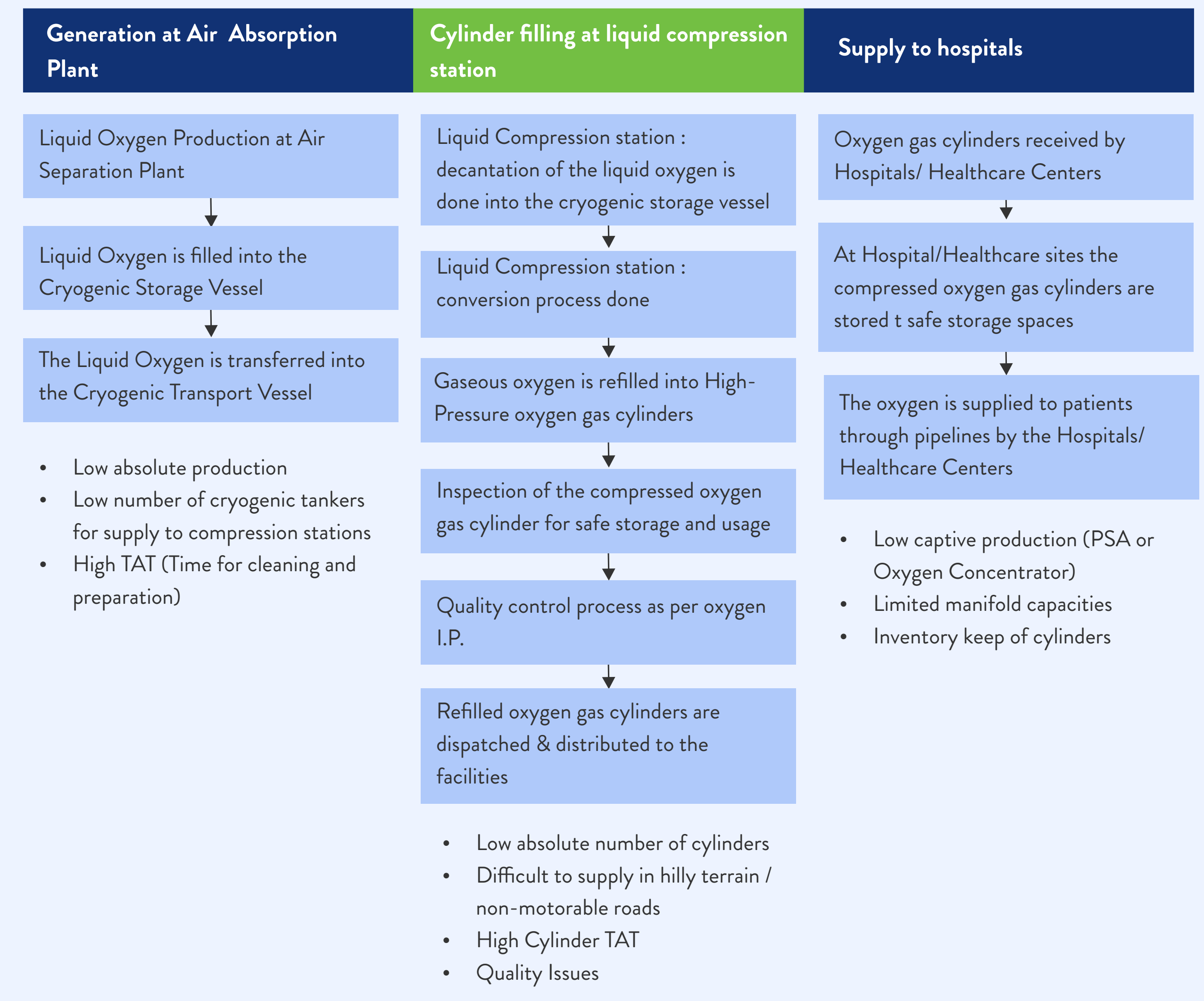
[24] Hospitals, cylinder traders, and medical practitioners as primary sources



**Generation at Air Absorption Plant**

- Liquid Oxygen Production at Air Separation Plant
- Liquid Oxygen is filled into the Cryogenic Storage Vessel
- The Liquid Oxygen is transferred into the Cryogenic Transport Vessel

- Low absolute production
- Low number of cryogenic tankers for supply to compression stations
- High TAT (Time for cleaning and preparation)

**Cylinder filling at liquid compression station**

- Liquid Compression station : decantation of the liquid oxygen is done into the cryogenic storage vessel
- Liquid Compression station : conversion process done
- Gaseous oxygen is refilled into High-Pressure oxygen gas cylinders
- Inspection of the compressed oxygen gas cylinder for safe storage and usage
- Quality control process as per oxygen I.P.
- Refilled oxygen gas cylinders are dispatched & distributed to the facilities

- Low absolute number of cylinders
- Difficult to supply in hilly terrain / non-motorable roads
- High Cylinder TAT
- Quality Issues

**Supply to hospitals**

- Oxygen gas cylinders received by Hospitals/ Healthcare Centers
- At Hospital/Healthcare sites the compressed oxygen gas cylinders are stored t safe storage spaces
- The oxygen is supplied to patients through pipelines by the Hospitals/ Healthcare Centers

- Low captive production (PSA or Oxygen Concentrator)
- Limited manifold capacities
- Inventory keep of cylinders

Bikkina S, Kittu Manda V, Adinarayana Rao UV. Medical Oxygen Supply During COVID-19: A Study with Specific Reference to State of Andhra Pradesh, India [published online ahead of print, 2021 Jan 26].
Mater Today Proc. 2021;10.1016/j.matpr.2021.01.196. doi:10.1016/j.matpr.2021.01.196

*Figure 9. Infrastructural challenges in supply chain*

## 3.2.2. Overview of LMO Produced in Air Separation Units

### 3.2.2.1. Process of Production

LMO is produced in air separation units. Cryogenic air separation (also known as “cryogenic distillation”) works by cooling air to about -112 degree Celsius until it is liquefied, at which point, the oxygen can be separated from the other components by fractional distillation because of the different boiling points of the gases. The air is purified before cooling to remove water vapor. Cryogenic separation produces ultra-pure (>99.5 percent) LOX needed for specific industrial processes in extractives, metallurgy, etc.

These facilities are highly capital intensive. An LOX plant can last for decades and is typically amortized over 30 years. The first cryogenic air separation plant was developed by Carl von Linde in Germany in the 1910s.

The technology has now scaled up globally, with thousands of plants in the world. A small number of companies own/operate LOX factories; Linde, Inox, and Air Liquide are the most well known.

### 3.2.2.2. Models Deployed for Supply of Oxygen from ASU Plants

LOX from ASU plants is typically transported to hospitals and other health establishments using three different types of supply chain: fill oxygen cylinders at the site of LMO production itself, and these cylinders are transported to the hospitals; travel on cryogenic tankers or ISO containers to regional cylinder storage cum filling stations, which are used to fill cylinders supplied to the hospitals; or, especially in medium to large hospitals that have storage tanks and the capacity to use it, supplied either directly via plants or by refillers (Figure 10).

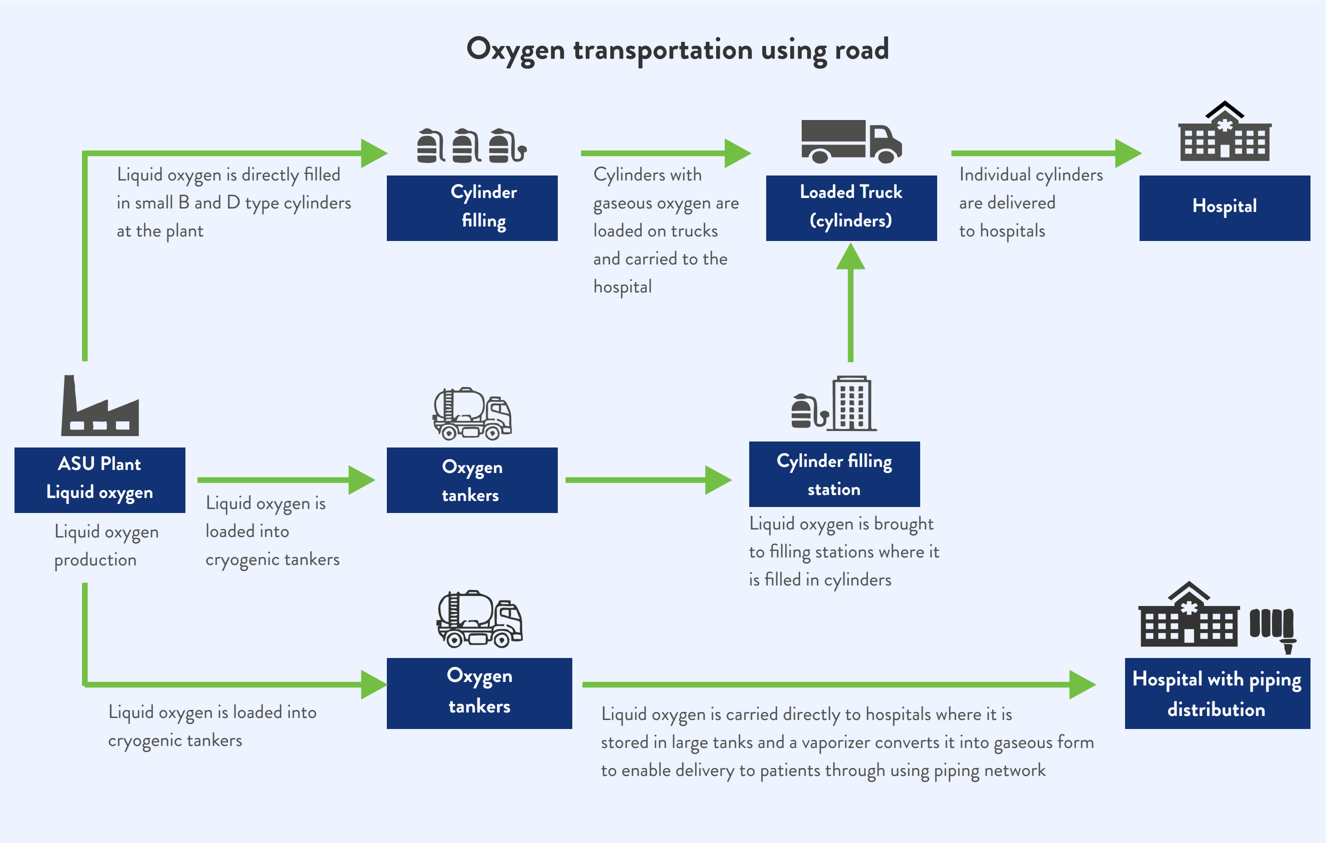


*Figure 10. Supply Chain of Liquid Medical Oxygen*

These supply chains typically require multiple stakeholder interventions; Table 4 provides a detailed overview.

*Table 4. Overview of stakeholders in supply chains*

| | |
|---|---|
| **Producers** | • Produces oxygen using air separation units (ASU) and PSA technology for industrial and medical use.<br>• The majority of demand is met by ASU plants near heavy industries, such as steel and electronics, which are major users (90+ percent).<br>• Producers also have large storage tanks to maintain consistent supply. |
| **Transporters** | • **Road:** Tanker trucks, ISO containers on trailer trucks, and cylinders in small trucks are the three major modes of transport.<br>- ~60 percent of the tanker truck supply is owned and managed by oxygen producers, such as Linde, Inox, and Air Liquide.[25]<br>- ISO containers on trailer trucks deliver large quantities over short distances. However, this mode is less prevalent, as evident from low container stock (an estimated < 200[26] containers are available for medical use).<br>- Cylinders in small trucks supply medical oxygen to hospitals that do not have a storage facility or pipe-based delivery system.<br>• **Rail:** Rail was used only during COVID-19 Wave 2 for excessive shortages. Oxygen is transported via two main models:<br>- ISO container: Containers are loaded on freight cars to transport large quantities over long distances faster than on the road.<br>- Roll-on, roll-off: Tanker trucks are loaded onto freight cars to enable faster deliveries than on the road. |

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[25] Estimates shared by medical oxygen suppliers and truckers

[26] Estimates shared by SME and industry participants.

Contd.

| | |
|---|---|
| **Re-fillers / traders** | - Offer oxygen storage and transportation services by taking bulk deliveries from producers and filling small cylinders as per hospital demand.<br>- Service hospitals that do not receive large quantities of oxygen in a single shipment, usually from oxygen producers. |
| **Hospitals** | - **Hospitals with large oxygen storage tanks:** Take direct deliveries from oxygen producers using tanker trucks or ISO containers. A single shipment may offer up to 20 MT.<br>- **Hospitals dependent on cylinders-based supply:** Generally, rely on refillers to supply individual cylinders to meet demand. A single shipment may contain 1–10 liquid oxygen cylinders or up to 50 gaseous oxygen cylinders. |

### 3.2.2.3. Cost of Production Using ASU Plants

ASU plants are typically set up to service industrial sector demand, with only 5–10 percent of LOX production diverted to medical suppliers. These are typically large-scale plants that require INR 100-120 crore investment. Table 5 shows the indicative cost for a typical ASU plant in India[27]:

*Table 5. Production details for ASU plants*

| Particulars | Value |
|---|---|
| Average installed capacity per unit | ~100 MTPDA |
| Useful life of plant | 25–30 years |
| Total capital expenditure (land obtained on lease) | ~INR 100-120 crore |

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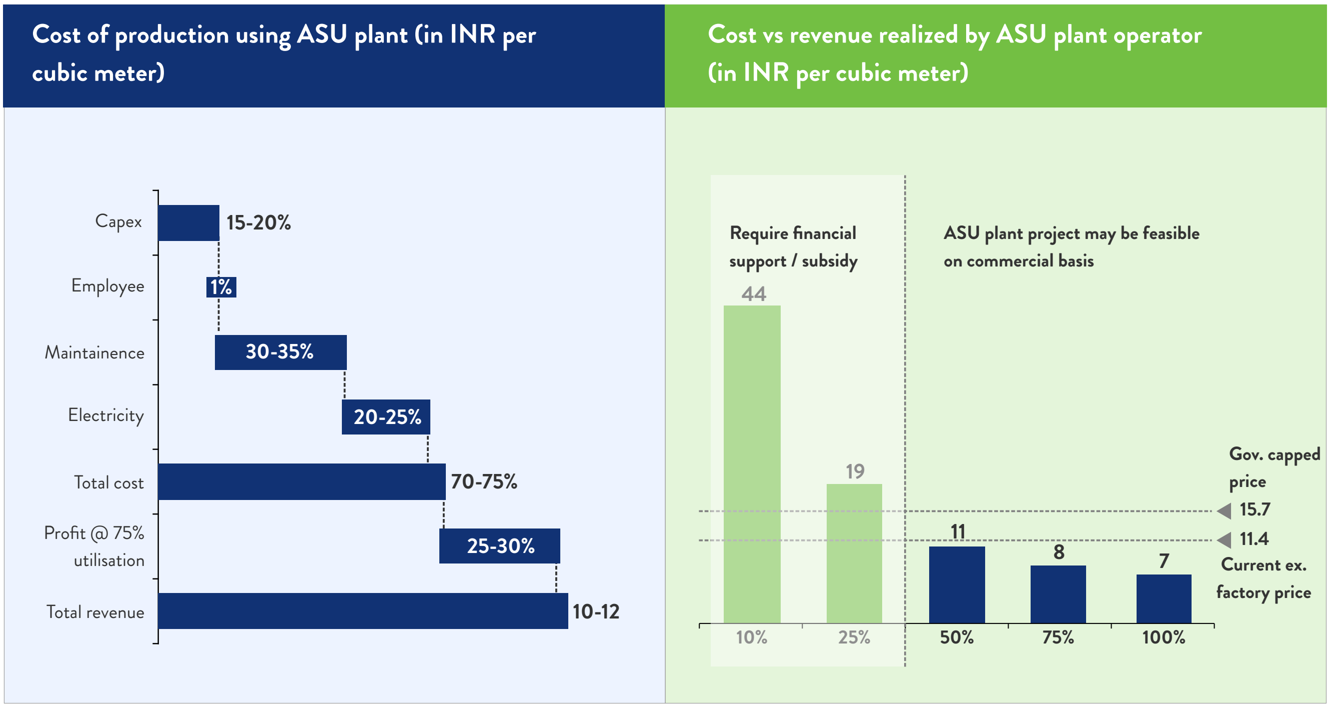
[27] PricewaterhouseCoopers (PwC) estimates based on feedback from ASU plant operators and plant technical specifications

*Table 6. Production costs per unit of Medical Oxygen for ASU plants*



In a real-world scenario, the estimated cost of production per unit of Oxygen (as shown in Table 6) may vary by up to 25 percent depending on plant configuration, local wage and power tariffs, maintenance contracts, etc.

## 3.2.3. Overview of Gaseous Oxygen Produced in PSA Plants

### 3.2.3.1. Process of Production

PSA plants use an adsorbent material (typically zeolite); as pressure increases, relatively more nitrogen than oxygen adsorbs, producing an oxygen-rich gas stream from the adsorption bed. When the zeolite surface is saturated with nitrogen, the pressure is reduced, and the nitrogen is desorbed, released from the material, and purged into the atmosphere. This oxygen is primarily used for medical purposes and 90–95 percent pure.

### 3.2.3.2. Pros of PSA Plants

- PSA plants can be easily set up and used at health facilities that are geographically difficult to reach.
- The major raw source is ambient air.
- Oxygen can be produced any time and any place.
- Plants do not depend on external suppliers for oxygen.
- Oxygen can be supplied straight to the site of use through a dedicated gas pipeline system or compressed to fill cylinders.
- Plants are easy to install, preassembled, and skid mounted or containerized.
- Plants require limited space—200–400 square feet.

- A control panel/user interface with numerical and graphical values is provided.

### 3.2.3.3. Cons of PSA Plants

- Medical oxygen purity is 93 percent + 3 percent, which is considered acceptable but not preferred. The plant has calibration mechanisms to stop production if purity falls below 90 percent, but in many cases, especially if the plant is not maintained properly, the mechanisms fail and purity drops significantly.

- Theoretically, the gaseous air from PSA plants can be used to fill cylinders, but this requires additional capital investment (5–7,000,000 INR) to set up the booster compressor and other infrastructure required and also limits the supply for nearby hospitals.

- PSA plants require 24/7 steady electricity and a dedicated electricity backup. The per-unit cost is significantly higher at lower capacities and meets the market rate only at higher capacities.[28] (Figure 11)

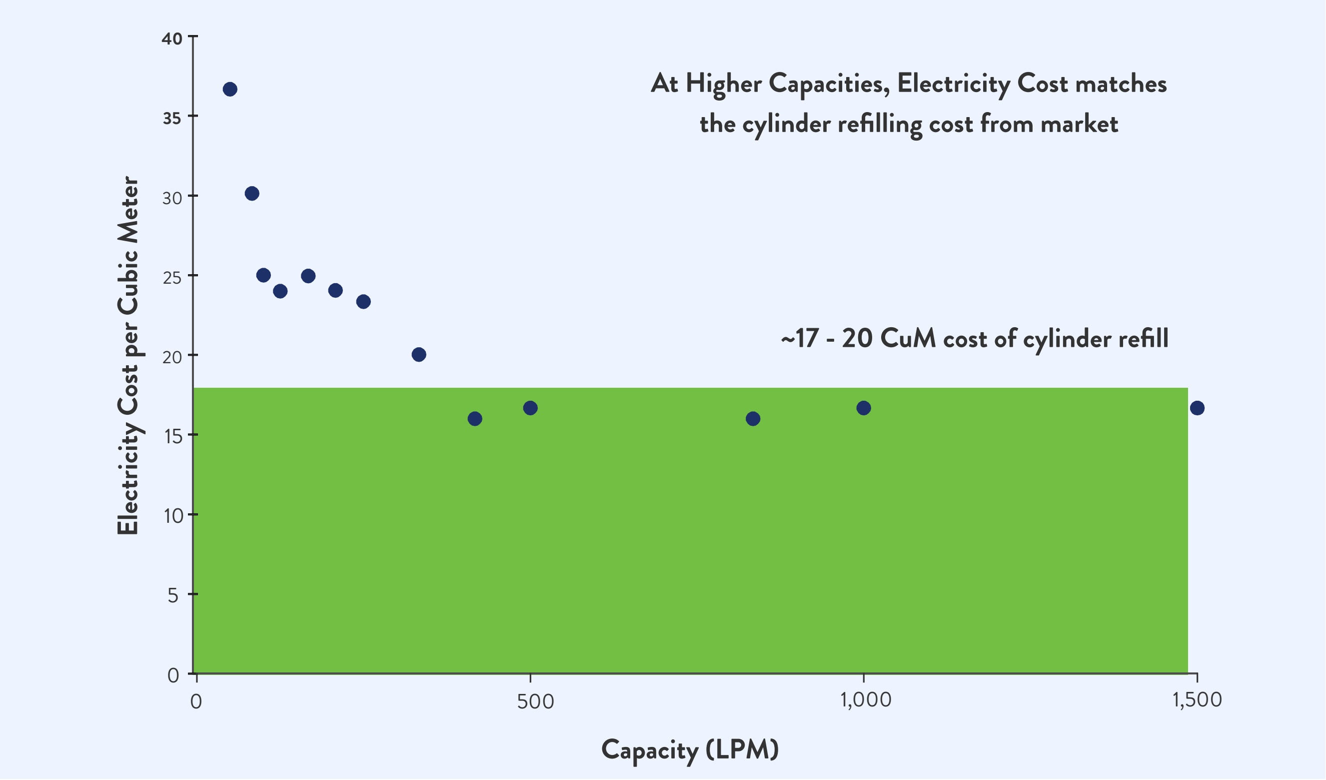


*Figure 11. Per-unit cost for PSA plants.*

- Excess noise occurs when the plant is in use, so it should not be in an enclosed space.

- Staff operating and maintaining the plants require specialized training. Strict maintenance schedules are needed to prevent any malfunctions. In resource-limited settings, adequate supplies and spare parts are needed to allow operations for a minimum of five years.

- The plant depends on manufacturer/distributor staff for any repairs.

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[28] Based on PwC analysis, primary discussions, product brochures

- Boot-up time is 1–4 hours once the plant is restarted.

- Plants come in varying capacity sizes, but their production cannot be finely regulated. Furthermore, they are limited by not having a storage chamber and hence are less suited to meet temporary peaks.[29]

- In large hospitals, the oxygen pressure drops at beds distant from the plant, which can result in ventilators failing.

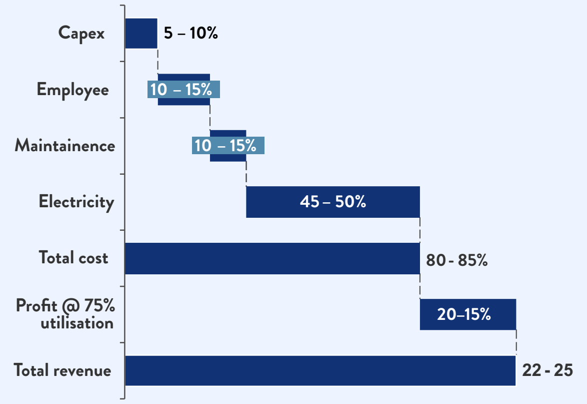
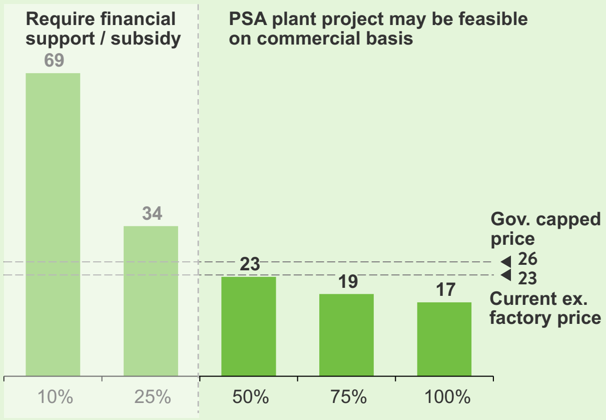
#### 3.2.3.4. Cost of Production Using PSA Plants

Oxygen from PSA plants is put into cylinders for transport and distribution. Apart from hospitals, many PSA plants have been set up at cylinder refilling stations. The typical capital expenditure for setting up these plants is ~0.9-1 crore INR (Table 7).

*Table 7. Production details for PSA plants*

| Particulars | Value |
|---|---|
| Average installed capacity per unit | 1–1.5 MTPD |
| Useful life of plant | ~10 years |
| Total capital expenditure (land obtained on lease) | 0.9–1 crore |

*Table 8. Production costs per unit of medical oxygen for PSA plants*

| Cost vs revenue realized by PSA plant operator (in INR per cubic meter) | Cost vs revenue realized by PSA plant operator (in INR per cubic meter) |
|---|---|
|  |  |

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[29] Many PSA plants have a surge chamber, which may store a very minimal amount of additional oxygen but is often unreliable.

In a real-world scenario, the estimated cost of production per unit of oxygen (Table 8) may vary by up to 25 percent depending on plant configuration, local wage and power tariffs, maintenance contract, plant use rates, etc.

### 3.2.4. Comparing Different Sources of Oxygen

ASU and PSA are the two commercially prevalent medical oxygen-production technologies globally. Oxygen concentrators contribute a miniscule share to total supply, as they are mainly used in emergency situations and for home delivery to patients with less severe conditions.

**3.2.4.1.** Table 9 presents a brief comparison of key production features of ASU and PSA technologies[30]:

*Table 9. Comparison of ASU and PSA plants*

| Particulars | ASU Plants | PSA Plant |
|---|---|---|
| **Approach to producing oxygen** | Cools air to about −112°C until it is liquified, at which point, the oxygen can be separated using fractional distillation to obtain liquid medical grade oxygen that is of 99+ percent purity. | Uses an adsorbent material (mostly power-intensive sodium zeolite rather than power-efficient lithium zeolite due to availability issues) to adsorb oxygen and nitrogen at different rates as the air pressure changes. |
| **Purity** | 99+ percent | 90–95 percent |
| **Average capacity** | 100–200 MTPD | 1–1.5 MTPD |

---

[30] Based on PwC analysis, industry expert interactions, and ASU and PSA plant operators

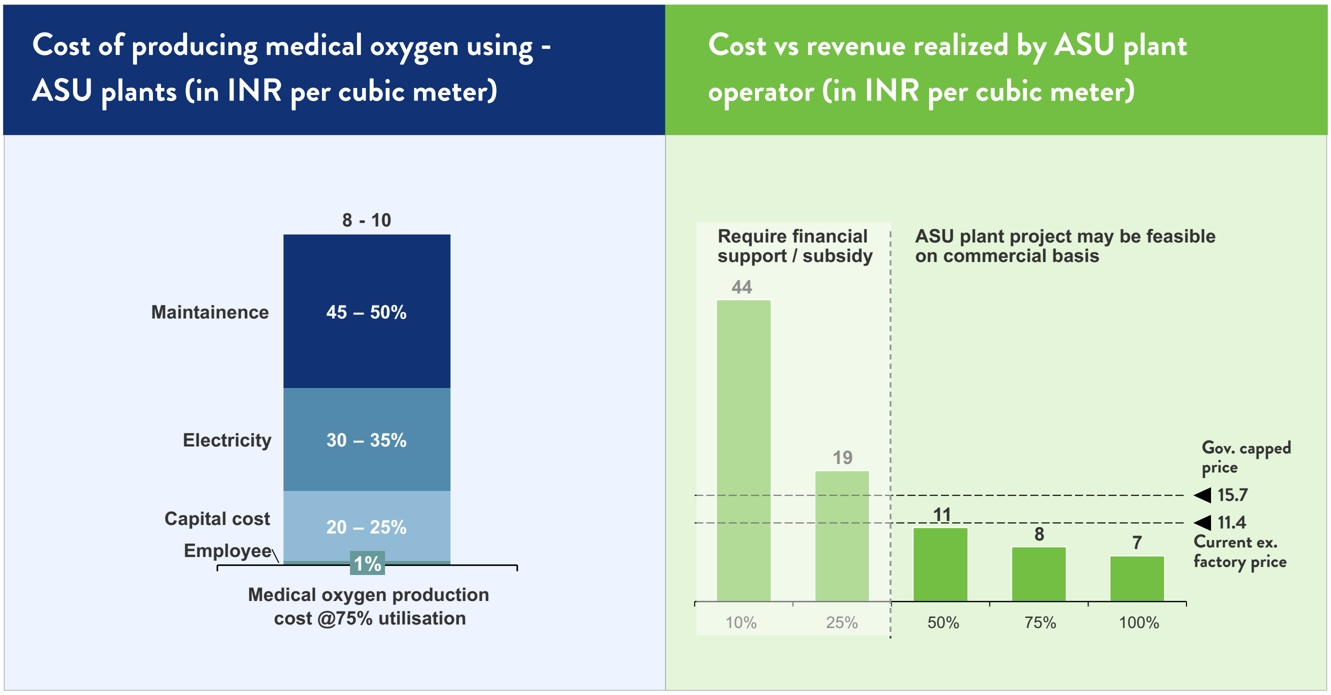
**Contd.**

| Particulars | ASU Plants | PSA Plant |
|---|---|---|
| **Business model and other noteworthy aspects** | • 90+ percent of the production is consumed by industrial clients, such as steel, electronics, and pharmaceuticals.<br>• Mostly co-located with large industrial units and away from medical oxygen demand centers in urban areas.<br>• High-cost logistics due to long lead transport need and need for cryogenics.<br>• Specialized players lead to more efficient operations.<br>• Low hazard risk at the hospital, mainly due to storage tanks. | • Generally, co-located with hospitals.<br>• Services demand from a single or a few hospitals located in a small area.<br>• Reduced need of logistics for consumption at the hospital with the plant. However, servicing demand from other hospitals materially increases overall cost to hospitals due to logistics.<br>• Diverts hospital management attention to a noncore activity (PSA plant operations).<br>• Has a high hazard risk. |

### 3.2.4.2. Economics of Producing Oxygen Using ASU Versus PSA Technology

Economies of scale associated with ASU plants enable a lower production costs. PSA use of adsorbent materials leads to increased electricity consumption and thus increased production costs. However, logistics costs are significantly higher for ASU plants, which offsets some of the production cost benefits (Table 10 and 11).

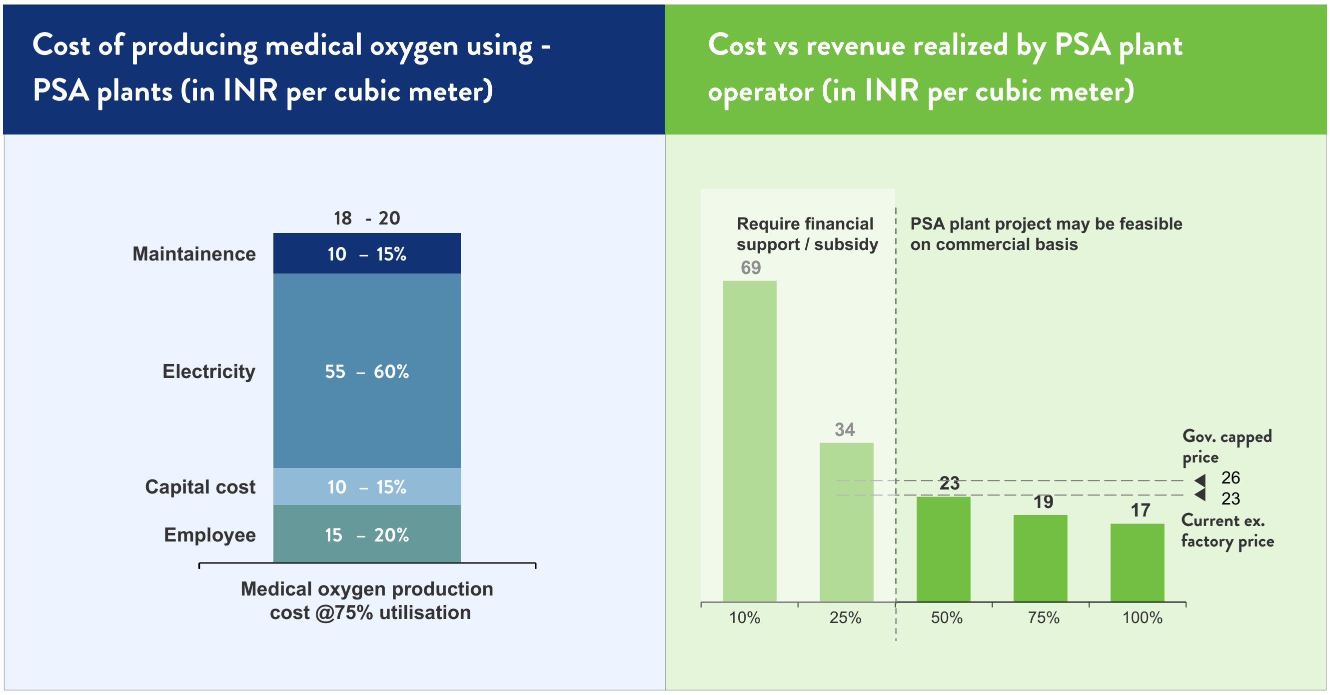
*Table 10. ASU plant production cost and revenue*



**Cost of producing medical oxygen using - ASU plants (in INR per cubic meter)**

**Cost vs revenue realized by ASU plant operator (in INR per cubic meter)**

*Table 11. PSA Plant production cost and revenue*



**Cost of producing medical oxygen using - PSA plants (in INR per cubic meter)**

**Cost vs revenue realized by PSA plant operator (in INR per cubic meter)**

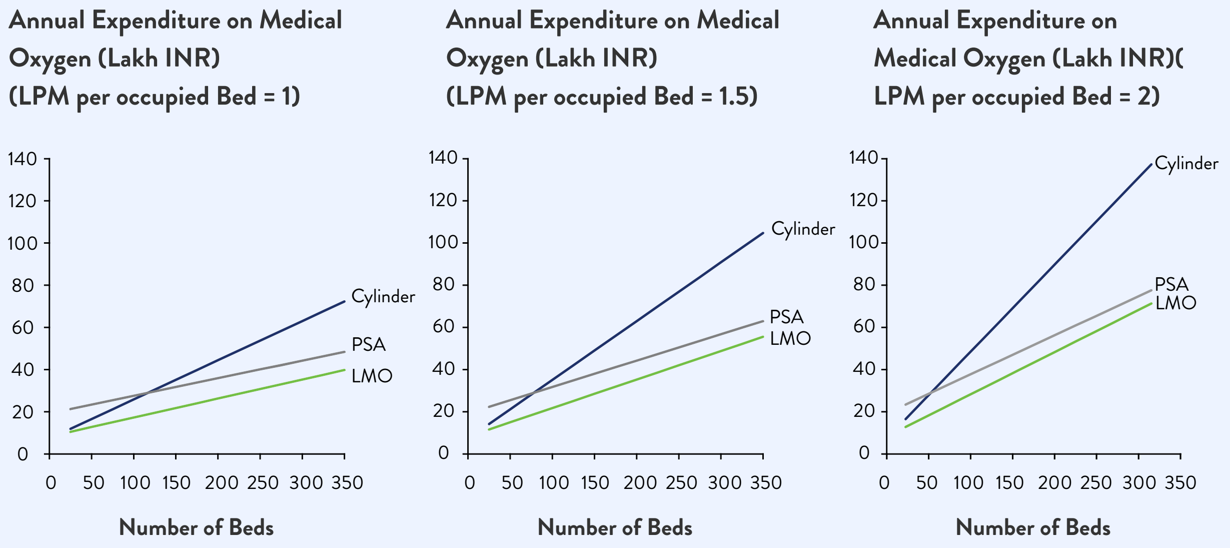
Overall, the use of ASU and PSA depends on the intended purpose.

ASU offers advantages, such as lower per-unit cost of production, high reliability, assured quality, and multiple uses, including industrial and medical oxygen and other gas production. However, setting up production capacity leads to concentration at a single location, increasing the need for logistics infrastructure, and entails a large initial investment, making estimated use factor a critical issue.

PSA technology addresses these concerns, as initial investment is estimated to be ~INR 1 crore versus the over INR 100 crore for an ASU plant, enabling installation closer to or within a hospital. This also increases supply chain resilience by enabling impromptu production ramp-up to augment traditional sources. However, they offer a limited scale of production, sufficient for a few hospitals only. A grid could leverage advantages of both technologies to balance economics with supply chain resilience to serve demand in emergency scenarios.

### 3.2.4.3. Comparative Analysis of Unit Economics

A comparative analysis was performed (costing) of eventual hospital expenditure for exclusive oxygen from the three sources—cylinders and LMO and PSA plants—over different hospital sizes and oxygen consumptions (Figure 12).



**Annual Expenditure on Medical Oxygen (Lakh INR) (LPM per occupied Bed = 1)**

**Annual Expenditure on Medical Oxygen (Lakh INR) (LPM per occupied Bed = 1.5)**

**Annual Expenditure on Medical Oxygen (Lakh INR)( LPM per occupied Bed = 2)**

**PSA plant of 666 LPM capacity is considered for analysis High upfront cost of LMO and PSA plant a deterrent for small hospitals**

* Source: PwC Analysis

*Figure 12. Annual Expenditure on Medical Oxygen by consumption and hospital size*

LMO are the most cost-effective source in any scenario. PSA plants are more cost-effective than cylinders for medium to large hospitals, but they require a significant up-front investment, comparable to that of LMO.

### 3.2.4.4. On-the-Ground Experience with PSA Plants

On-the-ground experience was gained from multiple hospitals that had installed (or were considering installing) a PSA plant during/after the pandemic. Almost similar findings were obtained from all of these hospitals.

LMO plants were the preferred choice due to low cost, low maintenance, and high purity.

PSA plants were installed but not commissioned in many cases due to pending issues of purity check and fencing. Even when the PSA plants were commissioned, they were largely disused, reserved for future exigencies. A brief description of some case studies is provided in the images.

**10,000 Liters**
**LMO Tank**

**1000 LPM**
**PSA plants**

- 980 Bed Hospital and Medical College in North Delhi
- LMO is the primary source of Oxygen
    - 10,000 L plant
    - (Auto Ordering at 50% Level)
    - 2 Year contract
    - Diameter of gas pipeline - challenge during COVID
- Cylinders - Used for backup (Both B and D Type Cylinders Used)
- PSA Plant
    - 1000 LPM plant installed after 2nd wave
    - Not yet Commissioned
        - ~ Wiring and fencing pending
    - Purity is a concern

*Figure 13. Large Public Hospital and Teaching Medical College, Delhi*

**2 PSA plants of**
**750 and 1160 LPM capacity**

**1,000 Liters**
**LMO Tank**

- 550+ Bed Medical College and Hospital in South Delhi
- Two Blocks
    - Block 1 - LMO (Primary Source)
    - Block 2 - Cylinders (Primary Source)
- PSA Plant
    - 2 Plants Installed one for each block 750 and 1160 capacity
    - Currently, not in use, high electricity consumption cited a reason
    - Pressure drops at extreme ends (especially when high usage)
        - ~ Used to supplement with LMO and cylinders
    - Purity is a concern (Dependent on AmbientAQI)
    not using it for cylinder filling
    - No storage capacity (only a surge vessel)
    - Significant Noise Open Area required

*Figure 14. Large Private Teaching Hospital and Medical College, Delhi*

### 3.2.5. Key learnings

**3.2.5.1.** LMO is the preferred source. Production happens in large ASU plants and requires a robust supply chain and logistics arrangement for supply and distribution.

**3.2.5.2.** PSA plants offer the convenience of on-site production. However, they are limited by operational and maintenance challenges. Hospitals are likely to use them for contingency or pandemic purposes (rather than routinely).

**3.2.5.3.** Cylinders are used in all types of hospitals, although usage may vary compared to LMO and PSA.

## 3.3 Demand–Supply Gap (India)

### 3.3.1. Absolute Production Capacity of Medical Oxygen

The oxygen-production industry is composed of ASUs, PSA, and oxygen concentrators. The industry is set up mainly to service industrial demand that depends on ASU plants and consumes 90–95 percent of total annual production.[31] PSA plants have been mainly installed in hospitals by the government in response to the COVID-19 pandemic. Oxygen concentrators service only individuals or a few patients at a time, when supply from traditional sources, such as ASU and PSA, is not possible.

India was estimated to have an absolute production capacity of ~10–11,000 MTPD per day (pre-COVID). This was largely ASU (LMO), of which ~90 percent was used in industrial oxygen; the remainder was medical oxygen (1,000–1,400 MTPD).

Post-Wave-2, significant efforts were made to expand production capacities. Almost 3,700 PSA plants are being set up and ASU plants expanded in capacity and number (Table 12). The absolute production capacity is now estimated to be 18–19,000 MTPD, of which ASU constitutes ~70–80 percent and PSA the remainder.[32]

In addition to this absolute increase in production capacities, based on interactions with leading industry players and small and midsized enterprises (SMEs), the plant use factor reflects potentially diverting 5–10 percent of capacity to medical use in emergencies without impacting overall operations. Increases beyond that level will require new capacity.

Given strong industrial growth in oxygen-consuming sectors, such as steel, automobile, and pharmaceuticals, private players, such as Inox and Linde, are planning capacity expansion[33]:

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[31] Estimated from news articles, government press releases, and interactions with oxygen manufacturers

[32] Estimates shared by SME and industry participants

[33] News articles and official press releases by companies

*Table 12. Capacity expansion by producer*

| Entity | Timeline | Location | Capacity Expansion |
|---|---|---|---|
| **New large-scale production plants (ASU plants)** | | | |
| INOX AIR | ~3 years; INR 2,000 crore | • Madhya Pradesh<br>• Uttar Pradesh<br>• Tamil Nadu<br>• West Bengal | ~8 ASU plants to be set up with LMO production capacity of 1,500 MTPD. |
| LINDE | October 2021 | IOCL in Orissa | Total gas capacity of 660 MTPD |

### 3.3.2. Absolute Demand Requirements and Demand Gap

It is estimated that India had an absolute need of ~1,000–1,400 MTPD in the pre-COVID BAU scenario. This need was significantly increased during COVID.

The central government of India had earlier constituted Empowered Group 1 to estimate the required medical supply.[34] It categorized patients into three groups:

- Class I: 80 percent of cases are mild and do not require oxygen.
- Class II: 17 percent cases are moderate and can be managed on non-ICU beds, and 50 percent of these may require oxygen @10L/min; and
- Class III 3 percent of cases are severe ICU cases requiring approximately 24L/min oxygen.

Going by this methodology and a caseload of 14 days, India had a peak need of ~3,800 MTPD in Wave 1 and ~16,000 MTPD in Wave 2.[35] Adding the normal business needs of ~1,200 MTPD, peak needs were ~5,000 MTPD and ~17,200 MTPD in Waves 1 and 2, respectively.[36] The need would have been lower in Wave 1, as the methodology was specifically for Wave 2 (Delta strain). These needs were based on diagnosed cases and will be much different if the testing rate is adjusted to account for regional variations. Peak sales were ~3,100 MTPD ~9,000 MTPD in Waves 1 and 2, respectively, indicating a significant absolute shortage in Wave 2 (Figure 15).

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[34] Supreme Court of India order, Suo Motu Writ Petition (Civil) No. 3, 2021.
https://main.sci.gov.in/supremecourt/2021/11001/11001_2021_35_301_27825_Judgement_30-Apr-2021.pdf

[35] Data on daily new cases from "OurWorldinData"

[36] https://pib.gov.in/PressReleseDetail.aspx?PRID=1,717,459

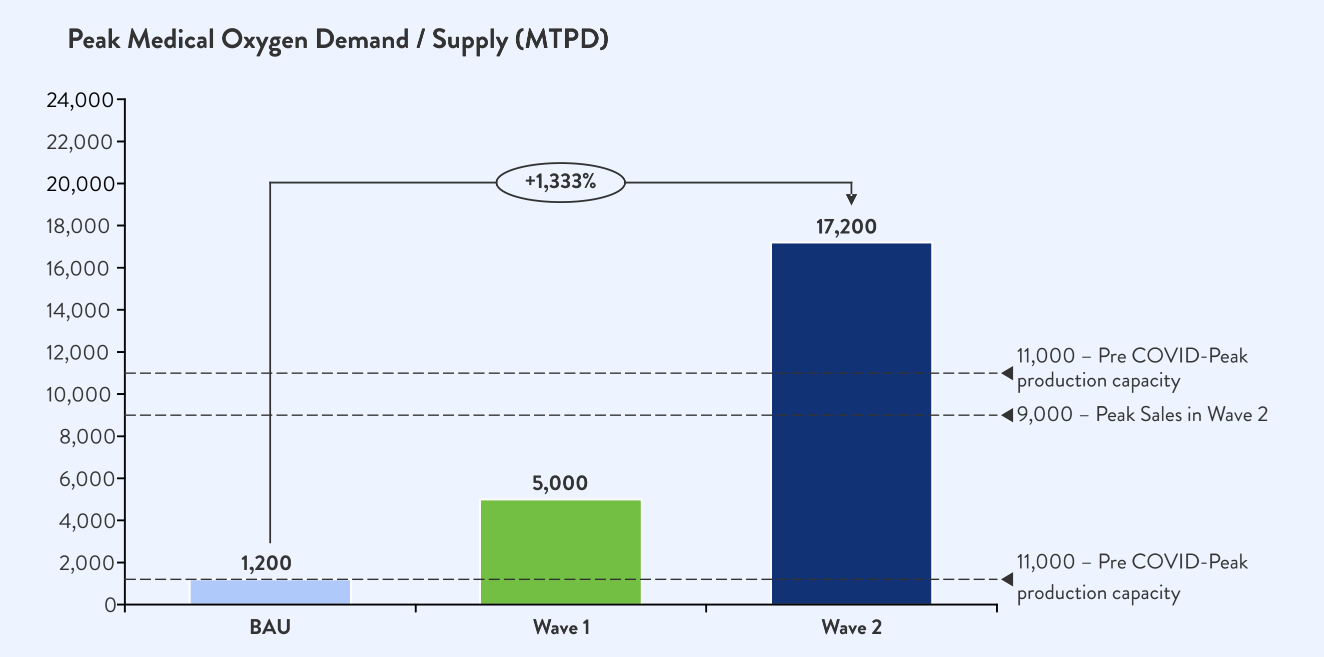

*Figure 15. Oxygen demand and supply during different COVID-19 waves in India*

## 3.3.3. Spatiotemporal Variations

The production capacity is not uniformly distributed, with regional variations in supply and demand patterns. The map reveals that the production capacity is highly concentrated in East India, and North India has a disproportionate demand (Figure 16).[37] These spatial variations are explored in a subsequent section.

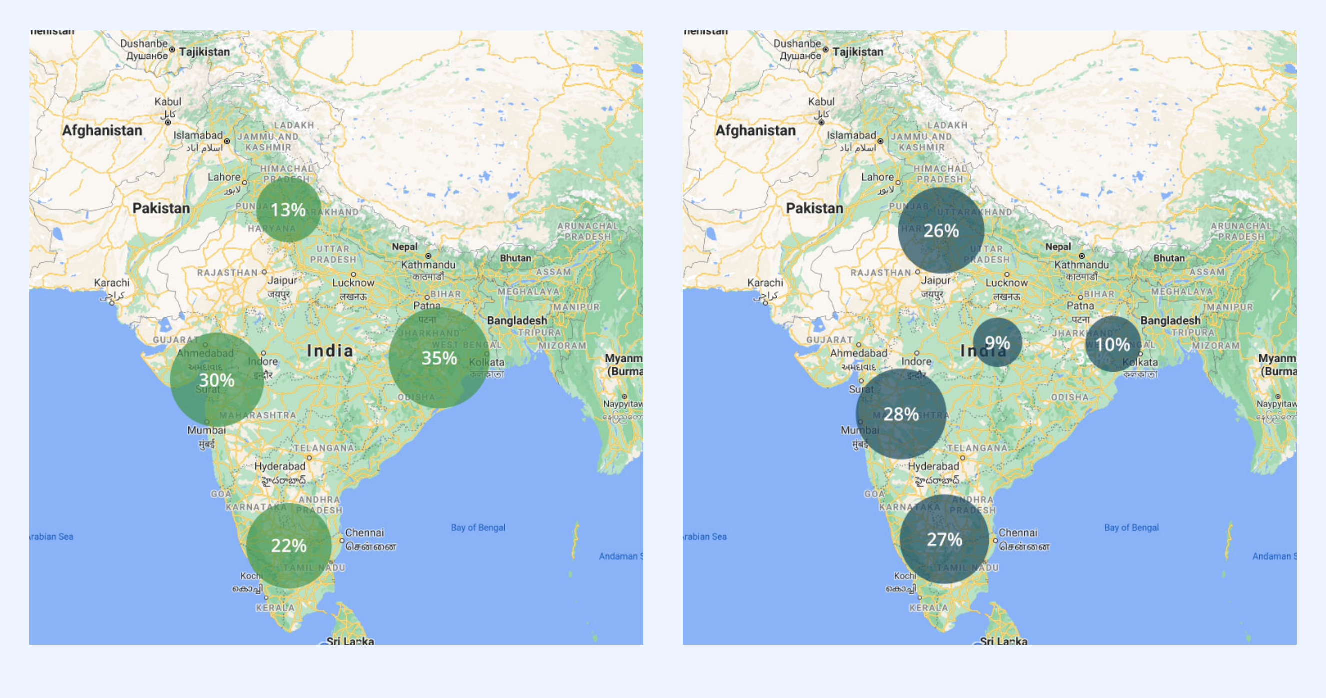

*Figure 16. Production and demand distribution*

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[37] https://inoxairproducts.com/covid-19/

Cases increase at different rates in different states, and the peak needs happen at different times.[38]

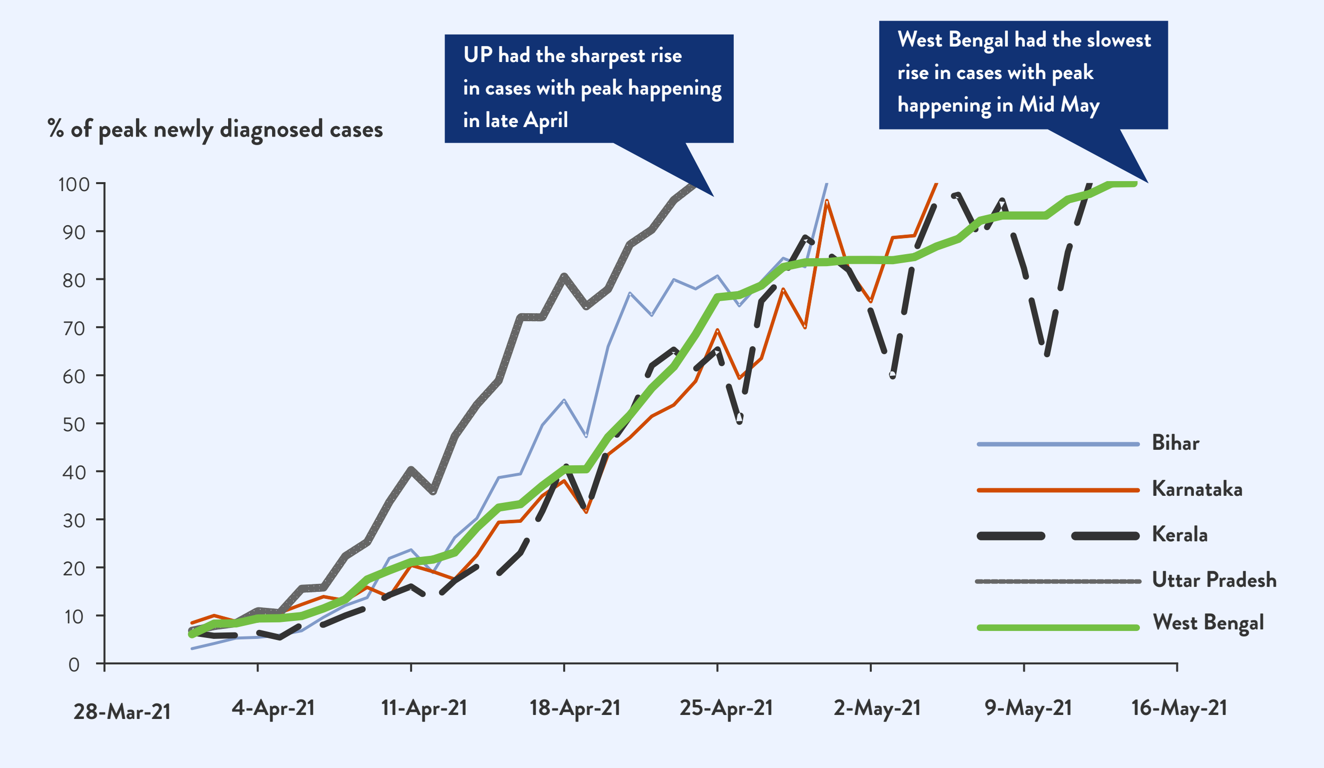

*Figure 17. COVID-19 cases by location*

## 3.3.4. Spatial Demand–Supply Gaps

The government took over supply and distribution during COVID-19, and allocation to states was by number of cases. As per public domain allocation data and the aforementioned demand methodology, ~35 percent of demand could not be met. State-level variations also occurred (see Table 13).

*Table 13. State-level demand*

| Name of State | Oxygen Allocation by central Govt (as per 8th May)^ (A) | Basis Officially Diagnosed Cases | | |
|---|---|---|---|---|
| | | Total Demand of Oxygen (B) | Unmet demand (B-A) | % demand which was met |
| Maharasthra | 1,779 | 2,350 | 571 | 76% |
| Karnataka | 1,015 | 1,734 | 719 | 59% |
| Kerala | 223 | 1,448 | 1,225 | 15% |
| UP | 894 | 1,214 | 320 | 74% |
| Rajasthan | 395 | 706 | 311 | 56% |
| Delhi | 590 | 862 | 272 | 68% |
| 7 NE states | 67 | 216 | 149 | 31% |
| Jharkhand | 120 | 246 | 126 | 49% |
| Odisha | 200 | 371 | 171 | 54% |
| **Total** | **+10,000** | **+15,000** | **+5,000** | **~65%** |

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[38] https://data.covid19india.org/

## District Level

Limited data are available at the district level to track supply and demand during COVID. For analysis, the gap was defined as the increase in oxygen needs (peak need) relative to regular usage (regular supply or consumption). Peak demand was estimated using the district-level data on the daily number of cases from covid19.org and the methodology for demand estimation.

For supply, the number of hospitals in each district was estimated from national health authority data. The routine supply (or routine consumption) was estimated using the average of 0.5 LPM per occupied bed. Table 14 shows the list of districts with the highest increases.

***Table 14. Districts with highest increases in consumption***

| S No. | State | District | Gap |
|---|---|---|---|
| 1 | Karnataka | Bengaluru Urban | 882 |
| 2 | Maharashtra | Pune | 444 |
| 3 | Maharashtra | Mumbai | 386 |
| 4 | Maharashtra | Nagpur | 304 |
| 5 | Tamil Nadu | Chennai | 264 |
| 6 | Maharashtra | Thane | 264 |
| 7 | Uttar Pradesh | Lucknow | 220 |
| 8 | Maharashtra | Nashik | 214 |
| 9 | Gujarat | Ahmedabad | 212 |
| 10 | Tamil Nadu | Coimbatore | 151 |
| 11 | Rajasthan | Jaipur | 147 |
| 12 | Chhattisgarh | Raipur | 134 |
| 13 | Andhra Pradesh | East Godavari | 131 |
| 14 | Uttarakhand | Dehradun | 104 |
| 15 | Andhra Pradesh | Chittoor | 102 |
| 16 | Bihar | Patna | 100 |
| 17 | Karnataka | Mysuru | 94 |
| 18 | Karnataka | Tumakuru | 94 |

Contd.

| S No. | State | District | Gap |
|---|---|---|---|
| 19 | Gujarat | Surat | 91 |
| 20 | Maharashtra | Satara | 91 |
| 21 | Maharashtra | Solapur | 90 |
| 22 | Andhra Pradesh | Anantapur | 89 |
| 23 | Andhra Pradesh | Visakhapatnam | 83 |
| 24 | Uttar Pradesh | Varanasi | 82 |
| 25 | Rajasthan | Jodhpur | 80 |
| 26 | Uttar Pradesh | Kanpur Nagar | 76 |
| 27 | Chhattisgarh | Durg | 74 |
| 28 | Andhra Pradesh | Srikakulam | 73 |
| 29 | Karnataka | Ballari | 73 |
| 30 | Madhya Pradesh | Indore | 70 |
| 31 | Andhra Pradesh | Guntur | 70 |
| 32 | Madhya Pradesh | Bhopal | 70 |
| 33 | Maharashtra | Sangli | 69 |
| 34 | Karnataka | Hassan | 69 |
| 35 | Maharashtra | Kolhapur | 68 |
| 36 | Tamil Nadu | Erode | 68 |
| 37 | Tamil Nadu | Tiruppur | 67 |
| 38 | Haryana | Faridabad | 65 |
| 39 | Maharashtra | Chandrapur | 64 |
| 40 | Maharashtra | Latur | 64 |
| 41 | Andhra Pradesh | West Godavari | 63 |
| 42 | Andhra Pradesh | Kurnool | 63 |

Contd.

| S No. | State | District | Gap |
|---|---|---|---|
| 43 | Tamil Nadu | Thiruvallur | 63 |
| 44 | Maharashtra | Nanded | 62 |
| 45 | Maharashtra | Aurangabad | 62 |
| 46 | Odisha | Khordha | 62 |
| 47 | Karnataka | Belagavi | 58 |
| 48 | Tamil Nadu | Tiruchirappalli | 58 |
| 49 | Jharkhand | Ranchi | 57 |
| 50 | Maharashtra | Yavatmal | 56 |
| 51 | Uttar Pradesh | Meerut | 56 |
| 52 | Karnataka | Mandya | 54 |
| 53 | Punjab | Ludhiana | 54 |
| 54 | Uttar Pradesh | Gautam Buddha Nagar | 52 |
| 55 | Andhra Pradesh | Prakasam | 52 |
| 56 | Tamil Nadu | Madurai | 52 |
| 57 | Karnataka | Dakshina Kannada | 52 |
| 58 | Chhattisgarh | Bilaspur | 50 |
| 59 | Maharashtra | Bhandara | 50 |
| 60 | Himachal Pradesh | Kangra | 48 |
| 61 | Maharashtra | Jalgaon | 48 |
| 62 | Tamil Nadu | Salem | 47 |
| 63 | Rajasthan | Udaipur | 46 |
| 64 | Madhya Pradesh | Gwalior | 45 |
| 65 | Haryana | Hisar | 45 |
| 66 | Odisha | Sundargarh | 44 |

Contd.

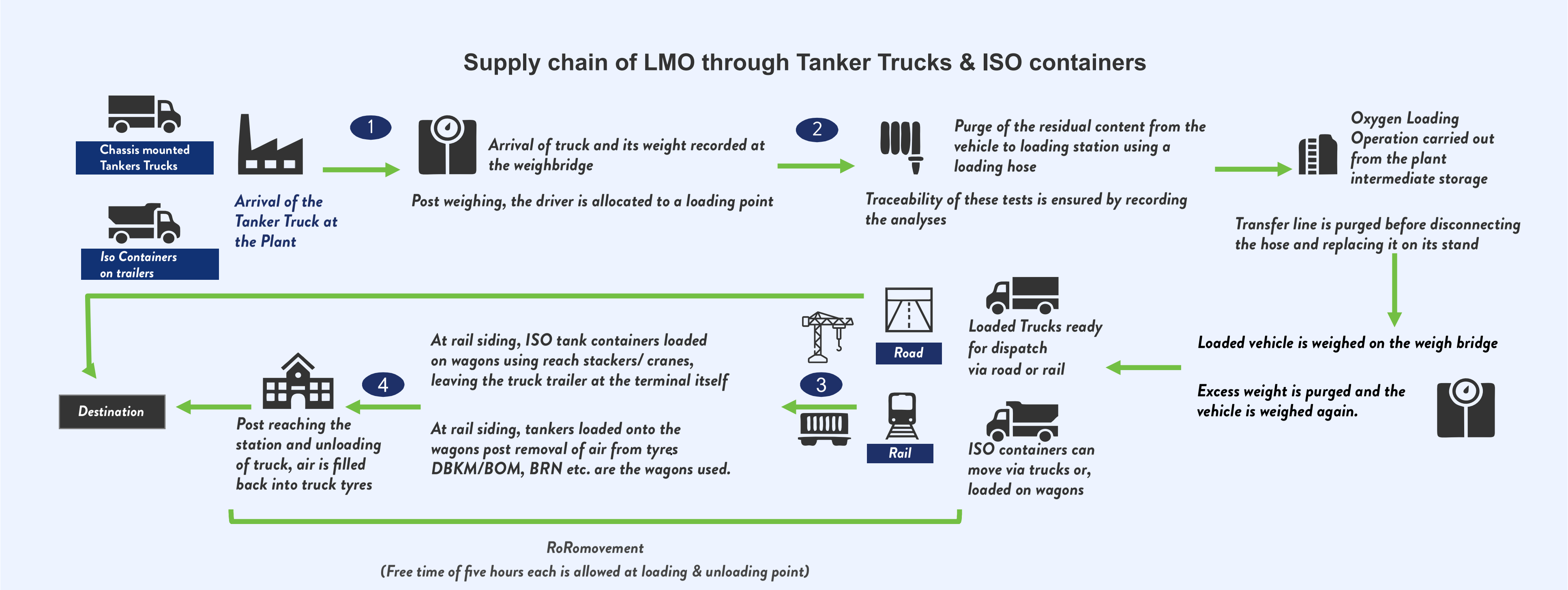
| S No. | State | District | Gap |
|---|---|---|---|
| 67 | Chhattisgarh | Korba | 44 |
| 68 | Chhattisgarh | Raigarh | 44 |
| 69 | Karnataka | Udupi | 43 |
| 70 | Rajasthan | Alwar | 43 |
| 71 | Chhattisgarh | Rajnandgaon | 43 |
| 72 | Uttar Pradesh | Gorakhpur | 42 |
| 73 | Jammu and Kashmir | Srinagar | 42 |
| 74 | Maharashtra | Amravati | 41 |
| 75 | Uttar Pradesh | Bareilly | 41 |
| 76 | Uttar Pradesh | Moradabad | 41 |
| 77 | Haryana | Sonipat | 40 |
| 78 | Karnataka | Uttara Kannada | 40 |
| 79 | Karnataka | Bengaluru Rural | 40 |
| 80 | Odisha | Cuttack | 40 |
| 81 | Rajasthan | Kota | 39 |
| 82 | Maharashtra | Wardha | 39 |
| 83 | Andhra Pradesh | Krishna | 38 |
| 84 | Andhra Pradesh | Vizianagaram | 38 |
| 85 | Tamil Nadu | Kancheepuram | 37 |
| 86 | Bihar | Gaya | 37 |
| 87 | Tamil Nadu | Thanjavur | 37 |
| 88 | Maharashtra | Parbhani | 37 |
| 89 | Tamil Nadu | Thoothukkudi | 37 |
| 90 | Karnataka | Dharwad | 37 |

Contd.

| S No. | State | District | Gap |
|---|---|---|---|
| 91 | Gujarat | Vadodara | 36 |
| 92 | Uttar Pradesh | Saharanpur | 35 |
| 93 | Uttar Pradesh | Ghaziabad | 35 |
| 94 | Uttar Pradesh | Jhansi | 35 |
| 95 | Maharashtra | Jalna | 34 |
| 96 | Uttarakhand | Udham Singh Nagar | 34 |
| 97 | Mizoram | Aizawl | 34 |
| 98 | Maharashtra | Ratnagiri | 33 |
| 99 | Tamil Nadu | Namakkal | 33 |
| 100 | Karnataka | Bagalkote | 32 |

## 3.3.5. LMO Logistics Supply Chain and Associated Challenges

Significant challenges exist in the supply chain (Figure 18).



Key challenges across the supply chain

1. Long queue of tankers at the plant due to lack of filling points leads to delay
2. Lack of knowhow among drivers of trailers transporting ISO containers
3. Wear and tear of tyres in Ro-Ro movement
4. Air filling and removal of truck tyres at loading/unloading points in rail leads to a delay by 2 hours

*Figure 18. Supply chain challenges*

### 3.3.6. Absolute Transportation and Storage Capacity

#### 3.3.6.1. Cylinder Capacity / Refillers[39]

India has an absolute shortage of cylinders for medical oxygen, which was highlighted during the pandemic, necessitating conversion of industrial cylinders.

Cylinders can be mainly of two types (Table 15):

***Table 15. Type of cylinders***

| Type | Cost (INR) | Capacity | Unit | Capacity | Unit |
|---|---|---|---|---|---|
| B – Type | ~ 5,000 | 7 | Liter | 0.01 | MT |
| D – Type | ~ 17,000 | 47 | Liter | 0.07 | MT |

Oxygen is mainly received by refillers as a liquid from ASU plants via cryogenic oxygen tankers or ISO tanks.

- The liquid oxygen is stored in storage plants at the filling stations, which usually have a capacity of 20 kiloliters (kL) each. Most refilling stations have 1–2 storage units.
- Although refillers are required to fill not more than ~250 cylinders daily under the BAU scenario, they can handle around ~ 1,500 (D-type) per day using optimum capacity.
  - To increase storage capacity, refilling stations can install another storage plant. The capital expenditure would be estimated to be more than Rs. 5,000,000, and additional Petroleum and Explosives Safety Organization (PESO) approvals would be required.
  - The cylinders at the refilling stations are owned by either the refillers or consumers.
  - Based on primary interactions with refillers, the potential for increasing their existing storage capacity by adding new bulk storage tanks (INR 30–35 per tank) is limited by lack of availability of additional land area. They also expressed concerns about capital recovery of new investment, given the adequacy of existing infrastructure to service medical oxygen demand in a BAU scenario.
- PESO published an approval stating the procedure to be followed to convert industrial cylinders:
  - Cylinders are completely degassed.
  - The valve is removed and cleaned with a cleaning solution and made completely dry with air flushing.
  - Mild detergent cleaning solution is used to degrease the cylinder internally and externally (organic solvents, such as carbon tetrachloride, are forbidden).

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[39] Only capacities registered with PESO are mapped; small unorganized refillers, at ~20 percent of the sector, are beyond the scope of this study.

- Cylinders are filled with warm water.
- Cylinders are drained and dried with air.
- Industrial oxygen valves without chrome plating are fitted.
- Cylinders are painted to indicate medical oxygen.
- Cylinders are converted at E and F licensed premises.

***Table 16. Suppliers by country***

| Company | Country |
|---|---|
| INOX CVA | India |
| Cryogas | India |
| Chart Industries | HQ—United States (also operating in India) |
| Bofort | Belgium |
| Cryolor | France |
| Wessington Cryogenics | UK |
| FIBA Technologies | US |
| Eurotainer | France |
| Greenfir | China |
| TriFleet | China |

### 3.3.6.2. ISO Containers

India has an absolute shortage of ISO containers.

20 ft and 40 ft ISO container tanks were found to be available (and 10 ft. were manufactured by some companies) both locally and globally.

Some players stated that the time required for import of containers (from China) was one week.

Considering the available fleet of some of these companies, about 55–70 containers could be available in the domestic market.

60 percent of these companies also leased their equipment.

### 3.3.7. Summary of the Key Challenges in the Supply Mechanism

- Production
  - Production capacity was sufficient for routine needs but not for a pandemic. The necessary buffer storage capacities are that production capacity post-COVID is expected to be ~18–19,000 MTPD. This includes predominantly industrial oxygen. The peak need in Wave 2 is estimated to be ~17,200 MTPD.
  - Production capacity is concentrated in certain geographical regions, requiring long-distance transport.
  - Throughput capacity of production sites is limited, often with a long queue of tankers at the plant due to lack of filling points, which leads to delay and high turnaround time.

- Transportation
  - Transportation capacities are limited, with an absolute shortage of ISO containers, cryogenic tankers, and cylinders (India had to resort to purchasing these or divert from other uses).
  - Refillers have limited storage and throughput capacities (most have 1–2 storage plants and process only 250 cylinders per day but can go up to 1,500). Turnaround time is high.
  - Minimal monitoring is being done at central command and control centers. Technology is not used to track the stock movement and consumption.

- Consumption: Challenges in Hospitals
  - Most hospitals depend on cylinders and cannot use tanks. For hospitals with tanks, many continue to rely on manual methods for reordering, with limited use of level sensors for automatic reordering.
  - Hospital gas pipeline manifolds are not designed to deliver higher loads; many hospitals have a small caliber of pipe.
  - Consumption is not being monitored. Usage protocols are not being followed.

### 3.3.8. Associated Regulatory Requirements

#### 3.3.8.1. Oxygen from ASU Plants

ASU plants generally manufacture high purity (99+ percent) oxygen in gaseous and liquid form. However, based on interactions with ASU plant producers, approving oxygen for medical use requires a license based on the Drugs and Cosmetics Act of 1940 (2018). Following are the standards prescribed for medical oxygen in India:

- Carbon monoxide less than 5 PPM

- Carbon-di-oxide not more than 300 PPM

- No halogen, polymer, oxidizing substances, and moisture, and

- No damage to the materials of cylinders, gas pipeline, anesthesia machine, and ventilators.

### 3.3.8.2. The Production Facility Must Also Comply with the Following Requirements:

- Procure the necessary site approval from PESO.

- Be located inside a fenced compound and accessible to the road tankers.

- Maintain all hazardous buildings, flammable materials, public access, vehicles, and surface water drains at least 5 m and in some cases 8 m from the nearest point of the compound.

- Ensure that the compound directly in front of the fill connection is concrete and designed to contain any liquid spillage, which increases the risk of fire.

- Never use tar and asphalt in the vicinity, as they form an explosive mixture with liquid oxygen.

- Take responsibility for routine check, maintenance, and demonstration of functioning of LMO and preventive measures for an emergency to hospital technical staff at its own cost.

- Ensure that the unit is the latest international version, fitted with standard accessories at the minimum, has undergone standard inspection, and has a certificate to that effect submitted.

### 3.3.8.3. Certification Requirements for Using Logistics Assets in the Supply Chain

- For storage tanks installed by LMO suppliers at hospitals, the license for installation will technically be in the name of the authority of the hospital, but the responsibility for safe and secured maintenance of the entire infrastructure will belong to the LMO supplier.

- The LMO producer will be responsible for routine check, maintenance, and demonstration of functioning of LMO and preventive measures for an emergency to hospital technical staff at its own cost.

- The storage vessel should be maintained so as to keep natural evaporation rate less than 1 percent. LMO vessel capacity: 990 liters (single tank)/2,600 liters/5 kL/6 kL/10 kL tanks.

- Depending on the consumption volumes, LMO should be supplied through mobile vehicles, tanks set up in a vertical configuration, and operating working pressure between 8–12 to 16 kg/cm2.

- The storage tank should be a compact unit including vessel and vaporizer. Vessel should be of standard material and technology, in light of safety and international standards. Tank dimensions can be decided based on hospital needs and studying the proposed site.

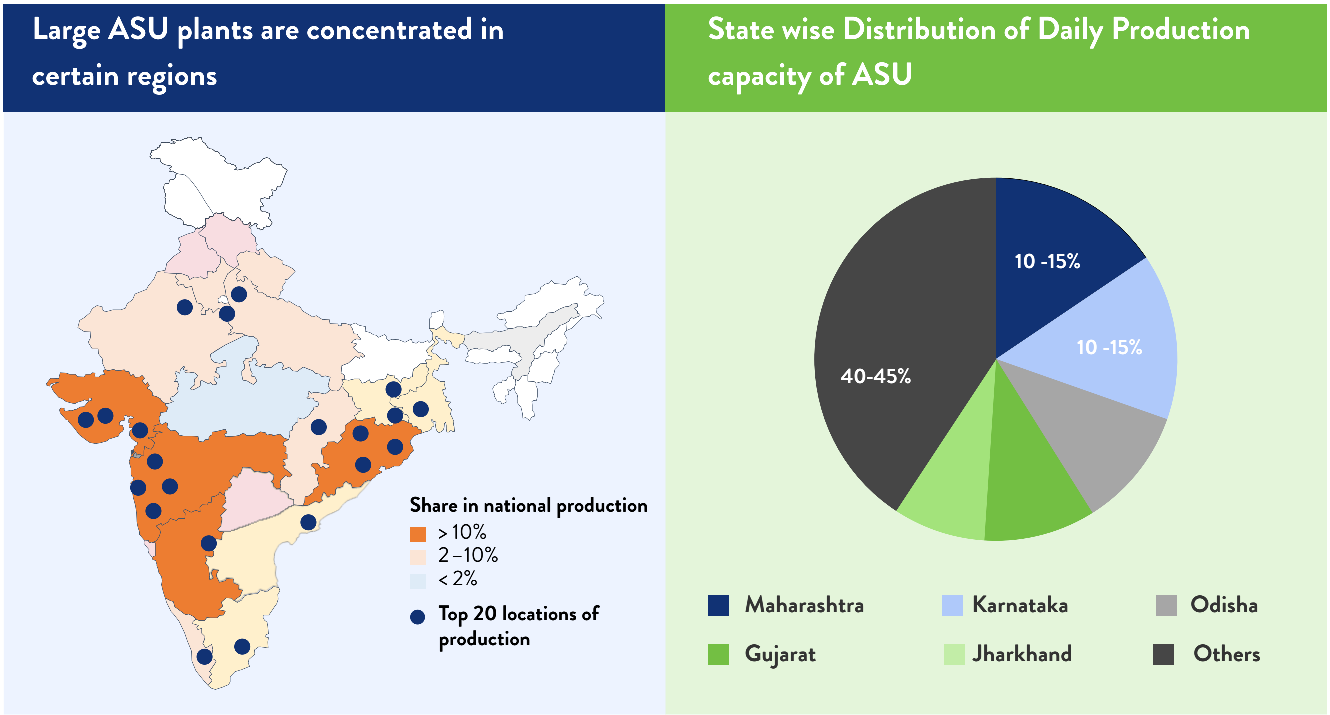
- The storage tank should have a content indicator and preferably low liquid level alarm with safety system in case of emergency/calamity.

A manufacturer needs to adopt good manufacturing practices and ensure compliance with safety and quality standard protocols at each stage to ensure that medical grade oxygen can be produced. A manufacturer is granted a license to supply medical oxygen on providing lab test showing compliance with these parameters.

## 3.3.9. Regional Disparities in Production and Storage Capacities

### 3.3.9.1. Spatial Spread of ASU Plants

ASU plants mainly service industrial sector demand. The main consumers are industries, such as steel, petrochemicals, automobile, electronics, and pharmaceuticals. These industries are in industrialized states in the western and eastern regions. Thus, within the organized sector, states such as Maharashtra, Karnataka, Odisha, and Gujarat represent over 50 percent (through May 2021) of the country's installed ASU oxygen generation capacity. Figure 19 shows the distribution of ASU-based Oxygen Generation Capacity (for Organized Players as of May 2021).[40]



Large ASU plants are concentrated in certain regions

State wise Distribution of Daily Production capacity of ASU

*Figure 19. Regional distribution of ASU plants*

- Spatial spread of oxygen-production capacity of ASU plants is ~10,000–12,000 MTPD.

- Organized and large units presented on the map represent an estimated ~80 percent of national ASU-ased oxygen-production capacity.

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[40] Estimated based on industry interactions, news articles, and government press releases

### 3.3.9.2. Major Oxygen and Other Gas Consumer Users[41]

- The majority of ASU plants serve industries, such as metals, machinery, electronics, and petrochemicals (Figure 20).

- High demand from industrial users lead to concentration of ASU plants away from medical oxygen demand centers in urban areas.

- Health care sectors consume only 5–10 percent of the national production. Servicing their demand requires an extensive transportation and logistics network, as healthcare facilities are located mainly in urban areas, whereas production centers are concentrated near heavy industry regions, away from urban areas.

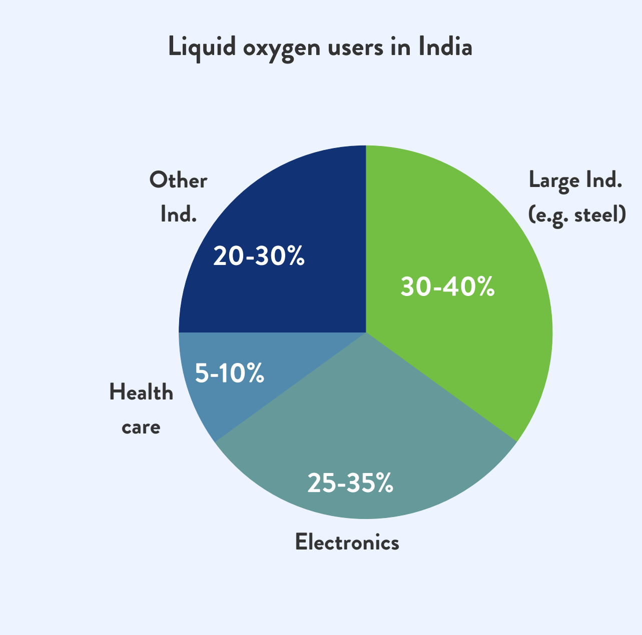

*Figure 20 Major users of Liquid Oxygen*

### 3.3.9.3. Major ASU technology-based oxygen producers[42]

- Specialist players such as Linde, Inox, Air Liquide, Air Water, etc. produce ~65% of total national oxygen using ASU technology.

- The remaining capacity is captive to industrial users such as Tata Steel, SAIL, JSW, Reliance, etc.

- Small and unorganized players contribute ~20% of the national LMO, which could not be mapped as part of this study.

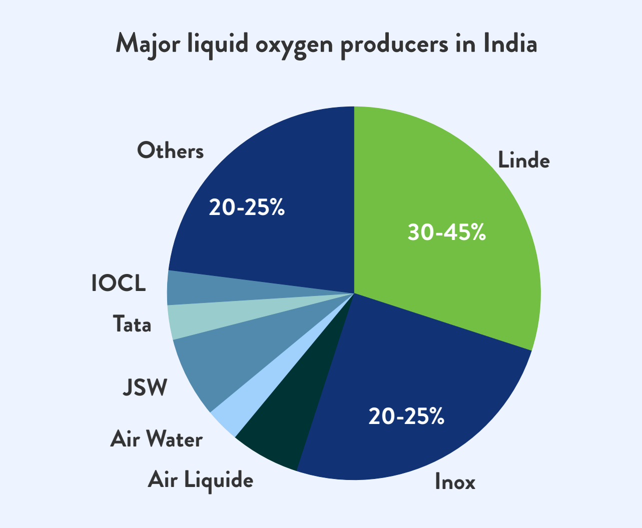

*Figure 21 Major Producers of Liquid Oxygen*

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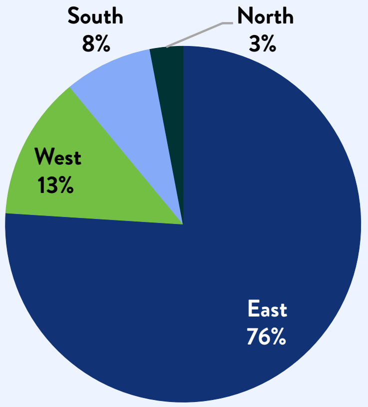
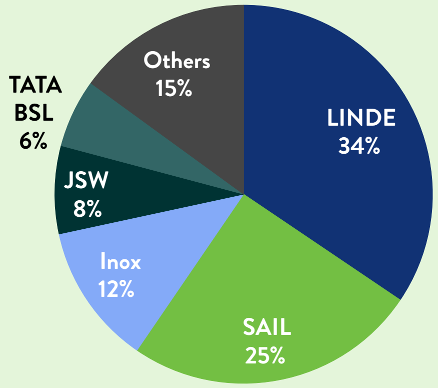
[41] Estimated from Linde investor presentations and SME inputs

[42] Based on interactions with industry players and secondary research

### 3.3.9.4. ASU Storage variations

*Table 17. ASU Storage Variations*[43]

| Region-wide distribution of storage capacity (~75,000 MTPD) | Distribution of current storage capacities by ownership |
|---|---|
|  |  |

Storage capacity is skewed in favor of the east (industrial plants, mostly steel plant clusters), increasing lead distance for a LMO demand spike in an emergency scenario, such as COVID-19 (Table 17).

- Specialist LMO producers and steel industry players control the majority of the storage capacity.
- These storage hubs are in industrial clusters in Odisha, West Bengal, Maharashtra, Karnataka, etc.
- This led to significant mismatch in LMO demand–supply in COVID-19-induced spikes due to the long distance from the rest of the country to North India.
- Several states have planned to enhance LMO storage capacity at the hospital level, such as Delhi (from ~170 MT to 420 MT), and Tamil Nadu (from 550 MT to 1,400 MT) (Figure 22); however, more is expected to be done to service expected demand spikes.

The diversion of existing production capacity and storage stock is a large opportunity for the economy. During Wave 2, the government and private sector collaborated to adjust production and deliveries of materials such as high-grade steel, glass, and auto parts to prioritize oxygen for medical purposes. For example, it is estimated that the steel sector saw lost production of up to 500,000 MT during the 15–30 days of diversion. However, interactions with industry players reflect that a provision will be made to ensure a limited impact on regular industrial activity, as this leads to lingering impact on the industry and customer confidence.

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[43] Industry reports

Considering the known daily production capacities of ASU plants and installed PSA units against the peak oxygen demand at each state, the majority of states showed a deficit in the oxygen level, and states such as Odisha, Jharkhand, Gujarat, Uttarakhand, and Himachal Pradesh produced more oxygen than their demand.

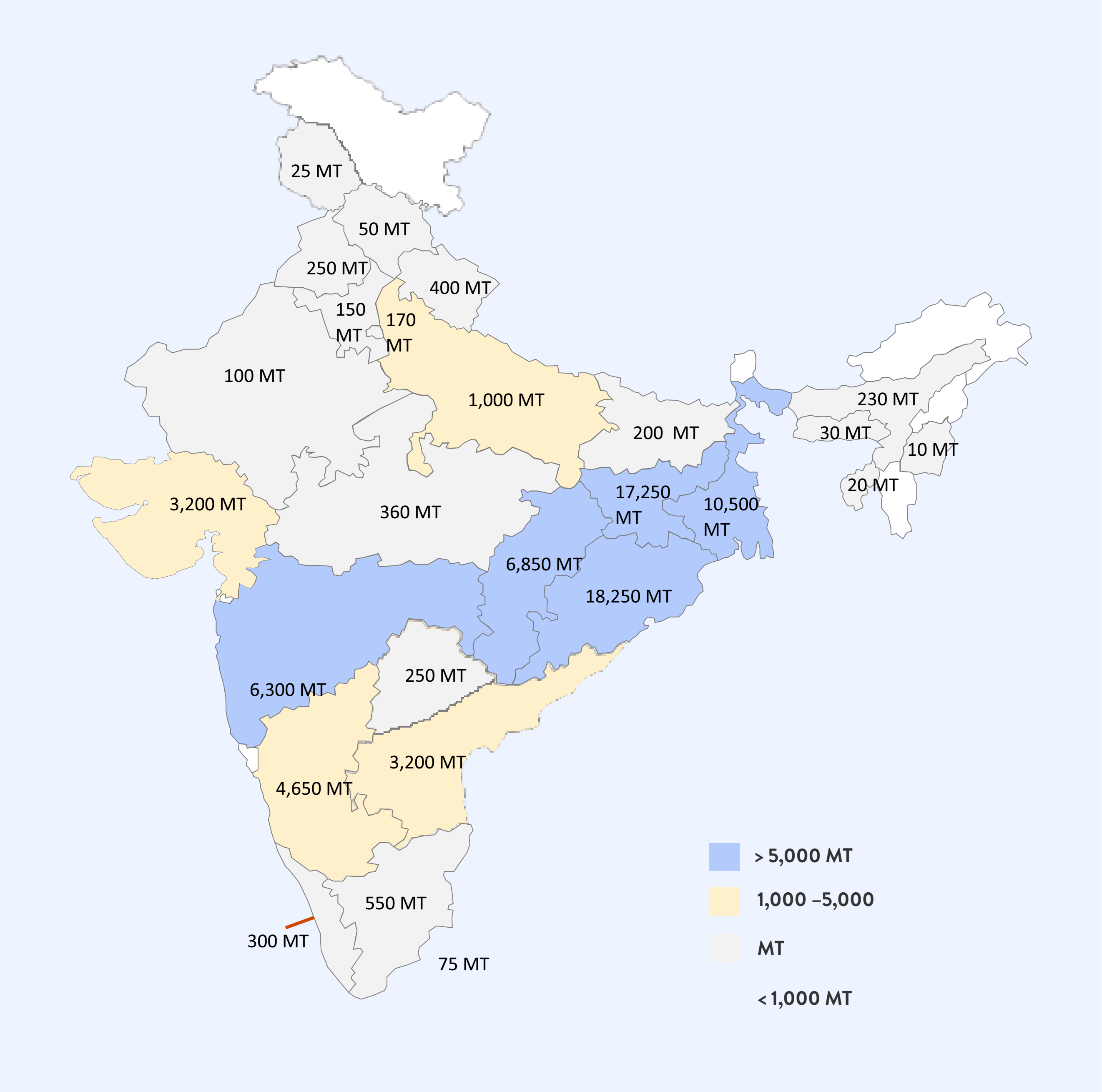

*Figure 22 Planned storage capacities (in MT)*

### 3.3.9.5 Oxygen Tanker Truck Capacity[44]

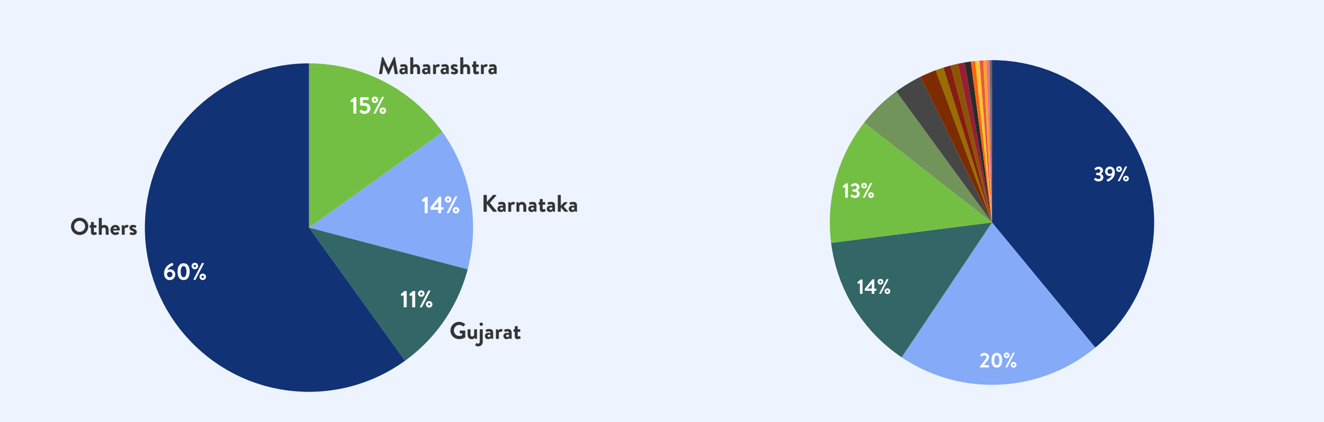

*Figure 23. Tanker truck capacity*

- Tanker trucks suitable for carrying oxygen (LMO tankers and argon or nitrogen converted tankers) are around ~1,600 nationwide.
- Maharashtra, Karnataka, and Gujarat are among the states with the highest number of tanker trucks registered (Figure 23).
- Most of these tanker trucks are owned by players such as Inox, Linde, and Praxair.

## 3.3.10. Key learnings

### 3.3.10.1. Spatial spread of ASU plants

**3.3.10.1.1** India had a significant demand–supply gap of medical oxygen, which was manifested in COVID Wave 2. The available infrastructure needs to be immediately augmented (production, transportation, storage etc.) to tide over any future pandemic-like crisis or meet increased oxygen needs as the healthcare system matures (highlighted in previous sections).

**3.3.10.2.** Spatiotemporal medical oxygen needs vary significantly in a pandemic-like crisis, and production and storage capacity vary regionally. This is a fertile condition for creating an NMOG to connect these disparate sites and allow free flow of oxygen seamlessly from surplus to deficit areas.

**3.3.10.3.** The infrastructure is heavily in the private domain. For a grid to function efficiently, it is imperative that the private sector collaborate, instead of creating a parallel, competing supply chain infrastructure.

**3.3.10.4.** Based on the source and target destination and form of oxygen, various supply chains are possible (see image). A combination of these supply chains can be used for transport (meeting the requirements of least cost and time). ASU and PSA plants follow different distribution pathways, which can be logistically complex and varied based on time and expenses. Long-haul transport can be via both road-based tanker trucks and ISO containers to transport cryogenic LMO.

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[44] Primary interactions

The proposed NMOG seeks to map demand centers (demand clusters) with supply centers, such as production units, to minimize the overall transit and cost of transportation. This can be done based on predesigned algorithms that ensure that deliveries could be made from supply points to demand centers within 24–48 hours with a limited impact on cost. Based on these variations, the following models can be devised for oxygen transport at end consumption points (Figure 24).

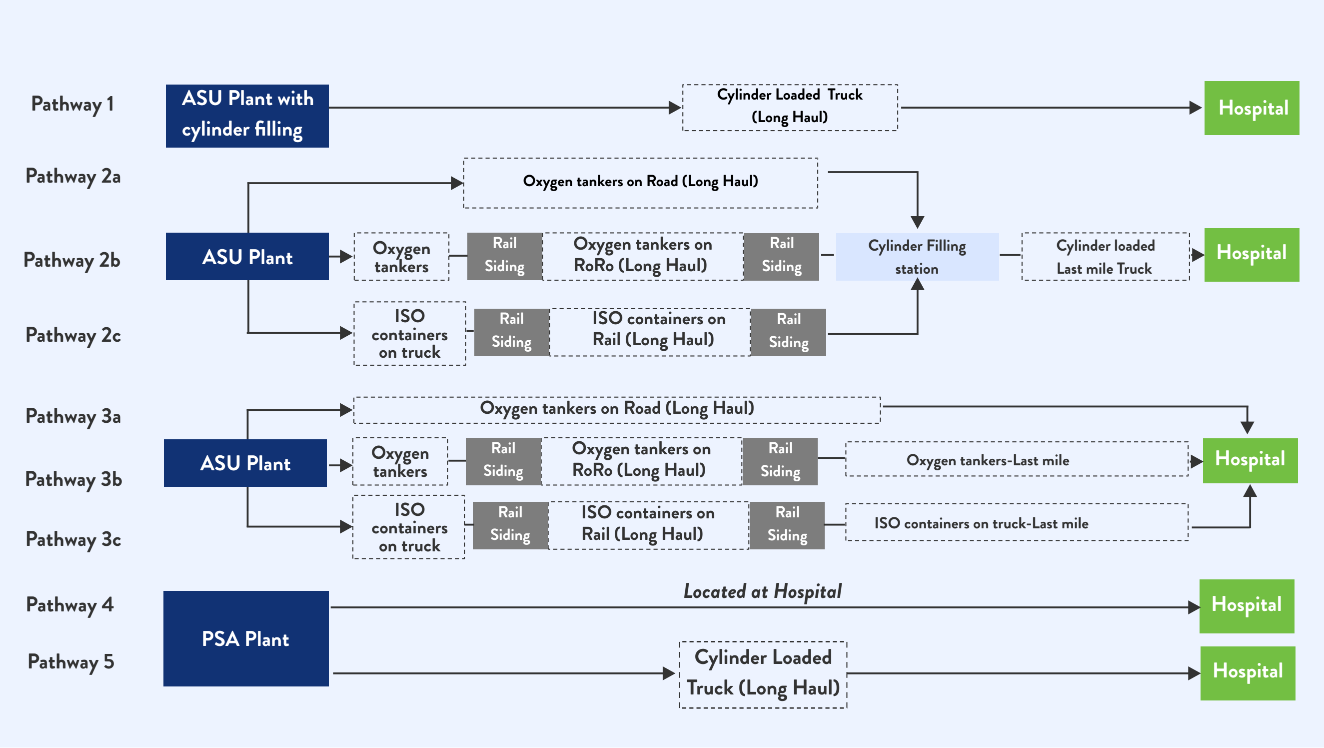
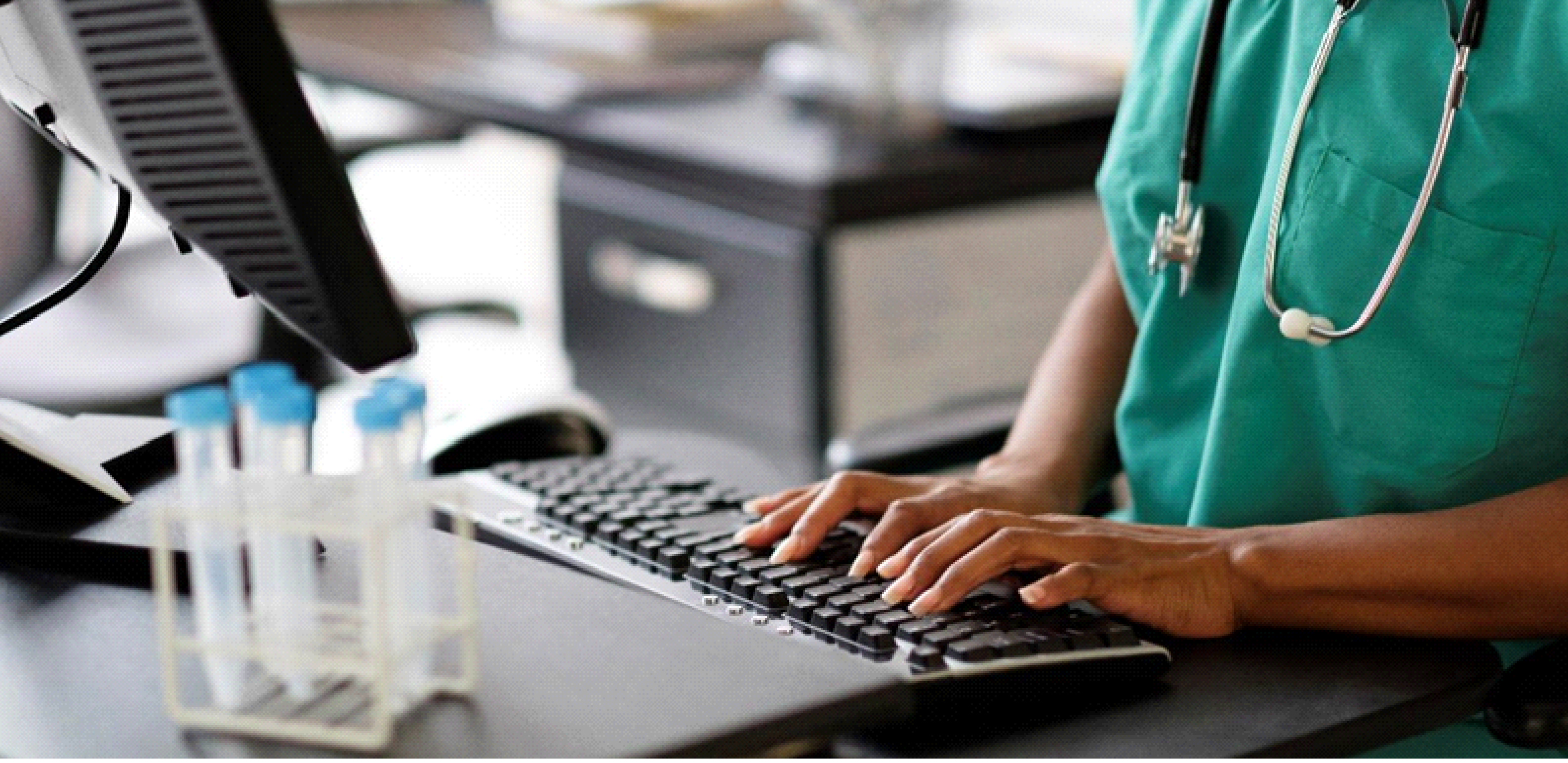


*Figure 24. Transport pathways at end consumption points*



# 4. Measures Undertaken to Mitigate the Oxygen Crisis and Other Best Practices

## 4.1. Measures by Central and State Governments

### 4.1.1. Augmentation of Physical Infrastructure[45]

A variety of measures were taken by both central and state governments to tide over the immediate oxygen crisis. The steps were also designed to augment long-term capacities to mitigate any future exigencies.

- The capacity use of oxygen production was significantly increased, from 84 percent in August 2020 to ~129 percent by August 2021.
- Diversion of oxygen for nonmedical purposes was curbed.
- More than 3,700 PSA plants[46] were set up, including the plants under PM-CARES, public sector undertaking (PSU) of central ministries (Defence Research and Development Organisation, Ministry of Petroleum and Natural Gas, Ministry of Health and Family Welfare, etc.), and other sources.
- LMO was imported from other countries.
- More than 100,000 oxygen concentrators were procured.

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[45] https://pib.gov.in/PressReleseDetail.aspx?PRID=$^{1}$,$^{717}$,$^{459}$; news articles, and discussion with industry stakeholders

[46] Lok Sabha reply given to a question by the minister of state for health Bharati Pravin Pawar on March 25. https://theprint.in/health/past-covid-peak-heres-how-govt-plans-to-keep-white-elephant-psa-oxygen-plants-up-running/903592/

- The number of oxygen tankers was increased from ~1,000 in March 2020 to ~1,700, by importing ~100 tankers and converting ~500 nitrogen and argon tankers.
- Railways and airways were used to transport oxygen from sites of production to sites of consumption. The number of cryogenic tankers for hospital storage was increased from ~600 to ~900 by May 2021.
- The number of oxygen cylinders was ramped up from 435,000 in March 2020 to ~1,100,000 by May 2021, and provisions were made for another ~460,000 cylinders.
- An allocation process was designed to establish an equitable supply to all states according to demand.

Some states also took innovative measures to become self-reliant and set up local oxygen grids (Figure 25).

**Regional Policy**

**Covid-19: Delhi cabinet approves policy to make city oxygen self-reliant**

The policy was drafted after Delhi faced a severe crisis of medical oxygen during the fourth wave of the Covid-19 pandemic – also the worst so far - in April this year, said chief minister Arvind Kejriwal.

**Regional Grids**

**FAST-TRACK PROJECT**

- Oxygen Grid to be established from **Saharanpur to Deoria**
- UP to get 770 tons of **oxygen and nitrogen** per day
- UPSIDA incentive for investors
- **19 firms in UP** have already shown interest in project
- **24X7 facility** for **online application** for allotment of land via **Nivesh Mitra portal**

**Air of hope: UPSIDA to set up oxygen grid across Uttar Pradesh**

Neha Lalchandani / TNN / May 13, 2021, 07:50 IST

*Figure 25. State measures to become self-reliant*

### 4.1.2. Usage of Technology

Technology was leveraged to set up digital systems to enable real-time tracking of oxygen movement. It was integrated with the GSTN database for E-waybill data entry, tracked tankers through GPS, SIM (driver cell number), and FASTag, and provided automated alerts for route deviation, unintended stoppages, and delays.

- **West Bengal Oxygen Management Information System:** To cater to the growing need among the public, the West Bengal government planned to monitor the supply chain management in the state through a dedicated web-enabled information system. The portal has a concentrated focus on oxygen management. It captures user self-declared transactional data related to the system and is being developed to oversee and monitor production status, flow of delivery systems, and supply chain management to each health facility in the state. Table 18 lists the salient features of this system.

*Table 18. West Bengal Oxygen Management Information System*

| Parameters | Manufacturers | Re-fillers | Dealers | Health Facilities (HF) |
|---|---|---|---|---|
| **Data capturing** | • Request for supply received from refillers/dealers/HFs (quantity and name)<br>• Supply delivered/released (quantity and the name of refillers/dealers/HFs)<br>• Opening stock/current stock (oxygen produced and supplied) | • Request for supply received from dealers/ HFs (quantity and name)<br>• Supply delivered/released (quantity and the name of dealers/HFs)<br>• Opening stock/current stock (oxygen received and supplied) | •<br>• •Request for supply received from HFs (quantity and name)<br>• Supply delivered/released (quantity and the name of Hfs)<br>• Opening stock/current stock (oxygen received and supplied) | • Approve the request for supply updated by manufacturers/ refillers/dealers in their name. (quantity and name of supplier)<br>• Approve the oxygen received as updated by manufacturers/ refillers/dealers in their name. (quantity and name of supplier)<br>• Supply received from other source |

Contd.

| Parameters | Manufacturers | Re-fillers | Dealers | Health Facilities (HF) |
|---|---|---|---|---|
| | | | | • Opening stock/current stock (oxygen received and supplied) |
| **Transaction time** | 6 AM to 6 AM | | | |
| **Cut-off time** | 11 AM | | | |

West Bengal
Oxygen Management
Information System

Government of West Bengal
May 2021

### 4.1.3. Designing Incentives for the Private Sector to Augment Capacities

Rules were also designed to incentivize the private sector to augment capacities. Many of these measures revolved around a mix of financial incentives to set up PSA plants (Figure 26).

| **Parameters** | **Delhi** | **Maharashtra** | **Karnataka** | **Uttar Pradesh** |
|---|---|---|---|---|
| Policy | Medical Oxygen Production Promotion Policy (Aug 3)<br>(Commissioning by December 31,2021) | Maharashtra Mission Oxygen Swawlamban.<br>(Commissioning by December 31, 2021) | - | Oxygen Production Promotion Policy |
| Capital Subsidy | • 100 % capital subsidy shall be provided to the approved units within 1 month of commissioning<br>• One-time subsidy of ` 20 lakh/MT capacity<br>• One-time subsidy of ` 3 lakh/MT for cryogenic tankers | • Units set up in Vidarbha, Marathwada, Dhule, Nandurbar, Ratnagiri and Sindhudurg: eligible for incentives up to 150 % of their eligible fixed capital investments<br>• Rest of Maharashtra : eligible for up to 100 % general incentives<br>• Interest subsidy for MSME units with a fixed capital investment of up to Rs 50 crore<br>• Special capital subsidy for units producing 25 MT to 50 MT of oxygen & going into production before December 31,2021 | • 25% capital subsidy on the value of fixed assets, subject to ` 10 crore minimum investment | • 25% for bringing up the plant in Bundelkhand or Purvanchal<br>• 20% for bringing it up in central UP<br>• 15% for bringing up in western UP |
| Power Subsidy | Rs 4 per unit consumed in the manufacturing process for the first 5 years from the date of commencement of commercial production | Rs 2 per unit power tariff subsidy and other benefits | • 100% exemption on electricity duty for 3 years<br>• Additional power tariff subsidy of ` 1,000 / tonne | - |

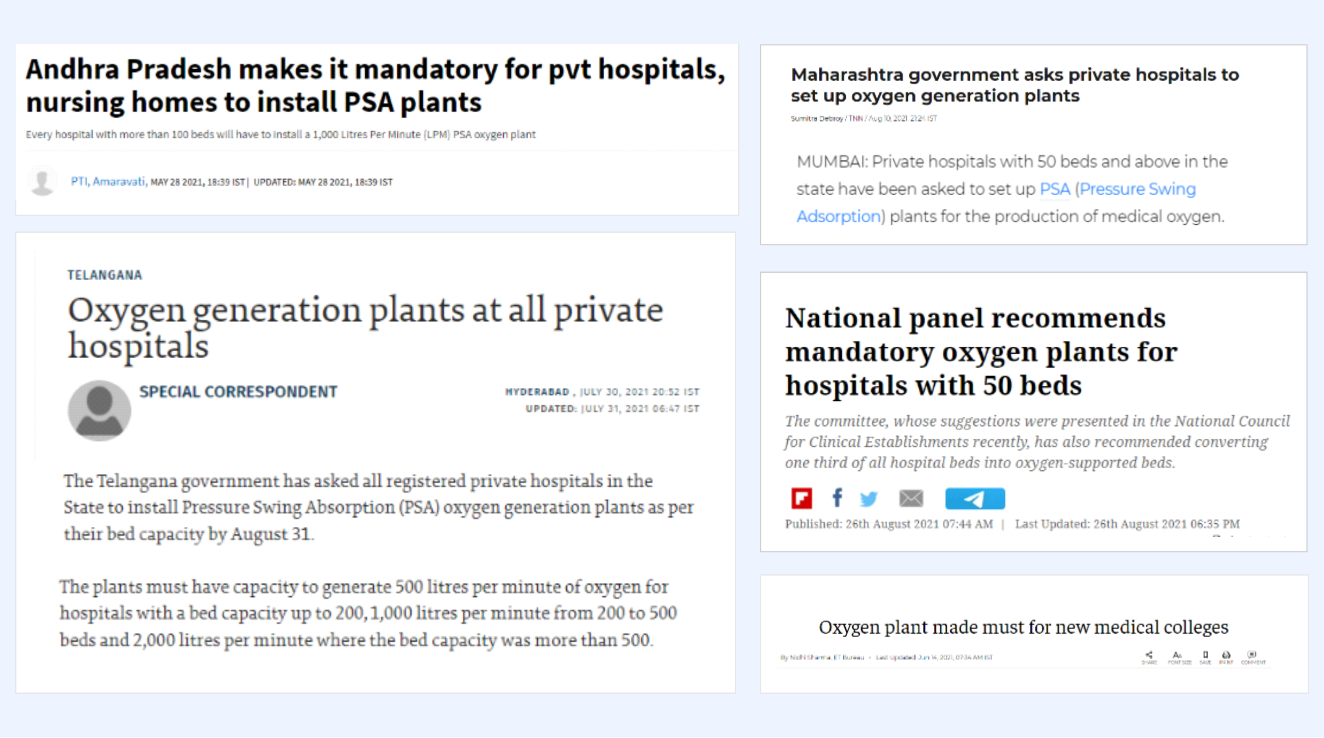
Contd.

| Parameters | Delhi | Maharashtra | Karnataka | Uttar Pradesh |
|---|---|---|---|---|
| Other benefits | - One-time subsidy of ` 1 lakh/MT on liquid medical oxygen storage for hospitals, nursing homes and re-fillers<br>- If unit wishes to avail 50% upfront payment as advance at the stage of proposal sanctioning, same shall be provided against a bank guarantee for an equivalent amount, extending up to the date of commissioning | Refund on :<br>- Gross SGST<br>- ElectricSta mp duty<br>- ity duty<br>- Unit subsidy of power cost<br>} 5 years | - | |
| Stamp duty reimburse ments / exemption | - | - | 100% stamp duty exemption on land and loan documents' registration & reimbursement of fees charged for conversion of land to set up oxygen plants | 100% stamp duty reimbursement<br>- 75% in central UP<br>- 50% in western UP |

*Source: News Reports. PIB

***Figure 26. Private-sector incentives to increase capacity***

In many other cases, regulation was sought to mandate PSA plants in hospitals and medical colleges (Figure 27).



**Andhra Pradesh makes it mandatory for pvt hospitals, nursing homes to install PSA plants**

Every hospital with more than 100 beds will have to install a 1,000 Litres Per Minute (LPM) PSA oxygen plant

PTI, Amaravati, MAY 28 2021, 18:39 IST | UPDATED: MAY 28 2021, 18:39 IST

TELANGANA

**Oxygen generation plants at all private hospitals**

SPECIAL CORRESPONDENT

HYDERABAD , JULY 30, 2021 20:52 IST
UPDATED: JULY 31, 2021 06:47 IST

The Telangana government has asked all registered private hospitals in the State to install Pressure Swing Absorption (PSA) oxygen generation plants as per their bed capacity by August 31.

The plants must have capacity to generate 500 litres per minute of oxygen for hospitals with a bed capacity up to 200, 1,000 litres per minute from 200 to 500 beds and 2,000 litres per minute where the bed capacity was more than 500.

**Maharashtra government asks private hospitals to set up oxygen generation plants**

Sumitra Debroy / TNN / Aug 10, 2021, 21:24 IST

MUMBAI: Private hospitals with 50 beds and above in the state have been asked to set up PSA (Pressure Swing Adsorption) plants for the production of medical oxygen.

**National panel recommends mandatory oxygen plants for hospitals with 50 beds**

*The committee, whose suggestions were presented in the National Council for Clinical Establishments recently, has also recommended converting one third of all hospital beds into oxygen-supported beds.*

Published: 26th August 2021 07:44 AM | Last Updated: 26th August 2021 06:35 PM

Oxygen plant made must for new medical colleges

By Nidhi Sharma, ET Bureau • Last Updated: Jun 14, 2021, 07:34 AM IST

*Figure 27. Regulations to increase capacity*

## 4.2. Case Studies

The supply chain, logistics, and distribution arrangement of medical oxygen are considered unique, but parallels can be drawn with other industries that share three basic features:

a) Disparate centers of production and consumption, necessitating long-distance transfer of goods or commodities;

b) Essential and relevant nature of the goods or commodities to most of the population (akin to a necessity good); and

c) Rising and predictable demand patterns, with intermittent spikes.

A summary of three such grids (electricity, FMCG, and oil and gas) is presented in the subsequent sections.

### 4.2.1. Electricity Grid

Electricity is an important commodity critical for economic growth. The existence and development of adequate power infrastructure is essential for the sustained growth of the Indian economy. Electricity planning is a complex mechanism involving multiple stakeholders. Demand and supply must match every second for the transmission grid to remain stable, so planning and operations are complex to ensure safety and stability. This sector employs multiple practices to make this possible; many of these can be adopted for the national medical oxygen supply chain ecosystem. Figure 28 shows a brief overview of the electricity grid and best practices.

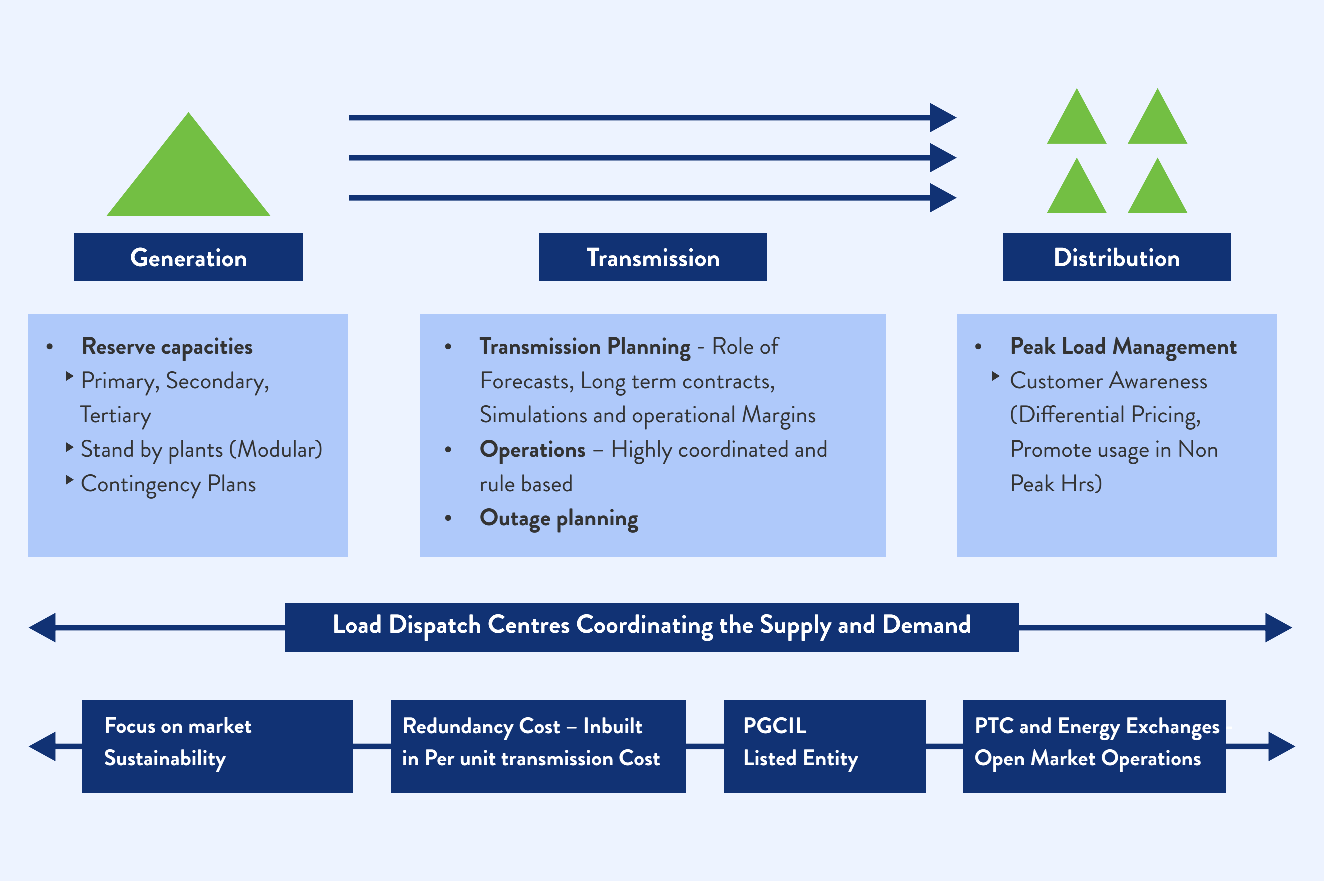
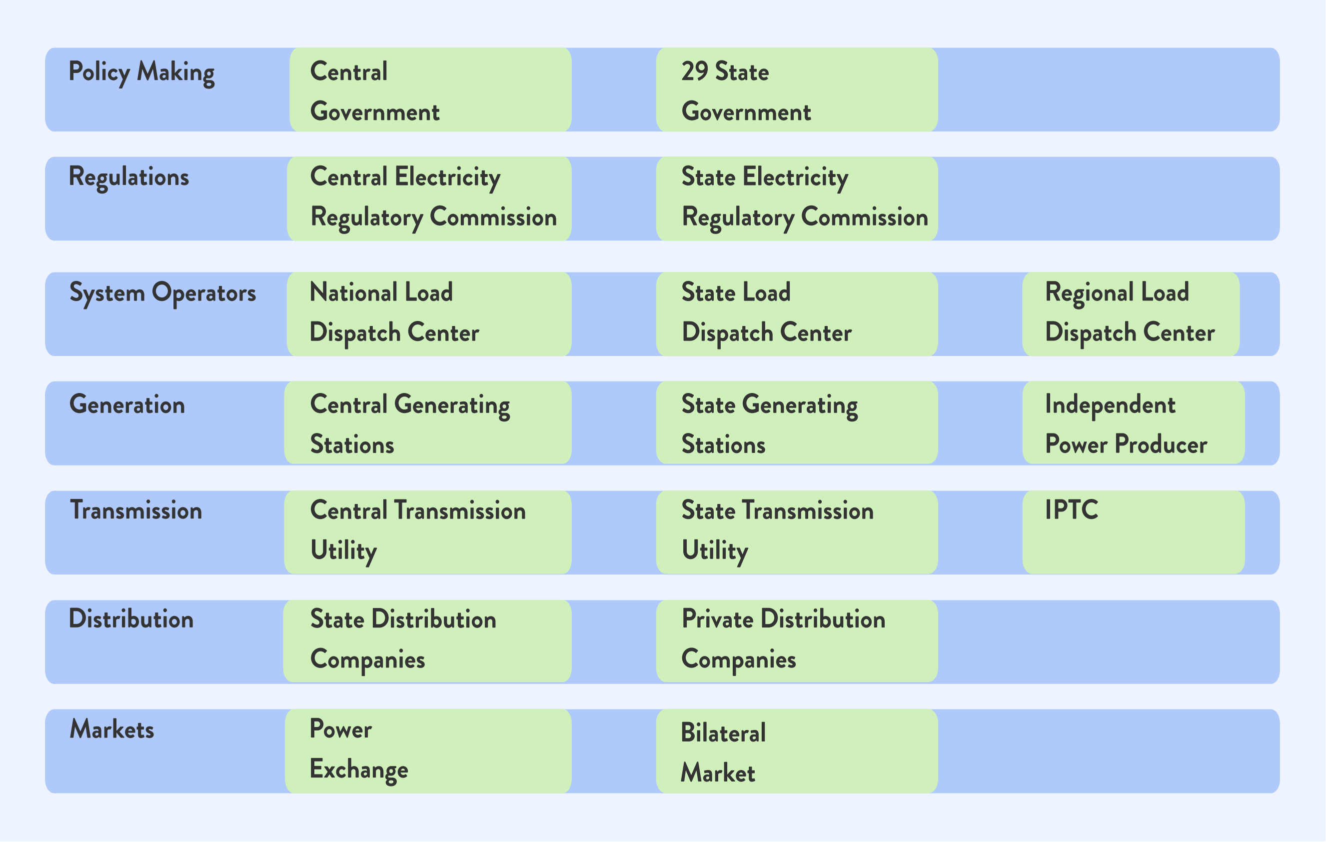


***Figure 28. Electricity sector: Major mechanisms to manage peaks***

"Electricity" is a concurrent subject in the Constitution of India and under the jurisdictions of the center and the states. The Electricity (Supply) Act of 1948 provides an elaborate institutional framework and financing norms of the performance of the industry. The act envisaged creating State Electricity Boards (SEBs) for planning and implementing the state power development programs. The act also provided for creating central generation companies to set up and operate generating facilities in the central sector. The Central Electricity Authority constituted under the act is responsible for power planning at the national level. In addition, the act also allowed from the beginning for private licensees to distribute and/or generate electricity in the specified areas designated by the concerned state government/SEB. The Electricity Act of 2003 established the roles and responsibilities of various stakeholders, and Figure 29 lists the various stakeholders in the sector. **Key Takeaway: A robust legislative framework is required for clear identification of roles and responsibilities between different stakeholders.**



| | | | |
|---|---|---|---|
| **Policy Making** | Central Government | 29 State Government | |
| **Regulations** | Central Electricity Regulatory Commission | State Electricity Regulatory Commission | |
| **System Operators** | National Load Dispatch Center | State Load Dispatch Center | Regional Load Dispatch Center |
| **Generation** | Central Generating Stations | State Generating Stations | Independent Power Producer |
| **Transmission** | Central Transmission Utility | State Transmission Utility | IPTC |
| **Distribution** | State Distribution Companies | Private Distribution Companies | |
| **Markets** | Power Exchange | Bilateral Market | |

*Figure 29. Major stakeholders in the electricity sector*

The Central Electricity Regulatory Commission determines the generation and transmission tariff for companies owned or controlled by the central government and advises the government on tariff policy and regulation.

The state electricity regulatory commissions are responsible for determining the distribution tariff for retail supply and transmission tariff for bulk supply. They also prepare appropriate state-level policy and regulations to promote competition, efficiency, and economy in the activities of the electricity industries, etc.

- **Typical Power Supply System**

An electric power system/grid is a large network of power plants connected to consumer loads (Figure 30). Electricity storage is not economical at a large scale; supply/generation must match the demand/load at that very instant.

Briefly put, the electricity grid caters to three major requirements: production matching demand, transmission over long distances, and distribution to a retail network.

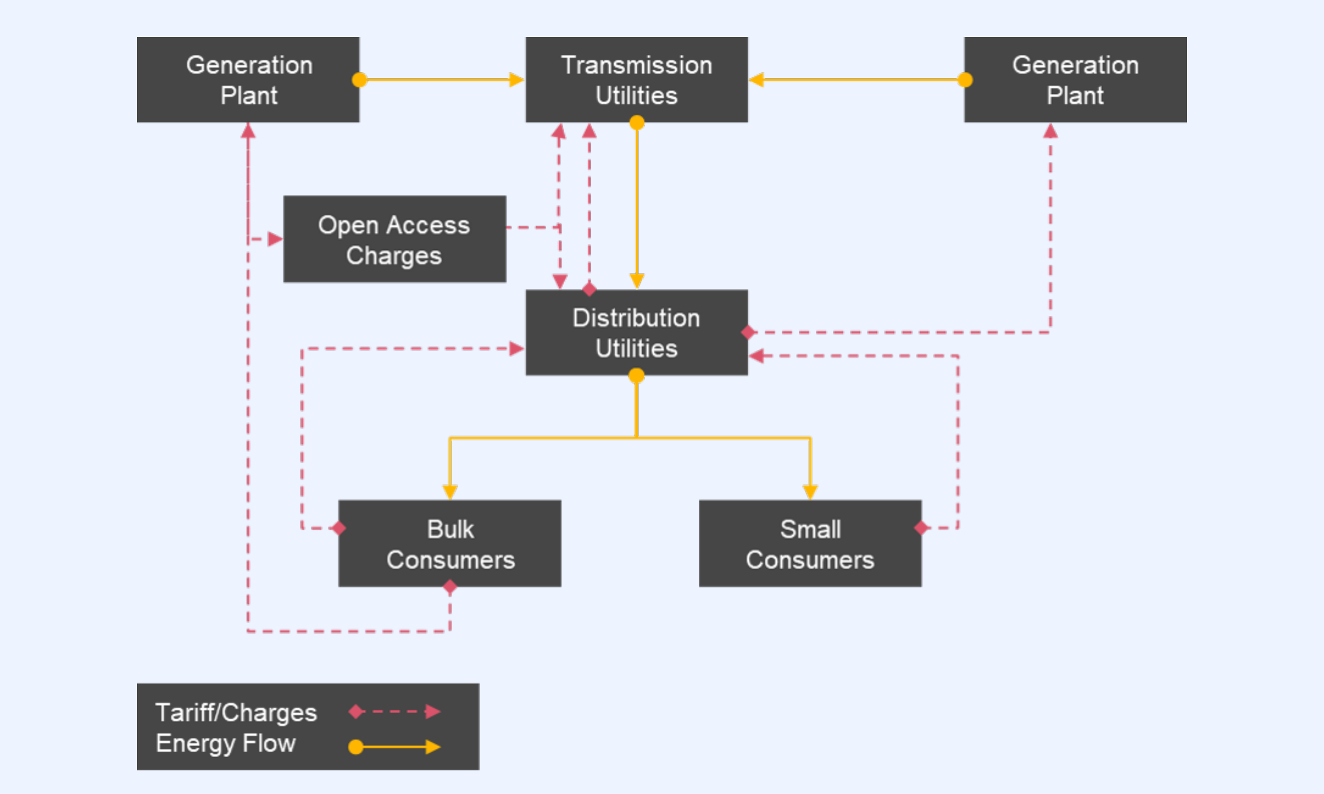


*Figure 30. Electricity grid*

- **Generation:** Spare production capacities (dedicated plants that start operations to meet additional demand, technical adjustments to motor speed and frequency of operations, and increased production via increase in plant load factor) are maintained to provide for additional supply. These are predetermined and implemented sequentially to stepwise meet an increase in demand. Similarly, contingency plans are well prepared as backups for production disruption in any other plant. **Key Takeaway: A Graded Response Action Plan should be deployed to meet increases in demand requirements.**

- **Transmission network:** The electric supply is transmitted to a load center through an overhead transmission system. The consumers are connected at various voltage levels and large distances from the generating station. It is effective and economical to transfer power at higher voltages, so long-distance transmission uses higher voltage. The increased demand and the constraint of generating station location has made possible the need of a very complex system called a “grid.” It connects multiple generating stations generating voltage at different levels into a combined system. **Key Takeaway: One single common system is required for connecting different entities on a common platform.**

- **Distribution Network:**

    - The electric supply is provided to those consumers where the supply voltage is less than 132 kV. The distribution network provides the electricity, and the voltage is stepped down by transformers in a substation for use. When the transmission lines near the demand centers, the voltage level is reduced to make it practical to distribute at different places of load. Therefore, power is taken from the grid and stepped down to the required voltage, depending on where it is being delivered. This is then transmitted to substations.

- From a behavioral perspective, incentives are aligned to change customer behavior to moderate the peak load, such as differential rate tariffs (higher rate at higher unit consumption), repeat educational and awareness campaigns, and promoting usage in nonpeak hours. **Key Takeaway: Significant work is required to improve customer awareness about the correct usage patterns to manage supply and demand situation.**

- Furthermore, the grid is being constantly monitored at all levels: production, transmission, and distribution. Smart sensors have enabled monitoring consumption even at individual device levels, allowing for better planning (smart grids). This is increasingly deployed across the supply chain. **Key Takeaway: It's imperative to deploy technology for successful functioning of a grid.**

- **System Operators**

The system operator is crucial to managing demand and supply on a real-time basis and ensures reliable delivery to consumers by managing the transmission and distribution network efficiently. They have two distinct grid responsibilities: planning for future security and operation for stability. **Key Takeaway: A Robust IT framework is essential for smooth functioning of the grid.**

- **Transmission Planning (Robust Demand–Supply Planning)**

Transmission planning is a continuous process of identification of transmission system requirements, timing, and need. The transmission requirements could arise from the following:

- **Planning term:** Short/medium/long term

- **Grid reliability:** Simulation studies, steady-state, contingency planning

- **Grid security:** Ancillary services, primary/secondary/tertiary reserves

- **Bottom-up planning:** divisional, state, regional, and central planning

- **Planning margins:** Each power plant and line with operational margins. **Key Takeaway: Safety margins need to be established during the planning stage to meet any future contingencies.**

- **Outage planning:** A clear outage and maintenance schedule maintained and planned

- **Peak planning:** Grid planned to support peak to the extent possible

Construction of a new transmission line takes at least 3–4 years; thus, proper long-term planning becomes crucial. Figure 31 shows the key planning steps.

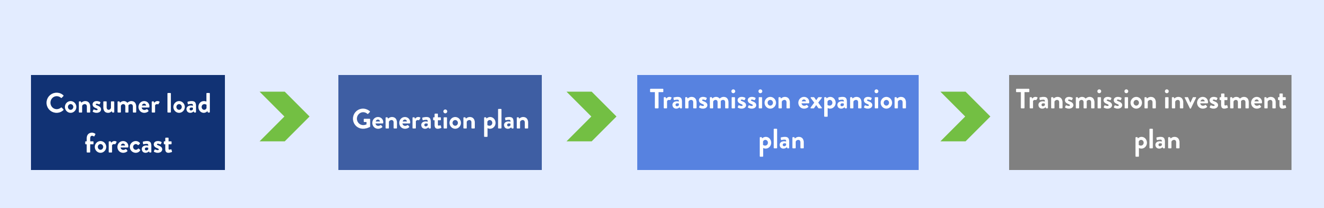


*Figure 31. Key transmission planning steps*

For an economic scale of transmission investment plan, at least 85 percent of capacity should be tied up in long-term PPAs (Power Purchase Agreements) for a minimum of 5 years in advance. Table 19 summarizes the key takeaways from Electricity Grid preparation and their implications for the NOG.

*Table 19. Key takeaways from the Electricity Grid*

| Activity | | Details | Implications for NOG |
|---|---|---|---|
| **Supply Side** | Technical Simulations | Electricity grid: Identify multiple dispatch lines and run simulations for grid planning. | **Simulation exercise:** needed to identify location and capacities of production and storage centers and ensure grid security under various scenarios. |
| | Grid Capacity | Plan for peak demand and not BAU. | Infrastructures need to align for potential peak demand, which should form the basis of grid capacity. |
| | Reserves | Supply reserves to support during a quick/unplanned demand increase. | **Graded response action plan** in oxygen grid. |
| | Storage Capacity | Technological shift happens in electricity, where storage could become economical. | **Storage should be significantly leveraged** and preferred (where production capacities are relatively infeasible—either too costly or too limited production capacity). |
| | Spare Capacities | Peak plants in electricity, which are designated only for managing peaks. Operating costs are socialized to all grid users. | Earmark certain production centers for peak alone.<br>**Modular Approach** (Not one single peak plant) |
| | Contingency and Maintenance Plans | Plan for outages. | NOG have outage planning, when the normal production centers are not able to supply oxygen. |

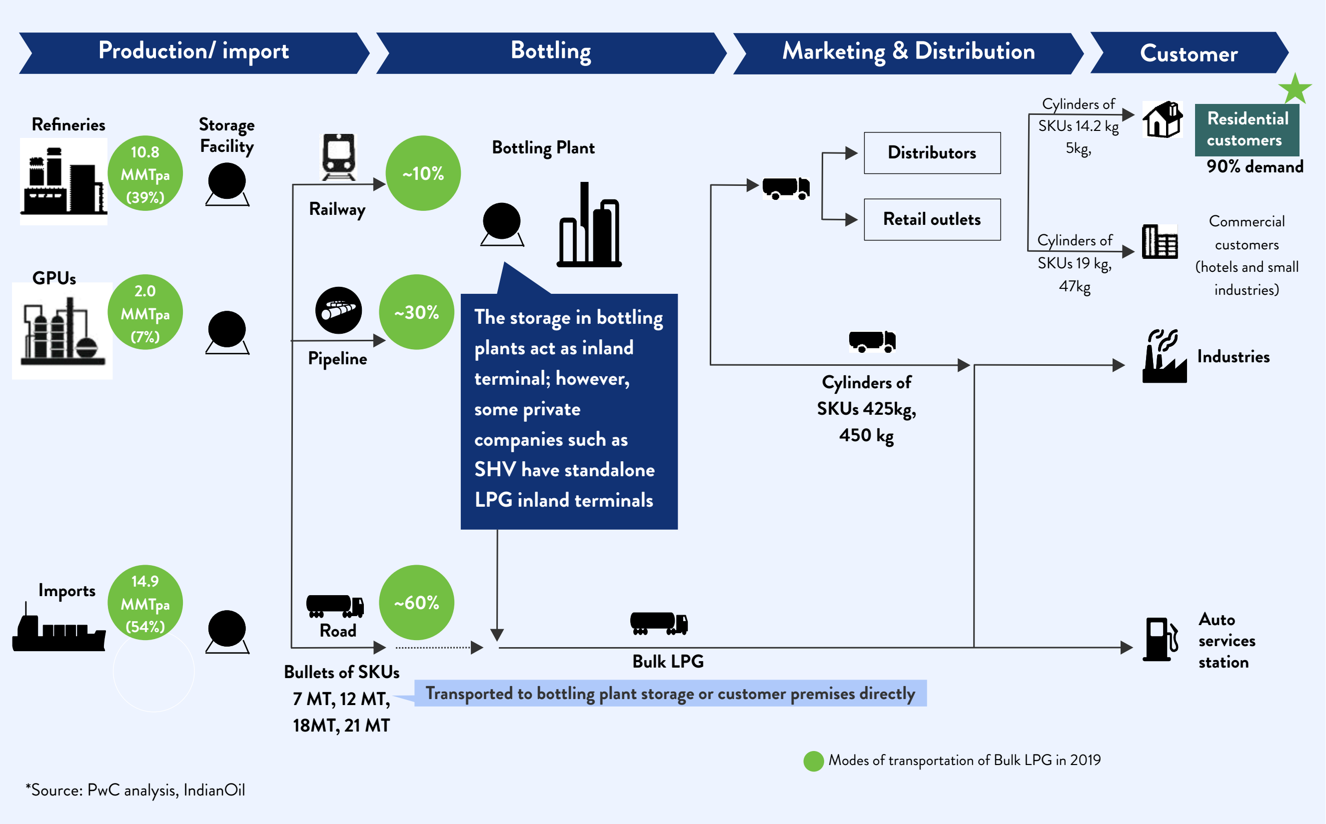
Contd.

| Activity | | Details | Implications for NOG |
|---|---|---|---|
| **Demand Side** | Tracking of demand **(essential)**/Data collection | Electricity grid: Demand is monitored on day-ahead, week-ahead basis.<br>Also gives signals for future planning and identifying network congestions. | Demand data is collected in a common digital platform from different hospitals nationwide and demand status updated on a day-ahead basis. This can help monitor the changes in demand. |
| | Losses and margins | Known losses and margins are built into the contracts along with capacities to account for them (10–15 percent). | Number of tankers and transport capacities have a **margin of 10–15 percent.** |
| | Consumer training | Electricity: Differential pricing (peak/off-peak) flattens the peak, spread over larger duration. | Need awareness for best usage of oxygen and spreading out demand (flattening the curve or use of best practices). |
| **Others** | Regulator | Have a concurrent list and strong regulator. Set standards. Set prices. | Need a robust legislative framework. |
| | Source for revenue | Costs for reserves and redundancies of electricity grid are recovered from every potential user (cost inbuilt in electricity usage cost). | Potential financing source must be identified. |
| | System operator | An independent system operator manages the grid efficiently to match demand and supply at the state, regional, and national levels. | A similar system operator is needed to coordinate and bring all stakeholders (such as manufacturers, distributor, refillers, and transportation) into a common platform to manage grid efficiently. |

### 4.2.2. Oil and Gas (LPG) Grid

LPG is a mixture of propane and butane. It is an essential commodity that is commonly known as a cooking gas and has several benefits over traditional cooking fuels, such as firewood and coal. LPG is colorless and odorless, but it is dosed with ethyl mercaptan to notify of leakage, which gives it a peculiar smell. It is also a fuel in hotel and small-scale industries (commercial), large-scale industries and transportation (auto services).

Figure 32 presents a brief overview of the LPG value chain.[47]



*Source: PwC analysis, IndianOil

***Figure 32. LPG value chain***

The LPG grid and oxygen supply chain system have certain inherent similarities. In India, LPG is primarily produced during crude oil distillation as a low boiling fraction along with other important fractions. It is also produced by processing natural gas processing units (GPUs).[48] This is akin to ASU plants. Furthermore, like ASU plants, the majority of the capacity is held by couple of players, such as Indian Oil Corporation Limited (IOCL), Bharat Petroleum Corporation Limited, Hindustan Petroleum Corporation Limited, Mangalore Refinery and Petrochemicals Limited, Numaligarh Refinery Limited and Chennai Petroleum Corporation Limited. These dominate the supply and account for more than two-thirds of the total production capacity. The remainder is with private players and JV refineries, such as Reliance, Nayara, Bharat Oman Refineries Limited, and HPCL-Mittal Energy Limited.[49]

The refineries and GPUs (supply points) are spread across India and cater to the fragmented demand across individual states. This is like the oxygen supply chain, which delivers oxygen to all parts of the country.

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[47] PwC analysis, Indian Oil

[48] MoPNG statistics, GAIL website, ONGC

[49] MoPNG statistics, HPCL, IOCL, HRRL

From a supply chain perspective, LPG is stored in horton spheres or mounted bullets after production at the refineries/GPUs. While a sphere is filled with LPG, another sphere is operated to fill the LPG dispatch tube. Bulk LPG is stored in underground storage tanks at the import terminals, which provides increased fire protection (Figure 33).[50] **Key Takeaway: Storage, wherever possible, is a preferred way to meet future peak requirements.**

Just like medical oxygen, LPG is transported in bulk and distributed to the bottling plants and storage terminals via multiple transport mechanisms such as pipelines (30 percent), railways (10 percent), and road trucks (60 percent). Pipelines are the most convenient, economical, and safe mode for bulk transportation over longer distances, but they pose significant challenges with respect to land acquisition, high capital costs, and regulatory aspects that limit the distribution network (Figure 34).

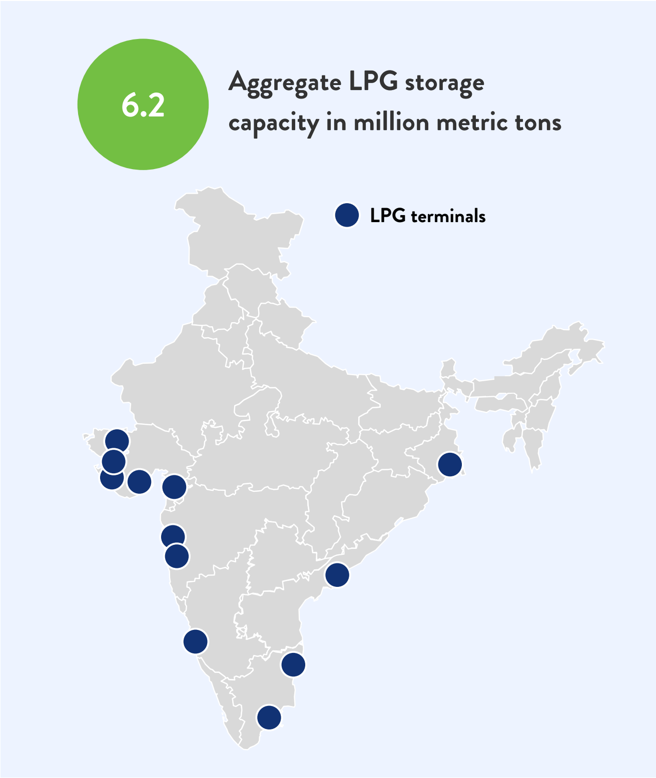
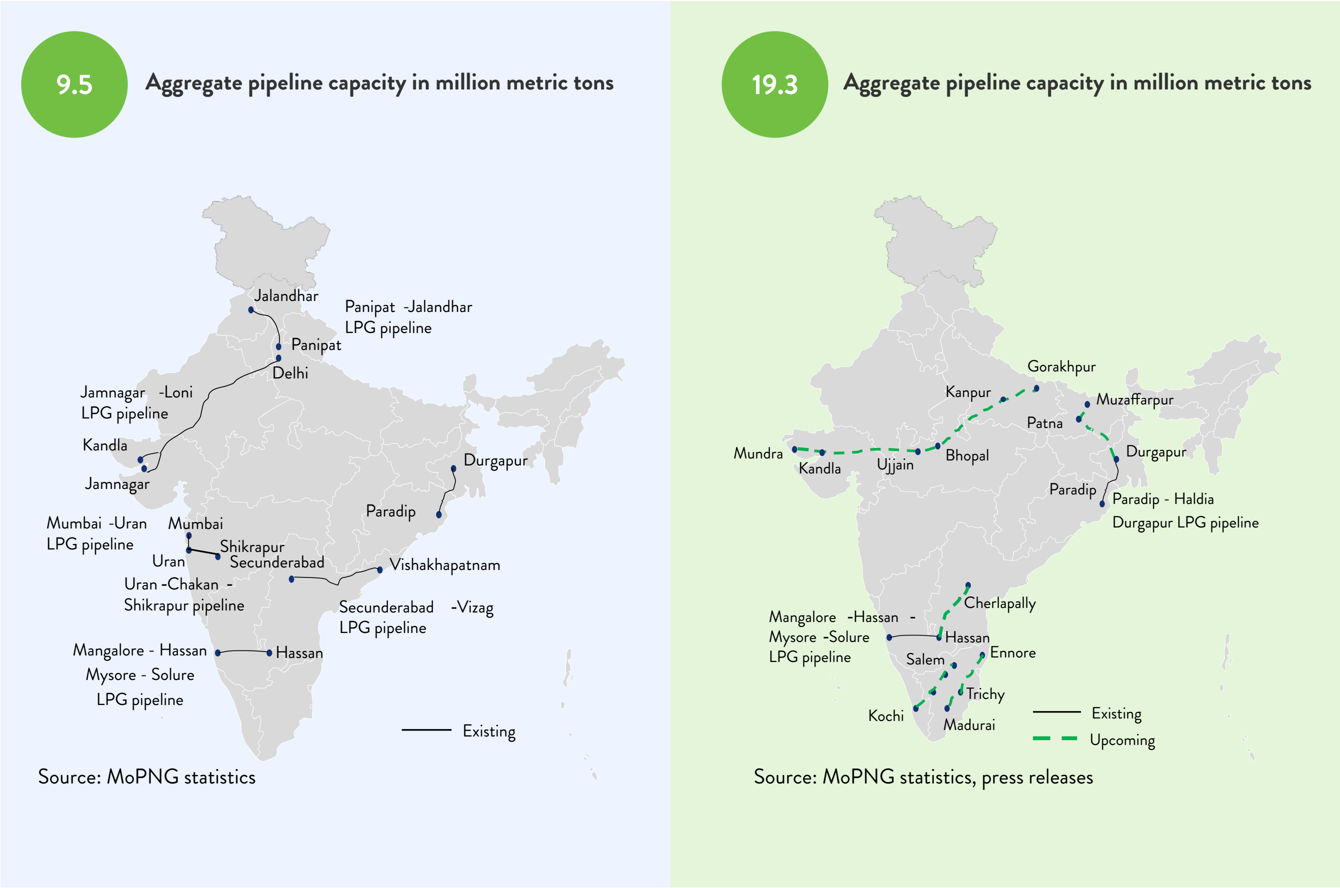


*Figure 33 LPG storage capacities*



Source: MoPNG statistics

Source: MoPNG statistics, press releases

*Figure 34. Existing and planned capacity*

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[50] Secondary research, World LPG Forum, PwC analysis

Existing railways network connected with refineries and LPG terminals are also convenient for bulk LPG transportation but limit the reach to within the rail network. On the other hand, road trucks offer convenience of last-mile connectivity but have limitations in transportation volume. Thus, for a cost-effective distribution, a mix of transportation modes is used for LPG distribution between supply centers and LPG bottling plants.

LPG coming from production sites or storage sites is received in the bottling plants where LPG is filled in the cylinders. **Key Takeaway: Storage should be made in readily usable format to meet contingency requirements**. This is akin to filling oxygen cylinders from bulk LMO at the refiller site. These bottling plants are uniformly distributed and operate at a high-capacity use rate of 90–95 percent. The number of cylinders placed at a bottling plant is decided on the peak demand of the respective district/delivery region. This inventory capacity allows for meeting any peak demand needs.

Figure 35 shows the regional distribution of PSU bottling plants in India (2019–20)[51]: North, 62; Northeast, 11; East, 29; West, 45; and South, 52.

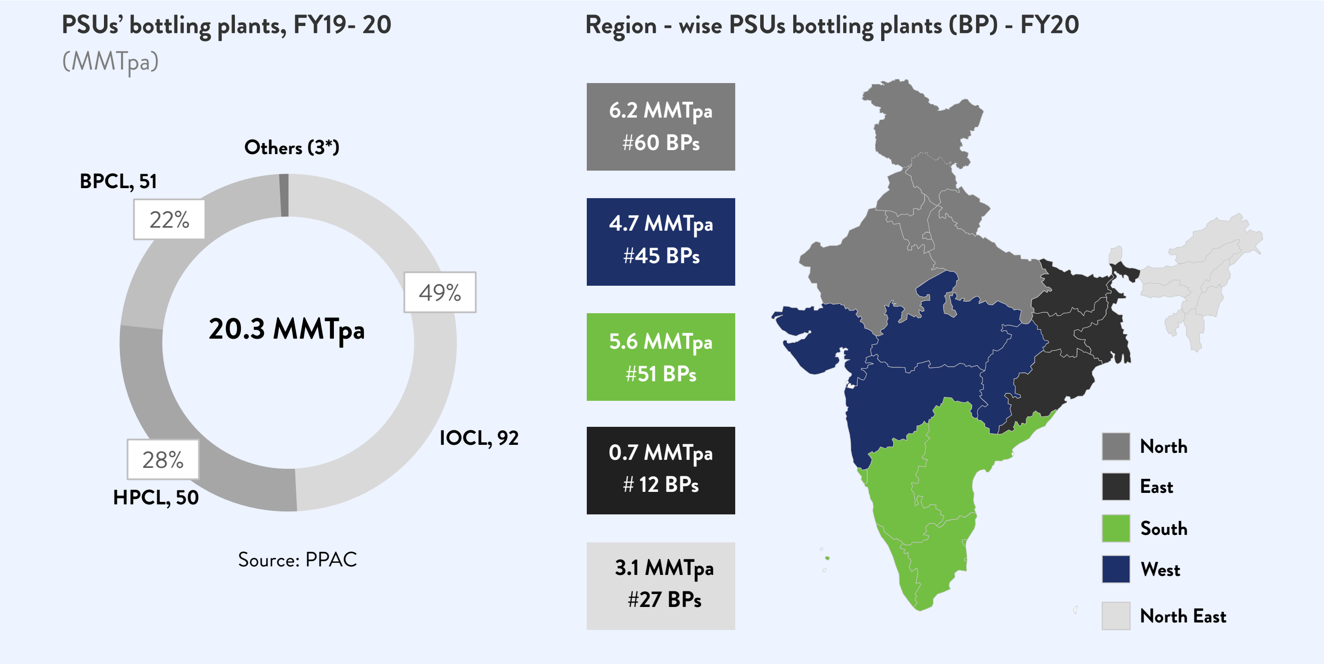

*Figure 35. Regional distribution of bottling plants*

The bottling plants supply LPG cylinders to various distributors spread across the states, which then deliver cylinders to households via mini trucks and three-wheeled vehicles. About 25,156 PSU-brand LPG distributors are uniformly distributed (North, 8,160; Northeast, 1,088; East, 5,080; West, 5,352; South, 5,476).[52] Each distributor has a dedicated software solutions company ID, and LPG cylinders are tracked at distributor level based on order size for filled and empty cylinders. **Key Takeaway: Meticulous tracking of cylinders and inventory is done for the efficient functioning of the grid.**

About 90 percent of consumption happens in small units (residential segment), and 10 percent is used in the commercial, industrial, and auto LPG segments. This is akin to hospitals, where small hospitals predominate and require more oxygen, compared to the relatively few large hospitals.

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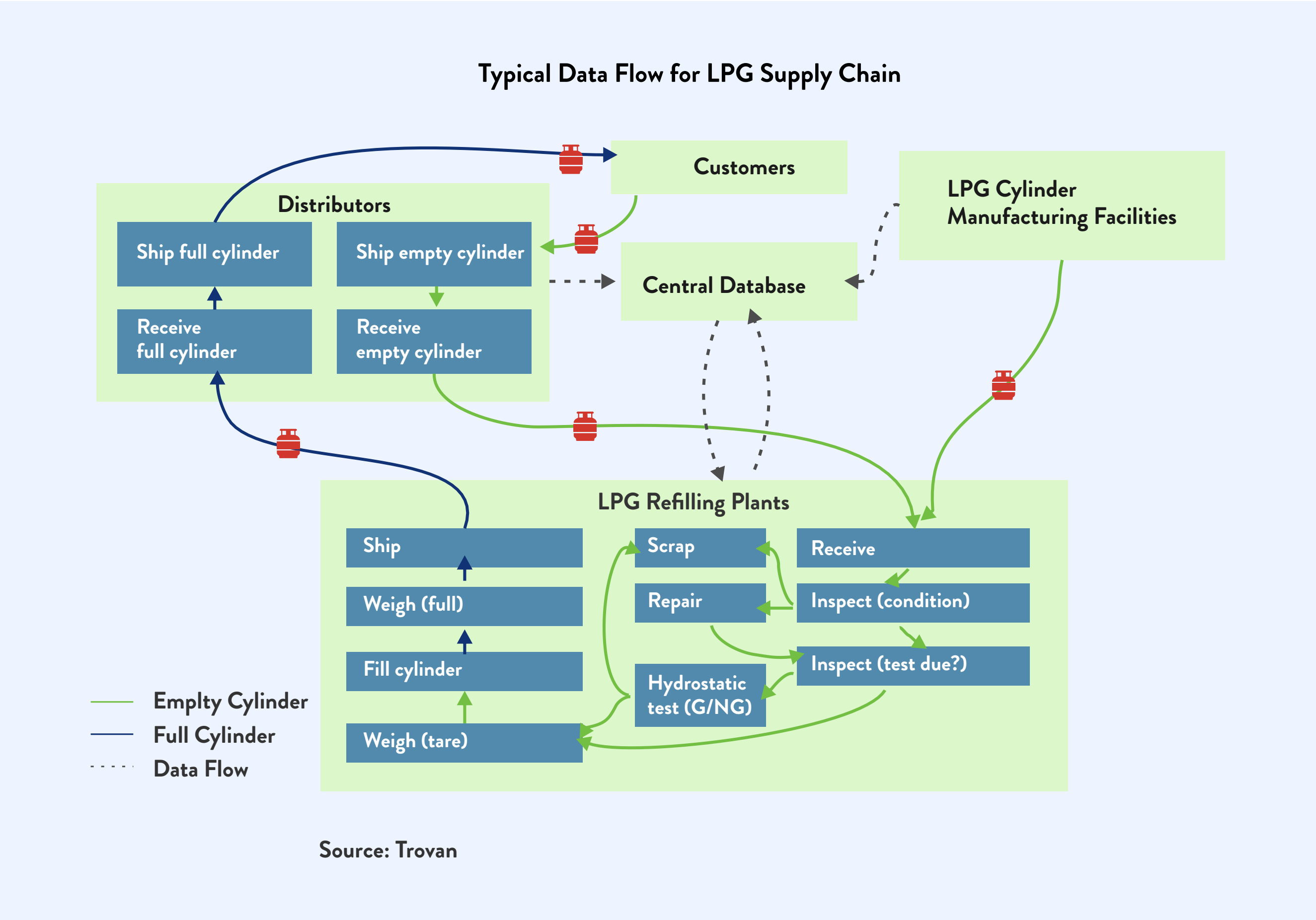
[51] Petroleum planning and analysis cell

[52] Petroleum planning and analysis cell

**LPG demand is estimated annually** based on the years of demand data (on a monthly basis) and list of new LPG connection registrations (Figure 36). PSUs have a good visibility of quarterly LPG demand and the designed capacity of bottling plants, and the distribution network is planned based on the existing and forecasted demand.



Typical Data Flow for LPG Supply Chain

Source: Trovan

*Figure 36 Typical data flow for LPG supply chain*

LPG demand peaks primarily during wedding and festive seasons, when bottling plants opt for the following measures:

- Store and fill of LPG 5–10 days in advance
- Tell nearest bottling plants to supply LPG cylinders in advance

Table 20 summarizes some of these best practices relevant to NMOG.

*Table 20. Key takeaways from the Oil and Gas Grid*

| Activity | | Details | Implications for NOG |
|---|---|---|---|
| **Demand Side** | Demand Prediction | • ~12-month demand is predicted using new LPG connection registrations and past demand fluctuation data (such as wedding seasons).<br>• Residential LPG consumption fluctuations are limited.<br>• To manage peaks, the nearest bottling plants fill the supply gap. | • Imperative to have a good demand prediction at the cylinder refiller level.<br>• Supply gap will be met by the nearest supply point during demand peaks. |
| **Supply Side** | Bottling Plants | • A network of bottling plants is distributed across major districts in each state; they are fed by nearest LPG pipeline tapping point/terminal or rail/road.<br>• Total cylinder stock for a bottling plant is based on peak demand. | • Distribute supply points (across major districts).<br>• Empty cylinder inventory backs the peak demand. |
| **Storage & Distribution** | Distribution | • LPG is distributed to residents through the network (25,156 distributors). | • Separate distribution network caters to the last-mile delivery. |
| | Storage | • LPG is commonly stored in skid bullet tanks/spheres aboveground at the bottling plants, but bulk LPG is stored in underground tanks, which provides increased fire protection.<br>• Filled LPG cylinders storage is only practiced before the demand surge times. | • Suitable storage options are needed to manage peaks.<br>• Gas cylinders can be filled and stored before a demand surge. |

Contd.

| Activity | | Details | Implications for NOG |
|---|---|---|---|
| **Tracking** | Tracking Level | • LPG cylinders are tracked on the distributor level (order size for filled and empty cylinders) through the respective software solutions company ID. | • Advance cylinder tracking methods can be implemented. |

### 4.2.3. FMCG Grid

As one of the largest sectors in the economy, FMCG has a significant impact on the country. India is a wide country geographically, so the distribution networks form a complex structure. The majority of consumers for FMCG goods live away from the source of production. The grid for FMCG products forms an important part of the economy and is considered a strategic advantage by most of the FMCG companies.

The FMCG grid is a network of pathways through which the products travel from manufacturers to consumers. Some FMCG manufacturers prefer dealing directly with consumers, but most use a distribution network. Thorough planning and investment are done to set up robust grids that give manufacturing companies (which usually have a localized production site) an edge over their competitors, forming an important element in a company's business strategy. This is akin to medical oxygen, where production is limited to certain areas but a dense distribution arrangement is required to deliver it to all the parts of the country.

Figure 37 shows a simplified version of various FMCG grids.

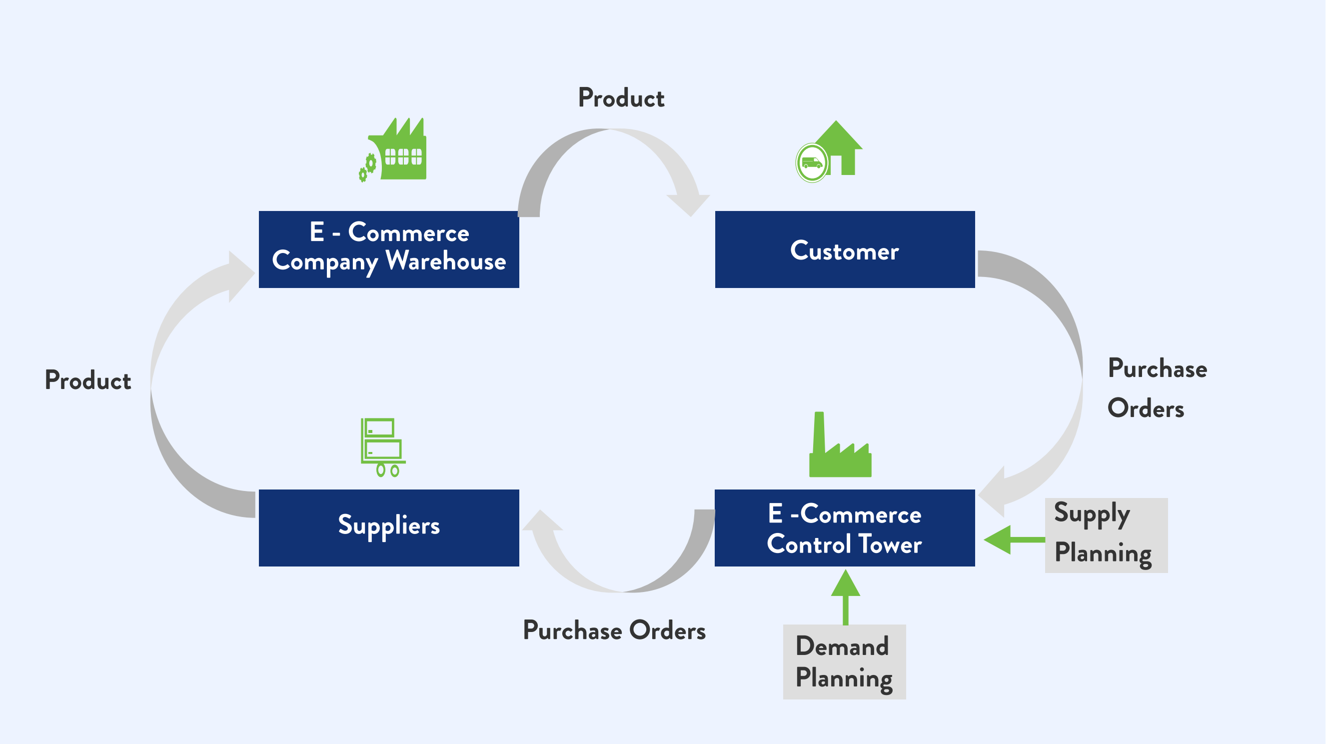


*Figure 37. Simplified FMCG grids*

The grid consists of different independent entities, ranging from the manufacturer to the distributor, that pass the products from the source to the ultimate customer.

One of the key aspects of FMCG grid is the e-commerce control tower (Figure 38), which is in charge of long-term supply and demand predictions. It coordinates with various suppliers, distributors, and consumers nationwide to facilitate ordering and supply arrangements, taking customer orders and passing them on to the appropriate suppliers. Advanced analytics and dashboards are used to minimize the turnaround times and fulfill all orders, even during periodic peaks. **Key Takeaway: Robust IT planning is required for the smooth functioning of the FMCG Grid).**

The suppliers' profiles are maintained, and their capacity is routinely mapped for quality control and assurance purposes. The refiller or the supplier end also has robust quality control mechanisms. Just like PNG and electricity grids, where the last-mile delivery is via specialized LPG distributors and distribution companies, specialized delivery/logistics companies take care of last-mile delivery to homes. The supplier network is typically geared toward this e-commerce warehouse.

Strategically designed (in terms of location and capacity) warehouses also exist, where inventory is kept for delivery. The location is designed to minimize the delivery time and associated costs. Long-term predictions are used to hold appropriate inventory levels and safety stocks and avoid shortages. Product segmentation addresses different customers' needs.

Technology is frequently used to track inventory levels and the movement of goods from warehouses to customers. Every step of the delivery chain is mapped and routinely scanned via a host of technological solutions.

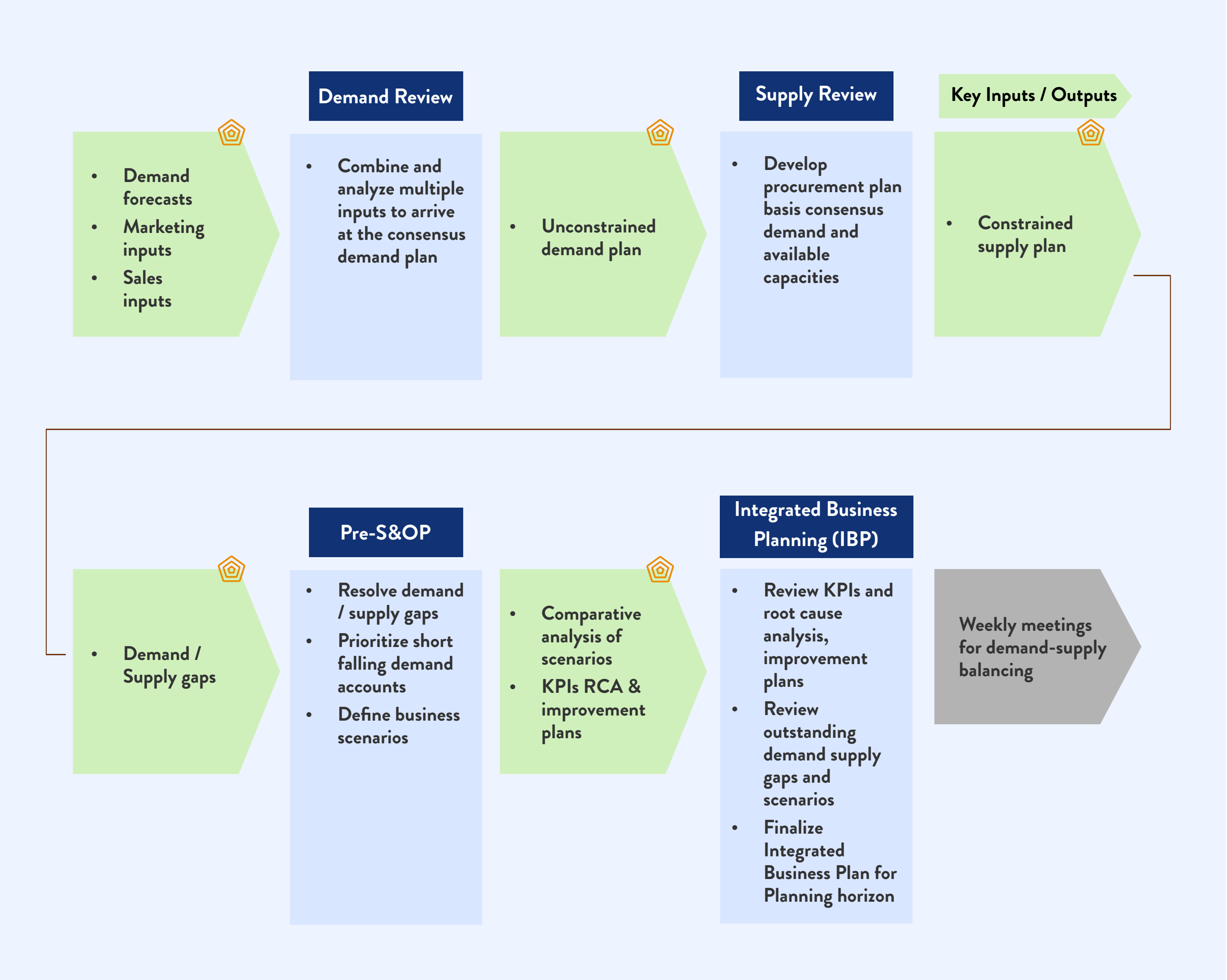


*Figure 38. Control tower sales and operation*

Table 21 summarizes some of these best practices that are relevant for NMOG.

*Table 21. Key takeaways from the FMCG Grid*

| Activity | | Details | Implications for NOG |
|---|---|---|---|
| **Demand Side** | Demand Prediction | • 36 months demand forecasting is accomplished using historical trends, seasonality, and promotions.<br>• "What if" analysis is incorporated to test hypothesis and achieve demand–supply mapping. | • Demand forecasting of total oxygen is at the district level.<br>• Supply gap is met through the nearest warehouse during BAU and at peak. |

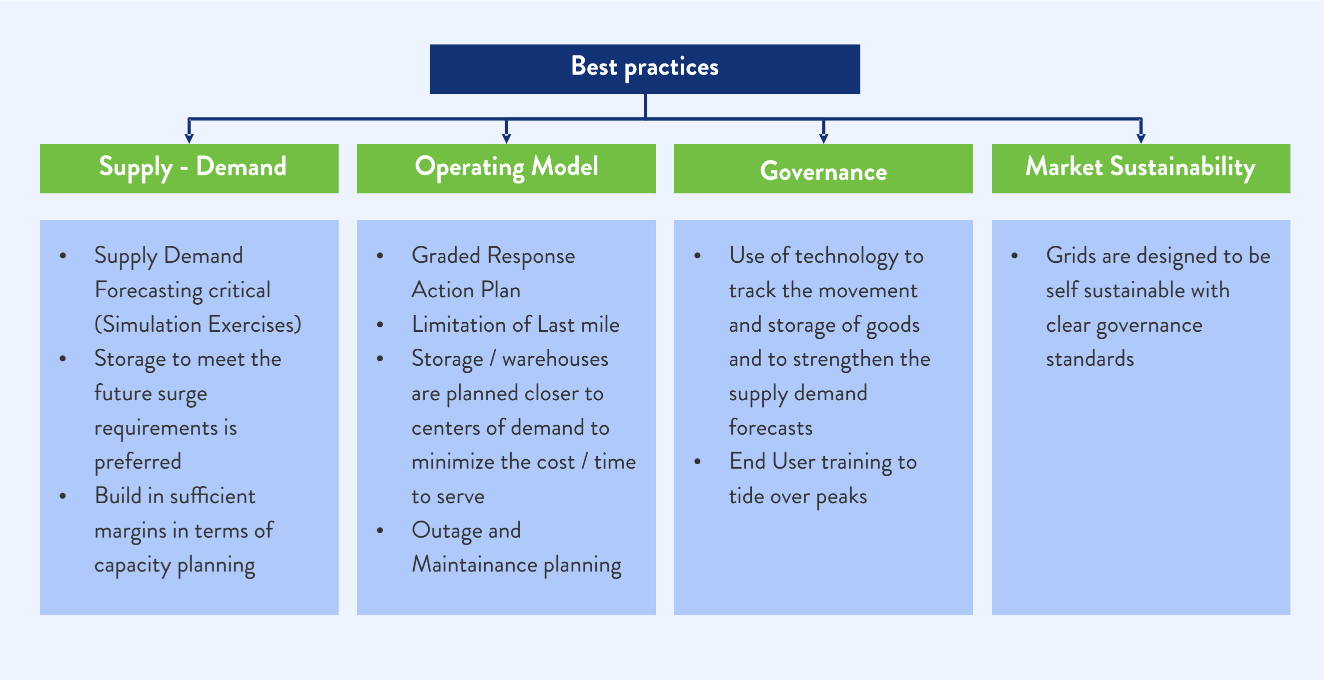
Contd.

| Activity | | Details | Implications for NOG |
|---|---|---|---|
| **Supply Side** | Production Plants and suppliers | • Advance dashboards/root cause analytics are used for product unavailability.<br>• Data on locations and capacities of suppliers predict overall network strength.<br>• Quality control and assurance offer a better end-user experience. | • Production units are distributed nationwide.<br>• Supplier profiles are maintained.<br>• Robust quality control is provided at the refiller end. |
| **Storage & Distribution** | Distribution | • Strategic storage location of warehouses reduces time to market.<br>• Supply network reaches the distributor level; the last mile is not in the scope of network. | • Supply network reaches the refiller level; the last mile is not in the scope of grid. |
| | Storage | • Safety stock management addresses unforeseen peak demands.<br>• Product segmentation addresses different customers' needs.<br>• Training/user manual ensures optimum usage of the product. | • Suitable storage options are needed to manage peaks.<br>• Oxygen can be stored in the required amount prior to demand surge.<br>• Training on IT and systems is provided at all level of the grid. |
| **Tracking** | Tracking Level | • Finished goods are tracked at the warehouse level. Demand and supply data are tracked daily. | • Advance oxygen volume tracking methods can be implemented. |

### 4.2.4. Best Practices for Setting Up a Grid

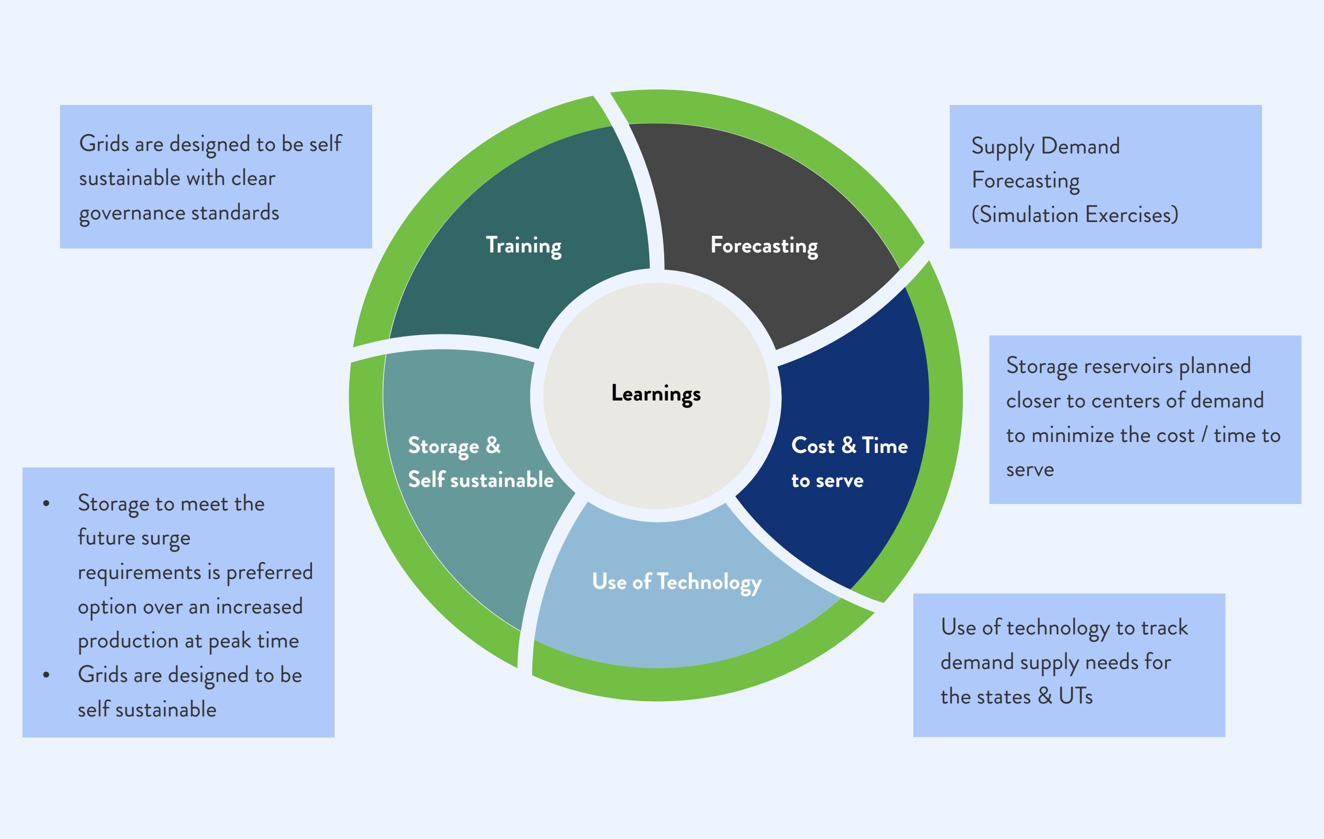
Table 22 and Figure 39 summarizes best practices identified from the case studies. These form the basis of NMOG.

*Table 22. Best practices from case studies relevant to NMOG*



**Best practices**

| Supply - Demand | Operating Model | Governance | Market Sustainability |
|---|---|---|---|
| • Supply Demand Forecasting critical (Simulation Exercises)<br>• Storage to meet the future surge requirements is preferred<br>• Build in sufficient margins in terms of capacity planning | • Graded Response Action Plan<br>• Limitation of Last mile<br>• Storage / warehouses are planned closer to centers of demand to minimize the cost / time to serve<br>• Outage and Maintainance planning | • Use of technology to track the movement and storage of goods and to strengthen the supply demand forecasts<br>• End User training to tide over peaks | • Grids are designed to be self sustainable with clear governance standards |



Grids are designed to be self sustainable with clear governance standards

Supply Demand Forecasting (Simulation Exercises)

Storage reservoirs planned closer to centers of demand to minimize the cost / time to serve

- Storage to meet the future surge requirements is preferred option over an increased production at peak time
- Grids are designed to be self sustainable

Use of technology to track demand supply needs for the states & UTs

*Figure 39. Learnings from case studies relevant to NMOG*

# 5. NMOG

## 5.1. Objectives

The NMOG is designed to fulfill multiple objectives.

**5.1.1.** Ensure a regular and timely supply of oxygen.

**5.1.2.** Ensure principles of reliability, purity, and economy matched with the rising expectation of a cleaner, safer, healthier environment.

**5.1.3.** Ensure optimal turnaround time for meeting any demand.

**5.1.4.** Create a robust and extensive system for ensuring efficient supply to the remotest areas.

**5.1.5.** Leverage the modern telecommunication technologies for establishing and operating a well-connected grid.

**5.1.6.** Alter oxygen production and logistics capacities to meet predicted and unforeseen demand scenarios.

**5.1.7.** Develop an efficient, coordinated, and economical system of oxygen transportation.

## 5.2. Basic Design Principles

Following are the four basic design principles for creating NMOG:

### 5.2.1. Preference for creating large storage reservoir capacity to meet exigency needs

This is considered more cost-effective than creating additional production capacities that will be idle in BAOU scenarios but still require routine maintenance and operations to keep them technically functional.

The storage capacity (and the eventual grid capacity) will be designed considering the potential peak needs. This capacity creation will have a natural cost and budgetary implication. Furthermore, the future peak needs are largely unknown. A suitable probability risk distribution framework may be designed to assess the quantum of storage capacity needed against other steps taken (such as vaccination, development of surveillance and early warning systems) to avoid pandemic-like crises.

### 5.2.2. Preference for creating an interconnected network allowing seamless flow from surplus to deficit areas (rather than creating self-sufficient centers).

This network should integrate all production, storage, and consumption sites using a tech-enabled IT platform and allow free flow of information about stock and consumption of oxygen and its transfer, following the principles of minimal cost and lowest transfer time. Besides stabilizing peak needs, this will help lower the overall production and storage costs.

### 5.2.3. Preference for Public–Private Partnership Models in Creating NMOGs

Most existing stakeholders (producers, logistic players, storage players, and the end consumers [hospitals]) are in the private space. The grid should plan to augment their capacity to meet any future needs instead of creating a parallel structure. Government becomes important in incentivizing the private players to build these capacities and in monitoring and governance.

### 5.2.4. Grid to act as a means to achieving oxygen self-sufficiency and should not be an end goal.

The grid should work in tandem with other aspects designed to improve the healthcare system (such as establishing clinical protocols and end-user training, surveillance and early warning indicator mechanisms, and suitable physical infrastructure [beds and hospitals]).

## 5.3. Approach for Grid Design

A four-step approach is being adopted to design NMOG.

- Perform a detailed demand-side assessment. This involves scenario modelling and planning exercise to estimate the demand-side needs for which capacity needs to be planned.

- Design clusters, which aims to divide this demand into manageable distribution areas. This would allow ease of operations from a management and governance perspective.

- Create a detailed supply-side assessment that is suitable to meet the demand forecasted in step 1.

- Design a grid network that would include detailed steady-state and exigency operational plans.

These four steps are further detailed in subsequent sections.

### 5.3.1. Demand-Side Estimation

A core purpose of the grid is to not only ensure a steady supply in normal times but also enable meeting peak needs. It is relatively easy to estimate the steady-state needs[53] but rather difficult to estimate needs for events such as the pandemic, wherein they increased significantly in a short span.

COVID-19 wave patterns across the globe differ significantly in their peak needs and time of onset (ramp-up curve).

Wave durations are getting smaller (except in the United Kingdom), especially in developing countries (such as India and Brazil) (shown in Figure 40).

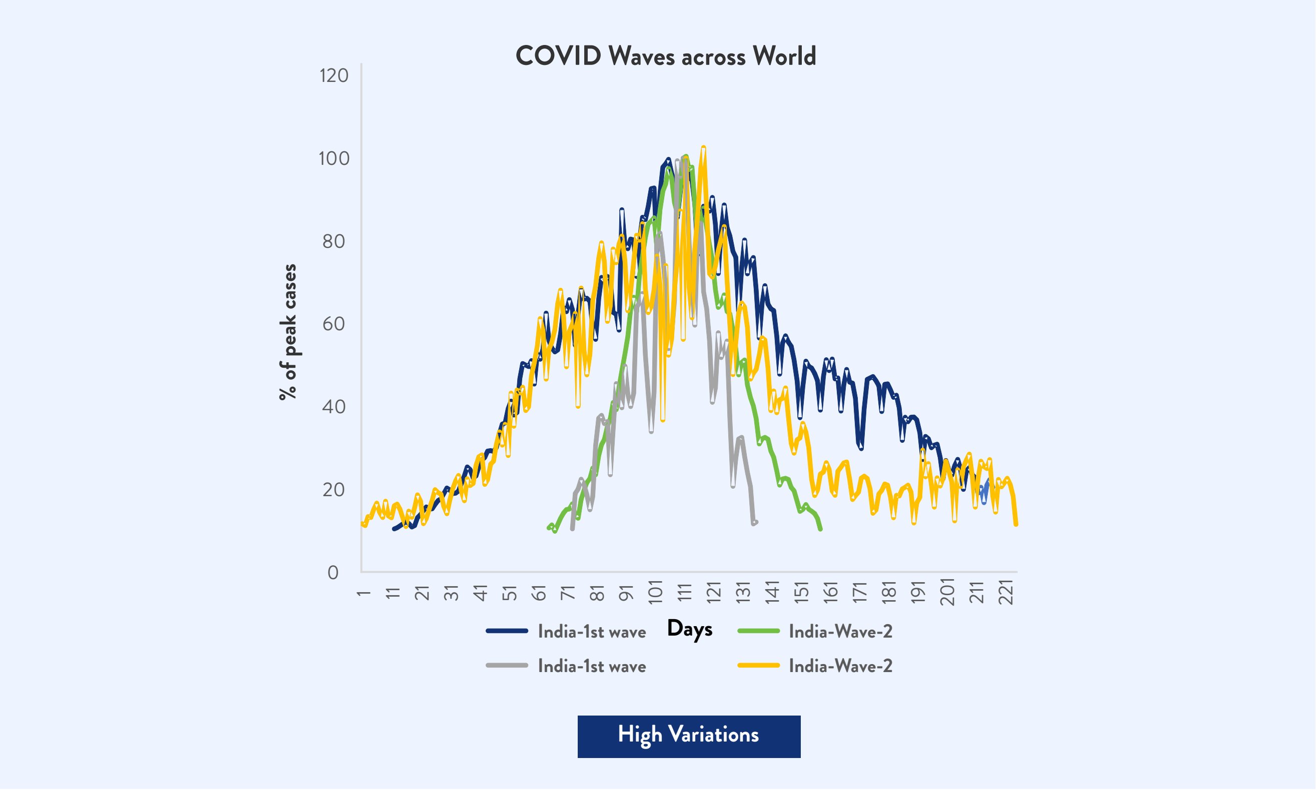


*Figure 40. Cases, deaths, and variations by wave, number of days*

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[53] Based on the historical use data and number of beds in a region (as explained in previous sections)

**Number of Days a Wave Lasted, Cases Per Million Data (Trends Are Similar, Except United Kingdom )**

| | First Wave | Second Wave | Third Wave | Fourth Wave | Fifth Wave |
|---|---|---|---|---|---|
| US | 89 | 101 | 143 | 117 | 67 |
| UK | 89 | 88 | 131 | 71 | 102 |
| France | 70 | 109 | 123 | 112 | 110 |
| India | 249 | 189 | 55 | | |
| Brazil | 226 | 213 | 63 | | |

Note: The period of waves differs in all countries (Source OWID, Business Standard Analysis)

**Number of days a wave has lasted, as per deaths per million data (In terms of deaths, all countries have followed similar trajectory)**

| | First Wave | Second Wave | Third Wave | Fourth Wave | Fifth Wave |
|---|---|---|---|---|---|
| US | 105 | 83 | 271 | 129 | 84 |
| UK | 163 | 210 | 145 | 53 | |
| France | 482 | 299 | 104 | 98 | |
| India | 302 | 223 | 48 | | |
| Brazil | 228 | 248 | 44 | | |

Note: The period of waves differs in all countries. Data on deaths differs from data on cases in terms of waves (Source OWID, Business Standard Analysis)

In India, the peak needs varied from ~5,000 to ~17,200 MTPD, and the wave duration (across different states) was assumed to be 30–45 days.

A Monte Carlo Simulation[54] was performed to estimate the total medical oxygen needs over one future pandemic wave (Figure 41). The graph provides a directional sense of the needs that a country must prepare for in such a crisis. These numbers reflect the overall oxygen needs, with part met by steady-state supply and the remainder from other sources (the concept of GRAP is explained in subsequent sections).

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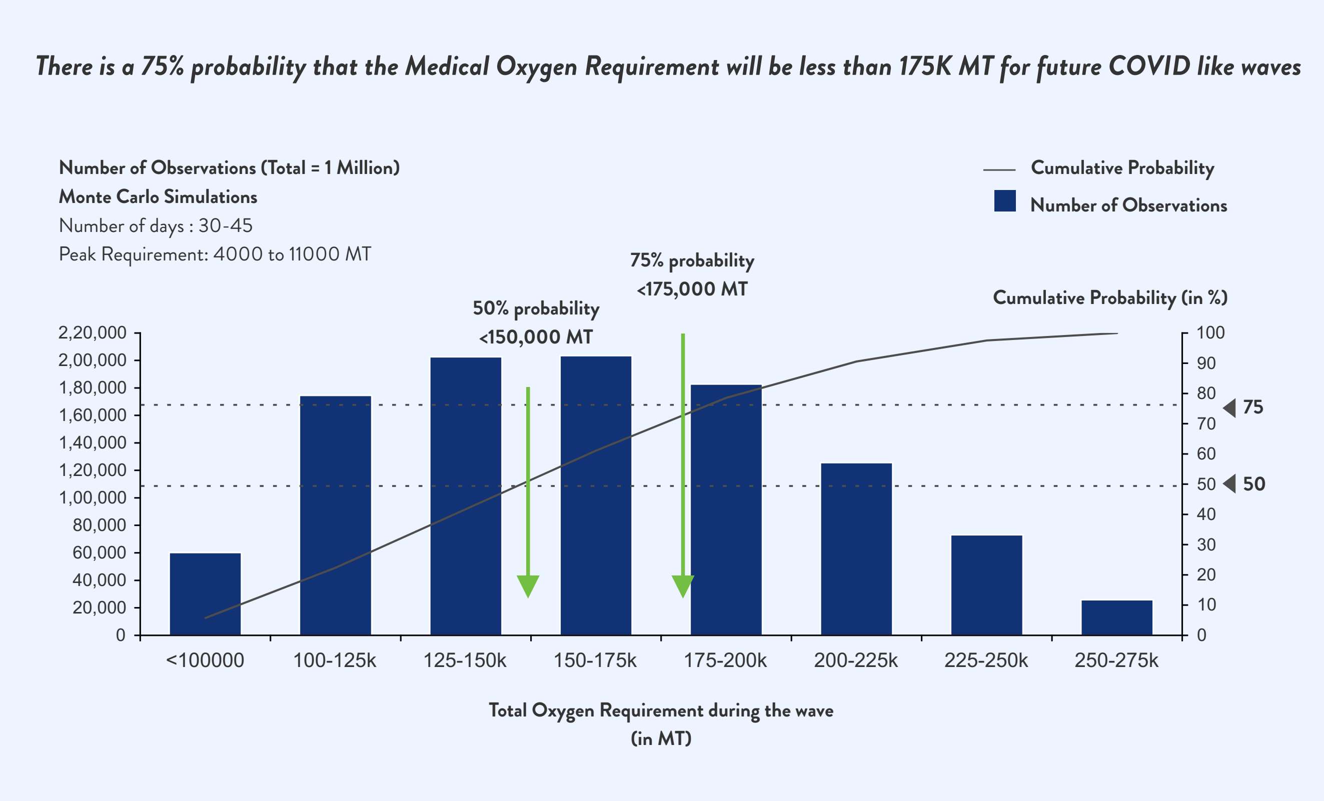
[54] Considering the high vaccine penetration, high herd immunity, and adaptive ecosystem changes (mask behavior, social distancing norms, strengthening of early warning indicators and surveillance capacities, etc.), future waves are assumed to be of relatively smaller needs (4–11,000 MT) and duration (30–45 days).



*There is a 75% probability that the Medical Oxygen Requirement will be less than 175K MT for future COVID like waves*

*Figure 41. Total oxygen requirement for a wave*

## 5.3.2. Cluster Design

Clusters form the organizational basis of grid design, by acting as unit structure, aggregating to form the larger network-like assembly. The basic idea is to define a boundary that can act as an independent whole, in terms of oxygen delivery within a unit of time and with minimal cost. The cluster will have storage capacity that is sufficient to meet local needs in a crisis and yet can be shared with or augmented by others depending upon need. This approach ensures efficient distribution of resources.

The clusters can be based on multiple parameters, such as a) the geographical radius that can be potentially served by a centrally located cryogenic tanker in one day, b) a contiguous area with a similar socioeconomic and demographic profile and healthcare infrastructure, or c) some natural geographic classification, such as a valley or plain. The size criterion for defining cluster boundaries is important. If the clusters are too small, the storage capacity will be heavily fragmented and it will be difficult to aggregate supply in a crisis. However, if the clusters are too big, they will require a significant logistical capability to reach the last hospital.

Administrative convenience is the most important criterion for the grid. This allows higher administrative, allocative, and distribution efficiency and leveraging existing administrative machinery for resource prioritization in a crisis. This convenience or administrative boundaries will be used to create the cluster design.
India is divided sequentially into various subnational administrative units—regions, states, divisions, districts, subdistrict, tehsil, blocks, village, etc.

Considering these factors, a division-level cluster is the most appropriate. These divisions have a more uniform population size (than individual districts or subdistricts), have a strong working administrative structure from a health perspective, and help keep clusters to a manageable number. Such clustering ensures the desired NMOG decentralization along with efficient use of funds and other resources required for establishing it.

Aggregated oxygen demands at the divisional level are comparable, maintaining a balance in the grid.

An administrative structure exists at the divisional level in all major states of the country. This ensures better administration and monitoring of NMOG. In many states, such as UP and Bihar, the department of health also has a well-defined administrative structure at the divisional level.

On the other hand, random clustering of district based on population or distance was a less favorable option, as monitoring and administration would be difficult. Clustering at the level of district or below would lead creating a large number of base units at the state level. At the district level, managing the demand and supply allocations for so many base units, especially during a crisis, will consume substantial effort and time, whereas divisional clustering ensures an optimum number of base units. Thus, in a crisis, national and state control rooms can efficiently monitor the grid.

### 5.3.3. Supply-Side Mapping

The supply-side perspective has two aspects:

1. Production capacity is sufficient to meet needs and fill in the reservoir capacity in a reasonable amount of time (before the next wave).

2. Logistics and distribution capacity is sufficient to enable transfer of medical oxygen between different clusters, in both the BAU scenario and a crisis.

With the current production capacities, India is believed to be self-sufficient in meeting BAU needs of 1,200 MTPD. Furthermore, if not more than two waves happen in a year, the newly created additional capacities are considered sufficient to fulfill the storage needs, in between the two waves.

The details of the supply side were presented in previous sections and are not replicated here.

### 5.3.4. Network Design

This is the last step in grid design creation, and it incorporates elements from the previous steps.

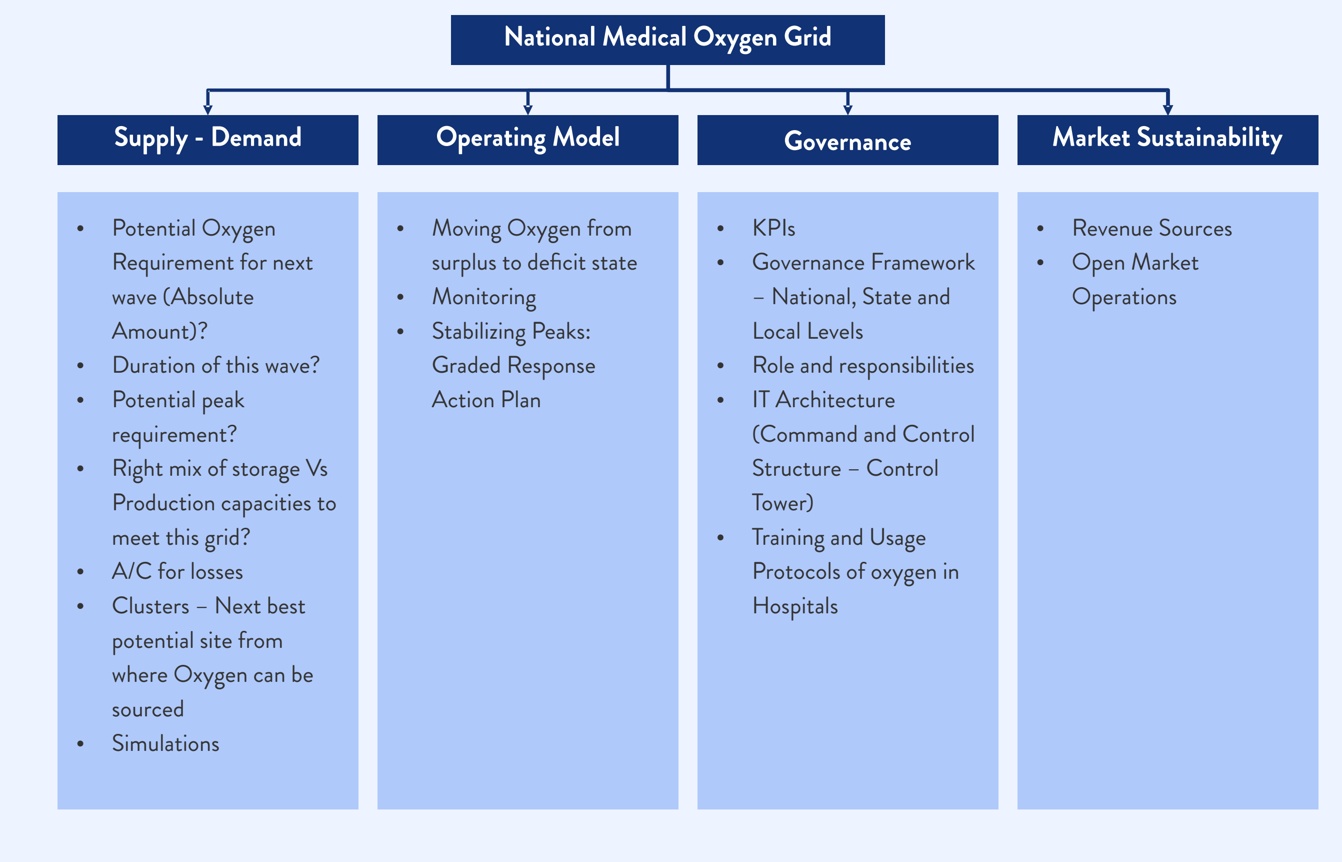


***Figure 42. NMGO network design***

## 5.3.5. Supply–Demand Planning

The basic functionality of any supply network is to enhance services for end consumers. It ensures that they receive their product in the anticipated quantity, making goods available at a precise time and location.

The NMOG will be used as a platform to manage the flow of medical oxygen nationwide, in normal times or during a pandemic. With proper administration and training to stakeholders, India can be better prepared to manage unexpected situations. The grid team can work out the best feasible approach to delivery. They must analyze the situation and take productive steps. The grid is critical to supplying this lifesaving commodity.

“Demand and supply mapping” is the process of documenting information across production plants, suppliers, distributers, and end consumers, to create a geographical map of the grid that can identify opportunities and mitigate risk in the supply chain. Hence, it must plot the information for different demand scenarios, such as volumes across geography and the supply side of the grid, to accommodate the different demands.

The mapping allows for strategies to rapidly react during supply chain problems, such as a consumer shortage, an order delayed in the system, a surge in demand, or something even more unexpected. It also develops a deeper understanding of the surrounding costs, time frames, and risks and thereby offers an advantage.

As explained, India's BAU oxygen need is estimated to be ~1,200 MTPD. In COVID-19, especially Wave 2, the demand was increased to ~17,000 MTPD. Adjusting for the entire wave duration, India should be prepared to supply ~150–175,000 MT of oxygen to meet a future crisis.

The supply is considered adequate to meet the steady-state BAU needs.

### 5.3.5.1. Logistics Across Nodes of the Grid

In a supply chain network, every key entity through which material is passed or stored or consumed is a node. Similarly, NMOG will have nodes connecting each other to form the network. For oxygen to be transferred, it must travel through certain modes—land, sea, or air—and sometimes be converted from one state another—solid, gas, or liquid. Transport service providers contribute to transit, and refillers play a role in the conversion.

#### *5.3.5.1.1. Role of Refillers*

Refillers and dealers are the intermediate nodes of the entire grid. These nodes connect one or more sources of the supply, along with one or more customers.

Refiller capacity is crucial, as it drives the conversion of medical oxygen from liquid form to gaseous form. Dealer capacity aids in storing medical oxygen at a shorter distance from patients.

Refillers and dealers must be tagged to a single cluster, which helps the cluster to arrive at the additional capacity required to serve the patients effectively. Once the amount of supply and storage in a cluster is decided, refillers' conversion capacity can be monitored.

**Refillers must declare their LMO and /B-/D-type cylinder oxygen capacity per day. Based on the requirement of conversion capacity in a cluster and refillers' actual capacity in it, either the capacity of existing refillers can be enhanced or new refilling centers can be established.**

**Similarly, dealers must declare the capacity to store medical oxygen in liquid and gaseous forms. Based the storage capacity required in a cluster and dealers' actual capacity in it, either the capacity of existing dealers can be enhanced or new storage centers can be established.**

#### *5.3.5.1.2 Transportation*

Assets for transportation of medical oxygen play a crucial role, especially in a pandemic. The cluster must have dedicated vehicles. A fixed number of vehicles in a cluster to transport either LMO or cylinders of oxygen assures timely distribution.

Similar to a firefighting station, these vehicles will be in standby mode and activated only in a pandemic.

#### *5.3.5.1.3. Storage Sites*

An important consideration in grid design is the location of storage sites (explained in detail in subsequent section) within a cluster. From an ease of convenience and continuity of the current structure perspective, refillers and large medical colleges can creating these storage capacities (Figure 43). Refillers already have storage tanks and vessels in which LMO is stored and then placed in smaller cylinders or transferred to hospitals. Their storage and fill capacity can be augmented, so that the turnover can be significantly increased in a crisis.

Similarly, government medical colleges tend to act as large hubs of patient treatment. A large capacity here can help address the immediate larger needs and act as supply channel to smaller hospitals.

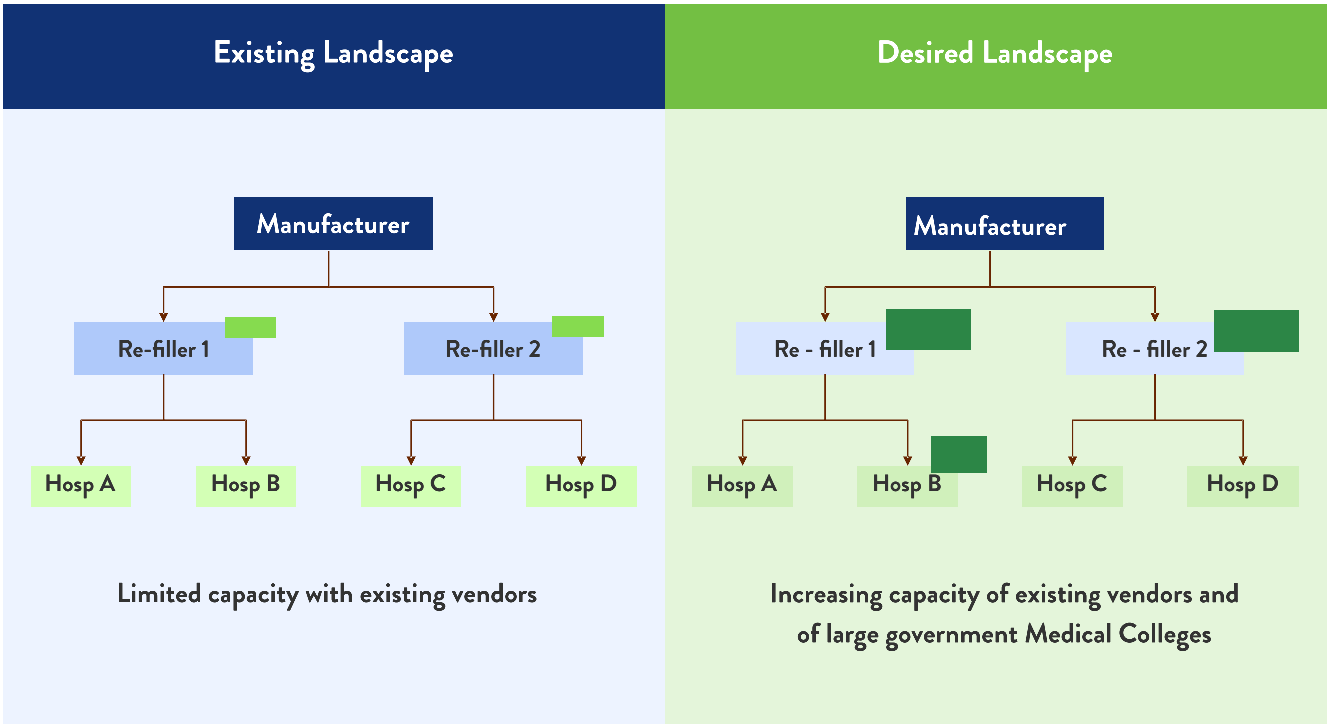


*Figure 43. Potential sites for expanding storage capacities*

### 5.3.5.2. Proposed Infrastructure Capabilities

To cater to the ever-growing demand because of growing respiratory diseases and unprecedented events, a country needs to accommodate new dedicated infrastructure. It would include key support systems and production plants. The system may include storage or transportation of the commodity.

The NMOG needs reliable infrastructure to connect supply chains and efficiently move goods and services across borders. The primary list includes reserves and vehicles to transport larger volumes, which is explained in detail in the next section.

#### *5.3.5.2.1. Need for Reserves*

Oxygen storage reserves are an extra quantity stored in either liquid or gaseous form to prevent an out-of-stock situation. They serve as a backup against sudden rise in demand. If reserves are maintained at an appropriate amount, grid would not rely on the producers and refillers to deliver oxygen quickly to patients, as during Wave 2, because of depleted inventory levels. Reserves cover grid demand until next batch of oxygen arrives.

Reserves protect the grid against the sudden demand surges and inaccurate demand forecasts that can happen during any unforeseen event, serve as a cushion when an order takes longer to reach patients than expected, ensure that medical facilities do not run out, and helps the grid fulfill demand consistently.

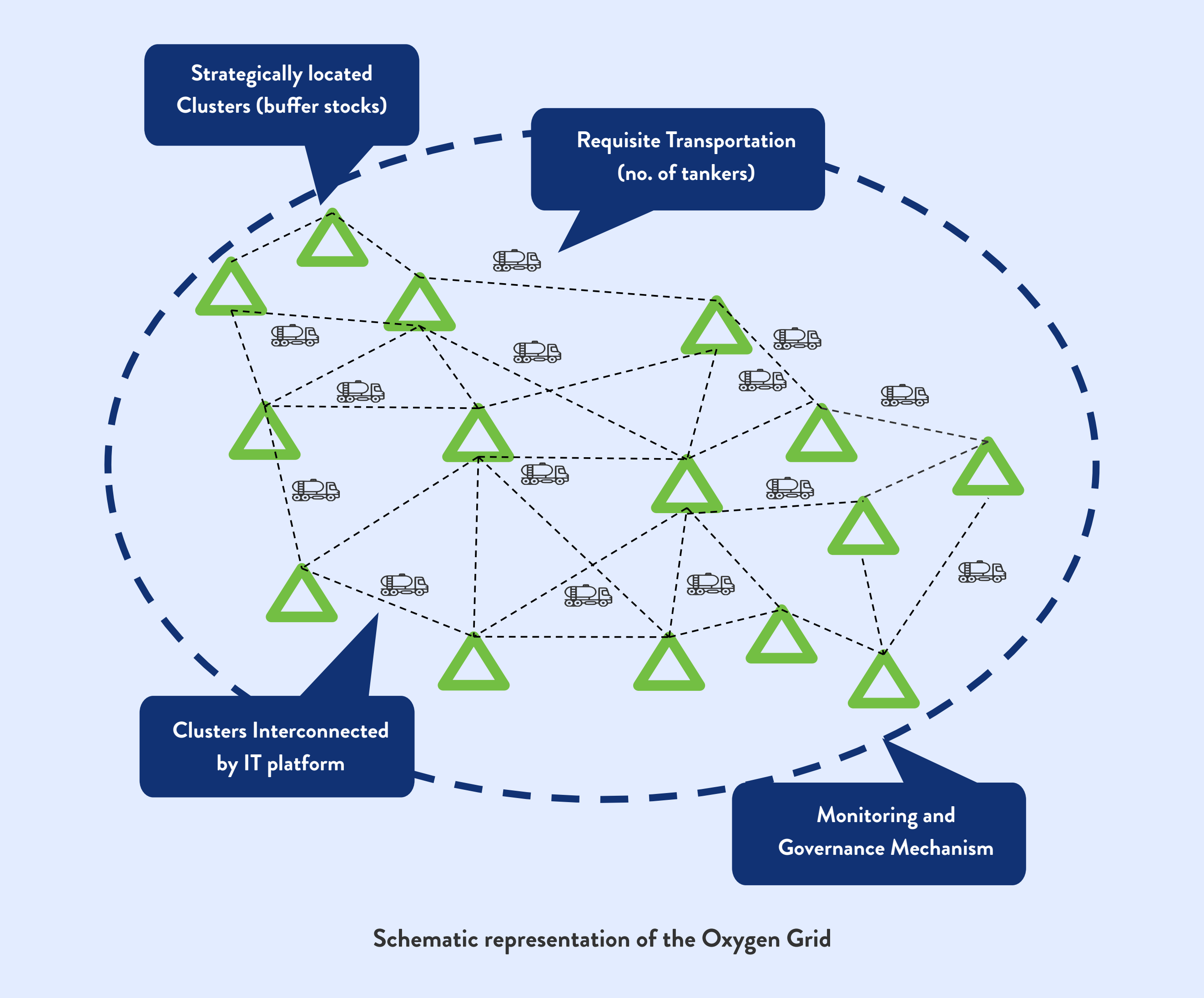


***Figure 44. NMOG schematic***

At times, producers and refillers will not be consistent in delivery and the grid may face a supply lag. Unexpected delays in production or transportation, such as a bottleneck at producer's end or a weather-related shipping delay, can cause oxygen to reach patients later than expected. During these situations, reserves act as a defense and help the grid fulfill demand until oxygen is delivered (Figure 44).

Nevertheless, unpredicted market fluctuations can cause the cost of oxygen to increase suddenly, as happened during Wave 2 due to unexpected demand surges. If the grid has enough reserve during these unpredictable situations, it can help patients to avoid buying oxygen at higher price.

## Available Storage Options

Few options are available to create the reserves. Primary research shows that the maximum user base (hospitals) depends on the gaseous form; the liquid form requires less space and can be stored in significantly higher volumes.

To create reserves, a trade-off between the form to fulfill the demand of the end user and amount of investment required to maintain that reserve has to be analyzed. Table 23 compares the different storage options available in the market.

*Table 23. Available storage options*

| | Gaseous Cylinder | | Liquid tanks | | Liquid Cylinders | |
|---|---|---|---|---|---|---|
| **Inventory Storage Space Requirement** |  | High |  | Low |  | Low (1 Cylinder = 27 Gas Cylinders) |
| **Ease of filling** | | Difficult (Need Bottling Plant) | | Easy | | Easy (Direct download from Liquid Tanks) |
| **Cost per unit storage** | | High (10x of Liquid Tank) | | Lowest | | Medium (2x of Liquid Tank) |
| **Ease of Usage** | | High | | Low | | High (Can be used directly at patient level) |
| **Portable** | | High | | Low | | High |

Based on the analysis, a combination of gaseous cylinders and liquid tanks are considered for creating reserves. Liquid tanks should hold the bulk of it (to reduce the associated inventory costs and space). However, cylinders will ensure a speedy ramp-up of delivery curve, especially for smaller hospitals, which may not have the necessary physical infrastructure (gas manifold and tanks) to store liquid oxygen and supply it to patients. Liquid oxygen cylinders offer a hybrid option, and they can be considered in special circumstances.

## Amount of Storage Required and Associated Investments

To arrive at the estimation of investment required for creating reserves of medical oxygen, we need the amount that these reserves should hold. As explained, a Monte Carlo algorithm was used, with data parameter as peak demand of 4,000–11,000 MTPD for 30–45 days of a pandemic wave. Based on the algorithm, India would need about 50–60k MT of medical oxygen to be stored at either liquid or gaseous form in clusters.[55] The amount per cluster varies by demand–supply gap in that cluster. For primary calculations, the assumption is 30 percent storage in gaseous form and 70 percent in liquid tanks. Thus, primary estimation shows India would need around INR 2,500–2,600 crores of investment for reserves. Table 24 shows the state-by-state primary calculation.

*Table 24: State-by-state reservoir calculations*

| State | Reservoir (MT) | Reservoir Cylinder(Units) | Reservoir LMO Storage (Units) | Reservoir Cylinder (INR Cr.) | Reservoir LMO Storage ( INR Cr.) |
|---|---|---|---|---|---|
| Uttar Pradesh | 10,215 | 3,06,437 | 291 | 368 | 145 |
| Bihar | 5,504 | 1,65,109 | 157 | 198 | 78 |
| Maharashtra | 5,098 | 1,52,944 | 145 | 184 | 73 |
| West Bengal | 4,185 | 1,25,562 | 119 | 151 | 60 |

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[55] The remaining amount will come from steady-state ASU supply, installed PSA plants, inventory capacity, etc. (the concept is explained in the GRAP section).

Contd.

| State/UT | Reservoir (MT) | Reservoir Cylinder(Units) | Reservoir LMO Storage (Units) | Reservoir Cylinder (INR Cr.) | Reservoir LMO Storage ( INR Cr.) |
|---|---|---|---|---|---|
| Madhya Pradesh | 3,185 | 95,551 | 91 | 115 | 45 |
| Rajasthan | 2,965 | 88,938 | 84 | 107 | 42 |
| Tamil Nadu | 2,642 | 79,263 | 75 | 95 | 38 |
| Gujarat | 2,225 | 66,749 | 63 | 80 | 32 |
| Telangana | 2,282 | 68,449 | 65 | 82 | 32 |
| Andhra Pradesh | 2,400 | 72,012 | 68 | 86 | 34 |
| Karnataka | 1,695 | 50,851 | 48 | 61 | 24 |
| Kerala | 1,469 | 44,075 | 42 | 53 | 21 |
| Assam | 1,324 | 39,722 | 38 | 48 | 19 |
| Odisha | 800 | 24,007 | 23 | 29 | 11 |
| Chhattisgarh | 817 | 24,522 | 23 | 29 | 12 |
| Punjab | 1,048 | 31,430 | 30 | 38 | 15 |
| Jharkhand | 622 | 18,664 | 18 | 22 | 9 |
| National Capital Territory of Delhi | 841 | 25,220 | 24 | 30 | 12 |
| Haryana | 443 | 13,290 | 13 | 16 | 6 |
| Himachal Pradesh | 161 | 4,820 | 5 | 6 | 2 |
| Jammu and Kashmir | 11 | 322 | - | - | - |
| Puducherry | 52 | 1,569 | 1 | 2 | 1 |
| Chandigarh | 12 | 371 | - | - | - |
| Lakshadweep | 4 | 124 | - | - | - |
| **Grand Total** | **50,000** | **15,00,000** | **1,422** | **1,800** | **711** |

## Enhancement of Fleet Capacity

To use the reserves during the pandemic, strong fleet strength is required. The strength will cater to the outbound flow from reserves to the destination. Similarly, during nonpandemic times, reserves need to be refilled, so that these reserves can store the desired level of medical oxygen.

The back-and-forth movement involving reserves requires dedicated fleet capacity. Additional required vehicles is calculated based on the amount of storage required in a state versus current available capacity in that state.
The primary calculation shows few requirements for vehicles carrying gaseous cylinders but a requirement for specific dedicated ISO tanks in various states. Table 25 shows the primary calculations; India would require around INR 40 crores investment in ISO trucks, which can be the basis of a public–private partnership.

*Table 25. State-by-state transportation calculations*

| State/UT | Vehicle Required (Gaseous Form) | Vehicle Required (Liquid Form) | Cost of Capex_ISO Trucks (INR Cr.) |
|---|---|---|---|
| Uttar Pradesh | 562 | 49 | 7.35 |
| Bihar | 303 | 27 | 4.05 |
| Maharashtra | 281 | 25 | 3.75 |
| West Bengal | 231 | 20 | 3.00 |
| Madhya Pradesh | 176 | 15 | 2.25 |
| Rajasthan | 164 | 14 | 2.10 |
| Tamil Nadu | 146 | 13 | 1.95 |
| Andhra Pradesh | 132 | 12 | 1.80 |
| Telangana | 126 | 12 | 1.80 |
| Gujarat | 123 | 12 | 1.80 |
| Karnataka | 94 | 10 | 1.50 |
| Kerala | 81 | 7 | 1.05 |
| Assam | 73 | 7 | 1.05 |
| Punjab | 58 | 6 | 0.90 |
| National Capital Territory of Delhi | 47 | 5 | 0.75 |
| Chhattisgarh | 45 | 5 | 0.75 |
| Odisha | 45 | 5 | 0.75 |
| Jharkhand | 35 | 4 | 0.60 |
| Haryana | 25 | 4 | 0.60 |
| Himachal Pradesh | 9 | 3 | 0.45 |
| Puducherry | 3 | 2 | 0.30 |
| Chandigarh | 1 | 2 | 0.30 |
| Jammu and Kashmir | 1 | 2 | 0.30 |
| Lakshadweep | 1 | 2 | 0.30 |
| **Grand Total** | **2,762** | **263** | **39.00** |

## 5.3.6. Operating Model

### 5.3.6.1 Graded Response Action Plan (GRAP)

A GRAP forms the premise of operational framework of NMOG. It is a sequential set of measures to be deployed to manage an evolving demand and supply situation, depending on the increase in demand compared to the BAU scenario. It overcomes an oxygen shortage by selecting least-cost and minimal time sourcing option available in the grid, reducing financial burden on the country and ultimately the patients (Figure 45).

In the BAU scenario, the plan does not include action by various entities to be taken throughout the year to tackle demand–supply gap fulfilling. The plan is incremental—therefore, when that gap increases drastically, the measures must be followed. GRAP will be successful in two new achievements—creating a step-by-step plan for a pandemic and getting several agencies on board, especially cluster authorities. The plan requires action and coordination among all entities across the country.

GRAP can be divided into stepwise categories, determined based on the combined supply capacity of different production entities. The following is a list of entities from which medical oxygen can be consumed or retrieved:

- ASU producing medical oxygen as per BAU
- Additional run by PSA, if any
- Reserves at ASU plants (generally stored to meet additional requirement for industrial use)
- Proposed medical oxygen reservoirs
- Diversion of oxygen meant for industrial use

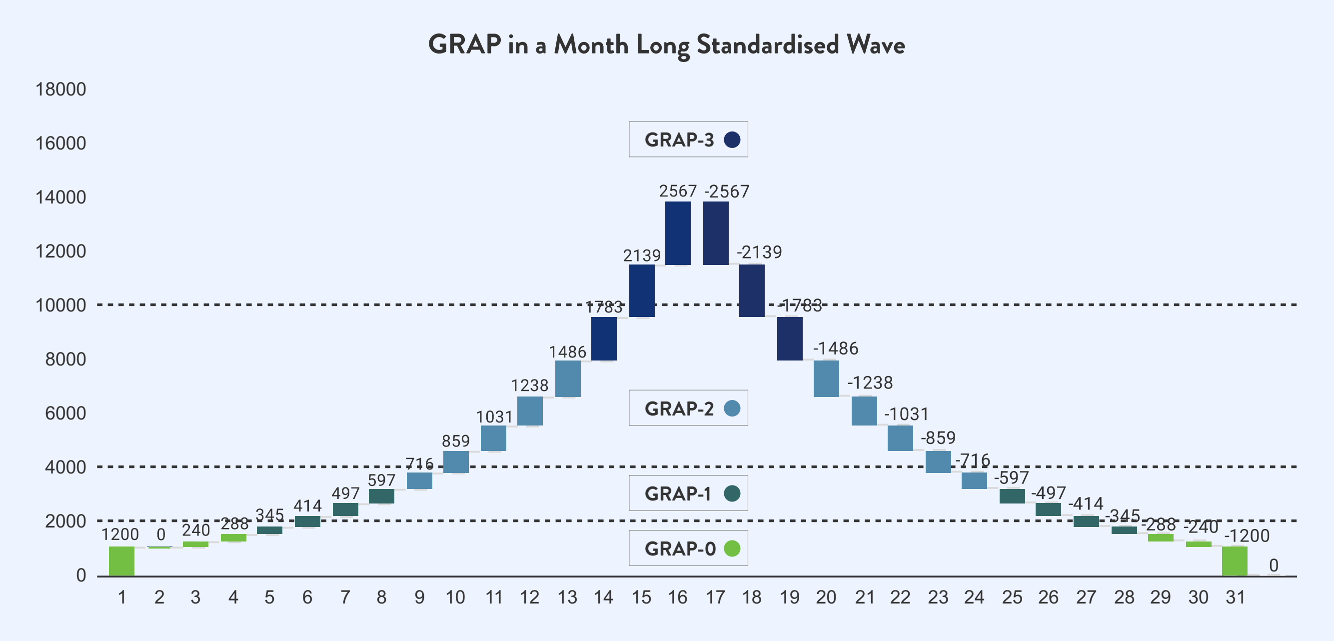

*Figure 45. Graded response action plan*

Figure 46 shows how a different category will be triggered in a pandemic lasting for a single month. As soon as the grid identifies need to add an entity to cater demand, it can pick the next least-cost entity to produce or supply the deficit in particular area. The last option is to divert oxygen from industrial capacity, as this option affects GDP directly.

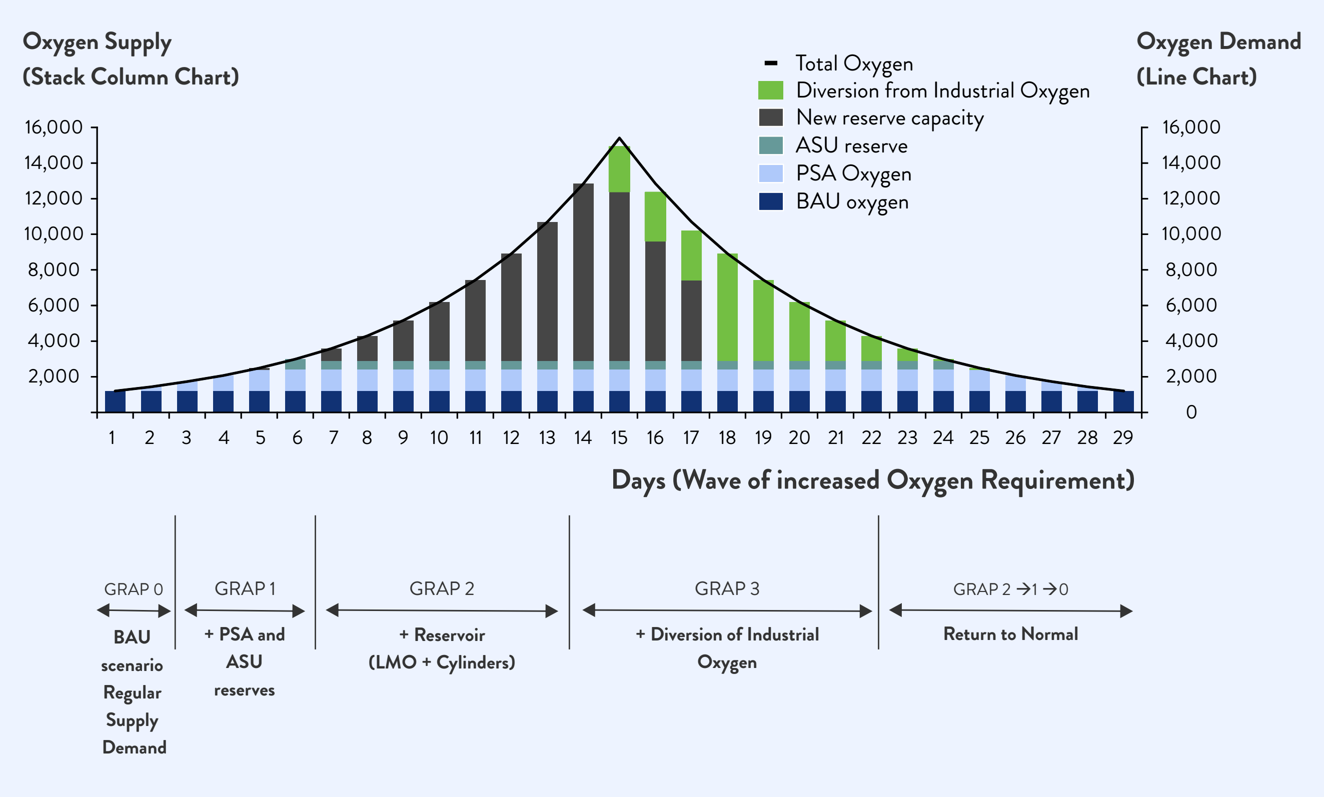

*Figure 46. Graded response action plan for a one-month wave*

### 5.3.6.2. Grid Operation in BAU and Pandemic Scenarios

With the aid of existing administrative structure within a state, clustering can be done from the bottom to the national level. The whole gride can be divided into three levels: cluster, state, and national. These levels predetermined the authorities to be involved and boundary for the decision.

### Level 1: Cluster-Level Control (Multiple Districts Form the Cluster) (Figure 47)

- Divisional headquarters (HQ) controls storage and distribution.
- Central reservoirs at divisional HQ are tagged to refiller(s) and manufacturer(s) for ensuring continuous supply.
- Districts monitors demand–supply and requests allocation from reservoir to divisional HQ if required.

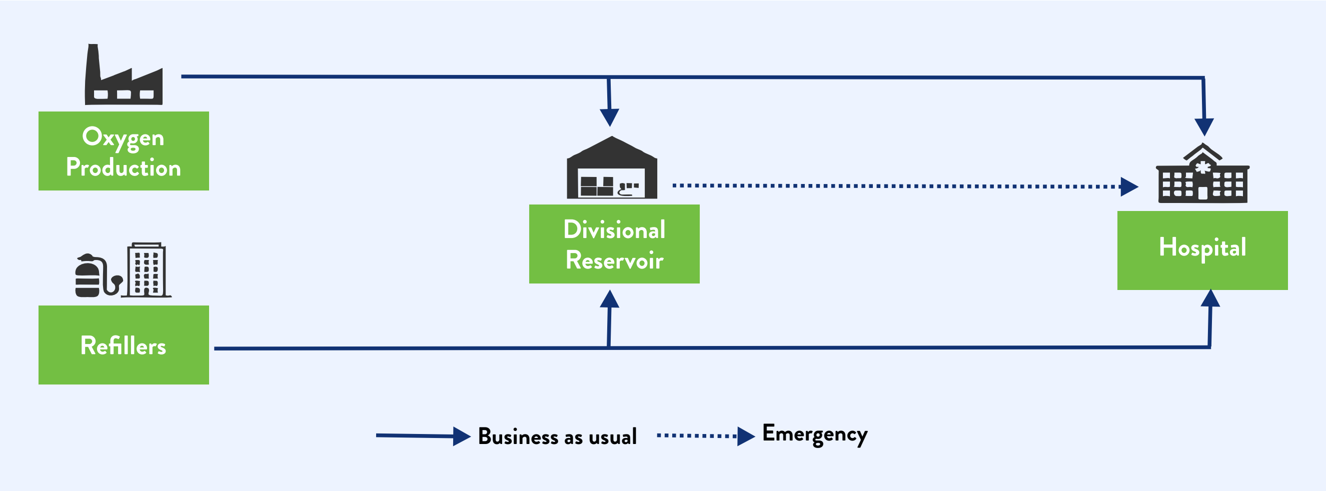

*Figure 47. Cluster-level grid operation in business-as-usual and pandemic scenarios*

### Level 2: State-Level Control (Multiple Clusters Form the State) (Figure 48)

- State HQ controls storage and distribution.
- State authority controls the distribution between clusters for an emergency in any of clusters.
- If all clusters combined cannot fulfill demand, the state authority requests allocation from the national authority.

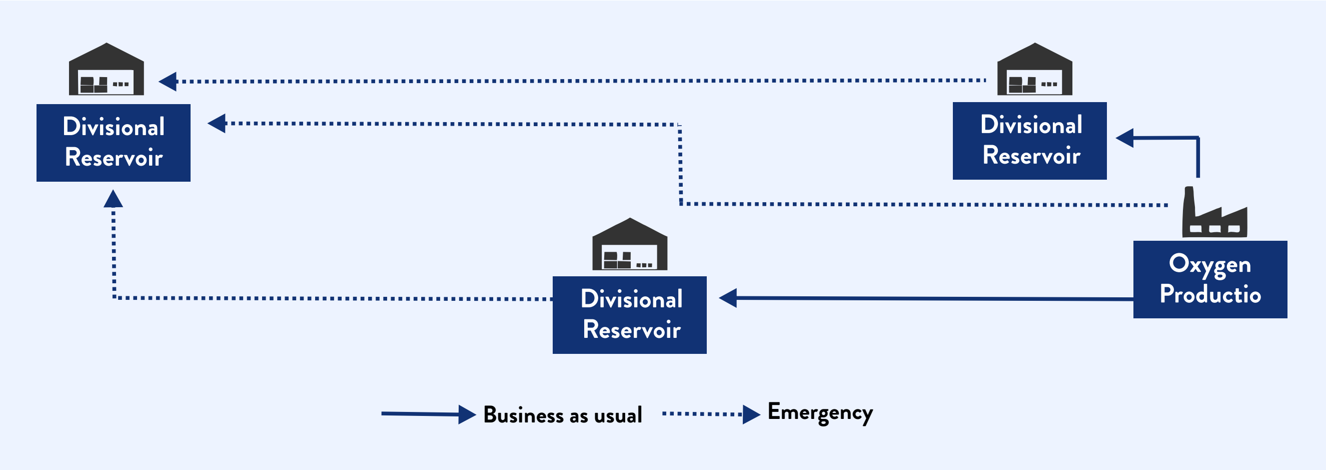

*Figure 48. State-level grid operation in business-as-usual and pandemic scenarios*

### Level 3: National-Level Control (Multiple States Form the Country) (Figure 49)

- National HQ controls storage and distribution.
- National authority prepares the high-level business case and road map on regular basis.
- National authority coordinates among state authorities in emergencies and directs the distribution.

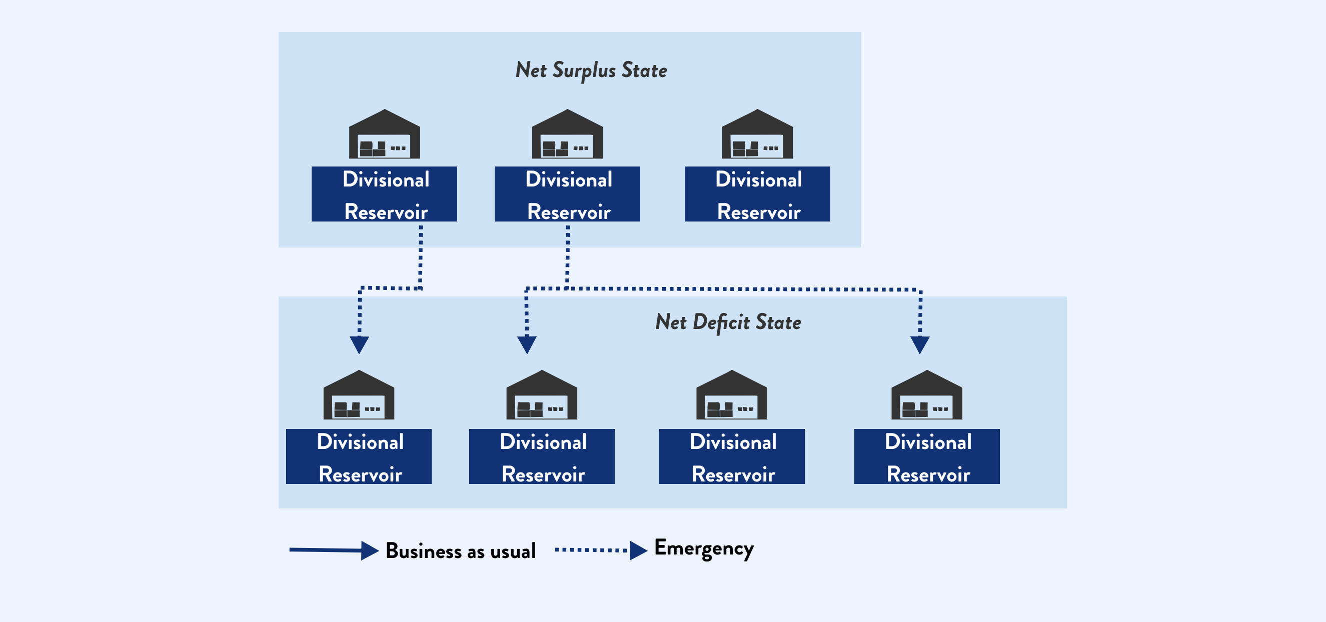

*Figure 49. National-level grid operation in business-as-usual and pandemic scenarios*

## 5.3.7. Governance Mechanism

The grid should allow for the flow of oxygen through various layers in the country. This would require a coordination across multiple stakeholders aided by a proper governance mechanism. The aspects of the governance mechanism are explained next.

### 5.3.7.1. KPIs

It is important to measure the performance of the grid, to focus on improvement areas. A few KPIs are used to track grid performance:

- Percent registration of all manufacturers, refillers, dealers, and health facilities in the oxygen ecosystem
- Percent production, storage, and consumption units, which are under comprehensive annual maintenance contract for five years
- % of maintenance records being mandatorily filled in and uploaded on the grid portal
  Percent of maintenance records being mandatorily filled in and uploaded on the grid portal
- Number of blackouts and stock-outs
- A 24/7 helpline system to address any acute shortage (Crisis Handling Unit)
- Number of regular training and orientation sessions conducted
- Percent compilation of production, stock, and consumption data at regular intervals by designated entities
- Price range of oxygen in the country (reflection of scarcity due to high consumption or artificial shortages from hoarding and stocking), and
- Purity of oxygen being delivered (should be LMO and 99+ percent pure, especially in a BAU scenario, where PSA oxygen need not necessarily be required)

### 5.3.7.2. Monitoring and Governance Framework

## Monitoring Framework of NMOG

The oxygen industry is currently operating with minimal regulations. The BAU scenario has hardly any demand–supply gap, and suppliers can fulfill the entire consumer demand. Against this backdrop, implementing a system such as NMOG would be a challenge, as different players may have reservations about adopting a new way of functioning. However, the participation of all stakeholders would be critical for the grid to succeed, because running in silos would mean that it would not be able to fulfill its objective. Hence, monitoring and governance become much more significant for bringing all the stakeholders along and keeping them together.

As mentioned, the sector is largely driven by private players. They can come up with a self-monitoring participatory watchdog mechanism to oversee the implementation of NMOG, but the grid also requires substantial support and resource pooling, which should better be performed by the government to make the grid an inclusive, long-term and successful solution. Under the overall guardianship of government, NMOG can run with active participation and coordination by public- and private-sector representatives. To create this fine balance between governance and participatory self-monitoring by the industry itself, an arrangement can be proposed where private-sector players are part of an advisory committee keeping a close watch on regular grid functioning.

This committee would provide recommendations to a monitoring committee comprising the heads of all the concerned government departments with the authority to make appropriate decisions and act.

For smooth and decentralized implementation of NMOG, the monitoring framework should be available at each level starting from the cluster level itself, which in NMOG has been envisaged at the divisional level. Figure 50 shows the proposed monitoring and advisory framework:

**Health Secretary**

- Responsible for overall supervision and Monitoring

**National Level Monitoring Committee**

- **Chairperson:** National Nodal Officer for Oxygen Supply
    - To be designated by MOHFW
- **Members:**
    - Representatives of Ministry of Chemicals and Fertilizers, Oil and Petroleum, Surface Transport
    - Representative of Drug Controller General
    - State Committee Chairpersons
    - NIC representatives
    - Chief Controller of Explosives (PESO nodal officer)

**Advisory Committee**

- Representatives of Oxygen manufacturers
- Representatives of Medical Gas Manufacturers Association
- National IMA President
- Association of Healthcare Providers of India - National President and Secretary
- Appointed members representing the Private Healthcare Sector

**State Principal Health Secretary**

- Responsible for overall supervision and Monitoring

**State Level Monitoring Committee**

- **Chairperson: State Nodal Officer for Disaster Management / Oxygen Control**
    - To be designated by state
- **Members:**
    - UP State Director for Drug control
    - Additional Director-Health & FW (All divisions)
    - NIC representatives
    - Deputy Chief Controller of Explosives (PESO State Nodal Officer)

**Advisory Committee**

- Representatives of ASU Plants
- Representatives of Medical Gas Manufacturers Association
- State IMA President
- Association of Healthcare Providers of India - State President and Secretary

**Support Groups**

- Civil Staff
- Patient Support Groups
- Volunteers

**Division Level Monitoring Committee**

- **Chairperson: Additional Director-Health & FW**
- **Members:**
    - District Nodal Officers for Oxygen supply
        - To be designated by CMO

**Advisors**

- District IMA Presidents
- Representatives of Oxygen Re-fillers/dealers

*Figure 50. NMOG monitoring and advisory framework*

Among other functions, a committee is proposed to advise on the following activities and act as an extended arm of the government for implementation. Some of these activities are the following:

- Identify ways to leverage technology to track and monitor the entire supply chain. This includes alignment on information to be shared, frequency of information, modality of information, and deployment of sensors. This will be led by all the stakeholders (manufacturers, transport agencies, dealers, and hospitals).

- Suggest ways to develop oxygen usage protocols. This will be largely led by the medical community.

- In a pandemic or oxygen crisis, this committee can advise on pooling of resources to enable transfer of oxygen from a surplus to a deficit area.

- The associations included in the committee will be tasked with disseminating the ideas and messages to their members and ensuring compliance with the same, using suitable mechanisms.

### Divisional (Cluster) Level

The division or cluster level will have a group of few districts having a common pool of oxygen reserves that will form the base unit of NMOG. States such as UP and Bihar, which have a well-developed divisional level health administration, can designate the divisional health in-charges as the chairperson for the NMOG monitoring committee. For states without a divisional health department designated officer, a suitable chairperson can be nominated by the divisional commissioner. This committee will also have participation from all the constituent districts in form of their designated nodal officers for NMOG/oxygen/disaster management as appointed by CMO or civil surgeon of the district.

At the advisory level, this divisional committee should have IMA presidents of all constituent districts representing the private practitioners and a divisional representative of oxygen refillers and supplier association appointed to represent the oxygen suppliers.

### State Level

At the state level, the monitoring committee should be headed by a chairperson appointed by the health department. It will include all divisional monitoring committee chairpersons, state-level representatives from the drug control department, national informatics center (NIC), and PESO state nodal officer.

At the advisory level, the state committee should have representation from state chapter of IMA (state president), oxygen manufacturers (located in or major suppliers to the state), state oxygen refillers and supplies association, and state-level president and Secretaries of Association of Healthcare Providers of India. States can also appoint 1–2 distinguished doctors or hospital owners as a representative for the health sector.

### National Level

At the national level, the health secretary would be the overall guardian of the national monitoring committee, and the ministry of health and family welfare should designate a nodal officer for oxygen availability/disaster management/NMOG to be the de facto chairperson of this committee. It will also have representation from other relevant ministries, such as chemicals and fertilizers, petroleum and natural gas, and surface transport, representatives of the drug controller general of India, PESO, and NIC, and the chairpersons of state-level monitoring committees.

At the advisory level, national presidents of IMA, APHI, and oxygen manufacturers and refiller associations should be the members. The group can also have 1–2 distinguished doctors or hospital owners or other experts who can represent the health industry and provide useful insights.

### Governance of NMOG

The monitoring framework will be inherently attached to the governance framework, as mentioned in Figure 50. The advisory committees with participation of all major stakeholders of the manufacturing and distribution ecosystem will be involved in keeping a close watch on different grid objectives and performance parameters, but the monitoring committees will have the power to make important decisions and give orders after considering the recommendations of the advisory committees. Hence, the onus for governance would be with the monitoring committees; at each level, these committees would have participation of senior government representatives of health and other concerned departments. The health department, as the overall custodian of the program, will own the governance mechanism. At the state and national levels, the health secretaries, as the senior officers of the health department, would be responsible for governance. At the divisional level, the administrative structure of the health department is not uniform, so apart from the divisional representatives (wherever available), the divisional commissioners will be responsible for grid governance.

### Role of other actors

A renewed spirit of cooperative federalism may be required to develop these local divisional grids, which scale up to state-level oxygen grids, before culminating in a national level oxygen grid. Other than the cited ministries, due experience may be leveraged from other players.

For example, the prime minister has recently launched the Gati Shakti—National Master Plan for Multimodal Connectivity,[56] essentially a digital platform to bring 16 ministries, including railways and roadways, together for integrated planning and coordinated implementation of infrastructure connectivity projects. The multimodal connectivity will provide integrated and seamless connectivity to move people, goods, and services from one mode of transport to another. It will facilitate the last-mile connectivity of infrastructure and reduce travel time for people. Linking to this can help solve the problem of tracking oxygen cryogenic tank movement across long distances and within state boundaries.

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[56] https://www.india.gov.in/spotlight/pm-gati-shakti-national-master-plan-multi-modal-connectivity

### 5.3.7.3. IT Architecture (Command and Control Structure—Control Tower)

IT architecture forms the backbone of NMOG and captures the flow of oxygen from the manufacturer through the cluster that is the end user. Manufacturers can supply oxygen to other manufacturers, dealers, or refillers or directly to the health facilities. Refillers supply the oxygen to other refillers or dealers or directly to the health facilities. Dealers supply the oxygen to other dealers, directly to the health facilities, or to retailers, such as ambulances, pharmacies, and patients.

IT architecture is a multilayer evolutionary structure that captures various functionalities as it evolved over time.

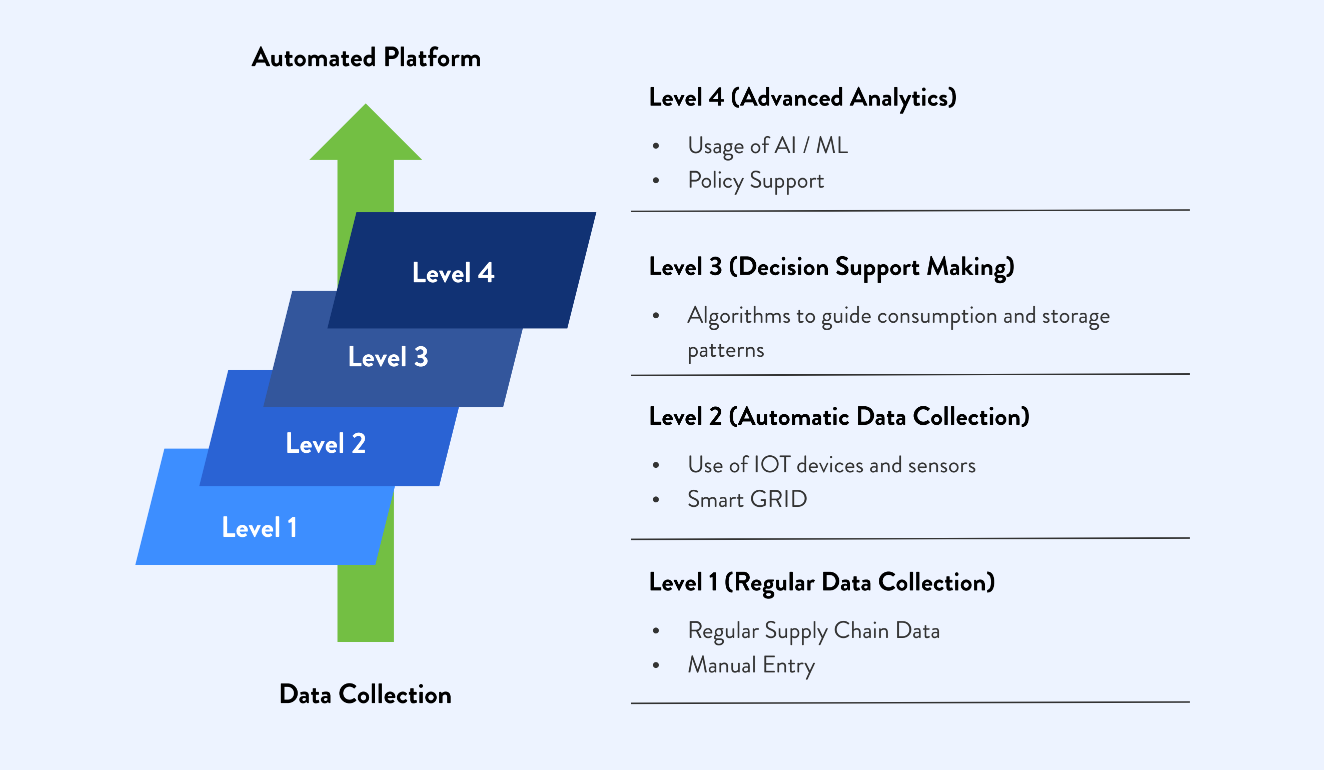

*Figure 51. NMOG IT architecture*

- Level 1 of this IT architecture allows for regular collection, through manual entry, of regular supply chain data, including order received, dispatched, inventory stocks, lead times, and price. Table 25 gives a detailed description of some data points to be entered by stakeholders in this system.

*Table 25. Data to be entered into NMOG architecture*

| Manufacturers | Re-fillers | Dealers | Health Facilities |
|---|---|---|---|
| • Request for supply received from refillers/dealers/ HFs (quantity and name)<br>• Supply delivered/released (quantity and the name of refillers/dealers/HFs)<br>• Opening stock/current stock (oxygen produced and supplied) | • Request for supply received from Dealers/HFs (quantity and name)<br>• Supply delivered/released (quantity and the name of dealers/HFs)<br>• Opening stock/current stock (oxygen received and supplied) | • Request for supply received from HFs (quantity and name)<br>• Supply delivered/released (quantity and the name of Hfs)<br>• Opening stock/current stock (oxygen received and supplied) | • Approve the request for supply updated by manufacturers/ refillers/dealers in their name. (quantity and name of supplier)<br>• Approve the oxygen received as updated by manufacturers/ refillers/dealers in their name. (quantity and name of supplier)<br>• Supply received from other source<br>• Opening stock/current stock (oxygen received and supplied) |

- Level 2 allows for collecting this supply chain data via technology. This is pertinent to ensure that the data collection is near seamless and regular. Table 26  describes possible methods.

*Table 26. Tracking methods*

| Tracking unit level consumption | Tracking Movement of Oxygen (Expanding Scope of ODAS and ODTS Developed During COVID Wave 2) | | Tracking Production and Storage |
|---|---|---|---|
| • Usage of RFID tags and QR codes to enable monitoring and tracking of oxygen cylinders | • Usage of IOT sensors to guide oxygen digital tracking systems[57] and demand aggregation systems[58]<br>• Oxygen level and pressure sensors and automatic reordering of LMO tanks<br>• Oxygen flow meters in hospitals and pressure gauges | • GSTN database for E-waybill based data entry<br>• Tracking of tankers through GPS, SIM (driver cell #), FASTag, etc.<br>• Automated alerts from system for route deviation, unintended stoppages, delays | • Oxygen quality sensors<br>• Oxygen leakage sensors |

Some of these technological tools are already deployed. For example, some large LMO tanks in hospitals have an auto-reordering mechanism, which places an order as soon as the oxygen drops below a certain level. The level is constantly gauged via level and pressure sensors. Most cryogenic vessels and ISO containers are GPS fitted and have temperature control sensors installed. These are routinely monitored by the transportation and logistics company. At the hospital level, these sensors are deployed in ventilators and other medical equipment to regularly monitor oxygen purity and pressure. Furthermore, in the gas manifold in hospitals and production centers, sensors detect any potential oxygen leakages. E-Way movement tracking is also well digitalized.

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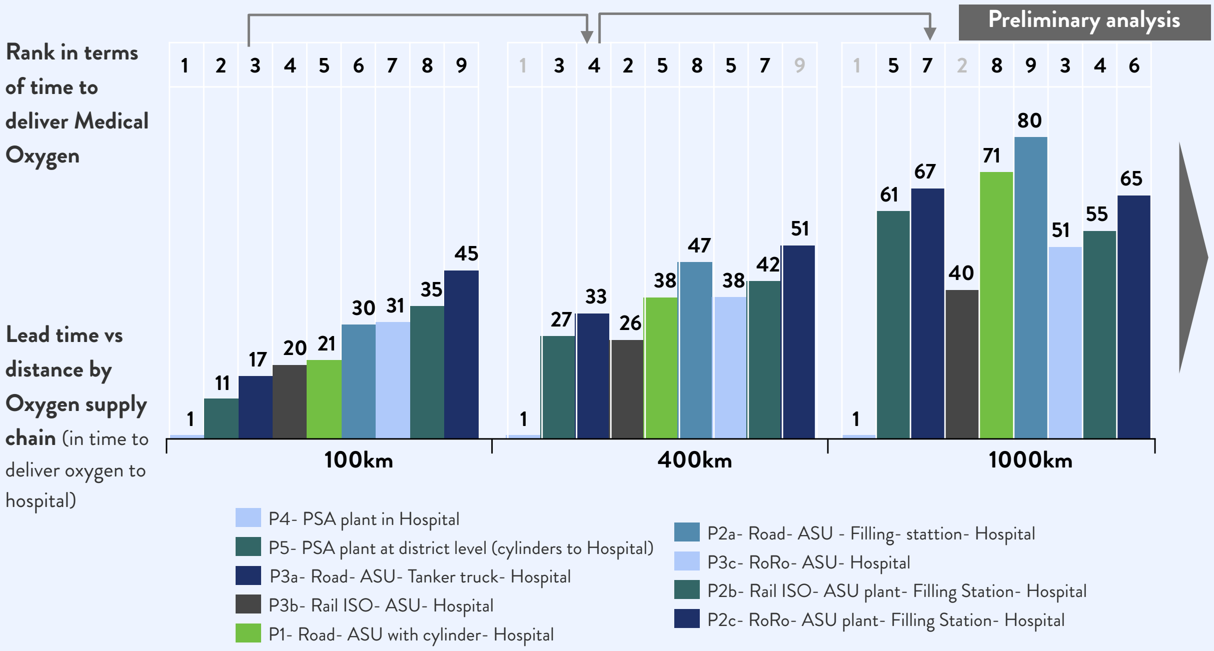
[57] The oxygen digital tracking system is an app and web-based platform developed during the second wave of the pandemic. The portal was launched to enable real-time tracking in the country. Information relating to oxygen demand in various states and its allocation from plants to states was regularly updated on the portal. In addition, it also helped track dispatch and deliveries along with the tankers in transit (including those on trains). The tracking platform also computed analytics on route optimization, making it easier for officials to select routes that would allow the smoothest supply and delivery of tankers. A virtual central control room was established with officers from additional/joint secretary officers of health, road, rail, industry, steel, and state governments. It monitored oxygen movement 24/7 and resolved any issues in transportation.

[58] The oxygen demand aggregation system is a digital platform developed to ascertain the demand from all medical facilities. During the third COVID-19 wave, the government and the ministry of health and family welfare issued directions for states/UTs to ensure onboarding of all healthcare facilities using oxygen in this system directly or through a state application programming interface.

An efficient grid will require collation of data from all these sensors and deployment of sensors in places where they do not exist. This is considered feasible considering limited number of oxygen producers, major refillers, and transport agencies in the country.

- Level 3 allows for decision support system by incorporating algorithms that can be designed to identify the next best place from where oxygen can be sourced fastest and with the lowest cost. These algorithms will vary by location and local considerations and need to be modified in discussions with primary stakeholders.
  The Figure 52 presents an illustrative example.



**Comparison of Oxygen supply chain Lead times for proposed pathways given all scenarios co-exists & no inefficiencies in ideal scenario**

**LMO SC P3a shifts from 3rd best to 7th best as lead distance increases**

**Key considerations**

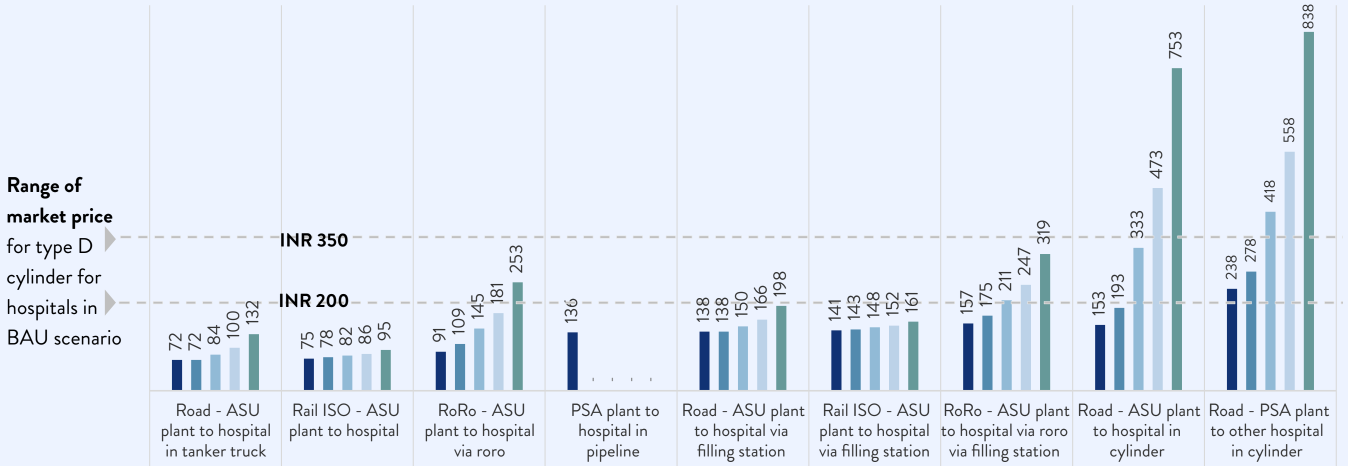
- PSA plants at hospital offers least time to deliver, however, they are available only with select hospitals or functional at select district level with limited capacity
- Hence, PSA plants are not expected to address demand at PHC and other medium and small-scale hospitals
- At longer lead distances, rail becomes more efficient due to faster travel speeds, however, it requires additional considerations such as infra availability & rail siding feasibility

**Time study to be used to develop a graded grid plan to determine most optimum Oxygen supply chain considering regional demand-supply situation, cost dynamics, and other infrastructure constraints**

*Figure 52a. NMOG algorithms*

**Comparison of cost of Oxygen using different proposed pathways given unlimited supply & no inefficiencies in ideal scenario**

**Preliminary analysis**



| | Road - ASU plant to hospital in tanker truck | Rail ISO - ASU plant to hospital | RoRo - ASU plant to hospital via roro | PSA plant to hospital in pipeline | Road - ASU plant to hospital via filling station | Rail ISO - ASU plant to hospital via filling station | RoRo - ASU plant to hospital via roro via filling station | Road - ASU plant to hospital in cylinder | Road - PSA plant to other hospital in cylinder |
|---|---|---|---|---|---|---|---|---|---|
| **100km** | 72 | 75 | 91 | 136 | 138 | 141 | 157 | 153 | 238 |
| **200km** | 72 | 78 | 109 | - | 138 | 143 | 175 | 193 | 278 |
| **400km** | 84 | 82 | 145 | - | 150 | 148 | 211 | 333 | 418 |
| **600km** | 100 | 86 | 181 | - | 166 | 152 | 247 | 473 | 558 |
| **1000km** | 132 | 95 | 253 | - | 198 | 161 | 319 | 753 | 838 |

**Evaluate market price by lead distances and build-up of market price across various elements in LMO supply chain to facilitate development of most financially attractive grid**

*Source: PwC Analysis, Primary discussions

*Figure 52b. NMOG algorithms*

- Level 4 reflects the eventual maturity from a data collection tool and a decision support system toward an autonomous platform. It helps create dashboards and enable policy support (Figure 53).

**Automated Dashboard and decision-making tools**

**Early Warning Indicator**

**Resource Mobilization and Prioritization**

**Epidemiological Studies**

**Potential Role in Other areas**

**Leverage GRID for other Medical Gases**

**Leverage GRID for other medical goods and consumables**

**Leverage GRID for Health Data Collection (Support initiatives like NHRR, ABDM)**

*Figure 53. NMOG analytics and policy support*

### 5.3.7.4. Roles and Responsibilities

A single IT platform must track the data and draw conclusions from it to drive action.

The key points for the platform are the following:

- All manufacturers, refillers, and dealers must participate and daily update their oxygen stocks. They can supply oxygen to other manufacturers, dealers, or refillers or directly to the health facilities (each to be mapped to the respective clusters in NMOG).
- All national, state, divisional, and district oxygen control rooms (OCRs) must be available.
- Divisions will update their demands for upcoming week by every Friday in BAU and daily in critical situations. Demand by state and country would be aggregated by NMOG as per divisional inputs. State and national OCRs can review the demands (weekly in BAU and daily in critical situations).
- Every week (on a particular day), districts will inform divisional OCR about oxygen demand for the upcoming week, supply received in the previous week, and any excess or deficit faced.
- Every week (on a particular day) each hospital should update the concerned district nodal officer about its demand for the upcoming week, oxygen for previous week, and any excess or deficit faced.
- Only national and state OCRs will have the right to edit state/divisional allocation data.
- The national OCR will review the aggregated state demands and update the state allocations; the state OCR will do the same for divisions.
- The NMOG will function regularly until oxygen demand is within BAU demand limits. If a higher demand is updated for any division, it will flag an issue. The state OCR will decide on allocation.
- Once higher allocation is fed to NMOG for a division, it will list sources of additional supply.
- Change in action plans will be suggested by NMOG if state/national demand rises above the designated level. Actual activation of concerned action plan will be done only by the national OCR.

To use the platform, training for stakeholders is must. It will enable all the stakeholders to understand the portal and have easy access. Several training sessions can be organized; people will be briefed on how to log in and fill in the details. Video tutorials and PDF documents for each login can be shared as user manuals in the portal. Detailed SOP manuals in the portal can also be made available.

To monitoring and support platform, a dedicated group must be formed to address and resolve issues related to supply from the manufacturer to health facilities across the state. Based on the clusters, the entire state can be divided and monitored. For convenience, each cluster can have a zonal officer. A 24/7 control room/support cell can be set up at the state in the health and family welfare department for real-time monitoring of production, distribution, and grievances/complaints and resolving these as quickly as possible.

Daily analytical reports will be shared with the state/district OCRs, zonal officers, and the enforcement agencies for the concerted efforts to ensure efficient and proper use of medical oxygen in the state.

This model will benefit the states in many ways:

- Tracking and monitoring the oxygen demand–supply flow at different levels daily throughout the state leveraging technology (Figure 54).
- Monitor the progress made in ensuring a proper demand–supply ratio of oxygen via daily dashboards.
- Track users who are filling in the data inaccurately.
- Prevent hoarding.
- Display the criticality of facilities where less than 24 or 48 hours of oxygen remains.

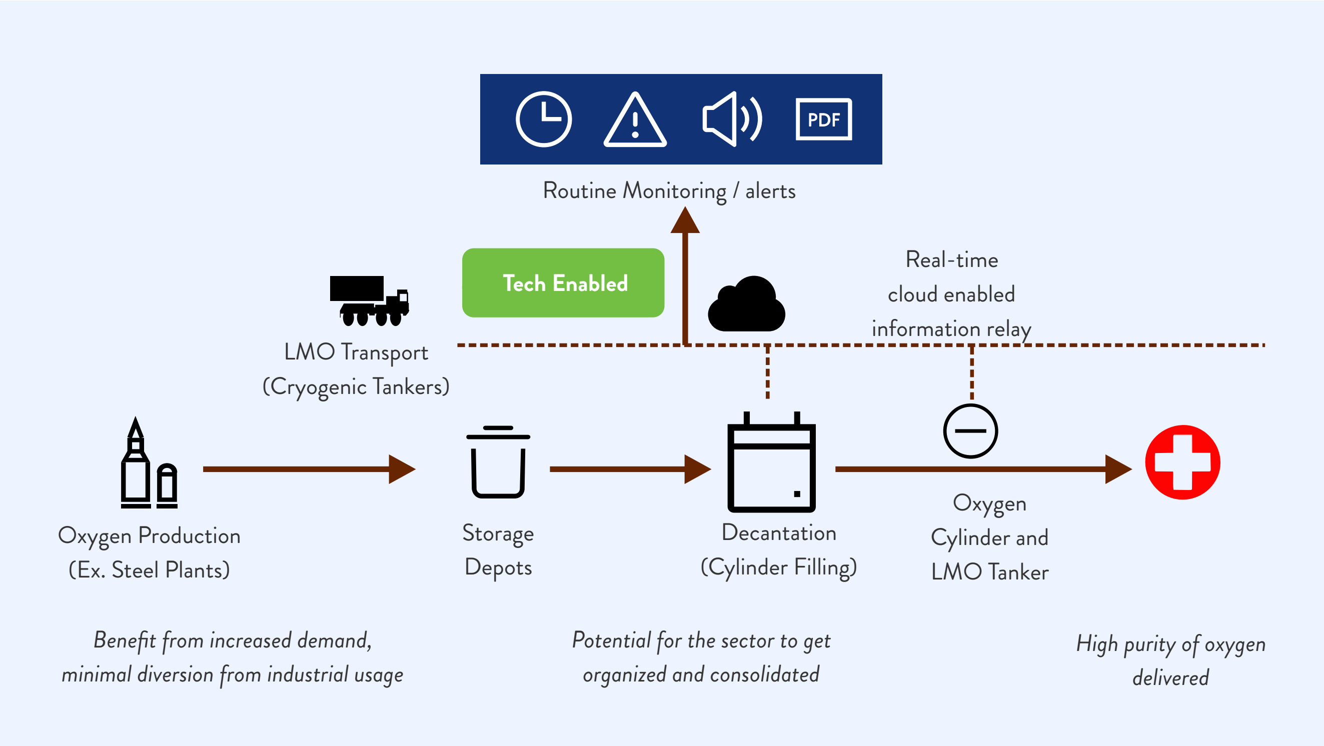


***Figure 54. Steady State Functioning of NMOG***

### 5.3.7.5. Training and Usage Protocols of Oxygen in the Country

Adequacy of medical prescriptions is an important consideration in driving optimal usage. Clinical protocols should be designed for all major and minor illnesses that require oxygen, in consultation with key opinion leaders and centers of excellence. These should be disseminated and monitoring mechanisms defined to ensure their adoption in routine practice. Similar mechanisms being developed by All India Institute of Medical Sciences (AIIMS) for medical professional training may serve as a guide.[59] (Figure 55)

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[59] The National Oxygen Stewardship program was launched at AIIMS in December 2021. It included training one steward per district, across the country. The steward/professional would a) lead the training on oxygen therapy in respective districts, b) support the audit of oxygen delivery, and c) help in preparedness for a surge scenario.

**A due emphasis needs to be laid on developing medical oxygen usage protocols \ across and training human resource**

**Multiple Medical Conditions requiring Oxygen**

**Common ailments**

- COPD (Chronic obstructive pulmonary disease )
- Interstitial Lung Disease etc. Pulmonary fibrosis, Cystic Fibrosis
- Others – Pneumonia, Sleep Apnea, etc.

**Ailment requiring Hyperbaric Oxygen**

- Non-Healing Diabetic Ulcers
- Decompression Sickness
- Serious Infections

**Proven Value of Long -Term Oxygen Therapy**

- Increased survival by reducing the risk factors (cardiac events, desaturation during sleep, quality of sleep
- Evidence from various studies - 24 hours/day oxygen therapy is beneficial for COPD patients than 18 hours/day
- Adequate adjustment of Oxygen flow at rest, during effort, and sleep

- **SubOptimal Usage in India**

**Need for clinical standards, training and protocols**

- Clinical Protocols
- Human Resource Training

**Govt launches programme to train healthcare workers on efficient management of medical oxygen**

*Launching the National Oxygen Stewardship Programme at the AIIMS here, Union Minister of State for Health Bharati Pravin Pawar said the country witnessed an increased demand for medical oxygen during the COVID-19 pandemic, hence its rational use has become mandatory and need of the hour.*

Written by PTI

December 22, 2021 3:23:48 pm

*Figure 55. Medical oxygen usage protocols*

## 5.3.8. Market Sustainability

To ensure scale-up, NMOG needs to be self-sustainable and cost-effective, especially considering that the ecosystem is largely driven by private-sector players.

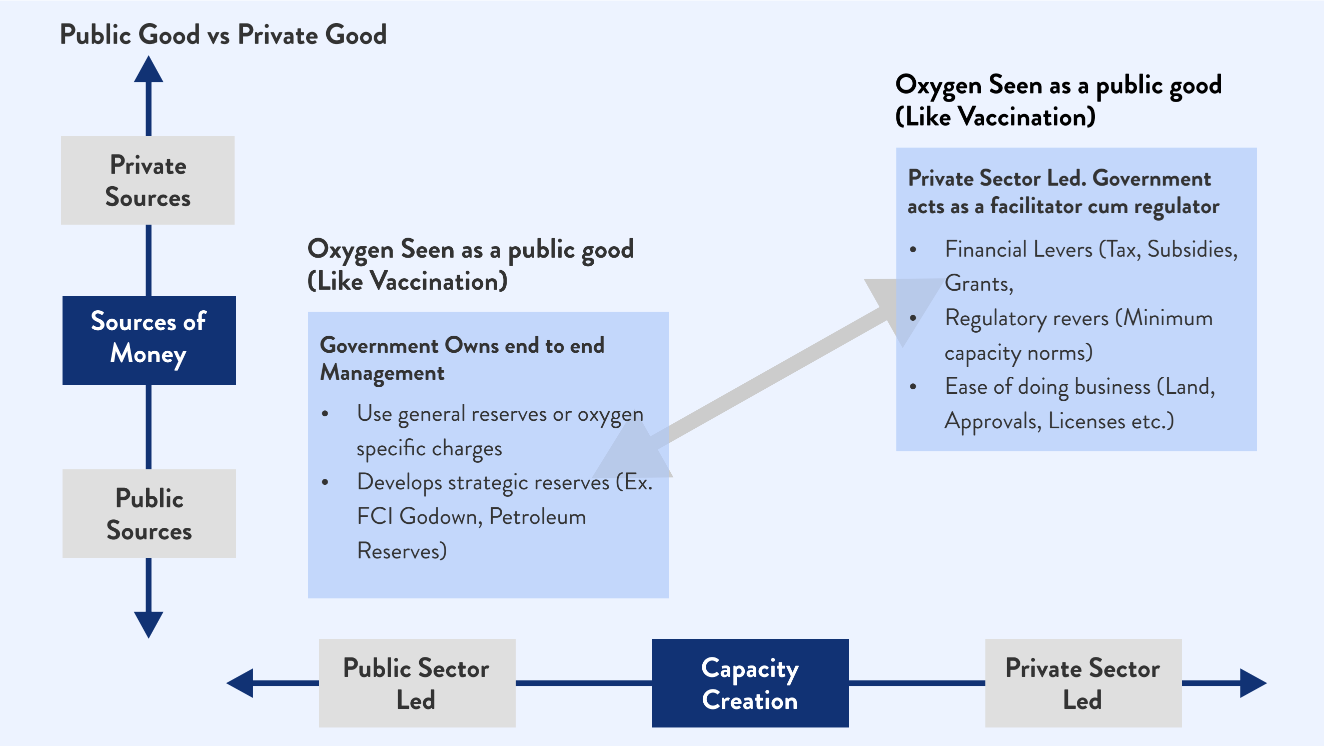

*Figure 56. Oxygen treated as a public versus private good*

Depending upon the ideology, the grid can be seen as either a public good (primarily financed and maintained by taxpayer money via a variety of financial instruments) or a private good (primarily financed by private money or user charges and with government acting as a facilitator cum regulator) (Figure 56). The nature of associated financial instruments and levers can vary depending upon the financial sources being deployed and lead actors involved in creating new capacities (Figure 57).

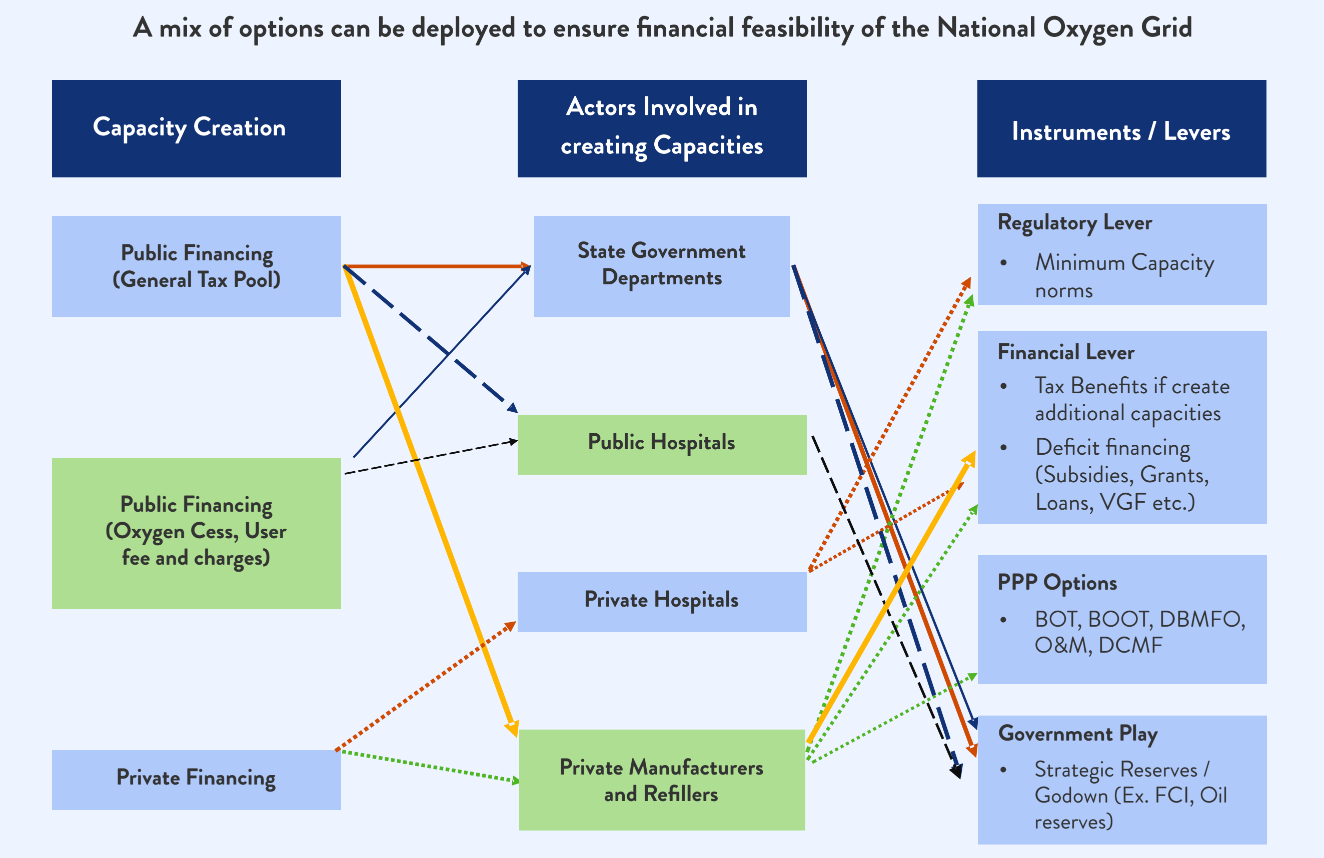

*Figure 57. Financial options for NMOG*

All major players in the industry are from the private sector. For example, this includes the majority of LMO manufacturers, dealers, distributors, and bottling plant owners. Private-sector big and small hospitals make up the bulk of consumers. Similarly, the manufacturers and maintenance service providers of PSA plants and oxygen concentrators are from the private sector. A significant involvement of the private sector is envisaged for creating capacities and financing the grid.

#### 5.3.8.1. Cost Estimation

A storage reserve of around 50–60k MT has been planned for the entire country. Based on the data and evidence, a 30:70 distribution of this storage reserve as cylinders and LMO is recommended. Creating a gaseous reserve in filled cylinders is important for the majority of smaller hospitals that do not have a gas pipeline system and depend on gaseous oxygen cylinders.

Apart from these two kinds of reserves, resources in transportation need to be pooled to ensure that lack of transportation does not become a bottleneck during a crisis.

The financial estimates for these two are summarized in Table 27

***Table 27. Financial Estimated for creating reservoir capacity and transportation resources***

| | | Quantity Required | No of standard units | Per unit price (INR) | Total Cost |
|---|---|---|---|---|---|
| **Reservoir Capacity** | **LMO (70 percent)** | 40,915 MT | 1,663 | 50,00,000 | 831.5 |
| | **Cylinder (30 percent)** | 17,456 MT | 17,53,669 | 12,000 | 2,104 |
| **Cryogenic tankers** | | | 270 | 15,00,000 | 40.50 |
| **Total Physical Infrastructure Cost** | | | | | 2,976 |

As health is a state subject, NMOG implementation will be at the state level; Table 28 shows the estimates.

***Table 28. Estimated cost for state-level NMOG***

| State/UT | LMO | | D-type Cylinder | | Cryogenic Tankers | |
|---|---|---|---|---|---|---|
| | Units | Cost (in crores) | Units | Cost (in crores) | Units | Cost (in crores) |
| Uttar Pradesh | 340 | 170 | 358,259 | 430 | 50 | 7.50 |
| Bihar | 183 | 92 | 193,031 | 232 | 27 | 4.05 |
| Maharashtra | 170 | 85 | 178,809 | 215 | 25 | 3.75 |
| West Bengal | 139 | 70 | 146,796 | 176 | 20 | 3.00 |
| Madhya Pradesh | 106 | 53 | 111,709 | 134 | 17 | 2.55 |

Contd.

| State/UT | LMO | | D-type Cylinder | | Cryogenic Tankers | |
|---|---|---|---|---|---|---|
| | Units | Cost (in crores) | Units | Cost (in crores) | Units | Cost (in crores) |
| Rajasthan | 99 | 49 | 103,979 | 125 | 16 | 2.40 |
| Tamil Nadu | 88 | 44 | 92,667 | 111 | 13 | 1.95 |
| Andhra Pradesh | 74 | 37 | 78,037 | 94 | 12 | 1.80 |
| Telangana | 76 | 38 | 80,024 | 96 | 12 | 1.80 |
| Gujarat | 80 | 40 | 84,191 | 101 | 12 | 1.80 |
| Karnataka | 56 | 28 | 59,451 | 71 | 10 | 1.50 |
| Kerala | 49 | 24 | 51,528 | 62 | 9 | 1.35 |
| Assam | 44 | 22 | 46,440 | 56 | 7 | 1.05 |
| Punjab | 27 | 13 | 28,067 | 34 | 6 | 0.90 |
| National Capital Territory of Delhi | 27 | 14 | 28,669 | 34 | 5 | 0.75 |
| Chhattisgarh | 35 | 17 | 36,745 | 44 | 5 | 0.75 |
| Odisha | 21 | 10 | 21,820 | 26 | 5 | 0.75 |
| Jharkhand | 28 | 14 | 29,485 | 35 | 4 | 0.60 |
| Haryana | 15 | 7 | 15,537 | 19 | 4 | 0.60 |
| Himachal Pradesh | 5 | 3 | 5,635 | 7 | 3 | 0.45 |
| Puducherry | 0 | 0 | 377 | 0 | 2 | 0.30 |
| Chandigarh | - | - | - | - | 2 | 0.30 |
| Jammu and Kashmir | - | - | - | - | 2 | 0.30 |
| Lakshadweep | 2 | 1 | 1,834 | 2 | 2 | 0.30 |
| Meghalaya | 0 | 0 | 145 | 0 | - | - |
| **TOTAL** | **1663** | **831** | **17,53,669** | **2104** | **270** | **40.50** |

#### 5.3.8.2. Capital Expenditure Sources

Creating oxygen reserves as LMO tanks and cylinders is the bulk of the cost required for NMOG. In comparison to any other mechanism through which oxygen supply can be ensured during a crisis, these storage reserves represent the most reasonable, efficient, and cost-effective solution. Creating storage capacities with only peak scenarios in mind may not be practical, and it would be better to plan infrastructural expansion while considering a "less than peak" situation and focusing on bringing overall efficiency to the system.

Considering the novelty of a COVID-like event, similar crises may be widely spaced; multiple such crises in a short span would be unlikely. Hence, the cost to create the additional storage capacity may not have immediate relevant financial returns and cause pure private investment to be rather difficult.

For example, fire trucks are meant only for emergencies and largely planned and maintained by government institutions. Other strategic storage reserves, such as food and oil, are also maintained by public institutions.

In the private space, inventory storage cost is kept as minimal as possible. Hence, a government financial involvement as seed money or one-time budgetary allocation is desirable. The money can come from a general taxpayer pool or the COVID-specific PM-CARES fund being created.[60]

From a private perspective, couple of options exist, each with its own challenges. One would entail passing on the cost to the consumers. This requires sufficient political goodwill to increase the price of oxygen, even making it unaffordable and out of reach for some segments. Another option involves leveraging a part of hospitals' 100x margin to finance the grid. This may not risk increasing the patient price, but from a logistical perspective, considering the concentration of small hospitals that are not regulated by any one single entity, this may be difficult to implement. Another option can be to look for more users for the storage capacities; these reserves will be not be readily used by anyone, and other players/industries may might need similar reserves as an insurance for their own peaks and share the cost of creating and running these reserves with hospitals.

Regulatory mandates may be another good option. The government can use its regulatory powers and make it mandatory for large hospitals to have their own oxygen storage tanks. Any hospital with 250+ beds is large and can be asked to have substantially large storage capacities. Many states, such as UP, Andhra Pradesh, and Karnataka, have already introduced such regulations for their medium and large hospitals.

The U.S. Regulatory Construct for Energy sector requires producers to maintain their own storage reserves for peak demand. The United Kingdom has mostly a contractor-based system with auctions for all storage-level upgrades; the regulator pays for it up front, and then the cost is passed on to the participants and consumers.

For India, the suitable model will be more public sector oriented; the government would either create oxygen reserves or allow certain incentives for the manufacturers to create reserves of their own.

Another option can be based on the UK model, where the government contracts out large procurement tenders for private vendors to provide LMO reserves that are used for both storage and supply to hospitals during peak demand.

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[60] The Prime Minister's Citizen Assistance and Relief in Emergency Situations Fund was created in March 2020, for the pandemic. It has been used in various emergency COVID relief purposes, including for education and welfare of children who lost parents.

This would mean the exchequer will not underwrite the capital expenditure for creating and maintaining the reserves; the contracting partner would bear the full cost, and the government would pay only a monthly fee. Maintenance and staff capacity-building will also not be required. The disadvantage would be that it would be a challenge to find such a vendor at all locations (especially remote/lower-demand clusters).

Impact social bonds can also be explored for financing NMOG.

Some of these options are summarized in Table 29.

***Table 29. Pros and cons of NMOG financing options***

| Capacity Creation | Pros | Cons |
|---|---|---|
| **Regulatory Lever**<br>• Minimum Capacity norms | • Readily available reserves<br>• Minimal stretching of fiscal space | • Business interests are hampered.<br>• It may be insufficient for longer waves. |
| **PPP Options**<br>• BOT, BOOT, DBMFO, OandM, DCMF | • Minimal stretching of fiscal space<br>• Cost on contracting partner<br>• Likely maintenance and capacity-building | • Financial feasibility may be lacking, so sufficient players may not be attracted. |
| **Government Play**<br>• Strategic Reserves/Godowns (e.g., FCI, Oil reserves) | • Easy availability during peaks<br>• Ubiquitous | • Capital expenditure is high.<br>• Maintenance and capacity building are needed. |
| **User Fee and Charges** | • Fragmentation of cost, lesser load on government resources<br>• NOG still self-sustainable | • Oxygen prices increase.<br>• Future expenses take precedence. |
| **Using existing margins**<br>• 100x margin being enjoyed by hospitals | • Fragmentation of cost, lesser load on government resources<br>• Justification for existing higher costs of oxygen paid by patients | • Price is capped. |

Contd.

| Capacity Creation | Pros | Cons |
|---|---|---|
| **Tax** | - Additional financial resources | - Another layer of tax is added.<br>- Fund monitoring is required. |

### 5.3.8.3. Operational Expenditures Sources

The grid would need to be maintained for routine operational expenses. However, once the capacity is created, these expenses are expected to be minimal, with costs largely incurred for data collection and maintenance of IT infrastructure. Routine staffing costs are expected to be rather low.

It will be difficult to base the operational expenses on the user charges, considering the large fragmented and unorganized nature of refillers and hospitals.

A per-unit charge may be levied on the ASU plants manufacturing LMO that form the mainstay of NMOG. This will be much easier to levy and collect from an administrative perspective. Furthermore, the eventual cost implications on per-unit cost are expected to be minimal.[61]

### 5.3.8.4. Road Map for Self-Sustainability

The grid will be set up using the various capital expenditures, but the goal should be to make itself sustainable in the long term. Multiple ways can be deployed toward this self-sustainability.

- **2–5 years:** Expand the user base to collect operational expenditures charges over time to include all manufacturers—LMO tanks, PSA plants, etc.

- **3–5 years:** The grid can also provide other medical gases, such as nitrous oxide, entonox, carbon dioxide, and heliox. In advanced phases, it can supply other medical goods and consumables to all hospitals.

- **4–5 years:** Champion the cause of oxygen usage protocols and training requirements for hospitals, paramedical staff, and other professionals via publishing research materials and other training materials.

- **4–5 years:** Proposed rating of hospitals and health establishments on best oxygen consumption practices and standards. Examples may be cited from other certifying sources, such as Energy Star rating, safety rating, and building standard rating.

- **5–10 years:** Start monetizing the data from oxygen consumption and disease patterns witnessed. For example, the Insurance Information Bureau of India[62] routinely publishes data on all insurance transactions happening and provides masked data for commercial and research/academic/public policy purposes.

- **8–10 years:** Transform from a monitoring function to assisting in setting up back-end functions. These can

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[61] A 10 percent annual operational expenses on 3,000 crore INR capital expenditure would be ~300 crore INR operational expenses. Spread over 10,000 MT per day of oxygen produced (industrial plus medical combined), this is less than 1 paisa per 10 liters.

[62] https://iib.gov.in/

include centralized ordering of oxygen, becoming a marketplace or an oxygen exchange bureau, etc., which can help stabilize prices.

#### 5.3.8.5. Incentivization

Considering that NMOG is meant to supplement the existing players, instead of creating a parallel structure, suitable incentivization policies should be designed for different stakeholders to join the grid. The incentivization policies require different levers.

No one single incentivizing mechanism is expected to work, so a host of options need to be deployed:

- **Financial Incentives:** An income tax benefit or capital subsidies can be extended to expand storage and turnover capacities. In return, stakeholders should formally join the network and expand their storage capacities. These financial incentives can be a tax break, direct subsidy, income tax incentive, or even periodic direct financial transfer. A favorable working capital loan can also be offered in certain cases.

  These financial levers need to be designed to incentivize refillers especially (these are significantly unorganized) to join the grid. Refillers need to increase their capacity because the majority of smaller hospitals are dependent on these B- and D-type cylinders, and their daily capacity to fill maximum cylinders may become a bottleneck during a crisis despite having sufficient LOX reserves.

- **Preferential treatment.** For example, a refiller that upscales its reserves may get priority for setting up a related unit or other projects. Furthermore, the government procurement required to fill the oxygen reserves and cylinders may be preferentially procured from players who agree to join the grid.

- **Regulatory lever** is needed to mandate data and capacity sharing as part of licensing requirement. This is needed for large ASU plant owners and logistics companies.

## 5.4. Potential Benefits

The benefits of NMOG are expected to be far reaching, including the following (Figure 58):

- **Ensure delivery in Tier 2 and 3 cities** – The grid will map the expected population in every cluster, with the number of beds and oxygen consumption. This will identify any dark spots with suboptimal consumption and help divert oxygen to them or take other actions (e.g., adding hospitals or training physicians).

- **Ensure Quality** – High purity is preferred for medical purposes. LMO is 99+ percent pure and the preferred form. The grid places a significantly greater reliance on LMO than PSA oxygen. The supply is ensured via a) incentivizing adding LMO tanks in all medium to large hospitals, b) developing hospitals' gas manifold structure, c) developing LMO reservoirs in tanks and cylinders that deliver high-quality oxygen, and d) employing purity sensors along the entire value chain to ensure delivery of highly pure oxygen only.

- **Kindle Innovation** – Technological innovations will be required to regularly collect data from the production, transmission, and distribution perspective, to enable the creation of a SMART grid.

- **Market Sustainable** – The grid will require one-time government support for initial setup (capital expenditures) and then be market sustainable, generating revenues from the ASU plants (per-unit charges).

- **Provide monitoring/early warning alert** - The grid will act as an early warning indicator of any new infection or pandemic-like event, by identifying any red spots where consumption trend has suddenly increased. Correlated with other disease burden patterns, this can be a sign of any new infection hotspots. Working with the government's Integrated Disease Surveillance Program, this can act as an alert system for ailments such as seasonal influenza.[63]

- **Have Low unit cost**- By leveraging economies of scale with a pan-India operation, the grid will help maintain the per-unit cost of medical oxygen in the entire country. Furthermore, through its monitoring functions, it will help in identifying the prevailing per-unit and cylinder-filling prices. Any increase in price due to demand increase or supply shortages will be met via surplus areas or storage tanks and containers.

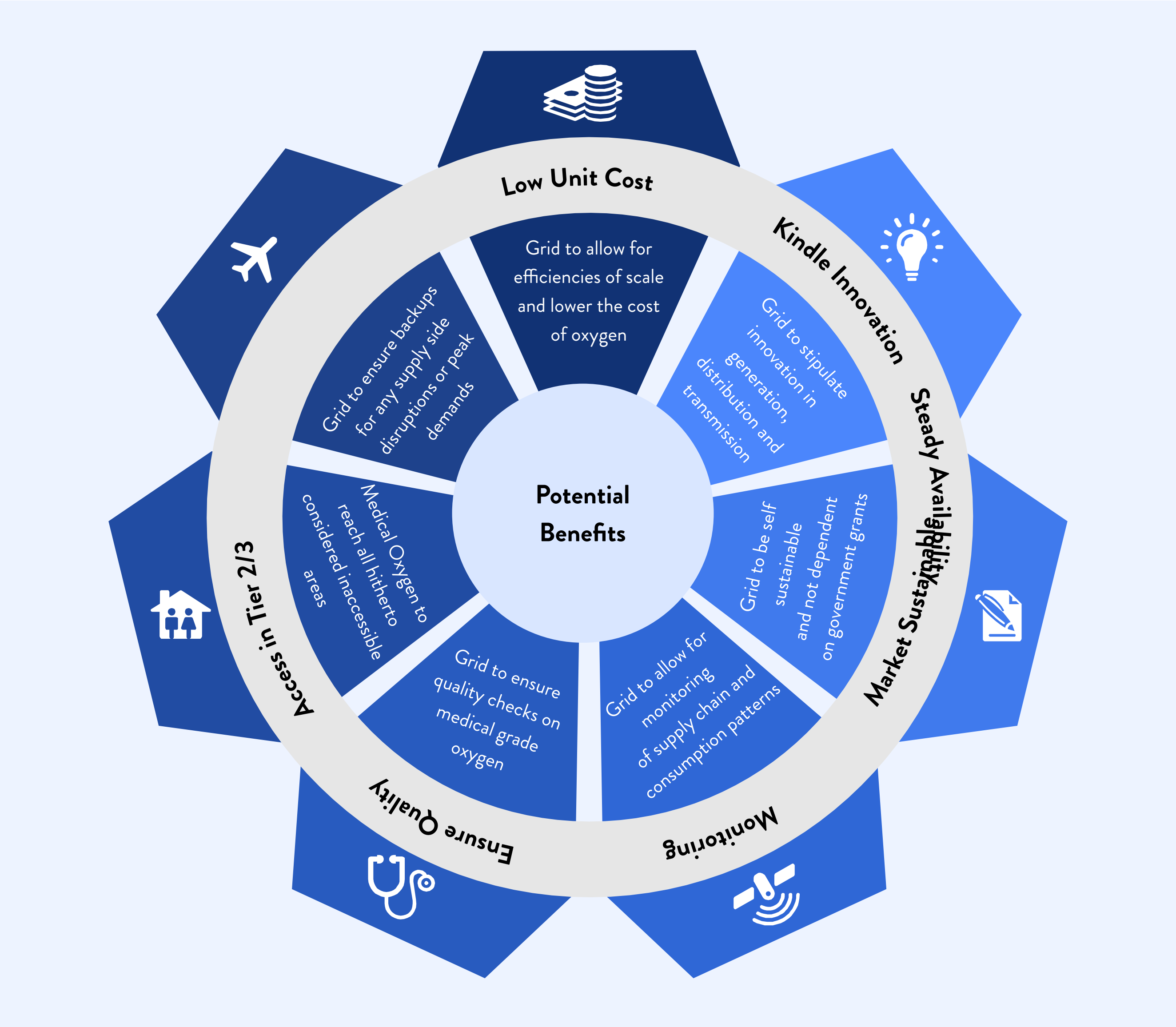

*Figure 58. Potential benefits of NMOG*

Table 30 captures the roles to be played by different stakeholders and the potential value they can derive in setting up this NMOG.

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[63] https://idsp.nic.in/index.php

## 5.5. Summary of key role to be played by each stakeholder

*Table 30. Summary of Stakeholder Key Roles*

| Stakeholder | Expected Role | Potential Value |
|---|---|---|
| **National and state governments** | • Set up monitoring committees (governance mechanism at three levels).<br>• Set up technical standards for oxygen storage and quality.<br>• Allocate storage sites in large government hospitals.<br>• Provide seed money to a) set up the IT infrastructure and storage sites and incentivize refillers to scale up capacities.<br>• Initiate necessary legislative changes: a) withdraw PSA guidelines, b) issue medical storage guidelines, c) establish guidelines necessitating producers, refillers, transporting companies etc. to join the grid, and d) mandate operational expenditures to be collected based on per-unit production from producers. | • Better visibility of supply and demand patterns of oxygen<br>• Better preparation to meet future exigencies<br>• Black spots (limited oxygen usage) identified<br>• Early warning indicators |
| **Medical Community** | • Offer medical oxygen usage protocols and guidelines. | • Optimal oxygen consumption<br>• Reduced mortality and morbidity |
| **Producers** | • Join grid, and share stock, production, and consumption data.<br>• Set up a basic minimum stock of ISO containers, cryogenic tankers, and cylinders.<br>• Remove bottlenecks to increase turnover capacities. | • Short-term benefit via increased demand to fill up the reservoir<br>• Long-term benefit from overall increased need (optimal usage) |

Contd.

| Stakeholder | Expected Role | Potential Value |
|---|---|---|
| **Refillers and Dealers** | • Join grid to share stock, consumption, and distribution data<br>• Increase storage capacities. | • Capital subsidy toward increased expansion<br>• Increased offtake |
| **Hospitals** | • Monitor usage efficiently (set up pressure, flow, leakage, quality, and level sensors).<br>• Revamp the medical gas pipeline system.<br>• Set up oxygen tanks. | • Reliable supply of high-quality oxygen |

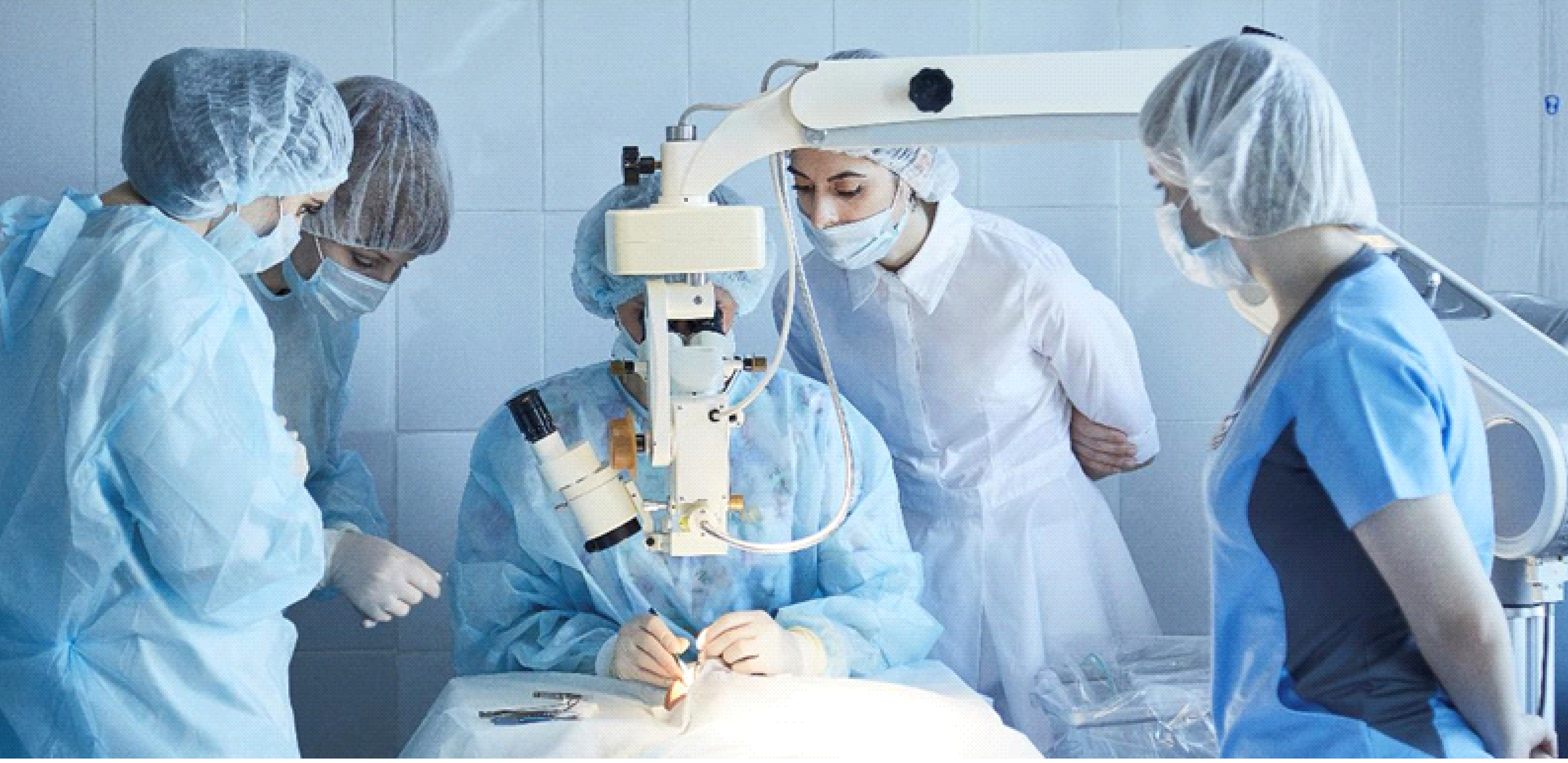
## 5.6. Limitations of the Grid

- The oxygen market in India can be described as a demand-constrained supply. Low numbers of beds and hospitals and suboptimal clinical protocols limit demand and hence delivery. The grid will need nationwide health reforms aimed at increasing beds or developing clinical protocols for delivering optimal oxygen.

- The grid will allow for creating enough capacities to meet any future exigencies, as storage tanks at the cluster level. Each cluster will have transportation trucks to supply oxygen to hospitals. However, considering hospitals' small and fragmented nature, significant on-the-ground intelligence, reporting, and data collection will be required to enable delivery to the last facility (which may be a small medical clinic operated by paramedical staff).

- The capacity may prove inadequate in black swan events. This may require diverting oxygen from other industrial sources. Increasing the storage capacity can reduce the possibility of such events but would entail a proportionately higher capital and operational expenditures.

- PSA plants are cost inefficient, requiring high maintenance and producing relatively low-quality oxygen. No PSA plants should be added and the existing regulations necessitating them withdrawn; the extant plants are required to be maintained through the end of their operational life-span. This would require a steady operational expenditures charge (estimated to be 4–500,000 per year per plant, or about 150–175 crore per year for about 3,700 plants). This cost will need to be borne by the hospital where the plant is set up and is not considered in NMOG.



# 6. Pilot Studies

## 6.1. Prepilot Preparation Roadmap

**6.1.1.** Build the team: liaison with a) different government departments, b) refillers and hospitals in the division, c) an IT expert, and d) funding agencies.

**6.1.2.** Approach the respective departments of the ministry of health. Obtain information on a) a state's oxygen information management system (data custodian, oppressiveness of data, geographical coverage, stakeholder coverage, regular updating of data, fields entered), b) storage tanks (in which districts or blocks, how much capacity, who is custodian, governance mechanism), c) number of hospitals in each division, and d) list of refillers in the state.

**6.1.3.** Based on this information, identify a) divisions to conduct the pilot (these are the divisions with relatively well-developed systems—oxygen reservoir is being set up, refillers are online and submitting data, hospitals are online, the governance mechanism is relatively easy, and can easily set up teams with divisional HQ to monitor), b) the basic minimum gaps to be plugged (may need local discussion with refillers and hospitals), and c) the funding requirement for the pilot.

**6.1.4.** Tap the funding sources (institutional—ministry of health, international financial institution, such as ADB/WB and banks; noninstitutional—CSR Money, Gates Foundation, etc.).

**6.1.5.** Plug the basic minimum gaps: a) IT system to relay data— leverage the existing oxygen information system for rapid scale-up and build API to integrate the new modules with this system, b) develop governance teams, c) have trucks and tankers ready; onboard state transport department/counterpart of ministry of road transport and highways for permission to use infrastructure to monitor their movement, d) onboard refillers and hospitals—need assistance from the local divisional HQ to issue requisite orders, e) form team to monitor the pilot, and f) onboard hospitals with a PSA plant that are willing to switch it on for the pilot in a defined time frame.

**6.1.6.** Develop the pilot plan (explained in subsequent sections) and communicate to all stakeholders. Align on the date, duration, etc.

**6.1.7.** Execute the pilot (sequentially introduce artificial increase in demand due to supply-side disruptions in one area or a pandemic-like event).

**6.1.8.** Monitor and document the response.

## 6.2. Pilot Design and Execution (UP)

This section contains information on the

a) Current landscape of oxygen demand and supply infrastructure and the resultant gaps

b) Initiatives taken in the wake of COVID-19 and their limitations

c) Proposed design of the state-level grid, and

d) Design of the pilot to demonstrate the efficacy of the grid.

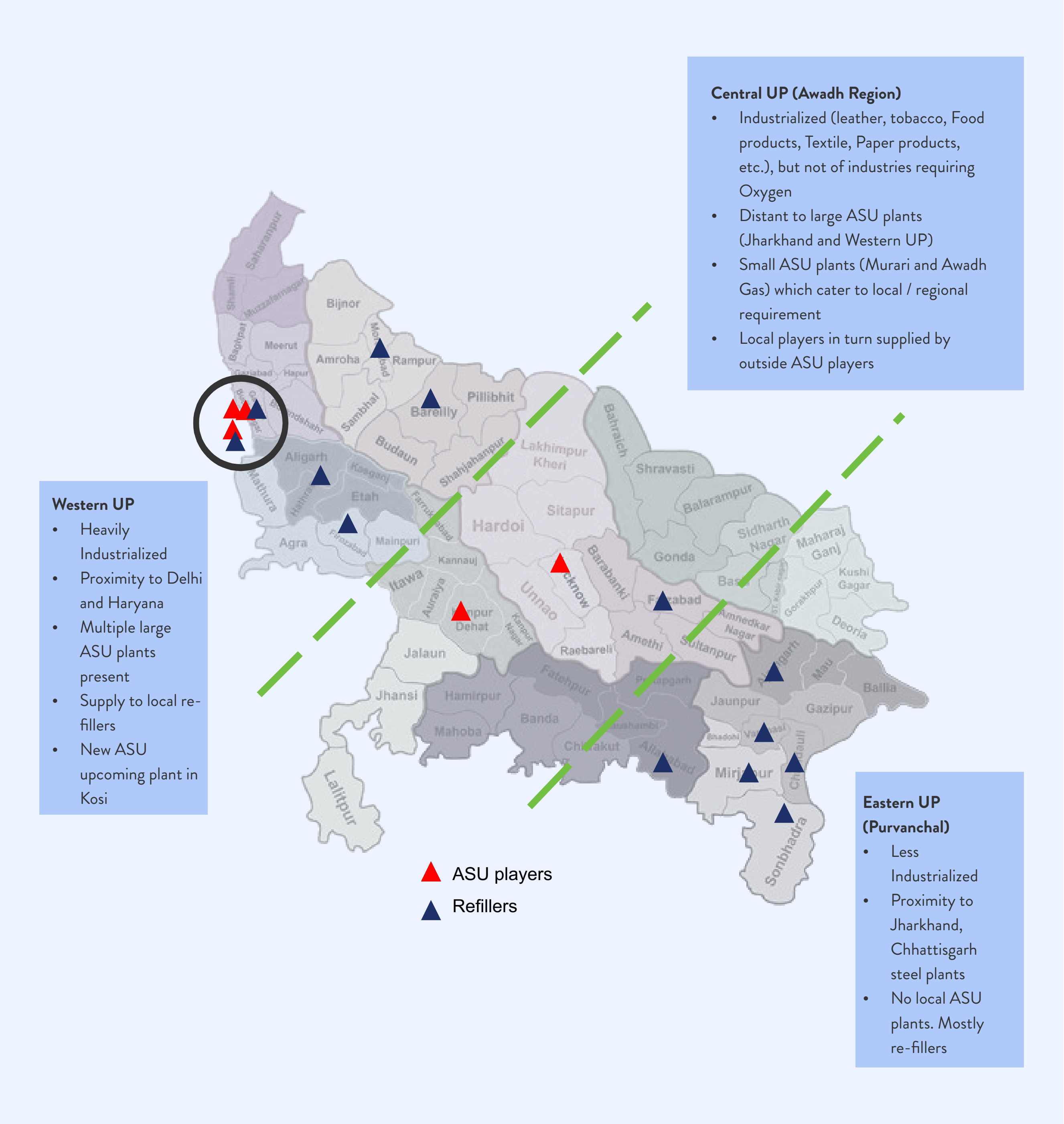
### 6.2.1. Current Landscape

UP has ~200,000,000 population and 19 administrative divisions. The state can be broadly divided into three broad regions with distinct supply–demand arrangements based on the local consumption pattern.

The western region is heavily industrialized and close to Delhi and Haryana. It also has a relatively well-developed medical infrastructure with many large hospitals. As a result, this region has high oxygen consumption and ASU players.

The Central UP (Awadh region) is also industrialized, but the industries are not heavy oxygen users (leather, tobacco, food products, textile, paper products, etc.). Hence, no ASU players are present. Some areas have good medical infrastructure, such as Lucknow and Kanpur, with some of the largest medical colleges and hospitals. Some midsize refillers or players with relatively small ASU plant capacity are operating. These players have their own indigenous production and act as refillers to obtain oxygen from outside.

The eastern region (Purvanchal) is relatively less industrialized and has relatively poor medical infrastructure. Furthermore, it is very close to eastern states, such as West Bengal, Jharkhand, and Orissa, which have steel plants and produce medical oxygen. Hence, this region almost no ASU players and only refillers, which procure oxygen from eastern states and supply to the local hospitals. Figure 60 provides additional details.



**Central UP (Awadh Region)**

- Industrialized (leather, tobacco, Food products, Textile, Paper products, etc.), but not of industries requiring Oxygen
- Distant to large ASU plants (Jharkhand and Western UP)
- Small ASU plants (Murari and Awadh Gas) which cater to local / regional requirement
- Local players in turn supplied by outside ASU players

**Western UP**

- Heavily Industrialized
- Proximity to Delhi and Haryana
- Multiple large ASU plants present
- Supply to local re-fillers
- New ASU upcoming plant in Kosi

**Eastern UP (Purvanchal)**

- Less Industrialized
- Proximity to Jharkhand, Chhattisgarh steel plants
- No local ASU plants. Mostly re-fillers

*Figure 59. Uttar Pradesh regional details*

The BAU demand was estimated at ~150–200 MTPD but is likely to almost double as the state progresses with its healthcare agenda.[64] In COVID Wave 2, as per case numbers, the peak demand was ~800 MTPD. However, the state had relatively low testing rate compared to states such as Kerala (Figure 60). If the testing and diagnosis rates are adjusted for, the state is expected to be prepared to handle needs up to 2,000 MTPD.

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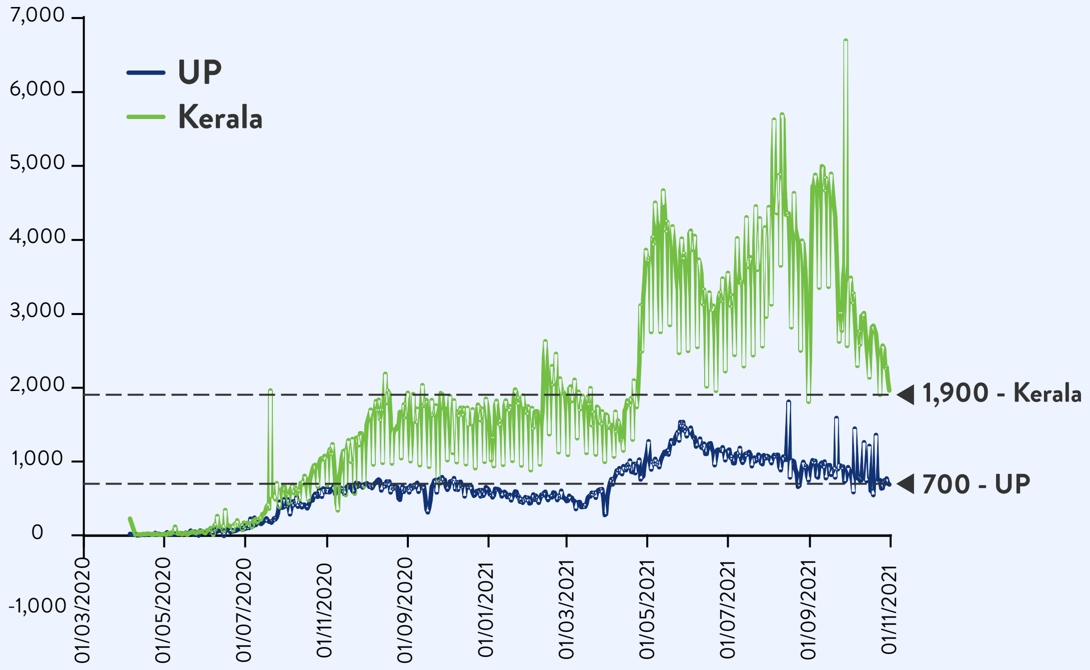
[64] Multiple state initiatives have recently been taken, including placing one medical college in every district of the state.

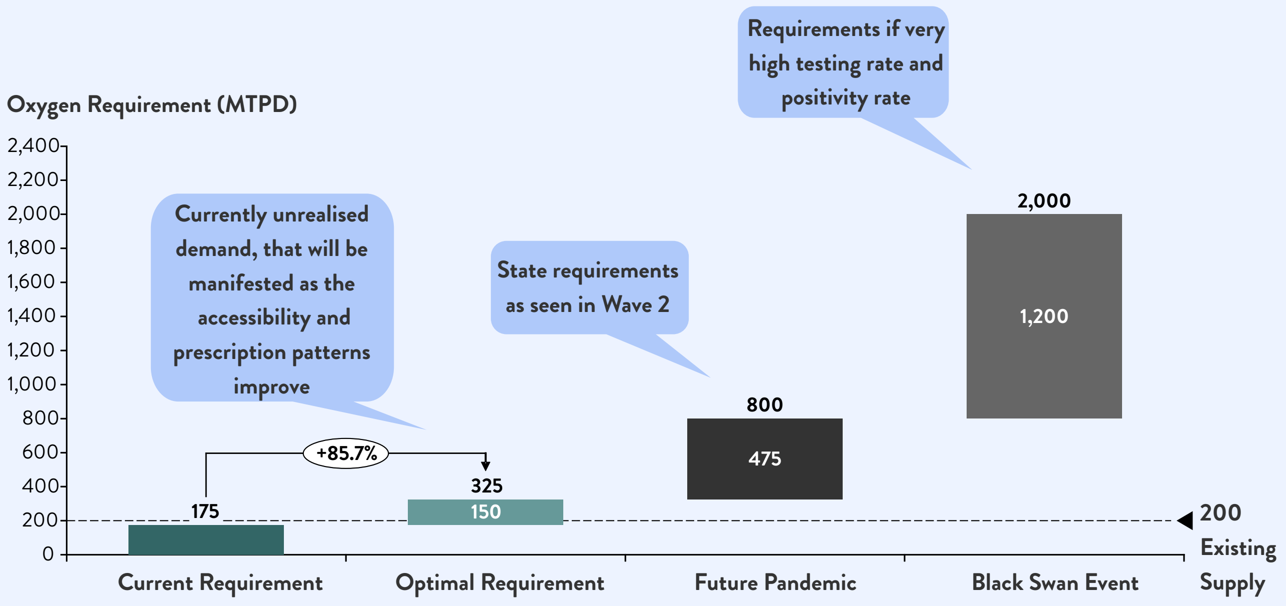

Tests per Million Population

- Peak Requirement can be as high as ~2000 MT

*Figure 60. Tests per million population*

The state supply arrangements can meet the BAU need but are likely to fall short of future needs or pandemics (Figure 61).

The current supply is insufficient to meet the optimal medical oxygen requirements of the state



Source :Govt. Information; CDDEP data

*Figure 61. Current and future needs*

### 6.2.2. Initiatives in Wave 2 of COVID-19

Considering the acute shortage seen in Wave 2, the state has taken multiple initiatives that are all well-meaning but do have some limitations (Table 31).

*Table 31. State initiatives*

| Type of Initiative | Details | Limitations |
|---|---|---|
| **Increasing Production Capacity** | • More than 550 PSA plants installed (March 2022; installed in CHCs and primary health centers [PHCs] also).<br>• All hospitals over 50-bed capacity required to install PSA plants.<br>• 19,000 oxygen concentrators procured for use in CHCs and PHCs.<br>• UP to establish a regional oxygen grid.[65] | • PSA plants have challenges of high capital expenditure, low purity, high maintenance and electricity costs, 24/7 electricity, and high unused BAU capacity.<br>• An industry response on a UP regional grid is yet to be seen. |
| **Increasing Storage Capacity** | • 1 LMO tank of 10–20,000 liters to be established by March 2022 in all 75 districts along with medical gas pipeline systems through the Emergency COVID Response Package II. | • Suboptimal focus on medical oxygen storage seen.<br>**Quantity**<br>• Total storage capacity planned is ~750 MT.<br>• This will be sufficient to meet 1–2-day peak demand only: 800 MT (COVID Wave 2).<br>**Form**<br>• Storage planned is only in LMO form; that may be unsuitable for many small hospitals, which depend on cylinders (LMO unviable). |

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[65] UP has also announced a regional oxygen grid. It will be a network of oxygen manufacturing units to be established from the Saharanpur district in the west to Deoria in the east. The nodal agency is the state industrial development authority, which will facilitate priority allotment of land within a week and prompt clearances through the Nivesh Mitra portal.

Contd.

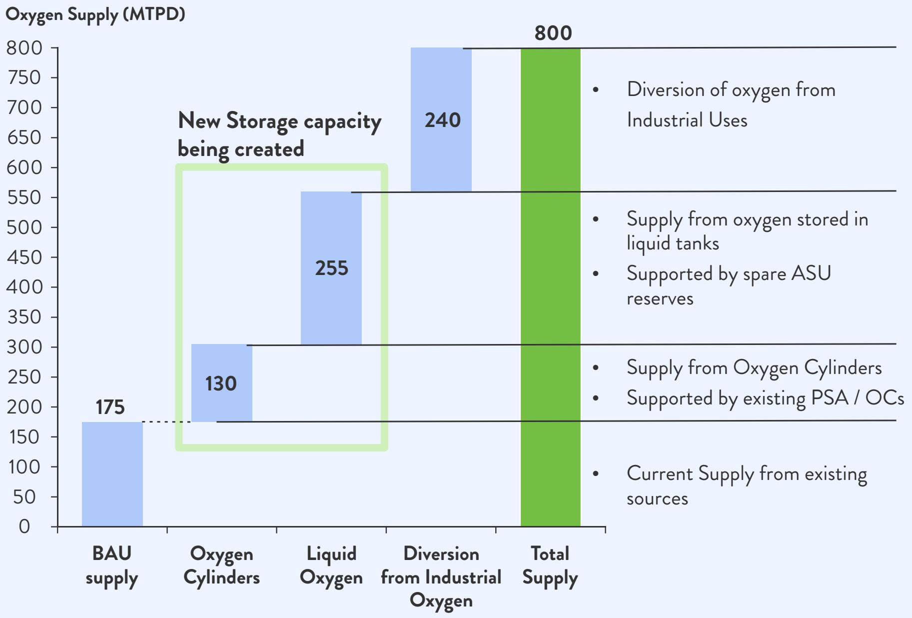
| Type of Initiative | Details | Limitations |
|---|---|---|
| | | **Distribution**<br>- Storage is uniformly distributed across districts. Higher storage capacity needed in regions where unmet demand is expected to be higher. |
| **Leveraging Technology** | - Live dashboard "Oxytracker" used to monitor the real-time movement of trucks in 2022; color coding identifies full, empty, loading, and unloading tankers.<br>- Oxygen monitoring system created: a web portal link for officers and employees associated with the supply chain. | - Manual data entry is more common.<br>- IOT devices and sensors (pressure, level, purity, flow rate, leakage etc.) could be leveraged for automated data collection and decision support. |
| **Monitoring and Governance Matrix** | - Local committees and team identified linked with various aspects of the supply chain. | - A robust monitoring and governance matrix is required, with active participation from the public and private sectors.<br>- The matrix should not be limited to monitoring COVID but also identify other aspects of oxygen consumption, such as protocol training, dark spots, routine demand–supply estimation, forecasting, standards, quality monitoring, and training/maintenance checks. |

### 6.2.3. Proposed Design of the State-Level Grid

The initiatives taken by the state government can be strengthened by incorporating learnings from similar grids in the country (details in previous sections). The grid would be like a constellation of interconnected storage sites with a common governance mechanism, always ensuring a supply at all places.

A significant focus will need to be on creating storage capacities across the state, which can supply up to 560 MTPD by itself and 800 MTPD by diverting some industrial oxygen (Figure 62).

**Need to create storage capacity to meet future oxygen requirements**

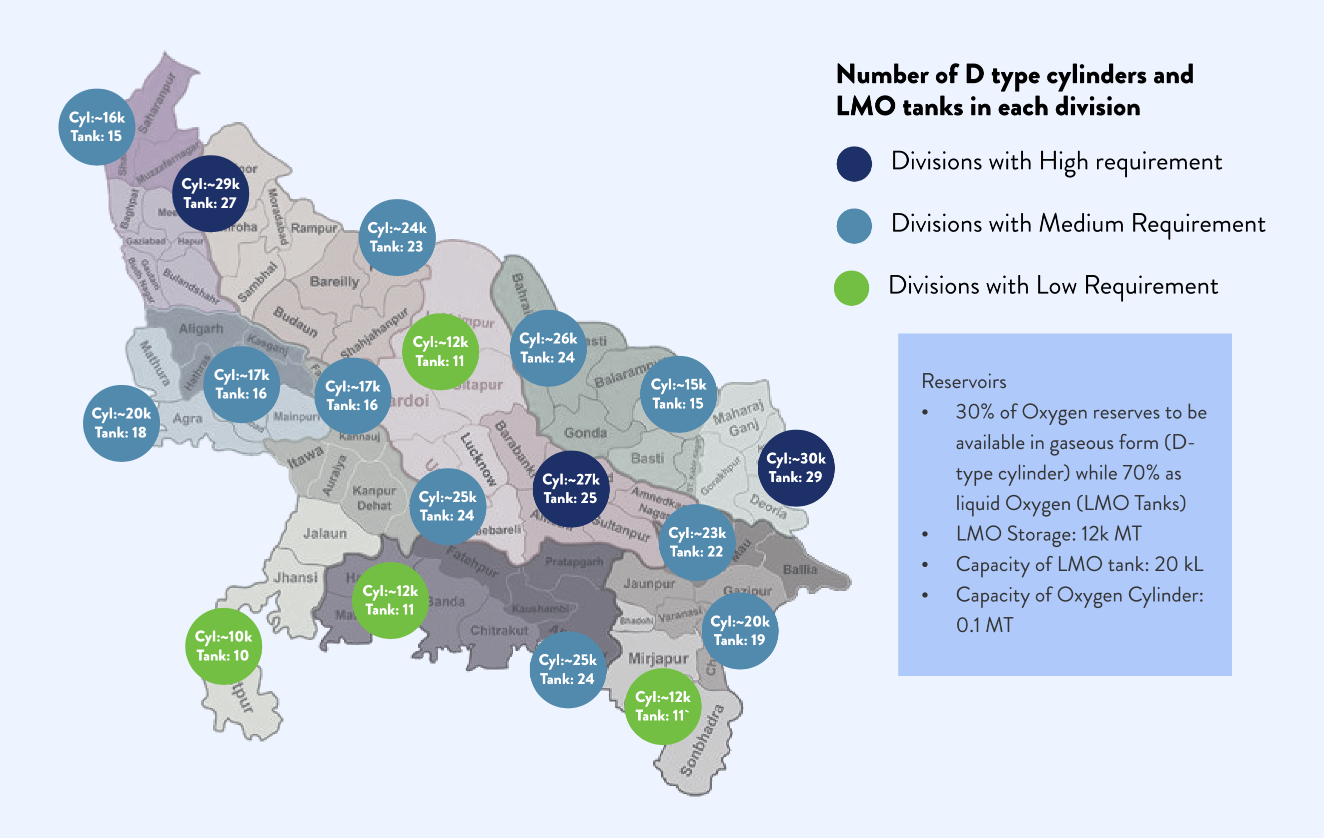


**Why Prefer Storage**

- Reduced Unutilized Capacity during non – peaks
- Economical to build storage than create new capacities
- Existing option (PSA Plants) to create new capacities are not considered technically viable in long term

*Figure 62. Needed storage capacity*

This would mean adding a reservoir capacity of ~10k MT that would need to be redistributed in various administrative divisions and prepared as LMO tanks and cylinders (Figure 63).



**Number of D type cylinders and LMO tanks in each division**

● Divisions with High requirement

● Divisions with Medium Requirement

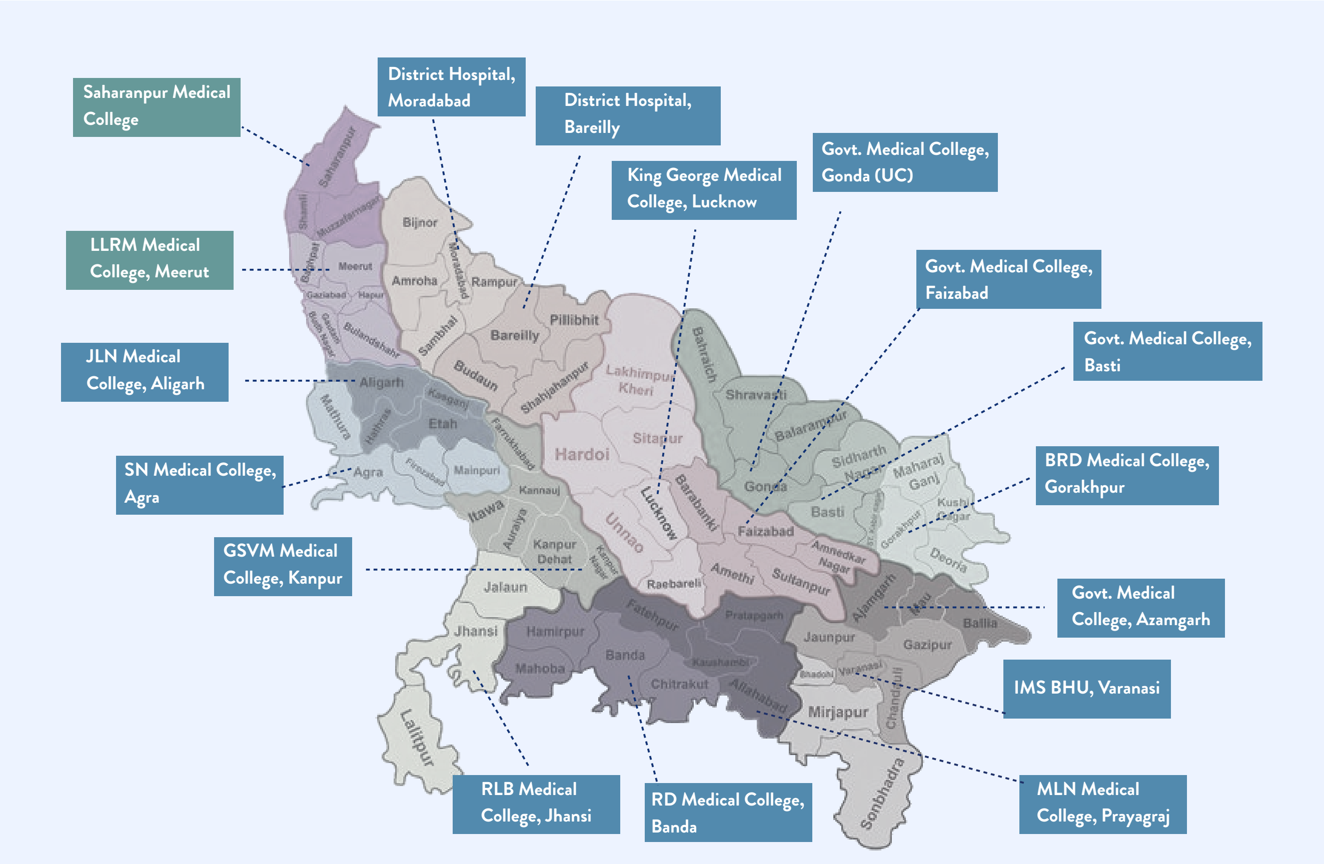
● Divisions with Low Requirement

Reservoirs

- 30% of Oxygen reserves to be available in gaseous form (D-type cylinder) while 70% as liquid Oxygen (LMO Tanks)
- LMO Storage: 12k MT
- Capacity of LMO tank: 20 kL
- Capacity of Oxygen Cylinder: 0.1 MT

*Figure 63. Necessary reservoir capacity*

This capacity augmentation needs to be at the refiller level and large government medical colleges in each division (Figure 64).



Saharanpur Medical College

District Hospital, Moradabad

District Hospital, Bareilly

King George Medical College, Lucknow

Govt. Medical College, Gonda (UC)

LLRM Medical College, Meerut

Govt. Medical College, Faizabad

JLN Medical College, Aligarh

Govt. Medical College, Basti

SN Medical College, Agra

BRD Medical College, Gorakhpur

GSVM Medical College, Kanpur

Govt. Medical College, Azamgarh

IMS BHU, Varanasi

RLB Medical College, Jhansi

RD Medical College, Banda

MLN Medical College, Prayagraj

*Figure 64. Necessary capacity expansion*

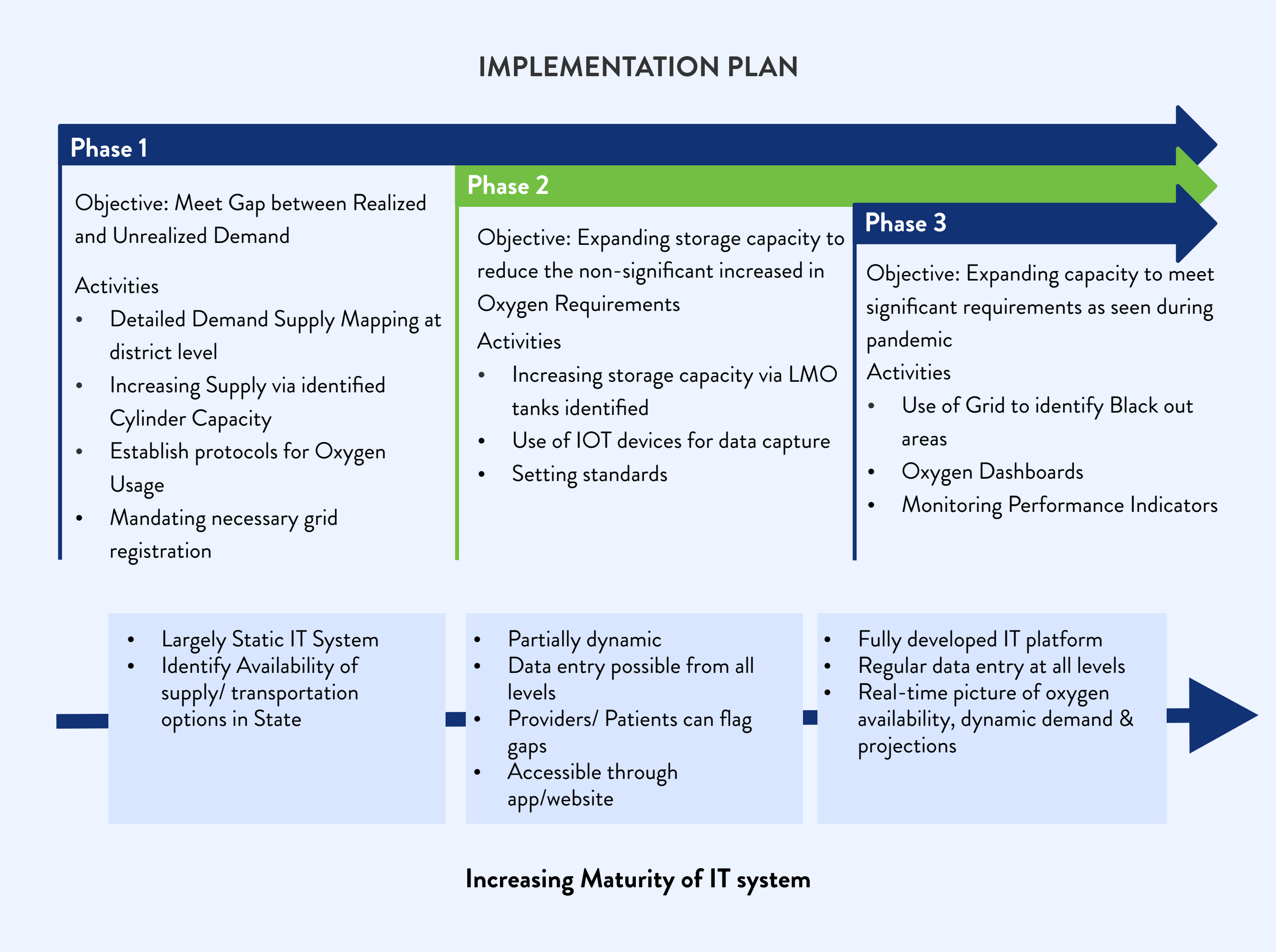
The storage capacity created will need to be supported by respective monitoring and governance matrix, oxygen training protocols, and an enabling IT platform (explained in previous sections).

The state-level medical oxygen grid is a large infrastructural building project and will require a phased implementation. At a broad level, three phases of implementation are conceptualized (Figure 65).

- Phase 1 would be to address the gap between realized and unrealized demand. This would involve a detailed demand–supply mapping at the divisional level, increasing supply via cylinder and LMO when possible, establishing protocols for oxygen usage, and mandating grid registration for all stakeholders. The IT system will be largely static yet allow for identifying available supply/transportation options in the state.

- Phase 2 will allow for expanding storage capacity to reduce the nonsignificant increase in oxygen needs. This would entail increasing storage capacity via LMO tanks identified and using IOT devices for data capture and setting standards. The IT system will be partially dynamic, allowing data entry from all levels, enable providers/patients to flag any gaps, and be accessible through an app/website.

- Phase 3 will target expanding capacity to meet significant needs, as during a pandemic. The grid will identify blackout areas and prepare and monitor oxygen dashboards and performance indicators. The IT system will be fully functional and give a real-time picture of availability, dynamic demand, and projections.



**IMPLEMENTATION PLAN**

**Phase 1**

Objective: Meet Gap between Realized and Unrealized Demand

Activities
- Detailed Demand Supply Mapping at district level
- Increasing Supply via identified Cylinder Capacity
- Establish protocols for Oxygen Usage
- Mandating necessary grid registration

**Phase 2**

Objective: Expanding storage capacity to reduce the non-significant increased in Oxygen Requirements

Activities
- Increasing storage capacity via LMO tanks identified
- Use of IOT devices for data capture
- Setting standards

**Phase 3**

Objective: Expanding capacity to meet significant requirements as seen during pandemic

Activities
- Use of Grid to identify Black out areas
- Oxygen Dashboards
- Monitoring Performance Indicators

- Largely Static IT System
- Identify Availability of supply/ transportation options in State

- Partially dynamic
- Data entry possible from all levels
- Providers/ Patients can flag gaps
- Accessible through app/website

- Fully developed IT platform
- Regular data entry at all levels
- Real-time picture of oxygen availability, dynamic demand & projections

**Increasing Maturity of IT system**

*Figure 65. NMOG implementation plan*

### 6.2.4. Design of the Pilot to Demonstrate Grid Efficacy

Considering the landscape, a step-by-step pilot is proposed:

- Prerequisites:

  a) Identify administrative divisions in which the pilot will be executed

  b) Establish a functional IT platform with access for all stakeholders, and

  c) Onboard partners—refillers (at least 80 percent in identified divisions), hospitals (80 percent of all units that have an IPD stay facility of more than 30 beds), transport department, etc.

- Phase 1:

  - Objective: assess the system readiness for informational relay between stakeholders to facilitate seamless flow of medical oxygen. This is designed to determine the grid functioning in a BAU scenario.

  - Length of time: five days

  - Target Stakeholders: All refillers and hospital sites in an administrative division chosen for the pilot.

  - Process: on a chosen day and time, divisional HQ will send a detailed request to all onboarded hospitals, refillers, and LMO storage sites to provide information on the available quantity of their stocks (that includes all forms of oxygen maintained directly or indirectly by the stakeholder itself and the oxygen on site in tanks and cylinders and in transit). From a producer or refiller perspective, it includes an oxygen contract that may have been signed but control not yet transferred (or oxygen not yet delivered). Only the absolute quantity information is needed. It excludes associated details, such as the place where stock is kept, form in which it is maintained, number of SKUs, and purity.

    - KPI:

      - percent of refillers and LMO storage sites that can share information within eight hours, and
      - Accuracy of data obtained (a sample of 10 percent of refillers that shared their data to be verified by on-the-ground assessment, within five days of the information being shared).

  - KPI will be considered as met if

    - 80 percent of refillers and LMO storage sites can share information
    - More than 80 percent of the sample set used for verification has shared accurate information (+/- 10 percent of actual stock)

  - Postphase 1—A detailed report must be prepared with details of the pilot, participants, and feedback. If the KPI is considered met, preparations may be started for Phase 2.

- Phase 2:

  - Objective: assess the system readiness to supply a marginal short-term increase in oxygen needs, as in the early part of a pandemic.

  - Length of time: five days

  - Target Stakeholders: All refillers and hospital sites in an administrative division chosen for the pilot.

  - Process: on a chosen day and time, divisional HQ will send a detailed request to all the onboarded hospitals, refillers, and LMO storage sites to provide ~100 oxygen cylinders to the HQ. All PSA plants will be made operational at full capacity. These requests are sent over the IT platform. The cylinders include those that are in stock or newly filled using the LMO tank. The cylinders may be sent via the logistics arrangement maintained by refillers or hospital or divisional HQ. They should be delivered within 48 hours of the request. PSA plants should continue functioning nonstop for the next five days.

  - KPI:
    - Percent of PSA plants made operational for five days
    - Purity of oxygen being produced by PSA plants made operational
    - Number of oxygen cylinders delivered to divisional HQ

  - KPI will be considered as met if

    - 80% of PSA plants are made operational for 5 days
    - 80% of operational PSA plants produce Oxygen which is more than 90% pure
    - More than 80 cylinders are being delivered to the Divisional HQ

  - Postphase 2—A detailed report must be prepared with details of the pilot, participants, and feedback. If the KPI is considered met, preparations may be started for Phase 3.

- Phase 3:

  - Objective: to assess the system readiness to supply peak increases in oxygen need

  - Length of time: 10 day

  - Target Stakeholders: All refillers and hospital sites in an administrative division chosen for the pilot.

  - Process: on a chosen day and time, divisional HQ will send a detailed request to all onboarded hospitals, refillers, and LMO storage sites to provide ~1,000 oxygen cylinders to the HQ. All PSA plants in the division will be made operational at full capacity. These requests are sent over the IT platform. The cylinders include those that are in stock or newly filled using the LMO tank. The cylinders may be sent via the logistics arrangement maintained by refillers or hospital or the divisional HQ and should be delivered within 10 days of the request being sent. PSA plants should continue functioning nonstop for the next 10 days.

- KPI:
  - percent of PSA plants made operational for 10 days
  - Purity of oxygen produced by PSA plants made operational, and
  - Number of oxygen cylinders delivered at divisional HQ

- KPI will be considered as met if
  - 75 percent of PSA plants are made operational for 10 days
  - 75 percent of operational PSA plants produce oxygen that is more than 90 percent pure, and
  - More than 800 cylinders are delivered to the divisional HQ

- Postphase 3—A detailed report must be prepared with details of the pilot, participants, and feedback. If the KPI is considered met, preparations may be started to expand the pilot.

## 6.3. Pilot Design and Execution (Karnataka)

This section contains information on the

a) landscape of the oxygen demand and supply infrastructure and resultant gaps

b) Initiatives taken in the wake of COVID-19 and their limitations

c) Proposed design of the state-level grid, and

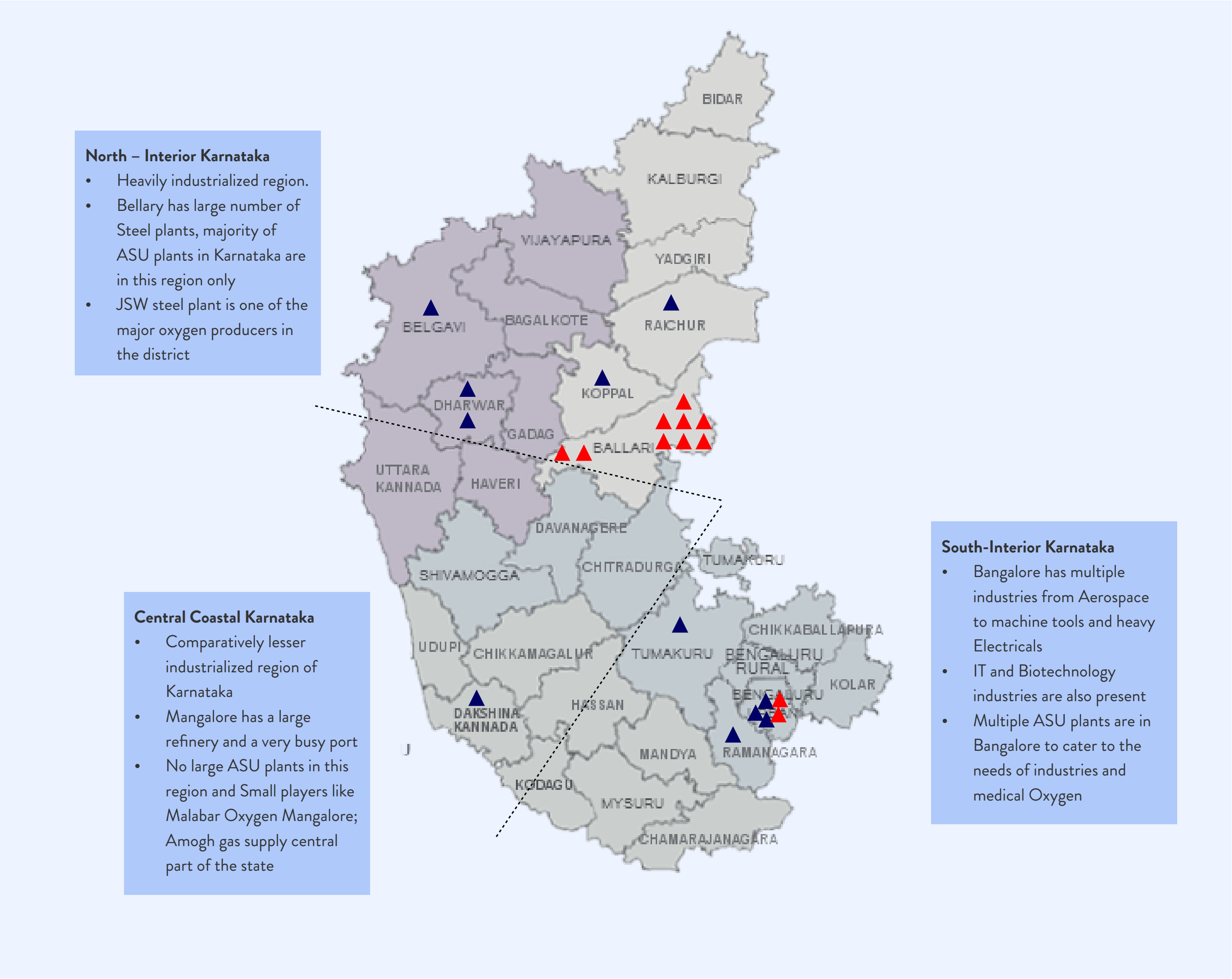
d) Design of the pilot to demonstrate the efficacy of the grid

### 6.3.1. Current Landscape

Karnataka has ~67,000,000 population and multiple administrative divisions. It can be broadly divided into three regions with distinct supply–demand arrangements based on local consumption patterns (Figure 66).
The north interior region is heavily industrialized. Bellary has large number of steel plants, and the majority of ASU plants are in this region only. The JSW steel plant is a major oxygen producer in the district.

The central coastal region is comparatively less industrialized. Mangalore has a large refinery and a very busy port. No large ASU plants are in this region, and small players, such as Malabar oxygen Mangalore and Amogh gas, supply the central part of the state.

In the south interior region, Bangalore has multiple industries, including aerospace, machine tools, heavy electricals, and IT and biotechnology industries, and multiple ASU plants to cater to industries and medical providers.



**North – Interior Karnataka**

- Heavily industrialized region.
- Bellary has large number of Steel plants, majority of ASU plants in Karnataka are in this region only
- JSW steel plant is one of the major oxygen producers in the district

**Central Coastal Karnataka**

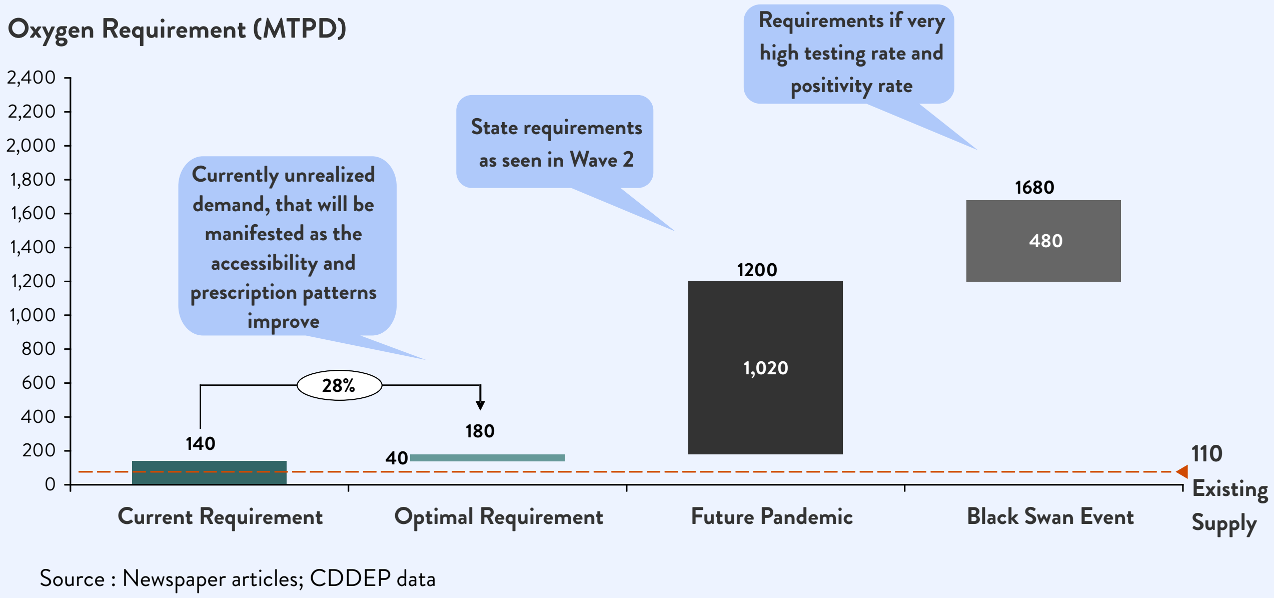
- Comparatively lesser industrialized region of Karnataka
- Mangalore has a large refinery and a very busy port
- No large ASU plants in this region and Small players like Malabar Oxygen Mangalore; Amogh gas supply central part of the state

**South-Interior Karnataka**

- Bangalore has multiple industries from Aerospace to machine tools and heavy Electricals
- IT and Biotechnology industries are also present
- Multiple ASU plants are in Bangalore to cater to the needs of industries and medical Oxygen

*Figure 66. Major state-level ASU plants and refillers*

It is estimated that the BAU need was ~140 MTPD. The state's production capacity (>1,350 MTPD) far exceeds this. However, only 5–10 percent of this capacity is used for medical oxygen. Hence, the state is likely to face challenges as the need increases due to advancements in healthcare accessibility and affordability and if a future pandemic wave were to strike. Karnataka also supplies oxygen to other parts of the country, so the absolute needs it must service are much higher (Figure 67).



Source : Newspaper articles; CDDEP data

*Figure 67. Current and future supply*

The state's peak need increased to ~1,200 MT in Wave 2 as per the official case numbers. If adjusted for the testing rate seen in states such as Kerala, the need increases to ~1,680 MT (Figure 68).

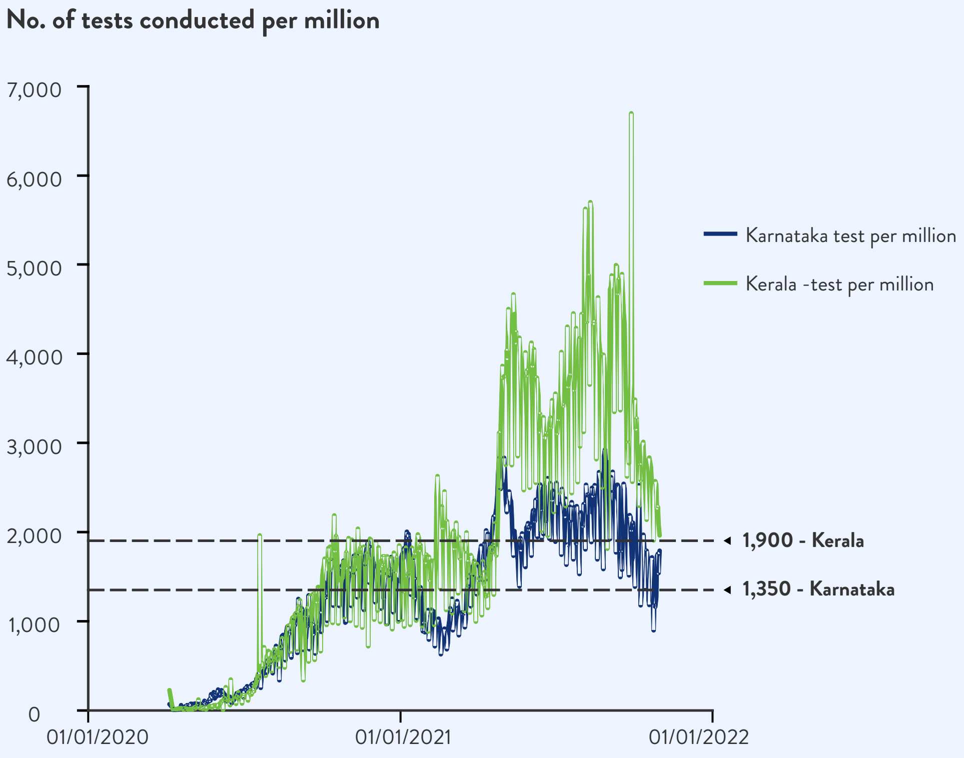


*Figure 68. Tests per million population*

### 6.3.2. Initiatives Taken in COVID-19 Wave 2

Considering the acute shortage in Wave 2, the state has taken multiple initiatives that are all well-meaning but do have some limitations (Table 32).

*Table 32. State-level initiatives*

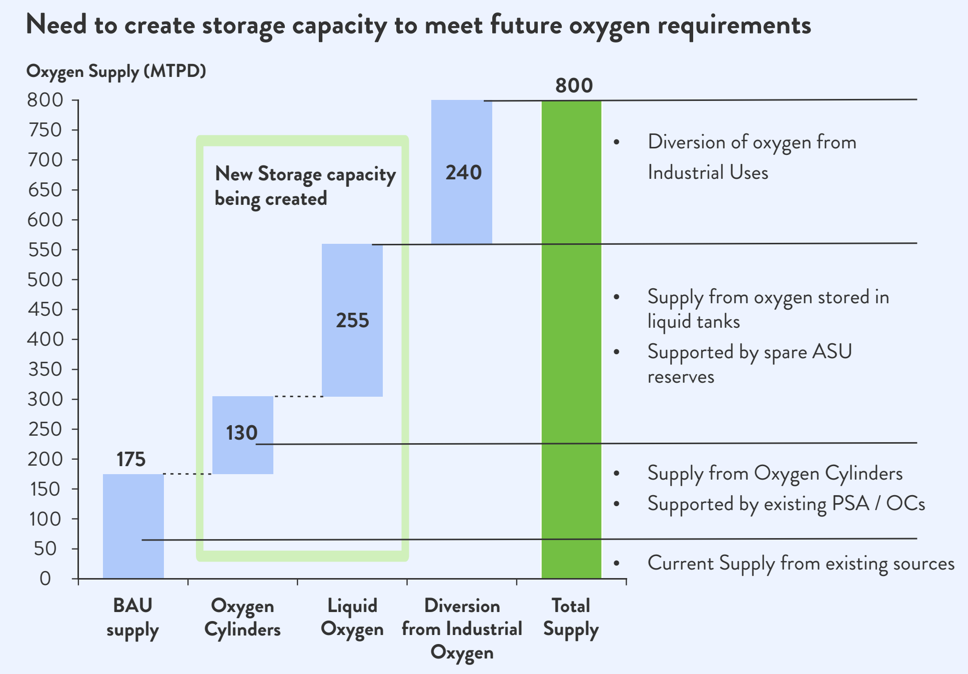
| Type of Initiative | Details | Limitations |
|---|---|---|
| **Increasing Production Capacity** | • ~250 new PSA plants were allocated under various initiatives and CSR funds.<br>• The state directed all medical colleges and private hospitals over 50 beds to install a PSA/refilling oxygen plant. | • Production via PSA plants has challenges of high capital expenditure, low purity, high maintenance and electricity costs, requirement of 24/7 electricity and high unused BAU capacity. |
| **Increasing Storage Capacity** | • Karnataka installed 6,000 L LMO tanks at 13 district hospitals and 1,000L LMO tanks in 11 taluk hospitals.<br>• The state will install 13,000 LMO tanks for eight medical colleges and 6,000 LMO tanks for 19 districts and 135 taluk hospitals by March 2022. These will be accompanied by installing MGPS in hospitals. | • Storage will be fragmented and difficult to aggregate in times of demand.<br>• Storage capacity has been planned primarily as LMO tanks.<br>• Cylinder reservoirs are required for smaller hospitals. |
| **Leveraging Technology** | • Focus on data collection and decision making is limited. | • Manual data entry is more common.<br>• IOT devices and sensors (pressure, level, purity, flow rate, leakage, etc.) can be leveraged for automated data collection and decision support. |

Contd.

| Type of Initiative | Details | Limitations |
|---|---|---|
| **Monitoring and Governance Matrix** | • Local committees and team are linked with various aspects of the supply chain. | • A robust monitoring and governance matrix is required with active participation from the public and private sectors.<br>• The matrix should not be limited to monitoring COVID but should also identify other aspects of consumption, such as protocol training, dark spots, routine demand–supply estimation, forecasting, standards, quality monitoring, and training/maintenance checks. |

### 6.3.3. Proposed Design of the State-Level Grid

The initiatives taken by the state government could be strengthened by incorporating learnings from similar grids set up in the country (details in previous sections). The grid would be like a constellation of interconnected storage sites with a common governance mechanism, always ensuring a supply of oxygen at all places.



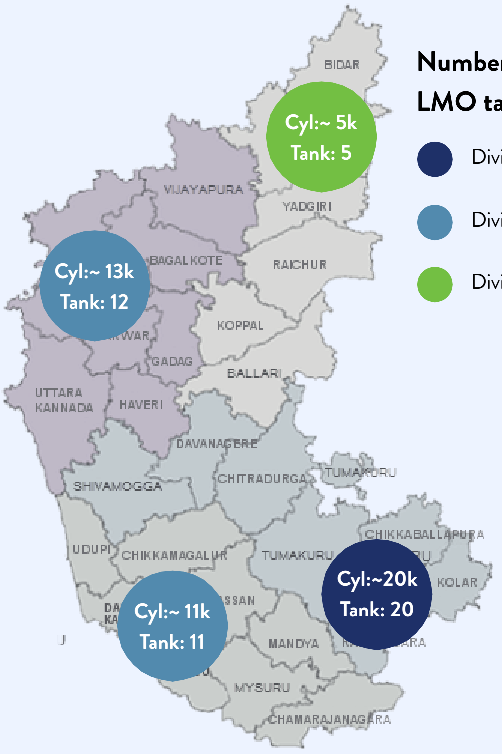
- Diversion of oxygen from Industrial Uses
- Supply from oxygen stored in liquid tanks
- Supported by spare ASU reserves
- Supply from Oxygen Cylinders
- Supported by existing PSA / OCs
- Current Supply from existing sources

**Why Prefer Storage**

- Reduced Unutilized Capacity during non – peaks
- Economical to build storage than create new capacities
- Existing option (PSA Plants) to create new capacities are not considered technically viable in long term

*Figure 69. Needed storage capacity*

A significant focus will need to be on creating storage capacities across the state, which can supply up to 840 MTPD of oxygen by itself and up to 1,200 MTPD by diverting some industrial oxygen (Figure 69). This capacity needs to be redistributed in administrative divisions and prepared as LMO tanks and cylinders.



**Number of D type cylinders and LMO tanks in each division**

● Divisions with High requirement

● Divisions with Medium Requirement

● Divisions with Low Requirement

**Reservoirs**

- 30% of Oxygen reserves to be available in gaseous form (D-type cylinder) while 70% as liquid Oxygen (LMO Tanks)
- LMO Capacity : 20 kL
- LMO Tanks can be built in a Public Private Partnership with the re-fillers based on Oxygen rental model
- Cylinder- D Type (0.01 MT)

**Cryogenic Tankers**

- 10 Tankers (14 MT each)
- 1 Truck to be stationed at 4 locations – Belgavi, Kalburgi, Bengaluru and Mysuru for emergency situations

(Contractual agreement with private vendors to provide tankers/trucks as per need)

*Figure 70a. Necessary capacity expansion*

This capacity augmentation needs to be done at the site of large government medical colleges in each division and at the refiller level. (Figure 70)

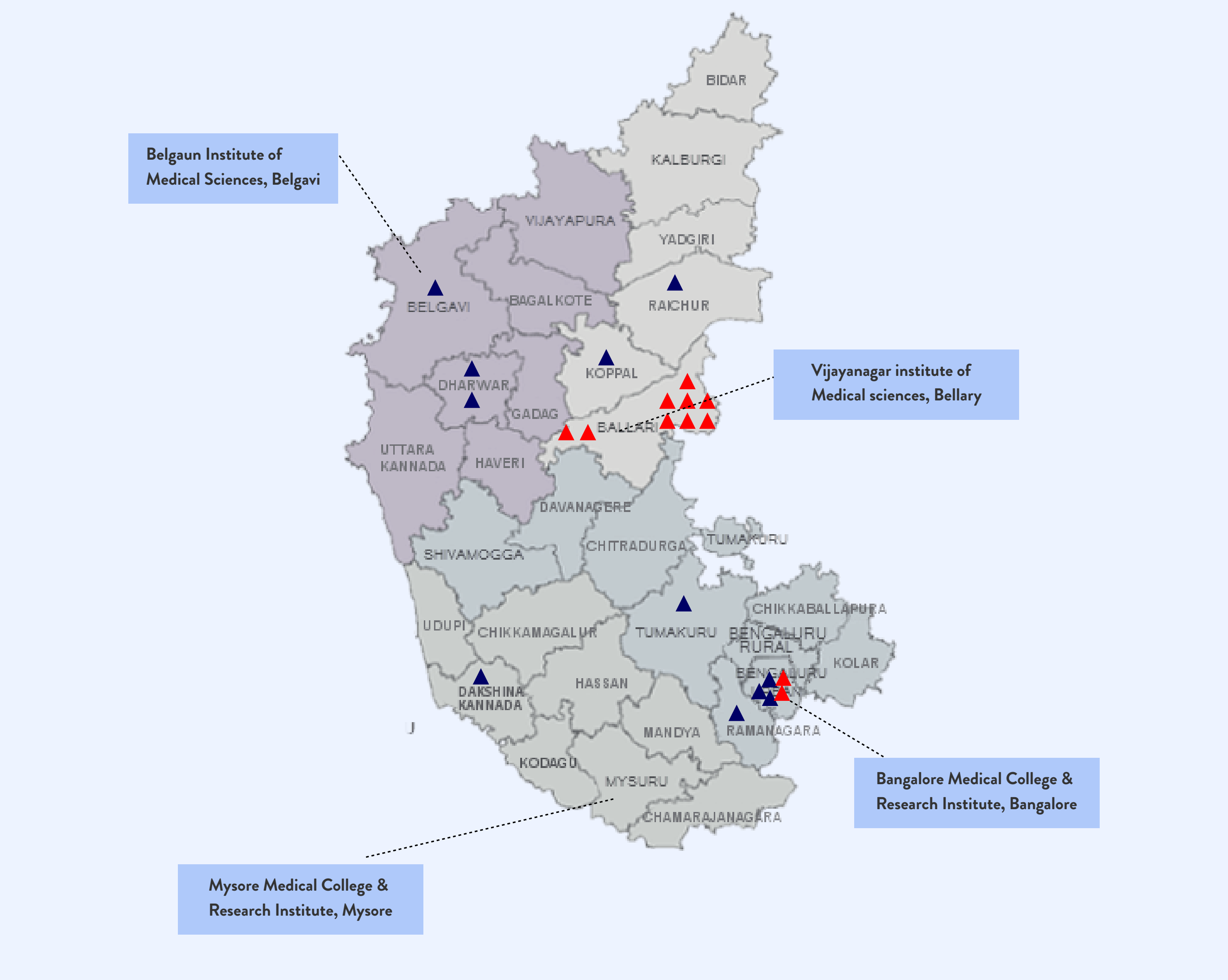


*Figure 70b. Necessary capacity expansion*

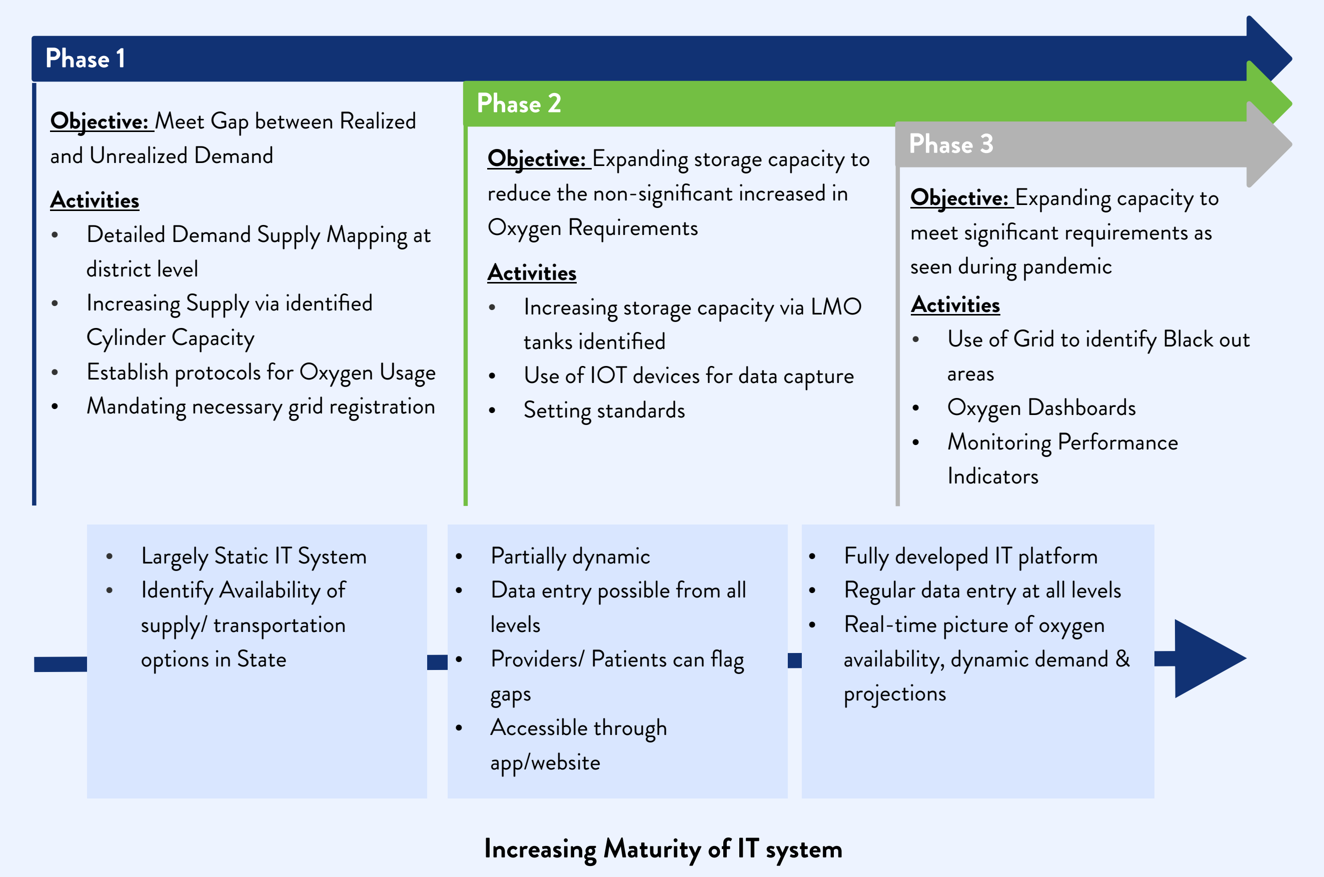
This storage capacity will need to be supported by respective monitoring and governance matrix, oxygen training protocols, and an enabling IT platform (explained in previous sections).

The state-level medical oxygen grid is a large infrastructural building project and will require a phased implementation. At a broad level, three phases of implementation are being conceptualized.

- The Phase 1 objective would be to meet the gap between realized and unrealized demand. This would involve a detailed demand–supply mapping at the divisional level, increasing supply via cylinder and LMO as possible, establishing protocols for oxygen usage, and mandating grid registration for all stakeholders. The concomitant IT system will be largely static but allow for identifying the available supply/transportation options in the state.

- Phase 2 will allow for expanding storage capacity to reduce the nonsignificant increase in oxygen needs. This would entail increasing storage capacity via LMO tanks identified, using IOT devices for data capture and setting standards. The IT system will be partially dynamic, allowing data entry from all levels, enable providers/patients to flag any gaps, and be accessible through an app/website.

- Phase 3 will target expanding capacity to meet significant needs, as during a pandemic. The grid will identify blackout areas and prepare and monitor oxygen dashboards and performance indicators. The IT system will be fully functional and give a real-time picture of availability, dynamic demand, and projections.



**Phase 1**

**Objective:** Meet Gap between Realized and Unrealized Demand

**Activities**

- Detailed Demand Supply Mapping at district level
- Increasing Supply via identified Cylinder Capacity
- Establish protocols for Oxygen Usage
- Mandating necessary grid registration

**Phase 2**

**Objective:** Expanding storage capacity to reduce the non-significant increased in Oxygen Requirements

**Activities**

- Increasing storage capacity via LMO tanks identified
- Use of IOT devices for data capture
- Setting standards

**Phase 3**

**Objective:** Expanding capacity to meet significant requirements as seen during pandemic

**Activities**

- Use of Grid to identify Black out areas
- Oxygen Dashboards
- Monitoring Performance Indicators

- Largely Static IT System
- Identify Availability of supply/ transportation options in State

- Partially dynamic
- Data entry possible from all levels
- Providers/ Patients can flag gaps
- Accessible through app/website

- Fully developed IT platform
- Regular data entry at all levels
- Real-time picture of oxygen availability, dynamic demand & projections

**Increasing Maturity of IT system**

*Figure 71. NMOG implementation plan*

## 6.3.4. Design of the Pilot to Demonstrate Grid Efficacy

Considering the landscape, a step-by-step pilot is proposed:

- Prerequisites: a) Identification of administrative divisions in which pilot will be executed, b) functional IT platform with access to all stakeholders, c) onboard partners—refillers (at least 80 percent in identified divisions), hospitals (80 percent of all units with an IPD stay facility of more than 30 beds), transport department, etc.

- Phase 1:

  - Objective: to assess the system readiness for informational relay between stakeholders to facilitate seamless flow of medical oxygen. This is designed to determine the grid functioning in a BAU scenario.

  - Length of time: five days

  - Target Stakeholders: All refillers and hospital sites in an administrative division chosen for the pilot.

  - Process: on a chosen day and time, divisional HQ will send a detailed request to all onboarded hospitals, refillers, and LMO storage sites to provide information on the available quantity of their stocks (that includes all forms of oxygen maintained directly or indirectly by the stakeholder itself and the oxygen on site in tanks and cylinders and in transit). From a producer or reflex perspective, it includes an oxygen contract that may have been signed but control not yet transferred (or oxygen not yet delivered). Only the absolute quantity information is needed. It excludes associated details, such as where stock is kept, form in which it is maintained, number of SKUs, and purity.

- KPI:
  - Percent of refillers and LMO storage sites that can share information within eight hours
  - Accuracy of data obtained (a sample of 10 percent of refillers which shared their data to be verified by on-the-ground assessment, within five days of the information being shared)
- KPI will be considered as met if
  - 80 percent of refillers and LMO storage sites can share information
  - More than 80 percent of the sample set used for verification has shared accurate information (+/- 10 percent of actual stock)
- Postphase 1—A detailed report must be prepared with details of the pilot, participants, and feedback. If the KPI is considered met, preparations may be started for Phase 2.

- Phase 2:
  - Objective: to assess the system readiness to supply a marginal short-term increase in demand, as may happen in the early part of a pandemic.
  - Length of time: five days
  - Target Stakeholders: All the refillers and hospital sites in an administrative division chosen for the pilot
  - Process: on a chosen day and time, divisional HQ will send a detailed request to all onboarded hospitals, refillers, and LMO storage sites, to provide ~100 oxygen cylinders to the divisional HQ. All PSA plants will be made operational at full capacity. These requests are sent over the IT platform. The cylinders include those that are in stock or newly filled using the LMO tank. The cylinders may be sent via the logistics arrangement maintained by refillers or hospital or the HQ. They should be delivered within 48 hours of the request being sent. PSA plants should continue functioning nonstop for the next five days.
  - KPI:
    - Percent of PSA plants made operational for five days
    - Purity of oxygen being produced by PSA plants made operational
    - Number of oxygen cylinders delivered to divisional HQ
  - KPI will be considered as met if
    - 80 percent of PSA plants are made operational for five days

    - 80 percent of operational PSA plants produce oxygen that is more than 90 percent pure
    - More than 80 cylinders are delivered to the divisional HQ.

  - Postphase 2—A detailed report must be prepared with details of the pilot, participants, and feedback. If the KPI is considered met, preparations may be started for Phase 3

- Phase 3

  - Objective: to assess the system readiness to supply peak increases in oxygen need.

  - Length of time: 10 days

  - Target Stakeholders: All the refillers and hospital sites in an administrative division chosen for the pilot

  - Process: on a chosen day and time, divisional HQ will send a detailed request to all onboarded hospitals, refillers, and LMO storage sites, to provide ~1,000 oxygen cylinders to the HQ. All PSA plants will be made operational at full capacity. These requests are sent over the IT platform. The cylinders include those that are in stock or newly filled using the LMO tank. The cylinders may be sent via the logistics arrangement maintained by refillers or hospital or the HQ. They should be delivered within 10 days of the request being sent. PSA plants should continue functioning nonstop for the next 10 days.

  - KPI:

    - Percent of PSA plants made operational for 10 days
    - Purity of oxygen being produced by PSA plants made operational
    - Number of oxygen cylinders delivered to divisional HQ

  - KPI will be considered as met if

    - 75 percent of PSA plants are made operational for 10 days
    - 75 percent of operational PSA plants produce oxygen that is more than 90 percent pure
    - More than 800 cylinders delivered to the divisional HQ.

- Postphase 3—A detailed report must be prepared with details of the pilot, participants, and feedback. If the KPI is considered met, preparations may be started to expand the pilot.

# 7. Conclusions and Key Recommendations

- Medical oxygen is a basic essential medical good. Under the current circumstances, the routine supply on is considered adequate to meet the existing demand (1,200 MTPD). But as the health system of India matures, the need will significantly increase. This warrants a change in the entire supply chain. In addition to catering to the BAU increases, these changes will also help meet any future oxygen surge needs, such as seen in COVID Wave 2 (up to 18,000 MTPD).

- The oxygen supply chain is characterized by infrastructural shortages.

  - The updated production capacity of 18–19,000 MTPD is a mix of both industrial and medical oxygen. A diversion of entire supply will mean significant reduction in industrial oxygen and cascading negative effects down the industrial value chain. Furthermore, even this entire supply will not be able to meet future black swan events if the need exceeds 18,000.

  - From a distribution perspective, India has an absolute shortage of ISO containers and cryogenic tankers.

  - From a consumption perspective, oxygen usage is not tracked. Furthermore, the infrastructural outlay of hospitals is not suited to deliver higher loads (e.g., the caliber of the medical gas pipeline is too small). Many hospitals also depend on cylinders, which is rather inefficient compared to LMO.

- Multiple steps have been taken to strengthen the supply chain. The key focus area has been in augmenting capacities using PSA plants.

- An analysis reveals that these PSA plants are rather inefficient in terms of oxygen purity, cost of operations, and ease of maintenance.

- A study of other grids in the country revealed the following best practices:
    - Prefer storage wherever possible.
    - Develop robust forecasting capabilities.
    - Develop a good governance mechanism, leveraging technology.
- Based on these considerations, an NMOG can be conceptualized, with the following basic constituents:
    - It will have a constellation of storage sites. The quantity of oxygen, form, and place of each site will be strategically decided to meet any future
    - A well-developed IT backbone will enable grid operations.
    - A well-developed three-tier governance framework will be created.
    - A well-developed mechanism of tracking of oxygen production, supply, storage, and consumption will be created.
    - Clinical protocols will be developed to guide on oxygen usage in different clinical settings.
- Top Recommendations
    - Withdraw all notifications and regulations that necessitate new PSA plants for medical colleges or hospitals. Instead, pass regulations to set up storage tanks and sites for existing and new hospitals..
    - Develop clinical protocols and training mechanisms for doctors and other health professionals for optimal usage of medical oxygen.
    - Mobilize financial and administrative mechanisms to set up an IT infrastructure and oxygen storage sites across different clusters. Set up governance units, connect all major and minor stakeholders in the value chain, specify basic minimum technical standards, partner with existing refillers, and leverage technology to create the grid. Develop the necessary capabilities to monitor it for policy purposes.
    - Collect granular on-site data in terms of number of hospital beds, storage capacities, refillers, and dealers to enable better supply chain forecasting.
    - Incentivize hospitals and health institutions to collect data on oxygen consumption—units, forms, category of patients, etc.
    - Develop a basic minimum infrastructure in terms of the number of ISO containers, cryogenic tankers, number of cylinders, etc. Furthermore, have well-defined quality and technical standards for storage of medical oxygen, oxygen cylinders, etc.

# REFERENCES

Bonnet, L., A. Carle, and J. Muret. 2021. “In the light of COVID-19 oxygen crisis, why should we optimize our oxygen use?” Anaesthesia Critical Care and Pain Medicine 40(4): 100, 932 [doi:10.1016/j.accpm.2021.100,932]

Drugs and Cosmetics Act, 1940. 2018. International Journal of Drug Regulatory Affairs 6(1), 35–40.

GBD 2016 Healthcare Access and Quality Collaborators. 2018. “Measuring performance on the Healthcare Access and Quality Index for 195 countries and territories and selected subnational locations: a systematic analysis from the Global Burden of Disease Study 2016” [doi: 10.1016/S0140-6736(18)30994-2]

Grainge, C. “Breath of life: the evolution of oxygen therapy.” 2004. Journal of the Royal Society of Medicine 97(10): 489–493 [doi: 10.1258/jrsm.97.10.489]

Kane, Binita, Samantha Decalmer, and B. Ronan O'Driscoll. 2013. “Emergency oxygen therapy: From guideline to implementation.” Breathe 9(4): 246–253 [doi: 10.1183/20734735.025212]

Stein, F., M. Perry, G. Banda, M. Woolhouse, and F. Mutapi. 2020. “Oxygen provision to fight COVID-19 in sub-Saharan Africa.” BMJ Global Health 5(6): e002786 [doi: 10.1136/bmjgh-2020-002786]

Stoller, J.K., R.J. Panos, S. Krachman, D.E. Doherty , and B. Make. 2010. “Long-term Oxygen Treatment Trial Research Group. Oxygen therapy for patients with COPD: Current evidence and the long-term oxygen treatment trial.” Chest 138(1): 179–187 [doi: 10.1378/chest.09-2555]

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Improving health and well-being worldwide

## What We Do

We live in an interconnected world: the health and well-being of the environment, animals, and humans are intertwined in ways that are becoming increasingly apparent. Tackling today's greatest challenges—whether climate change, pandemics, or drug resistance—requires an approach that recognizes these relationships.

The One Health Trust (OHT) uses research and stakeholder engagement to improve the health and well-being of our planet and its inhabitants. OHT continues and builds on the work of the Center for Disease Dynamics, Economics & Policy (CDDEP), which for more than a decade has conducted vitally important research on major global health challenges, including Covid-19, antimicrobial resistance, hospital infections, tuberculosis, malaria, pandemic preparedness and response, vaccines, medical oxygen shortages, and noncommunicable diseases. OHT's work now expands to take on issues related to climate change, biodiversity protection, and the effect of changing human diets on the planet.

At OHT, we believe that answers to the world's most critical questions lie between disciplines. Accordingly, our researchers employ a range of expertise—from economics, epidemiology, disease modeling, and risk analysis to clinical and veterinary medicine, geographic information systems, and statistics—to conduct actionable, policy-oriented research.

OHT has offices in Washington, D.C., and Bangalore, India, with researchers based in North America, Africa, and Asia. Our projects lead to policy recommendations and scientific studies published in leading journals. We are experienced in addressing country-specific and regional issues as well as global challenges. Our research is renowned for innovative approaches to design and analysis, and we communicate our work to diverse stakeholders.