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PREPARING FOR SURGE REQUIREMENT OF MEDICAL OXYGEN AND HOSPITAL BEDS FOR MANAGEMENT OF COVID-19

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Abbreviations

BAU	Business As Usual
BCC	Behaviour Change Communication
CCC	Covid Care Centres
CDRI	Coalition for Disaster Resilient Infrastructure
DCH	Dedicated Covid Hospitals
GPS	Global Positioning System
ICU	Intensive Care Unit
LMO	Liquid Medical Oxygen
LOP	Liquid Oxygen Plants
MBBS	Bachelor of Medicine and Bachelor of Surgery
MoHFW	Ministry of Health and Family Welfare
MT	Metric Tonne
PSA	Pressure Swing Adsorption
RFID	Radio-frequency Identification

EXECUTIVE SUMMARY

Since January 2020, countries around the world have faced recurring waves of COVID-19. The effectiveness of response across the globe has been contingent on the speed at which lessons were learned and strategic adaptations undertaken by national and sub-national governments.

This report presents recommendations for future preparedness on two major challenges concerning COVID-19 response: availability of medical oxygen and hospital beds. The study is based on lessons from the first two waves of COVID-19 in India and draws upon international experiences to put forward these recommendations to prepare for a possible third wave of the pandemic.

Based on a scientific assessment of future surge demand, it is estimated that the third wave in India may lead to a requirement between 13800 MT to 20600 MT of medical oxygen per day. Seven Indian states – Uttar Pradesh, Bihar, West Bengal, Tamil Nadu, Maharashtra, Madhya Pradesh and Andhra Pradesh together account for nearly 65% of this demand. A similar trend is estimated for requirement of beds for COVID-19 patients in hospitals.

However, the pandemic presents significantly dynamic scenarios given the diverse range of social, economic, administrative and clinical factors, that govern the actual spread of the disease. Assessment of surge demand for a large country like India, with a range of health system capabilities at the state level, has scientific limitations. The methodology followed in this report may be developed further with emerging data for more conclusive findings under different scenarios covered in the document.

With regard to managing the surge demand for medical oxygen, the study recommends a strategic approach that encourages self-sufficiency at the state level to meet the base demand while also leveraging other sources of production and supply of oxygen to meet the peak demand. As a short-term measure at the state level, independent PSA plants may be set up along with oxygen storage capacity to cater to peak demand for up to three days. Simple steps like deployment of trained oxygen technicians and efficient monitoring can save up to 25% of wastage of oxygen and disruptions in oxygen flow. At the state level, storage facilities to cater to surge demand within the state can be created. The facilities may store and generate oxygen onsite or receive it from repurposed industrial plants within or outside the state for further distribution to underserved areas in a hub-and-spoke configuration. Along with ongoing efforts for real-time monitoring of oxygen demand and supply, tracking and auditing need to be bolstered. Additionally, purchase agreements with different sources from which liquid and gaseous oxygen can be procured in bulk may also be established. In the long term, states should be encouraged to build onsite oxygen plants and storage facilities at hospitals.

Similarly, management of beds for care of COVID-19 patients requires systemic response preparedness that builds on the strengths of existing healthcare systems and leverages non-traditional options for effectiveness and efficiency. It is important to note that in addition to oxygen and ICU beds, there may be a demand for neo-natal and paediatric care units since under 18 population may be impacted in the next wave.

Based on the experiences of good practices across the USA, UK, Italy and India, it is imperative that the load on health facilities is optimized, through a digital decision support system for online triaging, real-time monitoring of emerging caseload, linking with telemedicine sources and monitoring availability of health care resources. Adequate planning for repurposing existing infrastructure within the health facility as well as those in the vicinity to serve as satellite facilities may need to be undertaken well in advance. This would include several steps, such as developing inventories of the desired critical care resources and matching them with available options for meeting demand. To prepare for an extreme scenario, adequate readiness for setting up temporary field hospitals needs to be planned by identifying suitable locations, vendors for temporary installations and supplies at short notice, as well as a roster of human resources to manage these facilities.

In addition, a cadre of trained workforce to manage various functions within the facilities needs to be swiftly developed through online short courses. Students of MBBS / paramedical courses, civil defence, paramedics, medical technicians and others may be suitably trained and included in the roster for assisting in emergency response. Further, campaigns for encouraging people's participation for effective management of the situation would also help in mitigating possible crises such as the non-availability of cylinders due to hoarding.

All these tasks may be undertaken in partnership between government, private sector and civil society stakeholders, involving expertise from health and non-health disciplines at various stages of the process.

1 INTRODUCTION

1.1 Background

The ongoing COVID-19 pandemic has impacted health care systems in most countries to varying degrees. Across the world, health infrastructure systems, especially in relation to oxygen supply and distribution as well as critical care beds have been under stress. Many countries including India, Brazil[1], Nepal[2] and Sudan[3] have been trying to keep pace with the health infrastructure demands of the current wave of the pandemic in 2021.[4]

Among the list of critical infrastructure requirements for COVID-19 treatment, availability of medical oxygen and hospital beds have been hugely strained as the pandemic has followed ascending trends during April – May 2021. Pre-COVID systems for medical oxygen production, supply and distribution have not been able to address the current surge in demand. Likewise, patient care facilities have required enhancements as well as expansion in huge proportions as compared to pre-COVID arrangements. This situation has prompted a holistic assessment and re-engineering of current approaches and systems to enhance availability and access of these resources for COVID-19 response.

With a possibility of an imminent third wave, this document attempts to estimate surge demand for medical oxygen and hospital beds for India. Drawing from the experiences of the second wave of COVID-19 in India, this document focuses on possible strategies and solutions in the short, medium and long term for meeting the surge demand of oxygen and ICU beds. These strategies and solutions may be considered by relevant stakeholders at the district, state, and national levels for developing a holistic response strategy that

[1] Brazil is suffocating covid surge creates severe oxygen crisis, Aljazeera, 17 March 2021, Accessed on 20/05/2021 <https://www.aljazeera.com/news/2021/3/24/brazil-is-suffocating-covid-surge-creates-severe-oxygen-crisis >

[2] Hopeless situation oxygen shortage fuels Nepal covid crisis, The Guardian.com, 10 May 2021, Accessed on 20/05/2021<https://www.theguardian.com/world/2021/may/10/hopeless-situation-oxygen-shortage-fuels-nepal-covid-crisis >

[3] Sudanese search for oxygen cylinders as COVID third wave swells, The Print, 10 May 2021, Accessed on 20/05/2021 <https://www.usnews.com/news/world/articles/2021-05-10/sudanese-search-for-oxygen-cylinders-as-covid-third-wave000000-swells >

[4] Why Some Hospitals Lack the Oxygen to Keep Patients Alive, New York Times, 4 May 2021, Accessed on 20/05/2021 <https://www.nytimes.com/2021/05/04/world/oxygen-shortage-covid.html>

would include other clinical and non-clinical resources that are not within the scope of this document.

The recommendations presented in this document may help India as well as other countries to develop systems for enhancing self-sufficiency while optimizing load on health care infrastructure and mobilizing surge capacity/ resources.

1.2 Approach

To assess possible scenarios in the event of a possible third wave and propose solutions for addressing the gap in demand and supply/ availability of oxygen and ICU beds, this study draws from open-source literature. It builds on lessons from technical reports, government documents and international practices collected mainly through interviews with engineers, supply chain managers, public health experts, virologists and epidemiologists and other experts (refer to Annexure-3) to propose solutions that are viable and contextual.

The study is structured in three parts. The first provides an assessment of surge requirement of oxygen and beds during the expected third wave. This is followed by key ideas on managing the surge demand of oxygen and ICU beds. The study concludes with recommended steps to be taken up at the central level and state level in the short and medium-term.

1.3 Scope and Limitations of this study

The analysis does not consider any new COVID variants that may emerge. If new variants emerge, where vaccination or previous infections do not confer immunity, these results may not hold. The findings of this study must be interpreted in light of the assumptions used. For example, any interventions that improve access to vaccines will reduce the oxygen and bed demand. The study provides a modelling framework to estimate oxygen and bed demand. The data can be updated to reflect the latest scenario.

2. DEMAND AND SUPPLY GAP FOR OXYGEN AND BEDS DURING SURGE

Based on historical data and expert interactions, the CDRI has attempted to develop a scenario-based assessment of possible future demand of oxygen and hospital beds, in the event of a third wave of the pandemic. The assessment considers available data and trends for key factors that may impact the spread of the disease in the future, unless the infection is caused by a new, significantly different variant of the virus. These factors include the total number of COVID-19 cases/ previous infections, vaccination rate, attack rate, manifestation of symptoms and severity of disease across all age groups in the different states of India.

Annexure-1 provides a detailed description of step-by-step calculations and assumptions followed for assessing demand. A total peak demand of 13,800 MT to 20,600 MT medical oxygen per day is estimated across the country for different scenarios; state-wise details are placed in Annexure 1. This total peak demand may distribute itself based on the timing of the wave across different states. If the development of the peak across states follows the same pattern as that of the second wave, then the peak demand across a **15-day window** may range between 6200 MT to 8560 MT. It may be noted that the bed and oxygen requirement assessments depend greatly on the assumptions made and will vary widely if assumptions are changed.

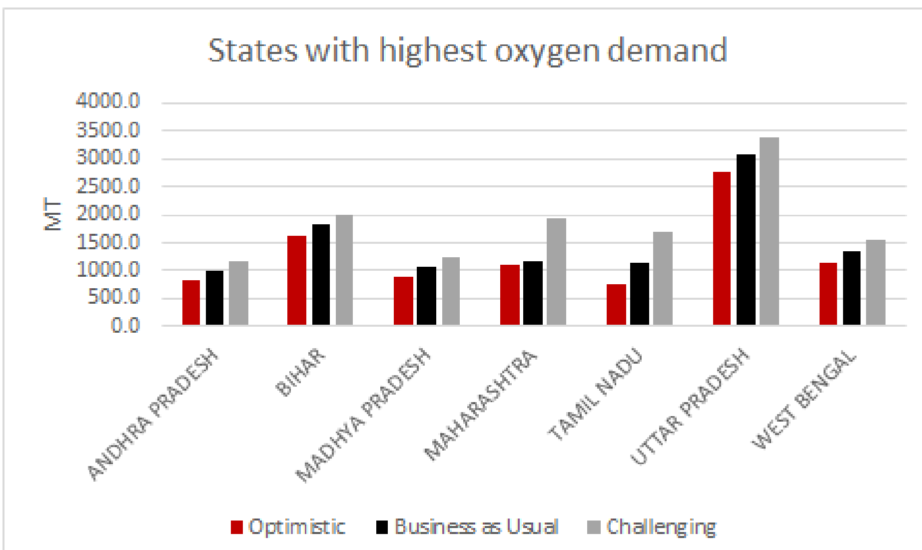
As illustrated in Figure 1, seven Indian states – **Uttar Pradesh, Bihar, West Bengal, Tamil Nadu, Andhra Pradesh, Maharashtra and Madhya Pradesh together are expected to account for nearly 65% of this demand.** These states merit focused attention for adequate preparedness for managing oxygen production, supply and distribution.

The oxygen demand scenarios developed in this report provide 'order of magnitude' planning figures. These are the best estimates based on our current understanding of the pandemic. There are uncertainties associated with these estimates, described in Annex I. These estimates are useful for advance planning for the third wave. In a sense these estimates provide an overall planning envelope for a three to six months' time scale.

In the real-world situation, should a third wave occur, real-time tracking of the pandemic – case load, positivity rate, doubling rate, hospitalization rate, the proportion of cases in ICU, disease characteristics, demographics of the caseload – will determine the actual requirements. Analysis of granular, real-time data on these parameters can give up to two weeks of lead time for responding to the oxygen demand in specific locations.

Given the overall planning envelope, and the analytical basis in real-time, the Oxygen supply strategy for COVID19 third wave needs to rest on two principles – 1) overall sufficiency at the national and to the extent possible state level; 2) a nimble system of reallocation depending on the real demand from specific locations.

Figure 1. States with the highest estimated peak oxygen demand across different scenarios

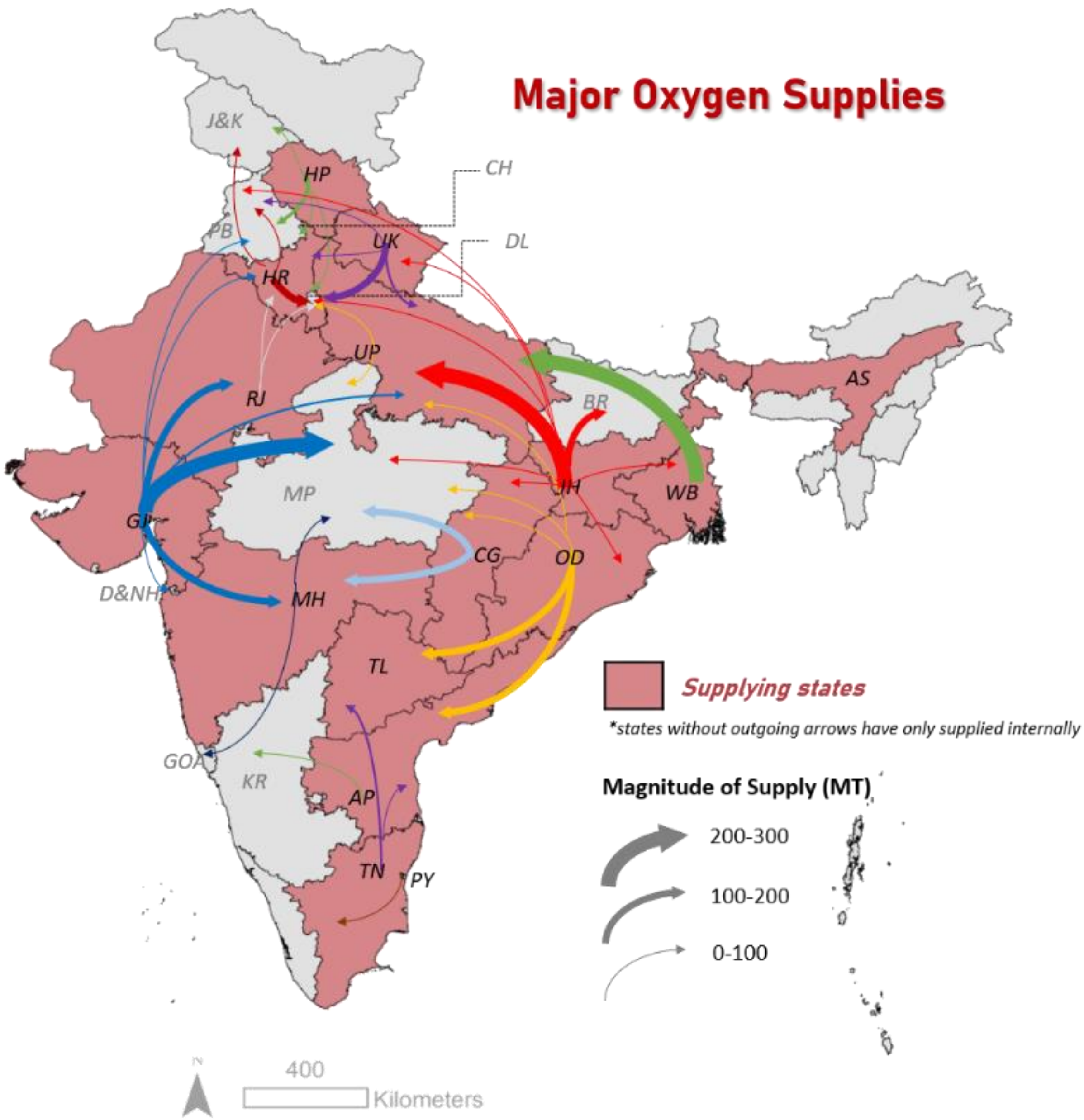


Source: CDRI analysis

Further, currently, oxygen (in MT) is being allocated from production facilities in Gujarat, Uttarakhand, Himachal Pradesh, Haryana, West Bengal, Jharkhand, Chhattisgarh and others to various states across India. This is presented in Map 1 below.

The current distribution of medical oxygen manufacturers/ refillers and industrial oxygen suppliers highlight that during the third wave, it is very likely for the majority of states in north and central India, such as Himachal Pradesh, Uttarakhand, Uttar Pradesh and Madhya Pradesh; UTs -Jammu and Kashmir and Ladakh and North- East India, to face shortages in supply of medical oxygen. States such as Kerala, Karnataka and Madhya Pradesh are also expected to be impacted.

Map 1: States supplying and receiving medical oxygen



Source: CDRI (adapted from MoHFW, 2021)

3. MANAGING SURGE DEMAND OF OXYGEN

At the peak of first wave in mid-September 2020, India reported about one lakh cases per day. This gradually reduced to about 9000 cases per day early in February 2021, before the second wave arrived with the new B.1.617 strain of the virus; daily cases peaked at about 4.1 lakh in early May[5][6][7]. In a narrow window of about 80 days, between February to May 2021, COVID cases rose fifty-fold, making the second wave even more challenging than the first one. This rapid, exponential rise in cases led to some unanticipated challenges:

1. Limited information about the forecast of second wave, its speed, and peak was available, the new strain added to the unpredictability of the entire situation. This led to a sudden surge in patients requiring oxygen and critical care, straining the already stretched resources.
2. Steep rise of cases over a very short time, hugely limited efforts to build additional capacities in terms of hospital beds and supply of critical items like oxygen and other essential supplies.
3. Strained oxygen supply chain dependent on a small number of cryogenic tankers carrying this critical resource from oxygen surplus states in the east to north and central Indian states struggling to keep up with the demand. The long transportation hauls with a turnaround time of at least 6-7 days for each tanker posed a peculiar challenge.
4. An overall sentiment of uncertainty led to hoarding of critical materials such as oxygen cylinders which further constrained supply systems.

In the backdrop of these challenges, this section explores possible solutions for oxygen preparedness for a possible third wave of COVID-19. Given the criticality and peculiar nature of oxygen for the purpose, its quality as well as the conditions for safe handling, systems for production and supply of oxygen must be planned carefully. For hospitals, especially those with more than 100 beds, to the extent possible, a dependable supply of Oxygen should rest on three sources: 1) Stored LMO; 2) PSA plants; and 3) cylinders. The

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[5] Worldometer, <Accessed on 07/06/2021> https://www.worldometers.info/coronavirus/country/india/

[6] 'Glaring lapses...': Parliamentary committee report flagged concerns over oxygen supply last year, Hindustantimes, 25 April 2021, <accessed on 07/06/2021> https://www.hindustantimes.com/india-news/glaring-lapses-parliamentary-committee-report-flagged-concerns-over-oxygen-supply-last-year-101619340185983.html

[7] A tragedy of errors: 10 reasons behind India's catastrophic Covid crisis, India Today 7 May 2021, <Accessed on 07/06/2021> https://www.indiatoday.in/magazine/cover-story/story/20210517-a-tragedy-of-errors-10-reasons-behind-india-s-catastrophic-covid-crisis-1799925-2021-05-07

stock of cylinders should hold enough oxygen to tide over at least one day of disruption in other sources.

3.1 Enhancing production and storage of oxygen

Medical grade oxygen is procured and stored in liquid or gaseous form[8] through commercial manufacturers and refillers or onsite production plants. Given the crisis, many hospitals in India use both systems. Several hospitals have managed to set up their own PSA plants to ramp up oxygen production locally and reduce the time lost in transportation.

To prepare for surge requirements in the event of a third wave of COVID-19, hospitals need to work on their self-sufficiency by:

- On-site production of oxygen at the hospital and health centre level
- Stockpiling Liquid Medical Oxygen (LMO) by enhancing on-site storage capacity at the hospital level
- Creating storage facilities for jumbo oxygen cylinders

3.1.1 Enhancing on-site production of oxygen

Setting up a PSA plant within a hospital compound is a cost-effective, decentralized and therefore efficient way of managing medical oxygen during surge. The capacity of a PSA plant can vary from 1 MT to 5 MT, requiring a floor area of about 150-1200 sq. ft. based on the capacity. The cost of setting up a 1 MT capacity PSA plant within a hospital compound is about INR 60-70 lakhs. This would be the first step towards self-sufficiency at the hospital level.

PSA plants are a tested solution for oxygen generation and are generally turn-key units complete with all the necessary equipment and supplies. However, the staff operating

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[8] **Liquid Oxygen:** In some hospitals oxygen is procured from manufacturers in the form of Liquid Medical Oxygen (LMO) and stored in cryogenic tanks. A vaporizer converts LMO to gaseous state and supplies it to patients in the hospital rooms through gas pipelines or through smaller individual cylinders.
Gaseous Oxygen: Hospitals without cryogenic tanks procure gaseous oxygen in cylinders from an intermediary entity called "refillers" wherein factory manufactured LMO is converted to gaseous state and refilled in cylinders. Refilling facilities may even produce their own gaseous oxygen through Pressure Swing Adsorption (PSA) technology[8] and store gaseous oxygen in cylinders at a pressure of 150 bar pressure. Some hospitals even have jumbo cylinders of 7000L capacity that store gaseous oxygen at a pressure of 150 bar. In this system, cylinders are arranged in a series (called manifold) and are used to pump oxygen into patient rooms via pipelines.

and maintaining them require specialized training. In resource-limited settings, adequate supplies eg of Zeolite filters and spare parts are needed to allow smooth operations. These plants may also subject personnel to oxygen-enriched (increased fire risk) atmospheres. Precautions, a basic knowledge of the behavior of these gases, and wearing of Personal Protective Equipment (PPE) can minimize exposure to these hazards.

Within the next 4-5 months, it is advisable for all hospitals with more than 50 beds to set up their own PSA plants. In the long term, states may include this provision in the accreditation requirements for such hospitals.

3.1.2 Enhancing on-site storage of reserve LMO within Hospitals

Experience of the second wave in India underscores the need for reserve oxygen at the hospital level equivalent to at least three times of peak capacity requirement[9]. As an illustration, if each ICU bed requires 30 LPM of oxygen, for a hospital of 10 ICU beds, the peak requirement is 0.62 MT. The planned reserve should be about 1.86 MT. Such a step will help minimize the need for emergency logistics management between hospitals and centralized oxygen storage facilities.

However, it may be noted that handling of cryogenic liquid medical oxygen or LMO can expose hospital staff to unique hazards such as cryogenic burns, frostbite, and respiratory problems. Hence, LMO must be managed only by trained persons as per guidelines[10].

Further, insulating LMO from surrounding environment all year round is essential to prevent hazards due to its low boiling point. It also requires higher technical knowledge and adequate ventilation to prevent over-pressurization due to expansion of small amounts of liquid into large volumes of gas. Mechanical and thermal shocks should be

[9] **Note:** It takes approximately 15-30 days to build a double-layer cryogenic tank for storing LMO.
[10] EIGA Doc 147, Safe Practices Guide for Cryogenic Air Separation Plants, www.eiga.eu
[2] CGA P-12, Safe Handling of Cryogenic Liquids, Compressed Gas Association, Inc www.cganet.com

prevented while transporting liquid oxygen cryogenic tankers. The containers should always be kept in upright position.

3.1.3 Repurposing industrial oxygen for medical purposes

Industries such as petrochemicals, petroleum, shipbuilding, steel, textiles, etc., produce oxygen for various chemical processes. In the event of a surge in oxygen requirement, states may restrict the production of industrial oxygen only to essential uses and repurpose the plants for production of medical grade oxygen.

Apart from these, sugar factories also have the potential to generate oxygen[11]. These industrial units and their oxygen production capacities may be mapped beforehand and suitable agreements for catering to surge demand for oxygen may be instituted, along with appropriate checks on the quality of oxygen produced. This arrangement may also prove to be more cost-effective in comparison to setting up new oxygen plants within the state that may become redundant once the peak demand period is over. To strengthen preparedness measures, industries along with the cooperation of State governments should make arrangements for storage cylinders, transportation, along with service areas that they may cater to etc. Additional equipment required such as compressors for oxygen must be procured and kept fit-for-purpose to ensure operability during surge.

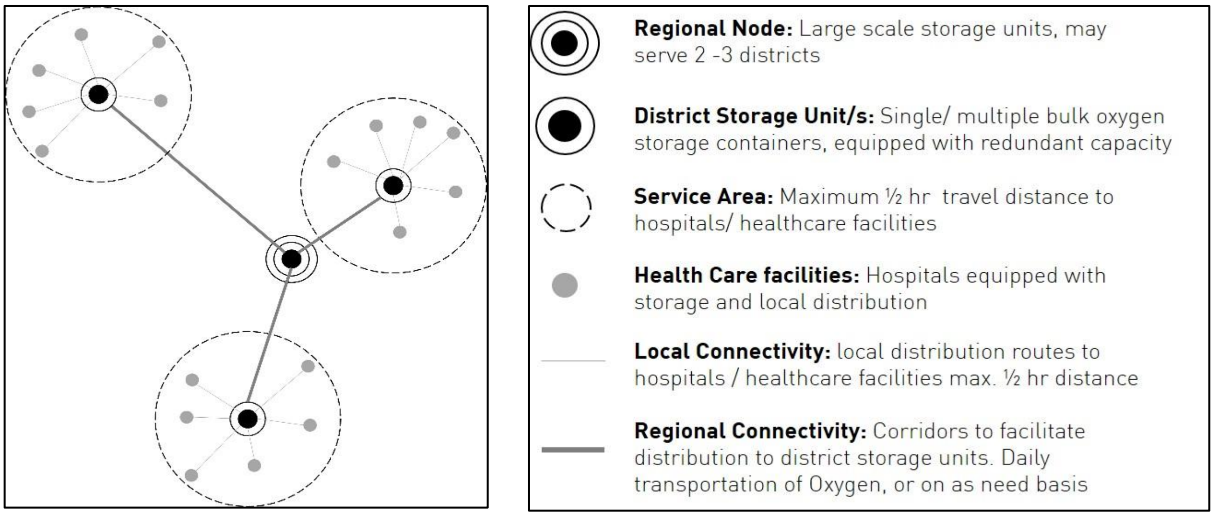
Given the need to be in readiness for a third wave in India, repurposing industrial units for oxygen production may be the most efficient solution in the near term. It is expected that this measure would cover a large portion of the surge demand and may therefore be adopted for a short time of 1-2 months, based on duration of the surge. The losses incurred by these industries may need to be compensated by the central government.

[11]Sugar factories in states such as Uttar Pradesh, Maharashtra and Karnataka that account for about 79% of the sugar produced in India, have the potential to service the demand for oxygen in their own as well as neighboring states.

3.2 Strengthening storage and distribution systems

In the event of demand surge, a graded approach to decentralized storage and distribution systems across the country is needed. Some of the key components of this approach are:

Fig 2: Schematic diagram of hub-spoke model



Box 1: Hub & spoke model for oxygen storage and distribution

- Develop large regional LMO/ gaseous oxygen storage hubs for 2-3 districts with three times, storage capacity for peak demand of the districts
- Create smaller LMO/ gaseous at district level for daily distribution to hospitals with three times, storage capacity for peak demand

  Link distribution system with real-time demand of hospitals. Monitor demand, supply and availability of oxygen through online portal

3.2.1 Systematizing state, regional storage, and distribution systems

Based on the experience of the second wave, storage plants near high-demand zones may be set up by states that are likely to face a huge demand for oxygen. A cluster model for storage and distribution of medical oxygen may be adopted to minimize transportation from production plants.

In a hub-and-spoke model formation, that is commonly used in the supply and logistics industry, states may identify suitable locations for setting up additional oxygen production facilities/ feeder units. The feeder units shall be connected to various hospitals for surge in demand. These may be planned to ensure a state-wide network. The regional nodes (hubs) for oxygen production that may cater to 2-5 nearby districts depending on the requirement, would supply oxygen to bulk storage facilities located within the district, which in turn would supply to nearby hospitals and COVID-19 centres. This would minimize delays and drastically reduce the risk and associated costs with transportation of oxygen. Accordingly, new COVID care centres may be set up near existing or proposed oxygen plants. Wherever deemed viable, laying a network of pipelines between high case load hospitals and existing oxygen plants in the proximity, may be considered.

States may also set up large LMO/ gaseous storage facilities at division and district level, equivalent to three days' anticipated peak demand. These facilities must be equipped with a vaporization and bottling bay. However, this measure must be taken up considering the availability of cryogenic tankers, cost of transportation and other logistical issues.

It is recommended that additional cryogenic oxygen tankers may be procured/manufactured swiftly to cater to the increased demand. At present, India has 1224 oxygen tankers (16732 MT capacity) and efforts are being made to increase this capacity to 2000 tankers through conversion of nitrogen and argon tankers and import of 138 cryogenic tankers[12]. These efforts need to be strengthened.

3.2.2 Streamlining interstate distribution system

During high-demand periods, states may continue to access oxygen from production units located in other states. A lead time of at least three days is required for interstate logistics to operationalize. In coordination with the centre, states may set up ‘green corridors for oxygen’, to facilitate swift supply and distribution.[13] For uninterrupted transportation of oxygen within and between states, “green routes” may be mapped by

[12] IN THE SUPREME COURT OF INDIA CIVIL ORIGINAL JURISDICTION Suo Motu Writ Petition (Civil) No.3 of 2021 IN RE: DISTRIBUTION OF ESSENTIAL SUPPLIES AND SERVICES DURING PANDEMIC.
[13] A green corridor is a dedicated and congestion-free special route created for transportation of emergency supplies over long distances.

the respective State Task Force in consultation with transport and railways departments. Empty oxygen tankers may also be airlifted to reduce turnaround time.

The Indian Railways through, 68 Oxygen Expresses, delivered nearly 4200 MT of LMO in more than 268 tankers to various states across the country during the second wave[14]. Although initially planned as a response mechanism, oxygen express can be developed as a viable model to ensure transportation of oxygen in regions with low resource settings, where it may be stored in LMO containers in readiness for the third wave.

3.3 Monitoring and managing oxygen distribution

Experience around the world suggests that oxygen demand may be optimized by about 25-30% through practices at various levels. These may include:

3.3.1 Developing oxygen dashboard

In a coordinated approach, states and central government may create a unified and interlinked oxygen portal for managing oxygen demand, supply and distribution. This system may track lifting of oxygen from sources as well as movement of tankers with GPS till the last mile delivery. The portal may capture demand placed by hospitals, number of patients admitted storage and generation capacity, surge demand estimation and requests for refilling from LMO manufacturers/ refillers.

To minimize misuse and hoarding during crisis and facilitate real-time tracking for refilling purposes, a system of RFID/ barcode tagging of oxygen cylinders may be developed by states for reverse logistics.

3.3.2 Administrative monitoring, skill development and behavior change communication

At the state level, through regular oxygen audits, officers may monitor pilferage or wastage, determine judicious utilization of oxygen at health care facilities, track and solve

[14] Centre undertakes multiple initiatives to enhance Oxygen availability, distribution, and storage infrastructure. PIB Delhi, 10 May 2021< Accessed on 07/06/2021> https://pib.gov.in/PressReleseDetail.aspx?PRID=1717459

demand, transportation and supply issues. The national level task force will continue to monitor, mobilize, and support distribution of oxygen to the states.

Additionally, a massive drive for training of personnel required for monitoring, maintenance and upkeep of infrastructure, such as PSA plants, Liquid Oxygen Plants (LOP), bottling of cylinders, etc., may be undertaken by each state. Short courses, media content and guidelines may be developed to upskill and develop the necessary technicians.

A Behaviour Change Communication campaign may be undertaken to spread awareness on measures being taken by the government for ensuring availability of medical oxygen, thereby discouraging hoarding of cylinders by individuals during crisis. This may be delivered through social media, news, online content, telephonic calls, etc.

Over the short to medium term, a large number of temporary centres, other health facilities as well as home care situations, would be using Bed Side Oxygen Cylinders. Safety precautions must be widely disseminated using print, broadcast and social media.

Conversion of Oxygen cylinders from industrial to medical purposes should be pursued with due diligence to ensure high standards of hygiene and safety. Similarly, conversion of LNG tankers for Oxygen storage and transportation needs should be pursued with necessary precautions and due diligence.

4. MANAGING SURGE DEMAND OF HOSPITAL BEDS

The COVID-19 pandemic requires a multipronged approach to ensure that health care systems are not overburdened. Based on the experiences gathered from countries such as the USA, UK, Italy and India, the following approach is suggested at the state level:

4.1 Optimizing load on health care systems

Triaging has been adopted by states in India and countries across the globe to efficiently manage caseloads. A state-led digital decision support system for triaging would aid in monitoring caseload, linking with telemedicine sources and monitoring health care resources such as availability of ICU beds, oxygen beds, oxygen supply and distribution, critical medicines, etc.

Box 2: Minimum Capability Framework of COVID-19 decision support system at state level

- Understand patient requirements based on reported symptoms
- Appropriate referrals – home isolation supported by telemedicine or CCC or DCH
- Refer to appropriate facility based on availability
- Link with ambulance service for patient transportation as per referral
- Maintain a record of cases of various categories (mild at home / moderate at CCC / severe at DCH)
- Monitor availability of beds, oxygen and other critical supplies across the state

In addition, to cater to mild cases of COVID-19, states may set up telemedicine facilities for remote management of such patients.

4.2 Enhancing capacity of health care facilities

Providing adequate treatment facilities within the state is essential to deal with demand surge. The following graded approach may be considered while planning for future waves of COVID-19 in India:

4.2.1 Augmenting and upgrading healthcare capacity

States may develop an inventory of critical care resources that may be mobilized in case the caseload exceeds 50% of the existing capacity of the health facilities. Existing built infrastructure such as non-critical specialty wards within the health care facility may be repurposed at short notice. These facilities must be equipped with adequate supporting infrastructure.

Although the number of young children requiring oxygen may not be very high, states must focus on adequate neonatal and paediatric ICU beds from an infrastructure perspective.

States may also identify potential health care providers from the private sector and civil society to partner with to set up home ICUs. These may include private hospitals, nursing homes, blood banks, hotels, etc.

4.2.2 Strengthening human resource for demand surge

Based on the expected number of beds for ICUs and oxygen, requirement of additional human resources including doctors, nurses, paramedics, support staff and others may be assessed. Short training courses may be delivered to upskill health care workers and support staff at the frontline of emergency response. Students of MBBS and paramedic courses, civil defence, paramedics, medical technicians and others may be suitably trained and included in the response roster.

4.2.3 Developing emergency field hospitals

States may need to create an inventory of government-owned land, public spaces (stadiums, community halls, open spaces, congregation areas, etc.), and non-essential building infrastructure (parking lots, semi-constructed buildings, etc.), for makeshift facilities. These potential sites must consider locational vulnerability such as floods, cyclones, tsunami, etc. Space for check-in, open-space queuing and triaging must be incorporated. As feasible, such facilities may adopt efforts to optimize design and construction for efficiency in implementation.

5. STRATEGIC FRAMEWORK OF ACTIONS FOR MANAGING SURGE DEMAND OF OXYGEN AND HOSPITAL BEDS

Strategic preparedness by states will require balancing oxygen supply with emergent demand. The tables presented in this section illustrate the estimated oxygen demand across scenarios (based on CDRI analysis) with sources of medical and industrial oxygen. The three scenarios differ with respect to assumptions on the timing of the next wave.

In the BAU scenario, the time difference between the first and second wave is estimated at six months. In the optimistic scenario, it is assumed that the onset of the next wave is delayed (after 210 days), and vaccinations are higher (133% of current rate) allowing for a larger proportion of the population to be vaccinated. In the challenging scenario, it is assumed that the next wave occurs within 120 days, and vaccinations are lower (67% of current rate) leaving little time for vaccination as well as preparation.

States may experience surplus or deficits of oxygen to varying degrees across the different scenarios. Under a BAU scenario, the cumulative deficit is estimated as 6,865 MT for India. This may increase to 11,500 MT under the challenging scenario and reduce to 5,541 MT under the optimistic scenario. It must be noted that the timing of peak demand may vary between states depending on the actual spread of the disease in different contexts. The actual deficit of oxygen is, therefore, expected to be lower than the cumulative deficit.

To meet the demand, reallocation of industrial oxygen will be required. We assume that states with production capacity for industrial oxygen will retain 60% to meet demand within their own state. The balance 40% will be distributed to neighboring states. Proximity will be the prime consideration for distribution. For example, it may not be prudent for Andhra Pradesh to supply oxygen to Mizoram, but it may supply to Karnataka or Tamil Nadu. Further, the distribution of the balance 40% will be based on demand. For example, if the requirement of Karnataka to Tamil Nadu is 4:1, then the oxygen from Andhra Pradesh may be distributed in the same ratio to the two states. For Jammu and Kashmir, we assume that the entire demand can be met only by industrial oxygen as low pressure at higher altitudes affects the performance of PSA plants.

Figure 3: Proposed allocation matrix of industrial oxygen under the Business-As-Usual scenario

Source State	Total produced	Receiving States																												
		MH	GJ	KR	MP	DL	HR	UP	PB	TN	KL	CG	RJ	TL	AP	UK	J&K	CH	HP	BR	WB	JH	OD	AS	PY	AR	MN	ML	NL	TR
AP	300			120											180															
AS	21																							21						
CG	400				190							210																		
GJ	1597		552		30			515	50		175		275																	
HR	287						172		65								50													
HP	130																52	20	58											
JH	878																			252	85	526	15							
MH	1226	735			440									50																
OD	457														45								274	10		28	33	25	16	25
RJ	120							48					72																	
TN	205									123				57	25															
PY	70									60															10					
TL	101			40										60																
UP	225					60		165																						
UK	305							167	55							83														
WB	200							80													120									
Total Allocation	6522	735	552	160	660	60	172	975	170	183	175	210	347	167	250	83	102	20	58	252	205	526	289	31	10	28	33	25	16	25
Total Demand		908	552	495	1075	103	246	2984	293	1036	292	255	576	338	966	83	108	44	58	1811	1337	568	630	485	10	28	33	24	16	25

Source: CDRI analysis based on MoHFW, 2021

(green)	Oxygen retained by states to meet their own demand
(white)	Existing Supply Linkages
(yellow)	New Supply Linkages

The analysis shows that during the peak, repurposing of industrial oxygen in addition to the current supply of medical oxygen will be required to meet demand across all scenarios. A large deficit is likely to remain, this deficit will need to be addressed by expanding the capacity of PSA plants. In the Business-as-Usual scenario, the deficit is expected to be roughly 6000 MT. This would mean installing about 2000 PSA plants with an average capacity of 3 MT. The Government of India is planning to build nearly 1500 PSA plants across India, which would mean an addition of 500 plants to take care of the demand.[15]

Under the BAU scenario, it is observed that states such as Bihar, West Bengal, Uttar Pradesh, Odisha and Tamil Nadu show the highest unmet demand. Unmet demand for oxygen is observed for the same states under the optimistic scenario, although the demand falls by nearly 25 to 30%. Based on this analysis, actions that the central government, state government and private sector can undertake are suggested in Section 5.1 and Section 5.2.

The strategic response framework for action by the central and state governments must be informed by a graded approach - from promoting self-sufficiency to building capacities for utilizing help effectively. A summary of these actions to prepare for the third wave of COVID-19 in India are presented for different phases:

- **Minimum preparedness** comprising minimum actions required to be self-sufficient
- **Surge Response** comprising actions to be taken up for demand surge, that may be anticipated about 15 - 20 days in advance, using a more real-time forecast model like Sutra.

5.1 Managing Oxygen

i. Recommended actions for **minimum preparedness** by **Central and State government** are as under:

[15] Centre undertakes multiple initiatives to enhance Oxygen availability, distribution, and storage infrastructure. PIB Delhi, 10 May 2021< Accessed on 07/06/2021> https://pib.gov.in/PressReleseDetail.aspx?PRID=1717459

Central government	
Set up National Oxygen Portal	• Monitor demand and supply of oxygen by states through an online data portal to facilitate equitable distribution of oxygen to states.
Contingency Oxygen Plan	• Create an oxygen supply chain management plan for interstate supply of oxygen to meet surge requirements through state and private sector sources.
Develop Green Corridors	• Coordinate with railways, roads, aviation ministry and state transport departments for emergency transport routes using rail or road-based green corridors.
Develop Human Resources	• Develop course materials and trainers for training and certification of additional emergency staff, including oxygen technicians and logisticians for refilling, transportation and handling of liquid and gaseous medical oxygen through the supply chain.
State government	
Storage of oxygen	• Create on-site storage facilities in all District Hospitals (DHs). Issue orders to private hospitals with more than 50 beds to create the same. • Create temporary safe storage for cylinders at government-designated locations, other than hospitals, Dedicated COVID Hospitals (DCH)s, COVID Care Centres (CCC)s, etc.
Transportation	• Plan the supply and transportation system by connecting oxygen sources (industries and PSA plants) to destinations (DHs, private hospitals and other COVID-care facilities) • Earmark alternate industry sources to obtain liquid or gaseous oxygen and establish contracts for need-based supply.

On-campus PSA plants	• Identify hospitals with more than 100 beds that can house PSA plants within the campus and commission setting up of PSA plants of at least 3 MT capacity. • Make amendments to hospital license requirements for mandatory construction of PSA plants for hospitals with more than 100 beds.
Digital monitoring and decision support system	• Create State Oxygen Dashboard for real-time monitoring of oxygen resources. • Set up real-time reporting systems to provide updates on oxygen usage and requirement for timely delivery. • Mobilize and monitor supply logistics, including reverse logistics through RFID or Barcode tagging of cylinders, oxygen tankers for real-time information on route, demand and supply. • Train and prepare a roster of specialized clinical and paramedic staff such as oxygen nurses for managing supplies efficiently
Optimize use of oxygen	• Train and prepare a roster of specialized clinical and paramedic staff such as oxygen nurses for managing supplies efficiently
Behaviour Change Campaigns (BCC)	• Undertake BCC initiatives to spread awareness on availability of medical oxygen, thereby discouraging hoarding of oxygen cylinders.
Repurpose industrial oxygen production for medical oxygen	• Map potential industrial units for oxygen production beforehand and formulate suitable agreements for catering to demand surge. • Ramp up oxygen availability by entering into agreements with industry, e.g., Petrochemicals, steel, petroleum, shipbuilding,

	textile, etc., for production of medical oxygen by repurposing their units during peak demand.
Support under CSR	• States may request public and private sector organizations to train volunteers, field technicians, logisticians, etc. through CSR.

ii. Besides the recommended actions for **State and Central government** for minimum preparedness, **Surge Response** necessitates the following additional steps:

Central Government	
Manage Oxygen Allocation	• Define the rules and algorithm for allocation of oxygen across states to meet the dynamic demand • Ensure inter-state coordination for routing oxygen as per allocation • Ensure that no state prevents transport of oxygen and allocation rules are adhered to
State government	
Human resource mobilization	• Mobilize trained staff—oxygen nurses, doctors and other staff for optimum performance of systems. • Monitor wastage, determine judicious utilization of oxygen at health care facilities, track and solve bottlenecks related to transportation, supply and logistics.
Repurpose industrial oxygen production for medical oxygen	• Mobilize oxygen distribution from the state's internal oxygen reserves stored before the onset of surge. • During peak demand, restrict the production of industrial oxygen only to essential uses and repurpose the plants for production of medical grade oxygen.
Supply from other states	• Mobilize **oxygen express** through pre-existing agreements with states having surplus.

5.2 Managing hospital beds

i. Recommended actions for **minimum preparedness** by **State and Central government** are as under:

Central government	
Develop Human Resources	• Prepare and deliver short training courses to upskill health care workers and support staff at the frontline of emergency response. • Prepare a roster of MBBS and para medical students, civil defense, paramedics, medical technicians and others that may be suitably trained and included for assisting in response.
State government	
Digital monitoring and decision support system	• Set up a state-level digital decision support system for key emergency management functions including: - Triaging of cases to optimize load on COVID treatment facilities. - Referrals based on severity of cases. - Linkage with telemedicine for patients under home care/self-isolation. - Monitoring availability of beds and oxygen at different government and private health care facilities.
Managing load on hospitals	• Set up remote teleconsultation services to reduce load on health care facilities.
Preparedness for surge demand	• Create a **human resources management plan** for surge capacity. • Develop an inventory of potential social infrastructure (religious buildings, institutes, playgrounds, etc.) that can be converted to makeshift hospitals if caseloads exceed 50% of the existing capacity of the health facilities.

	• Set up formal arrangements / commercial agreements with private and civil society healthcare providers for catering to referrals from government hospitals in case the demand exceeds the capacity of government facilities. • Identify potential partners from private sector and civil society for ancillary services, e.g. blood banks, pharmacy companies, biomedical waste management agencies, etc. • Create neonatal and pediatric ICU beds within existing facilities in readiness for a surge of cases among children.

ii. Besides the recommended actions for **State and Central government** for minimum preparedness, **surge response** necessitates the following additional steps:

Central government	
Augmenting capacity	Assist in mobilization of resources and deployment of **emergency field hospitals** in resource deficient states
State government	
Augmenting capacity	Mobilize field hospitals – infrastructure, human and other resources to augment existing health infrastructure

In addition to the above-mentioned stakeholders and their recommended actions, other actors in the local context can potentially make substantial contribution in managing the crisis. Elected representatives, civil society volunteers and people's groups, faith leaders and other such influencers can help prevent the spread of the infection by promoting COVID-appropriate behaviors and vaccination.

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Annexure 1: COVID-19 Cases, Oxygen and Bed requirement for states across India

Table 1. Oxygen and beds requirement

State & UT	Oxygen (MT)			Oxygen Beds			ICU Beds		
	Optimistic	Business-as-usual (BAU)	Challenging	Optimistic	BAU	Challenging	Optimistic	BAU	Challenging
ANDAMAN & NICOBAR	1.1	2.8	4.1	25	72.8	112	11	24.6	36
ANDHRA PRADESH	809.5	989.6	1169.6	21269	25821.9	30373	7284	8946.2	10608
ARUNACHAL PRADESH	26.5	27.5	18.5	685	716.2	493	240	249.2	165
ASSAM	386.5	484.3	582.0	10323	12829.6	15336	3438	4332.5	5227
BIHAR	1635.7	1818.9	1997.7	42831	47489.4	52036	14753	16437.2	18081
CHANDIGARH	39.4	43.8	45.5	1106	1232.9	1282	338	375.3	390
CHHATTISGARH	243.3	255.2	321.8	6515	6856.2	8566	2161	2260.4	2869
DADRA & NAGAR HAVELI	6.3	7.4	8.1	171	196.7	216	56	65.7	73
DAMAN & DIU	1.9	2.9	3.8	49	77.1	105	17	25.2	33
DELHI	78.6	143.4	167.6	3473	3473.1	3473	1178	1177.9	1178
GOA	5.8	11.7	15.6	134	303.8	418	56	105.7	139
GUJARAT	586.1	656.6	830.4	15657	17687.9	22153	5214	5806.0	7393

HARYANA	247.9	266.3	334.8	6647	7174.7	8940	2200	2354.0	2978
HIMACHAL PRADESH	28.0	66.4	79.6	656	1761.7	2143	271	593.3	705
JAMMU & KASHMIR	79.9	108.8	124.3	2068	2900.7	3348	726	969.1	1100
JHARKHAND	525.0	567.7	610.4	13799	14890.7	15983	4723	5114.4	5506
KARNATAKA	610.3	630.8	1040.8	16309	17513.1	27411	5427	5778.5	9350
KERALA	316.9	348.3	564.4	8331	9236.1	14768	2850	3114.2	5092
LADAKH	1.7	1.6	1.7	44	43.7	44	15	15.2	15
LAKSHADWEEP	0.4	0.3	0.4	4	4.0	4	4	4.0	4
MADHYA PRADESH	898.6	1075.4	1252.6	23917	28424.4	32941	8014	9637.6	11265
MAHARASHTRA	1101.2	1179.6	1947.1	29377	31635.1	51162	9805	10464.2	17519
MANIPUR	29.5	32.7	46.5	792	885.7	1243	261	288.6	414
MEGHALAYA	22.7	28.4	33.6	606	769.7	909	261	288.6	414
MIZORAM	6.2	8.9	11.6	158	237.7	315	56	79.8	102
NAGALAND	15.1	16.1	23.7	408	436.9	630	134	142.0	212
ODISHA	390.7	633.6	876.2	10526	16685.1	22837	3454	5691.9	7927
PUDUCHERRY	10.8	18.0	24.9	292	475.7	652	95	161.5	225
PUNJAB	150.6	321.4	491.7	4239	8598.1	12945	1289	2855.8	4418
RAJASTHAN	564.4	632.1	657.2	14954	16904.4	17628	5049	5617.9	5829
SIKKIM	3.0	4.7	6.3	77	124.9	172	28	42.0	56

TAMIL NADU	752.3	1124.3	1700.6	19996	21663.0	44195	6715	7201.3	15417
TELANGANA	319.5	342.4	503.9	8512	9170.6	13304	2848	3039.7	4519
TRIPURA	14.3	24.5	34.8	342	633.9	933	137	222.0	309
UTTAR PRADESH	2773.5	3076.1	3377.3	73397	81148.1	88863	24833	27602.6	30360
UTTARAKHAND	66.2	90.5	103.6	1702	2402.8	2781	605	809.0	919
WEST BENGAL	1137.4	1344.7	1555.9	30594	35955.3	41418	10068	11953.4	13874
Total	**13886.9**	**16387.6**	**20568.8**	**369986**	**426433.6**	**540132**	**124616**	**143846.7**	**184720**

A step-by-step guide to the analytical approach

Step 1: Collate population data

Population data for the year 2021 has been obtained from projections based on Census 2011 data. For each state, the population data were segregated into three age groups – 0-18 years, 18-45 years and for 45+ years. In addition, data on urban and rural distribution of the population was also obtained.

Source: Data retrieved from https://www.worldpop.org/w

Step 2: Collate vaccination data

Data on the number of vaccinations by state were collated from the CoWIN portal (https://dashboard.cowin.gov.in). Assuming that there will be adequate protection in the vaccinated individuals after the first dose, only data of the first vaccination dose was used for the present analysis.

From the total population, the number of people who received the first dose of the vaccine was deducted for 18 – 45 and 45+ age groups. This provided the population yet to receive the first dose of the vaccine.

Step 3: Possible timing of the next wave

Predicting the timing of the next wave of COVID-19 is difficult.

To establish a timeline, the duration between the peaks of the first and second wave for each state were analyzed. First, daily data on the number of confirmed COVID-19 cases from 1 March 2020 to 16 May 2021 for each state were collated. Following this, a 7-day moving average was applied to these data. The peak COVID-19 cases were identified during the first and second wave, respectively. The difference between these two peaks was taken as the duration between the two waves.

Based on this analysis, it was observed that for four states – Delhi, Himachal, Gujarat and Rajasthan—the duration between the two waves were approximately 150 days. For other states, the duration was more than 200 days **(see Annexure Table A1).**

It was assumed that the duration between the current and next wave will be 150 days for Delhi, Himachal, Gujarat and Rajasthan. For all other states, it was assumed that duration will be 180 days. This has been done to be on the safe side. If the duration between the second and third wave is more than six months, the intensity of wave will decrease because of higher vaccinations.

Step 4: Expected number of vaccinations and COVID-19 cases until the next wave

The analysis accounted for people who will receive vaccines between now and the onset of the next wave. Based on the available CoWIN data, for each state, the average daily vaccination was calculated. **It was assumed that over this duration the vaccination rate will remain unchanged**. The daily vaccinations were multiplied with the duration between two waves (as determined in Step 3).

Further, it was assumed that 60% of all vaccines will be given to the 45+ age group as this group is at high risk for COVID. The balance 40% would be given to 18 – 45 age group. Also, preference would be given to those who are yet to receive the first dose.

The study did not account for new covid cases that might emerge until the next wave.

Step 5: COVID-19 cases and underestimation

COVID-19 Cases and Mortality Data: The data for the state-wise cumulative number of total confirmed cases as reported on 16 May 2021 and is collected from the COVID-19 INDIA Dashboard (https://www.covid19india.org/). Similarly, data for state-wise total number of deceased persons is collected from the portal and is used for calculation of the underestimation of the infections.

Data on all age, gender, and state for all COVID-19 cases on 16 May 2021 was collated. The proportion of COVID-19 cases by age group were calculated. It was assumed that all the cases were distributed in the same proportion across age groups.

Underestimation factor: The actual infections are likely to be more than those who have been confirmed as COVID-19 positive. For calculation of the underestimation factor, it was assumed that the likely underestimation factor is same as reported in the 3rd National Serosurvey data carried out by the Indian Council of Medical Research (ICMR) from 18 December 2020 to 8 January 2021 (Results available at https://pubmed.ncbi.nlm.nih.gov/34022338/).

For example, as per the third serosurvey conducted by the ICMR, the expected infections in the country were 25.30 crores. The reported cases in India on 8 January 2021 were 1.04 crore. Hence, the underestimation factor was 25.30/1.04 = 24.33.

Considering the same underestimation factor, the total number of expected infections for 16 May 2021 was estimated. The total reported cases on 16 May were 2.524 crores. This number was multiplied by the underestimation factor to arrive at total expected cases of 61.40 crores.

Data were analyzed separately for the urban population and rural population of India.

For urban population, the number of fatalities reported in Delhi was taken as a basis. Here, the assumption is that fatalities are better recorded as compared to infections. The underestimation factor was calculated for Delhi. Based on newspaper reports that compared reported deaths to funerals, the underestimation factor for deaths comes out to be about 1.5. Assuming an infection fatality ratio of 0.30%, it was found that the expected infections in Delhi are 56% of the total population.

For urban populations across all states, it was assumed that the spread of infection will be at the same scale and hence 56% of urban population has already been infected. This estimate worked out to be 23.80 crores.

The expected infections of urban areas were deducted from the total expected infections (calculated using the ICMR approach) to arrive at the expected infections for rural areas. Therefore, the total rural infections were estimated to be 37.59 crores [i.e., 61.40 – 23.80]. This number was divided by the rural population to understand the percentage underestimation in rural areas.

Based on this analysis, the infection spread in rural areas was found to be about 39.9% **(see Annexure Table A2 & Table A3**).

Step 6: Population at risk

Individuals who have not been vaccinated or have not been infected are considered as population at risk.

To arrive at the population at risk, the population who had either received the first dose of the vaccine or been infected with COVID-19 were deducted from the total population. To avoid double-counting, it was assumed that there is some degree of overlap across these two categories (vaccinated and previously infected) and adjusted for this. It was assumed that the percentage of vaccinated people in the total population and the percentage of vaccinated COVID-positive people are the same. The total COVID-19 cases were multiplied by the ratio of vaccinations to total population to arrive at this number.

Attack rate: The attack rate is the proportion of non-immune (or susceptible people) who will get infected over the course of a wave. An attack rate of 25% is assumed based on discussion with epidemiology experts.

Infected individuals: The product of the attack rate and population at risk provides the total number of people infected by COVID-19.

Probability of infection following vaccination: An observational study by Apollo hospitals finds that approximately 2.6% of persons are at risk of reinfection after vaccination[1]. The present assumptions (attack rate of 0.25 * 10% of vaccinated population at risk of reinfection) are consistent with this finding.

Symptomatic persons: Not all people who are infected develop symptoms. It was assumed that 5%, 20% and 40% of infected people across 0-18, 18-45 and 45+ age groups respectively, would show symptoms. This distribution was based on discussion with epidemiology experts.

Step 7: Disease severity and symptomatic persons

Severity of disease: It was assumed that based on age, the percentage of people experiencing mild, moderate or severe disease would vary. It was assumed that those with moderate disease would require oxygen beds and those with severe disease would require ICU beds. This distribution was based on discussion with epidemiology experts.

Table 1. Distribution by severity of disease across age groups

	0 – 18 years	**18 – 45 years**	**45 +**
Mild	97.5%	90%	80%
Moderate - need oxygen	2.0%	8%	15%
Severe-need ICU care	0.5%	2%	5%

Those in the age group of 45+ years are at the highest risk of developing moderate or severe disease.

Step 8: Estimating oxygen and bed demand

It was assumed that these cases would be distributed over a period of two months and applied the normal distribution formula to arrive at the peak bed requirement. It was assumed that moderate cases would only require oxygen beds, whereas severe cases would require ICU Beds.

Total oxygen bed requirement at the peak of third wave was assumed to be 3 days per patient for ←18 years, 6 days per patient for 18 - 45 years and 9 days per patient for above 45 years.

Total ICU bed requirement at the peak of third wave was assumed to be 5 days per patient for ←18 yeas, 7 days per patient for 18 - 45 years and 10 days per patient for above 45 years.

For moderate disease we assumed that low-flow oxygen beds would be needed, whereas high-flow ICU beds would be needed for severe patients.

Table 2. Oxygen requirement

Oxygen requirement	Flow (LPM)	FiO2	Effective Oxygen needed (LPM)
Oxygen beds	10	75%	7.5
ICU Beds	30	100%	30

It was further assumed that 5% of patients who require ICU beds would need oxygen at home at 5 LPM and 40% FiO2.

Table A1. Duration between waves and vaccinated population

State & UT	Percentage recd. 1st Vaccine (16 May)		Duration between 1st & 2nd Wave Peak (days)	Our Assumption for duration between 2 waves	Percentage expected to rec. 1st Vaccine			Total Vaccinated population for 1st Dose
	18 - 45	45+			0 - 18	18 - 45	45+	
ANDAMAN & NICOBAR	6	99	260	180	0%	90%	100%	75%

ANDHRA PRADESH	4	32	261	180	0%	30%	100%	41%
ARUNACHAL PRADESH	9	53	235	180	0%	90%	100%	58%
ASSAM	4	29	259	180	0%	31%	100%	34%
BIHAR	3	24	265	180	0%	18%	69%	20%
CHANDIGARH	1	49	238	180	0%	14%	100%	18%
CHHATTISGARH	4	69	213	180	0%	25%	100%	34%
DADRA & NAGAR HAVELI	5	35	256	180	0%	16%	91%	23%
DAMAN & DIU	9	94	na	180	0%	46%	100%	43%
DELHI	13	59	150	150	0%	100%	100%	71%
GOA	8	62	246	180	0%	78%	100%	68%
GUJARAT	6	55	154	150	0%	32%	100%	52%
HARYANA	7	49	233	180	0%	39%	100%	40%
HIMACHAL PRADESH	4	81	164	150	0%	55%	100%	52%
JAMMU & KASHMIR	5	67	237	180	0%	48%	100%	42%
JHARKHAND	3	30	235	180	0%	16%	68%	21%
KARNATAKA	3	45	211	180	0%	34%	100%	42%
KERALA	5	51	214	180	0%	50%	100%	56%
LADAKH	15	99	192	180	0%	73%	100%	59%
LAKSHADWEEP	10	100	na	180	0%	93%	100%	79%
MADHYA PRADESH	3	36	216	180	0%	15%	74%	23%
MAHARASHTRA	5	41	213	180	0%	36%	100%	43%

MANIPUR	6	30	218	180	0%	39%	100%	40%
MEGHALAYA	6	39	229	180	0%	40%	100%	33%
MIZORAM	6	75	253	180	0%	59%	100%	47%
NAGALAND	6	38	244	180	0%	31%	100%	32%
ODISHA	3	40	222	180	0%	24%	92%	35%
PUDUCHERRY	7	36	229	180	0%	31%	96%	42%
PUNJAB	5	34	233	180	0%	34%	100%	42%
RAJASTHAN	5	62	159	150	0%	30%	100%	34%
SIKKIM	7	100	275	180	0%	52%	100%	47%
TAMIL NADU	3	18	298	180	0%	40%	100%	49%
TELANGANA	3	42	254	180	0%	35%	100%	42%
TRIPURA	6	92	256	180	0%	100%	100%	57%
UTTAR PRADESH	2	21	224	180	0%	13%	53%	16%
UTTARAKHAND	7	61	230	180	0%	55%	100%	47%
WEST BENGAL	3	31	204	180	0%	22%	83%	31%

Source: CDRI analysis

Table A2. Underestimation of COVID-19 cases

State & UT	Rural Population	Total Expected Rural Infections	Total Rural Infections	Urban Population	Total Expected Urban Infections	Total Urban Infections	Total Expected Infections	% Infections	Total Confirmed Cases
ANDAMAN & NICOBAR	2,36,314	0.399	94330	1,31,033	0.56	73378	1,84,645	50	6638
ANDHRA PRADESH	3,34,93,072	0.399	13369475	1,68,64,877	0.56	9444331	2,52,14,243	50	1454052
ARUNACHAL PRADESH	13,36,102	0.399	533333	3,91,690	0.56	219347	8,48,438	49	22106
ASSAM	3,01,97,694	0.399	12054054	49,48,598	0.56	2771215	1,69,89,527	48	335023
BIHAR	11,17,62,599	0.399	44612428	1,42,38,076	0.56	7973323	6,05,95,737	48	657829
CHANDIGARH	1,09,821	0.399	43837	38,83,668	0.56	2174854	22,26,563	56	55987
CHHATTISGARH	2,22,19,910	0.399	8869551	67,27,341	0.56	3767311	1,42,29,356	49	919054
DADRA & NAGAR HAVELI	3,14,833	0.399	125672	2,74,963	0.56	153979	3,02,215	51	5613
DAMAN & DIU	62,048	0.399	24768	1,87,741	0.56	105135	1,34,350	54	4077

DELHI	4,86,698	0.399	194276	1,89,81,223	0.56	10629485	1,08,58,642	56	1398391
GOA	5,62,355	0.399	224476	9,24,177	0.56	517539	7,82,319	53	137418
GUJARAT	3,99,99,167	0.399	15966522	2,96,61,521	0.56	16610452	3,54,43,700	51	759754
HARYANA	1,92,04,713	0.399	7665971	1,02,45,851	0.56	5737677	1,47,80,043	50	701915
HIMACHAL PRADESH	68,24,184	0.399	2724019	7,61,614	0.56	426504	36,39,610	48	163786
JAMMU & KASHMIR	1,06,54,963	0.399	4253156	39,82,986	0.56	2230472	72,47,266	50	247952
JHARKHAND	2,99,04,898	0.399	11937179	94,69,556	0.56	5302952	1,93,83,404	49	318009
KARNATAKA	4,05,83,227	0.399	16199662	2,54,80,955	0.56	14269335	3,33,77,582	51	2242065
KERALA	1,71,16,918	0.399	6832583	1,56,23,935	0.56	8749404	1,68,08,750	51	2169370
LADAKH	2,03,650	0.399	81291	1,05,896	0.56	59301	1,55,188	50	16582
LAKSHADWEEP	12,482	0.399	4982	44,462	0.56	24898	30,776	54	4986

MADHYA PRADESH	6,11,47,406	0.399	24408293	2,33,45,348	0.56	13073395	4,18,64,101	50	737306
MAHARASHTRA	6,65,88,719	0.399	26580309	5,49,90,100	0.56	30794456	6,21,47,155	51	5405068
MANIPUR	24,53,109	0.399	979211	10,61,877	0.56	594651	17,49,675	50	40059
MEGHALAYA	30,30,330	0.399	1209621	7,61,374	0.56	426370	18,53,173	49	23966
MIZORAM	6,46,175	0.399	257934	6,86,419	0.56	384395	6,88,640	52	9068
NAGALAND	14,51,561	0.399	579422	5,92,028	0.56	331535	10,14,990	50	18349
ODISHA	3,74,88,782	0.399	14964448	75,04,955	0.56	4202775	2,18,54,031	49	633302
PUDUCHERRY	4,38,296	0.399	174955	9,44,776	0.56	529075	7,35,442	53	87749
PUNJAB	1,92,21,567	0.399	7672699	1,15,28,020	0.56	6455691	1,55,05,993	50	504586
RAJASTHAN	6,06,25,544	0.399	24199981	2,00,90,132	0.56	11250474	3,97,95,466	49	871266
SIKKIM	5,04,778	0.399	201493	1,67,990	0.56	94074	3,31,745	49	11480

TAMIL NADU	4,01,26,184	0.399	16017223	3,77,13,164	0.56	21119372	4,00,12,424	51	1631291
TELANGANA	2,27,71,686	0.399	9089805	1,44,85,654	0.56	8111966	1,88,33,809	51	532784
TRIPURA	29,70,674	0.399	1185808	10,53,539	0.56	589982	19,88,697	49	41894
UTTAR PRADESH	18,07,41,891	0.399	72146985	5,18,13,296	0.56	29015445	11,41,16,138	49	1628990
UTTARAKHAND	82,40,001	0.399	3289172	35,56,708	0.56	1991756	58,71,486	50	291005
WEST BENGAL	6,80,77,960	0.399	27174772	3,18,74,999	0.56	17849999	4,99,03,894	50	1152433
Total	**94,18,10,310**		**37,59,43,697**	**42,51,00,542**		**23,80,56,303**	**68,14,99,212**		**2,52,41,203.00**

Table A3 – Underestimation calculation

Assumptions	**The underestimation factor is same as in third serosurvey conducted by ICMR in Dec 2020-Jan 2021**
The reported cases by 8.1.21 - in Cr	1.04
Expected cases as per serosurvey - in Cr	25.30
At that time, the under-estimation factor was as per serosurvey	24.33
Reported cases–16 May 21- in Cr	2.524

Expected cases 16 May 21- in Cr	61.40
Underestimation factor in urban areas for deaths (Delhi)	1.50
Assuming same infections as in Delhi with Infection Fatality Rate of .30%	0.56
Cases in rural areas	37,59,43,696.52
% Of infection in rural area	39.9

[1] Hospitalization chances after COVID-19 vaccination are 0.06%: Apollo Hospital study | Hindustan Times

Table A4. Clustering of states based on the second wave

Observed month of second wave peak	Observed second wave peak	State & UT	Oxygen (MT) Requirement as per three scenarios		
			Optimistic	Business-as-usual	Challenging
Cluster 1 (Observed month of second wave Peak - April 15-30)	18-Apr-21	MAHARASHTRA	1101.2	1179.6	1947.1
	20-Apr	DELHI	78.6	143.4	167.6
	20-Apr	LADAKH	1.7	1.6	1.7
	22-Apr	DAMAN & DIU	1.9	2.9	3.8
	23-Apr	CHHATTISGARH	243.3	255.2	321.8
	24-Apr	DADRA & NAGAR HAVELI	6.3	7.4	8.1
	24-Apr-21	UTTAR PRADESH	2773.5	3076.1	3377.3
	25-Apr-21	MADHYA PRADESH	898.6	1075.4	1252.6
	28-Apr	JHARKHAND	525.0	567.7	610.4
	30-Apr	GUJARAT	586.1	656.6	830.4
	Total Oxygen (MT) Requirement as per Analysis done by CDRI		**6216.2**	**6965.9**	**8520.8**
Cluster 2 (Observed month	01-May-21	ANDAMAN & NICOBAR	1.1	2.8	4.1
	02-May-21	RAJASTHAN	564.4	632.1	657.2
	06-May	BIHAR	1635.7	1818.9	1997.7

of second wave peak–May 1 - 15)	07-May	GOA	5.8	11.7	15.6
	07-May-21	TELANGANA	319.5	342.4	503.9
	07-May-21	UTTARAKHAND	66.2	90.5	103.6
	08-May	PUNJAB	150.6	321.4	491.7
	09-May	CHANDIGARH	39.4	43.8	45.5
	09-May	HARYANA	247.9	266.3	334.8
	09-May	JAMMU & KASHMIR	79.9	108.8	124.3
	09-May	KARNATAKA	610.3	630.8	1040.8
	12-May	KERALA	316.9	348.3	564.4
	13-May	HIMACHAL PRADESH	28.0	66.4	79.6
	14-May-21	WEST BENGAL	1137.4	1344.7	1555.9
	Total Oxygen (MT) Requirement as per Analysis done by CDRI		**5203.2**	**6028.8**	**7519.1**
Cluster 3 (Observed month of second wave peak–May 15 - 31)	17-May-21	PUDUCHERRY	10.8	18.0	24.9
	18-May-21	NAGALAND	15.1	16.1	23.7
	19-May	TRIPURA	14.3	24.5	34.8
	20-May	ANDHRA PRADESH	809.5	989.6	1169.6
	20-May	MEGHALAYA	22.7	28.4	33.6
	21-May	TAMIL NADU	752.3	1124.3	1700.6
	21-May	ARUNACHAL PRADESH	26.5	27.5	18.5
	21-May	LAKSHADWEEP	0.4	0.3	0.4
	22-May	ASSAM	386.5	484.3	582.0
	25-May-21	MIZORAM	6.2	8.9	11.6
	25-May-21	ODISHA	390.7	633.6	876.2
	28-May	SIKKIM	3.0	4.7	6.3
	30-May	MANIPUR	29.5	32.7	46.5
	Total Oxygen (MT) Requirement as per Analysis done by CDRI		**2467.5**	**3392.9**	**4528.9**

Figure 4, Allocation matrix of industrial oxygen under the **optimistic scenario**

Source State	Total produced	Receiving States																												
		MH	GJ	KR	MP	DL	HR	UP	PB	TN	KL	CG	RJ	TL	AP	UK	J&K	CH	HP	BR	WB	JH	OD	AS	PY	AR	MN	ML	NL	TR
AP	**300**			120											180															
AS	**21**																							21						
CG	**400**				140							210		20							30									
GJ	**1597**		482		30			695			156		235																	
HR	**287**						172	20	65								30													
HP	**130**							40									50	20	20											
JH	**878**				33															210	110	527								
MH	**1226**	736			440									50																
OD	**457**														45								274	35		27	30	18	15	14
RJ	**120**							48					72																	
TN	**205**									123				57	25															
PY	**70**									60															10					
TL	**101**			40										60																
UP	**225**					25		200																						
UK	**305**							235	10							58														
WB	**200**							80													120									
Total Allocation	**6522**	736	482	160	643	25	172	1318	75	183	156	210	307	187	250	58	80	20	20	210	260	527	274	56	10	27	30	18	15	14
Total Demand		830	482	474	900	39	228	2682	123	665	260	243	508	315	785	58	80	40	20	1628	1130	525	387	385	3	27	30	18	15	14

Figure 5, Allocation matrix of industrial oxygen under the **challenging scenario**

Source State	Total produced	Receiving States																												
		MH	GJ	KR	MP	DL	HR	UP	PB	TN	KL	CG	RJ	TL	AP	UK	J&K	CH	HP	BR	WB	JH	OD	AS	PY	AR	MN	ML	NL	TR
AP	**300**			120											180															
AS	**21**																							21						
CG	**400**				190							210																		
GJ	**1597**		552		30			515	50		175		275																	
HR	**287**						172		65								50													
HP	**130**																52	20	58											
JH	**878**																			252	85	526	15							
MH	**1226**	735			440									50																
OD	**457**														45								274	19		19	33	25	16	25
RJ	**120**							48					72																	
TN	**205**									123				57	25															
PY	**70**									60															10					
TL	**101**			40										60																
UP	**225**					60		165																						
UK	**305**							167	55							83														
WB	**200**							80													120									
Total Allocation	**6522**	735	552	160	660	60	172	975	170	183	175	210	347	167	250	83	102	20	58	252	205	526	289	40	10	19	33	25	16	25
Total Demand		1675	726	904	1252	128	315	3285	463	1612	292	322	600	500	1145	96	124	45	72	1990	1548	610	872	582	17	19	46	29	24	34
Deficit		940	174	744	592	68	143	2310	293	1429	117	112	253	333	895	13	22	25	14	1738	1343	84	583	542	7	0	13	4	8	9

(green)	Oxygen retained by states to meet their own demand
(white)	Existing Supply Linkages
(yellow)	New Supply Linkages

Annexure 2: International experiences

Around the world, governments, industries and civil societies are working together to manage the COVID-19 pandemic. Recent experiences in varied situations, especially from emergency health facilities and oxygen supply, provide valuable lessons that can improve the preparedness for future waves of the pandemic. This annexure summarizes such experiences that support the recommendations in the main document.

Oxygen production and supply

Reports suggest that one in five COVID-19 patients require oxygen therapy. This has led to substantial increase in the demand for medical-grade oxygen throughout the world. While some countries have managed to meet this increased demand for oxygen, several countries have faced enormous crises leading to significant increase in mortality of COVID-19 patients. To mitigate oxygen crises, countries have resorted to several measures such as – diversion of industrial oxygen for medical use, ramping up of the production capacity, use of concentrator, speeding up the transportation channels, etc. However, due to the complex nature of oxygen production, supply, and management at hospital level, countries faced diverse challenges. The following international experiences, briefly highlight various steps that were critical in addressing the challenges around oxygen production and supply chain:

- **Increased generation and efficient monitoring of oxygen in Kerala:** The Indian state of Kerala has significantly scaled-up production of oxygen in the last year[16] as a preparedness measure for COVID-19. With the new 149-tonne Inox plant at Kanjikode, Kerala has now become the only oxygen surplus state in the country during the second wave. Kerala has also been a trendsetter exploiting industrial sources to increase production capacity and provide to neighboring states. For example, oxygen produced at Kochi refinery and Kochi shipyard has combined generation of 8.45 MT/day.

[16] From 50 liters per minute in April 2020 to 1250 liters per minute in April 2021; ←Accessed on 20/05/2021→
'Did Kerala Anticipate the Medical Oxygen Crisis Last Year? Here's How the State Managed its Supply', 23 April 2021 (https://www.news18.com/news/india/did-kerala-anticipate-the-medical-oxygen-crisis-last-year-heres-how-the-state-managed-its-supply-3671612.html)

Additionally, a public sector company Kerala Minerals and Metals Ltd. plant, set up in September 2020, is generating 7 MT/day[17]. Along with increased generation, Kerala has also set up "Oxygen war room" for real-time monitoring of demand, supply and consumption of oxygen. With use of digital technology, the oxygen war room facilitates real-time tracking of oxygen tankers, cylinders, refillers and patients in need. (Comment: Please check if a hyperlink is missing in footnote 10.)

- **Ethiopia's oxygen production from Textile Industry:** Setting the example for local-level solutions in smaller towns and villages, Velocity Apparels, a denim factory in Ethiopia, is working with the local health authority, to scale up its production of oxygen used in bleaching, for supply to nearby hospitals and health care facilities[18]. The industry is being incentivized to set up oxygen plants with cheaper land and long-term purchase agreement with hospitals.
- **Oxygen production at sugar factory in Maharashtra, India[19]:** As a response to the ongoing pandemic, sugar factories in Maharashtra have come forth to produce medical grade oxygen. The production of medical-grade oxygen at Dharashiv Sugar Factory, is an ongoing pilot project in Osmanabad district, Maharashtra. Through an indigenous technology, tested at a smaller scale, the plant is in the process of retrofitting its existing ethanol distillation columns to separate oxygen from atmospheric air at approximately 95% purity. The project is planned to be completed by 21 June 2021. At present, the plant can deliver a daily output of 200 cylinders at $7m^3$ each. With the improvement of pneumatic technologies, the plant will be able to deliver a daily output of 500 cylinders. The pilot project is an example of low-cost, short-term adaptive reuse of existing industrial machinery to produce medical-grade oxygen and has the potential to be scaled to sugar plants that have ethanol distillation processes across the country. With this solution, sugar factories in states such as Uttar Pradesh, Maharashtra and Karnataka that account for about 79% of the sugar

[17] How Kerala became an oxygen-surplus State in one year', May 1, 2021 ←Accessed on 20/05/2021→ (https://www.thehindubusinessline.com/news/national/how-kerala-became-an-oxygen-surplus-state-in-one-year/article34452802.ece)
[18] Stein F, Perry M, Banda G, et al. 'Oxygen provision to fight COVID-19 in sub-Saharan Africa'. BMJ Global Health Journal, May 2020
[19] Oxygen plant at Dharashiv Sugar factor inaugurated by CM, 14 May 2021 ←Accessed on 20/05/2021→ http://www.uniindia.com/oxygen-plant-at-dharashiv-sugar-factory-inaugurated-by-cm/west/news/2395516.html→

produced in India, have the potential to service the demand for oxygen in their own as well as neighboring states.

- **Mumbai Model of Oxygen Distribution[20]:** The Municipal Corporation of Greater Mumbai (MCGM) has devised an innovative oxygen distribution system. The system works on a hub-spoke model for better efficiency, where six strategic points are identified within 30-minutes travel time from the hospitals. The strategic points are equipped with 6 vehicles with 25 jumbo cylinders each. These sites also host an emergency capacity of 26-kilo litres of LMO. Hospitals are instructed to generate alerts at least four hours before oxygen exhaustion for timely replenishment. In addition, each ward has two officers assigned exclusively to look after oxygen problems in their jurisdiction. In anticipation of the third wave, MCGM is planning to install self-generating oxygen plants in all hospitals which will cater to 100% demand and an additional demand surge of 50%, if required.
- **Kenya's hub-and-spoke model of oxygen production and distribution:** Kenya's Siaya County has partnered with social enterprise Hewatele by providing land for the construction of an oxygen plant. The enterprise supplies oxygen at subsidized rates to the county hospital and trains health care workers on the handling and bottling of oxygen[21]. The supply chain network has been devised as a hub and spoke model, to optimize the transportation process. This has resulted in supply of oxygen to nearby rural health care facilities at 30% cheaper rates due to reduced transportation costs.
- **Odisha's model of dedicated 'green corridors' for oxygen transportation:** Odisha has led the way in transporting more than 10,000 tonnes of oxygen to 11 Indian states including Delhi[22]. This has been possible through dedicated interstate 'green corridors[23] involving state road transport and zonal railways departments.

[20] Judicious distribution helps seamless supply of oxygen in Mumbai, The Hindu Businessline, 14 May 2021 ←Accessed on 20/05/2021→ https://www.thehindubusinessline.com/news/national/judicious-distribution-helps-seamless-supply-of-oxygen-for-maharashtra/article34551960.ece
[21] Stein F, Perry M, Banda G, et al. 'Oxygen provision to fight COVID-19 in sub-Saharan Africa'. BMJ Global Health Journal, May 2020
[22] Odisha dispatches more than 10,000 tonnes of oxygen to 11 states including Delhi', The News 21, 12 May 2021 ←Accessed on 20/05/2021→ https://thenews21.com/odisha-dispatches-more-than-10000-tonnes-of-oxygen-to-11-states-including-delhi
23 A green corridor is a dedicated and congestion-free special route created for medical emergencies like transplantation of organs to reach the destined hospital.

- **Nigeria's experience of reducing wastage and increasing efficiency regarding oxygen usage[24]:** Experts underline that by training medical staff and technicians for efficient use of oxygen, 20-25% wastage of medical oxygen at the hospital level can be avoided. Experience in Nigeria suggests that this can be achieved by improving use of pulse oximeter and oxygen, deployment of biomedical engineers to optimize oxygen systems. These lessons are even more relevant in the Indian context, as oxygen generation capacity is being increased many folds, demand for trained staff for oxygen management at all levels will rise. To develop a pool of 'oxygen technicians' contents have been developed in line with WHO guidelines.
- **Constraints of pipeline capacity in UK-NHS hospitals**: Generally, hospitals in the UK are designed with on-campus storage for liquid oxygen, from where the gaseous oxygen is supplied to patients through well-integrated oxygen pipeline. When demand increased, the tanks could be refilled more frequently, and hospitals did not face challenges of availability of oxygen. However, when cases rose, hospitals also expanded their bed capacity, requiring additional oxygen outlets. As the pipelines were designed with a given capacity of oxygen, additional outlets created situations of pressure drop between inlet and outlet points, creating a challenge that oxygen of sufficient pressure may not be available to patients. This constraint poses a challenge that number of oxygen beds in a hospital with pipelines connection cannot be increased unrestricted. Given the smaller size of the UK and other European nations, they are likely to have a better-managed oxygen supply chain.
- **Reliable oxygen supply in remote hospitals with oxygen concentrators in Gambia[25]**: A 42-bed hospital in the Gambia has managed to ensure uninterrupted oxygen supply for eight years straight, using oxygen concentrators. Oxygen cylinders were replaced with oxygen concentrators as the primary source of oxygen. An uninterruptable power

[24] Improving hospital oxygen systems for COVID-19 in low-resource settings: Lessons From the field, Global health: Science and practice, December 2020. https://doi.org/10.9745/GHSP-D-20-00224

[25] Implementation and 8-year follow-up of an uninterrupted oxygen supply system in a hospital in the Gambia. International Journal of Tuberculosis and Lung Diseases, 2016;20:1130–4. < https://europepmc.org/article/PMC/4937752>

supply (UPS) ensured continuity of power. The hospital staff was trained on the use of the new system. Post eight years of installation, assessment highlights saving of at least 51% of oxygen supply costs compared to cylinders. The users found the concentrators more reliable and convenient than cylinders.

- **Solar-powered oxygen supply system[26]:** In Uganda, a pilot project for the solar-powered oxygen plant has been successfully tested. Researchers speculate that further improvement can help in solving the oxygen problem in a low-resource setting in remote areas where power and other resources are not accessible.

Preparing for surge capacity–creating emergency healthcare facilities

The case studies presented below provide insights on preparatory actions for addressing the surge demand of patient care facilities in the event of a third wave of COVID-19 in India.

- **Temporary set up of COVID-19 field hospitals in the UK as "ultimate insurance policy"[27]:** As part of the COVID-19 pandemic response, temporary hospitals were set up in the United Kingdom. A network of emergency Nightingale hospitals was set up to cope with the predicted surge of COVID-19 cases by the National Health Services (NHS). In London, a 4000-bed facility was created at the ExCel Centre. The project was executed in 9 days with the support of military engineers. The field hospitals were never used at a large scale in the past due to limitations in deploying a large field staff for operations. However, they were considered the "ultimate insurance policy" in case existing health care systems were overwhelmed.
- **Lessons from large field hospitals in the USA[28]:** Several countries have set up large field hospitals to serve the increased caseloads. In setting up 17 field hospitals of

[26] Solar-powered oxygen delivery: proof of concept. The International Journal of Tuberculosis and Lung Disease, 20(5), pp.696-703. http://dx.doi.org/10.5588/ijtld.15.0796

[27] Covid-19: Nightingale hospitals to close from April, BBC, 8 March 2021 <Accessed on 20/05/2021> https://www.bbc.com/news/health-56327214

[28] U.S. Field Hospitals Stand Down, Most Without Treating Any COVID-19 Patients, 7 May 2020, < accessed on 28/05/2021> https://www.npr.org/2020/05/07/851712311/u-s-field-hospitals-stand-down-most-without-treating-any-covid-19-patients

varying sizes with a cumulative capacity of 14,827 beds (some hospitals never completed), about ₹ 4,500 crores were spent. Till the report, these hospitals have treated 1,177 patients only. It was observed that setting up large field hospitals is time-consuming and could not be planned properly with rising in caseloads. Under normal circumstances, the field hospitals borrow workforce from existing hospitals. So, though the infrastructure was created, medical professionals could not be borrowed from already resource-stressed hospitals. The scarcity of trained medical professionals for these hospitals was the main constraint leading to underutilization. Some hospitals preferred to increase their capacity with the repurposing of other departments and repurposing of adjacent buildings.

- **NGOs and private organizations' collaborative approach to set up a makeshift hospital in India**[29]: A fully functional, temporary 200-bed capacity facility was set up within four days in Delhi to provide free medical care to COVID-19 patients. Manned by a team of 10 doctors and 18 nurses, the temporary hospital was established in a college through a partnership between Bada Business Private Limited, a private entity and ISKCON, a religious sect. It is an example of how partnerships could be formed to set up health care facilities in addition to government facilities.

[29]Bada Business and ISKCON setup 200-bedded makeshift hospital for COVID-19 patients, Express Healthcare, 8 May 2021, <Accessed on 20/05/2021> https://www.expresshealthcare.in/news/bada-business-and-iskcon-setup-200-bedded-makeshift-hospital-for-covid-19-patients/428522/

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Annexure 3: Experts consulted

The CDRI humbly thanks the following experts, affiliated organizations, and Member Countries for their valuable feedback, advice and guidance during preparation of this report:

Date of Discussion	Name	Designation and Affiliation
14 May 2021	Dr. Vasant Matsagar	Professor, Department of Civil Engineering, IIT Delhi
14 May 2021	Dr. Sreedevi Upadhyayula	Professor, Department of Chemical Engineering, IIT Delhi
14 May 2021	Dr. Varun Ramamohan	Assistant Professor, Department of Mechanical Engineering, IIT Delhi
14 May 2021	Mr. Mukesh Kumar Surana	Chairman and Managing Director, Hindustan Petroleum Corporation Limited
14 May 2021	Dr. Jacob John	Professor, Department of Community Health, CMC, Vellore
17 May 2021	Dr. P.R. Swarup	Director General, Construction Industry Development Council
17 May 2021	Mr. Ajay Kolge	Chief Engineer, Dharashiv Sakhar Karkhana Ltd., Chorakhali, Osmanabad, Maharashtra
18 May 2021	Mr. Hans- Peter Teufer	Director International Programs, The UPS Foundation, USA
18 May 2021	Mr. S Bharathan	ED, Research and Development Head, Hindustan Petroleum Corporation Limited
23 May 2021	Dr. Anand Krishnan	Professor, Centre for Community Medicine, AIIMS, Delhi
23 May 2021	Ms. Amrita Agarwal	Vice President, Group Strategy, Mahindra Group
23 May 2021	Mr. Kamal Kishore	Member, National Disaster Management Authority, Delhi

27 May 2021	Ms. Ramani Moonesinghe	National Clinical Director for Critical and Perioperative care, NHS England and NHS Improvement, United Kingdom
27 May 2021	Ms. Gemma Hagen	Chief People Officer, National Health Service, United Kingdom
27 May 2021	Ms. Tara Sood	Consultant, Emergency Medicine, Royal Free London NHS Foundation Trust, United Kingdom
27 May 2021	Dr. Sudhakar Shinde	Chief Executive Officer, State Health Agency, Maharashtra

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