



## Solid Waste Management and Material Recovery Facility Planning in Leh-Ladakh, Western Himalaya

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**ABSTRACT:** Rapid urbanization, tourism growth, and changing consumption patterns have significantly increased solid waste generation in Leh Ladakh, a high-altitude cold desert region of India. This study examines the existing status of waste generation, segregation, and disposal practices in Leh, the largest town in Ladakh, and assesses the feasibility of establishing a Material Recovery Facility (MRF). Field-based inventory, secondary datasets, and the Solid Waste Management (SWM) Manual 2016 were used to estimate waste quantities and design MRF requirements. Results indicate that Leh generates approximately 13.02 tonnes per day (TPD) of solid waste, with 80% comprising dry waste and 20% wet waste. The dry fraction includes paper and cardboard (30%), tetra packs (20%), textiles (17%), PET (8%), and multilayer plastics (7%). Currently, segregation and limited recycling occur at a municipal facility powered by solar energy. However, the absence of a formal MRF, shortage of equipment, and lack of skilled manpower remain key challenges. The study proposes a manual MRF model suitable for <15 TPD, with an estimated operational cost of Rupees 3.06 lakh per annum. Establishing such a facility would improve recycling efficiency, reduce environmental risks, and promote sustainable waste management in this ecologically fragile Himalayan region.

**KEYWORDS:** Solid waste management, Material Recovery Facility, waste segregation, recycling, Ladakh

### 1. INTRODUCTION

Solid waste management is the process of collecting, transporting, processing, recycling, and safely disposing of solid materials that are no longer useful. The aim is to protect public health, reduce environmental pollution, and make efficient use of resources (Hoorweg & Bhada-Tata, 2012). Waste can come from households, industries, agriculture, and construction (Sharholi et al., 2008). Modern SWM emphasizes waste segregation at the source, recycling, composting, energy recovery, and reducing the amount of waste sent to landfills (Ahmed & Alam, 2013). A Material Recovery Facility is a specialized plant where collected waste is sorted, separated, and processed to recover useful materials such as plastics, paper, metals, and glass (EPA, 2020). MRFs play an essential role in recycling systems by ensuring that valuable resources are diverted from landfills and reintroduced into the economy. They can be manual, semi-automated, or fully automated, depending on the technology used. By recovering materials, MRFs support sustainable resource management, reduce greenhouse gas emissions, and create opportunities for a circular economy (Hoorweg & Bhada-Tata, 2012). The high-altitude regions of Leh, Ladakh, present unique challenges for waste management due to their fragile mountain ecosystem, harsh climatic conditions, limited infrastructure, and increasing tourism pressure (Kumar et al., 2017; Singh & Kumar, 2020). In recent years, rapid urbanization and a growing tourist population have significantly increased the generation of municipal solid waste, particularly plastics and packaged food waste, which are difficult to manage in such remote areas (Mihai et al., 2020; Vinti et al., 2022). Leh town, the administrative headquarters, generates significant quantities of waste, which, if not managed properly, can cause ecological degradation and public health concerns (Gondhalekar et al., 2014). Studying SWM in Ladakh is therefore crucial to protect its ecologically sensitive environment, maintain its cultural and touristic value, and ensure long-term sustainability. Developing context-specific solutions such as decentralized waste treatment, material recovery facilities, and community participation can serve as models for other remote and mountainous regions (Khanday et al., 2024). Currently, the Leh Municipal Committee manages waste through limited segregation, composting of organic materials, and rudimentary recycling of plastics and metals. However, a formal Material Recovery Facility (MRF), which enables systematic sorting, baling, and storage of recyclables, has not yet been established. According to the SWM Rules 2016, MRFs are essential for ensuring circular economy practices and minimizing landfill dependence (MoEFCC, 2016). This paper evaluates waste generation and composition in Leh and proposes an operational framework for a manual MRF tailored for <15 TPD waste processing capacity.

## 2. STUDY AREA

Ladakh, a Union Territory of India, covers an area of 59,146 km<sup>2</sup> and comprises two districts: Leh and Kargil. Leh district, spanning 45,110 km<sup>2</sup>, is one of the largest in India. It extends from 32°15' to 36°00' N latitude and 75°15' to 80°15' E longitude, with an elevation ranging between 2,300 and 6,000 meters above sea level. According to the 2011 Census, Leh had a population of 133,487, which is estimated to have grown to 152,175 by 2021 (Census of India, 2011). Approximately 34.2% of the population resides in urban areas, with Leh town alone housing 45,671 residents. Seasonal influx from tourism, defense establishments, and educational institutions further adds to population variability and increases waste generation.

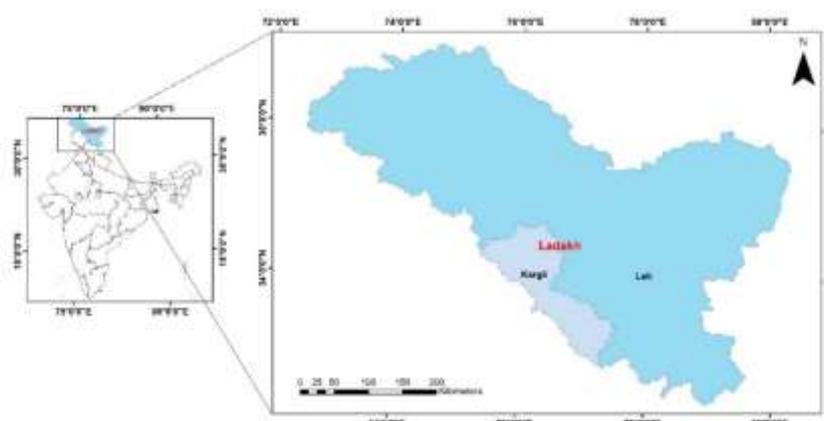


Fig 1: Map of Ladakh

Table No. 1: Population Details

District	Population (2011)	Population (2020 est.)	percentage
Leh	133,467	152,175	48.67
Kargil	140,802	160,514	51.33

## 3. METHODOLOGY

### 3.1 Collected Information

A 30 tonnes per day (TPD) sanitary landfill is currently under development near Leh, with completion expected by the end of 2021. Adjacent to this site, the Leh Municipal Committee (LMC) has established a waste sorting facility to manage daily solid waste. Waste is collected through a stationary container system, and municipal trucks transport the waste to the facility approximately ten times per day.

At the sorting yard, waste is segregated into biodegradable and non-biodegradable fractions. Biodegradable waste is directed for composting, while non-biodegradable waste, including plastics, textiles, metals, and e-waste, is manually sorted by a team of 10-12 workers. Among the recyclables, PET plastics are transported to recycling units in Kashmir, whereas multilayer plastics (MLP) are shredded on-site. The facility is also equipped with a Black HOLE plasma pyrolysis machine, which decomposes MLP and other complex waste into ceramic ash, a by-product suitable for road construction. However, certain waste fractions, particularly Tetra Pak and cardboard, remain problematic due to the lack of viable recycling or reuse pathways in the region.

### 3.2 Site Characteristics

- Location: Approximately 4 km from Leh town
- Energy Source: Entire facility operates on a 100-kW solar photovoltaic system
- Waste Intake: Minimum 7-8 TPD, maximum 12-15 TPD
- Total Area: 5,000 m<sup>2</sup>
- Tipping and Sorting Area: 1,728 m<sup>2</sup>
- Infrastructure: Includes compartments for category-wise storage, an office space, a kitchen, and a toilet facility for staff

### 3.3 Categories of Waste Segregated and Stored

The facility manages and stores a wide range of non-biodegradable wastes for recycling or further treatment, including: Multilayer plastics, tetra pack, cardboard, Hard plastics, metals, PVC, PET bottles, clothes, textiles and glass items etc.

This facility represents an important intermediate step in formal solid waste management in Leh, integrating solar-powered technology and innovative plasma pyrolysis treatment with traditional segregation and composting methods. Nonetheless, the absence of solutions for certain high-volume waste streams, such as Tetra Pak and cardboard, remains a major limitation for achieving a comprehensive circular waste management system in the Himalayan region.



Fig 2: Sorting and tipping point



Fig 3: Trommel Machine

## 4. RESULTS

According to the Census of India (2011), Leh district recorded a population growth rate of 13.5%. By 2021, the estimated population of the district reached approximately 152,175 individuals, with 34.21% residing in urban areas and 65.79% in rural settlements. This translates to about 52,064 people in urban centres and nearly 100,116 people in rural villages. Notably, solid waste collection and management services are currently limited to urban areas, as handled by the Leh Municipal Committee, while rural settlements lack formal waste management infrastructure (Census of India, 2011; LAHDC-Leh, 2020).

The uneven provision of waste management services highlights a significant challenge for sustainable urban planning in the Indian Himalayan region, Leh. With rising urbanization, unmanaged rural waste poses risks of environmental pollution, affecting fragile mountain ecosystems and local water resources (Thakur et al., 2021).



#### 4.1 Waste Generation

According to the Solid Waste Management (SWM) Manual, 2016, the per capita waste generation rate for towns producing less than 15 tonnes per day (TPD) is estimated at 0.21 kilograms per person per day (MoUD, 2016).

Total Quantity of waste generated =  $52064 \times 0.21 / 1000$   
 = 13.016 TPD

Total wet fraction = 20% Total dry fraction = 80%

Total dry waste = 10.5 TPD

#### 4.2 Dry Waste Fraction

**Table No. 2: Total dry waste composition (Data from site)**

Recyclable waste	Percentage	Waste kg	Density Kg/m <sup>3</sup>	Volume m <sup>3</sup>
Paper + Cardboard	30	3120	500	6.24
Tin cans	3	312	90	3.466666667
Tetra pack	20	2080	84	24.76190476
MLP	7	728	32	22.75
PET	8	832	29	28.68965517
Glass	6	624	300	2.08
Cloths rags + textile	17	1768	117	15.11111111
HDPE	4	416	25	16.64
Total recyclables	95	9880	1177	119.7393377
RDF	5	520		

##### 4.2.1 Storage and Handling of Recyclable Materials

In order to prevent odor and maintain hygienic conditions, baled, wrapped, and compacted recyclables should be stored in 20-foot color-coded containers within a designated storage yard. The facility must be equipped with a sufficient number of such containers to accommodate a 15-day storage capacity of sorted materials. To ensure smooth logistics, a minimum clearance of 5 meters with all-around road access should be maintained, allowing for easy movement of trucks (MoUD, 2016; CPCB, 2020).

The storage yard should be planned to hold containers for the following categories of dry waste:

Glass, Aluminum, Metal, Tetra Pak, Hard plastic, PET bottles, Mixed plastics, Thermocol and Styrofoam, Cloth, rags, textiles, leather, rubber, Paper and cardboard etc

##### 4.2.2 Material Recovery Facility (MRF)

As per the SWM Advisory Manual on Material Recovery (MoUD, 2016), a manual MRF system is considered most suitable for towns generating less than 15 tonnes per day (TPD) of solid waste.

The major components of a Manual MRF include:

1. Tipping floor
2. Manual sorting section
3. Baling unit
4. Storage yard

##### 4.2.3 Plant Design and Capacity

Based on the assessed waste generation data, the total dry waste received by the plant is approximately 10,088 kg/day, corresponding to a volume of 120 m<sup>3</sup>/day. For a 15-day storage requirement, the total storage volume is estimated as:

$$15 \times 120 = 1,800 \text{ m}^3$$

This storage capacity translates into an area of approximately 30 m × 12 m × 3 m. Additionally, the actual tipping and sorting area required for plant operations is calculated to be 48 m × 36 m = 1,728 m<sup>2</sup>.

Such a facility design ensures efficient handling, segregation, and temporary storage of recyclables, thereby enhancing resource recovery and reducing the environmental burden of unmanaged waste (CPCB, 2020; MoUD, 2016).

#### 4.3 Existing Waste Management Practices

- **Facility:** 30 TPD landfill (under construction)
- **Segregation:** Manual sorting by 10–12 workers
- **Technology:** Solar-powered (100 kW) sorting area; Black HOLE plasma machine for plastic decomposition
- **Gap:** Lack of MRF, baling equipment, weighing scales, and skilled operators.

#### 4.4 Equipment

Table No. 3: Available and unavailable equipment at the study location

Available equipment at site	Not Available equipment at site
Weighbridge	Weighing scale
Trommel	Push cart
Shredder	
Baler	
Trucks	

Table No. 4: Equipment's required at the site

Weighing scale	Material	Steel
	Weighing Capacity	10 TO 500 kg and above
	Use	Office, Industrial, Business
	Frequency	60 Hz
	Voltage	240 V
	Additional Detachable Display	With 6 Meter Cord
	Cost	Rs. 4500/unit
Push cart	Material	Steel
	Production Capacity	100 Litre Approx.
	Cost	Rs. 3500/Piece



4.5 Financial Assessment

Table No. 5: Equipment cost

Particulars	Nos	Unit Rate	Amount
Handcart	3	₹4500	₹13,500
Weighing scale	2	₹4500	₹9000
First aid kit	1	₹1000	₹1000
Sand buckets	4	₹150	₹600
CO2extinguishers	2	₹5150	₹10,300
<b>Total Equipment cost</b>			<b>₹34,400</b>

Table No. 6: Operation cost

Particulars	Unit	Quantity	Rate	Amount	Remarks
Manpower		10	₹15,000	₹150,000	Per month
Supervisor	Nos	2	₹18,000	₹36,000	Per month
Helpers/Loader	Nos	1	₹12,000		Per month
Security	Nos	1	₹15,000	₹15,000	Per month
<b>Consumables</b>					
Water	KL	15	₹100	₹2,250	Per month
MRFO&M				₹68,400	Per month
<b>Cost per annum</b>				<b>₹271650</b>	<b>Per year</b>

$$\begin{aligned} \text{Total cost} &= \text{Capital cost} + \text{Operational cost} \\ &= 34,400 + 271,650 \\ &= 306,055 \end{aligned}$$

5. DISCUSSION

The findings highlight that Leh produces a relatively small but compositionally complex waste stream dominated by packaging waste such as tetra packs, multilayer plastics, and PET bottles. While organic waste composting is in place, non-biodegradable fractions require systematic segregation and recycling. Manual MRFs are cost-effective and suitable for small towns (<15 TPD), requiring low capital investment compared to mechanized plants (Gupta et al., 2019).

However, major challenges include:

1. Lack of skilled workforce for scientific waste handling.
2. Seasonal spikes in waste generation due to tourism.
3. Absence of local recycling industries, necessitating transportation of recyclables to other regions (e.g., Kashmir for PET).

Integrating decentralized composting, community awareness, and public-private partnerships can strengthen Leh’s waste management system.

6. CONCLUSION

Leh faces growing solid waste management challenges driven by rapid urbanization, expanding tourism, and limited local waste-handling capacity. With daily waste generation estimated at approximately 13 TPD, the introduction of a manual Material Recovery Facility emerges as a technically feasible and financially sustainable solution for the region. Effective segregation, baling, and storage of recyclable materials can significantly reduce the burden on existing landfill sites while improving resource recovery. Beyond operational benefits, an MRF would support the long-term transition toward circular economy practices. An imperative for safeguarding the ecologically fragile Himalayan landscape. Strengthening institutional coordination, community participation, and awareness will further enhance the effectiveness and sustainability of solid waste management initiatives in Leh.



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