Importance of Lithium-Based Energy Storage in Achieving India's Climate Goals

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Abstract

Energy storage is the key for the effective integration of the upcoming stochastic renewable energy systems with the electricity grid and accelerating the adoption of electric vehicles. In order to meet the emission targets in 2030, the Indian electricity and transportation sectors require ~ 1650GWh of lithium battery based energy storage during 2020-30. With the present advancements in the technologies of Lithium-Ion battery, the transformation involving US$ 150-200 billion, requires ~330 kilotons of lithium, policy decisions in favor of investments in battery research, mass manufacturing capabilities, foreign collaborations, recycling facilities for environmental sustainability and purchasing of lithium assets abroad.

Introduction

With the objective of reducing the greenhouse gas emissions to an average of 5% below pre-industrial levels, the global investment in the clean energy technologies has reached US$ 2.6 trillion. Subsequent to the foundations of the United Nations Framework Convention for Climate Change (UNFCC) under the Kyoto protocol, the Copenhagen and the Cancun agreements, the 2015 Paris convention has set countries' minimum obligations, stronger transparency and accountability that hold the respective government accountable for their commitments. India has committed to increase its cumulative installed non-fossil-fuel-based electricity generation capacity in the national electricity generation portfolio to 40% by 2030 and reduce the emissions intensity by 35% from the 2005 levels, considering economic growth priorities, energy security and cleaner environment [1]. The increased use of renewable energy and early transition to electric mobility helps in achieving emission targets and reducing hydrocarbon imports. During the forth coming decade, the use of the lithium batteries are expected to play a major role in the realizing energy storage systems (ESS) in the energy sector, especially, in the power and transportation segments.

Lithium battery technologies

Subsequent to the foundation of the Lithium-ion (Li-Ion) battery laid during the 1970 oil crisis and introduction of the first commercial Li-Ion battery in 1985, Li-Ion battery technologies have developed and attracts significant attention in the energy storage applications because view of their superior energy density of 75-200Wh/kg, specific density of 150-315 Wh/l, cycle stability, efficiency and reliability (Table.1). Li-Ion battery technologies have made a strong footprint in portable electronics, renewable energy, smart electric grid, transportation sector, including road vehicles, green ships, aircraft and in niche segments, including space and subsea applications involving time-critical applications [2][3][4]. The Li-ion cells use lithium transitional metal oxides as cathode, graphite as anode and non-aqueous carbonated liquids as the electrolyte. The charge and discharge of the cell occurs through intercalation and de-intercalation of the lithium ions. During the charging process, lithium ions are transferred across the electrolyte from the anode host structure to the cathode electrode. The performance of the lithium cells vary significantly based on the electrode chemistry.

Table.1. Comparative details of the electrochemical batteries [2]

Type	Maximum size (MW)	Cycles at 80% DoD (x1000)	Expected useful life(Years)	Round-trip Efficiency (%)
Vanadium RFB	10	10-13	15-20	75-85
Zn-Br-RFB	2	5-10	5-15	72-80
Lead-acid	20-70	2-4.5	5-15	65-90
Li-ion	10	1.5-4.5	5-15	85-95
NaS	8	2.5-4.5	10-15	75-90

According to the World Intellectual Property Organization (WIPO) patent database, materials for energy storage are one of the most-researched areas. The matured materials for the cathode include lithium-nickel-manganese-cobalt (NMC), lithium–nickel-cobalt-aluminium oxide (NCA), lithium- manganese oxide (LMO) and the lithium iron phosphate (LFP). Graphite with improved structure is used as anode to enable faster charging rate and the lithium-titanate (LTO) is used in heavy-duty applications because of its capacity to extend cycle life. The use of solid polymer as the electrolyte and lithiated-carbon has greatly improved the safety of the li-ion cell [5]. The features of the matured Li-based cell technologies are shown in Table.2. The reliability and safety of the presently operating li-ion batteries are ensured by using battery management systems (BMS) that continuously monitor the health status of the individual cells including voltage, temperature and the charge status.

Tab.2. Matured Li-based technologies for this decade [5]

Feature	NMC-Graphite	NMC-LTO	LFP-Graphite
Specific weight	200 Wh/kg	100 Wh/kg	140 Wh/kg
Cost/kWh	US$ 150-200	US$ 450	US$ 320
CDC	2500 @ 1.5C with 80% DoD/ 500 @ 3 C	10,000@10C	

The recent developments in cathodic materials such as $LiFePO_4$ and $Li_4Ti_5O_{12}$ are expected to reduce the cost and increase safety. Reduction of cobalt content in the existing cathode chemistries aims to reduce cost and increase energy density, in combination with other anode technologies. The upcoming lithium metal cathodes are expected to improve the performance without relying on cobalt in combination with anodes made of silicon composites. Even though, research in Li-air and Li-sulphur battery are fast progressing, their technology readiness level is low, and hence may not be commercially available before 2030 [6].

Lithium batteries in the power sector

In the power sector, ESS are required for effective management of the demand shifts, peak reductions, frequency regulation, voltage support and renewable resources integration (Fig.1). The global investments in the ESS installed in the power sector has reached ~ US$ 1 trillion in 2019.

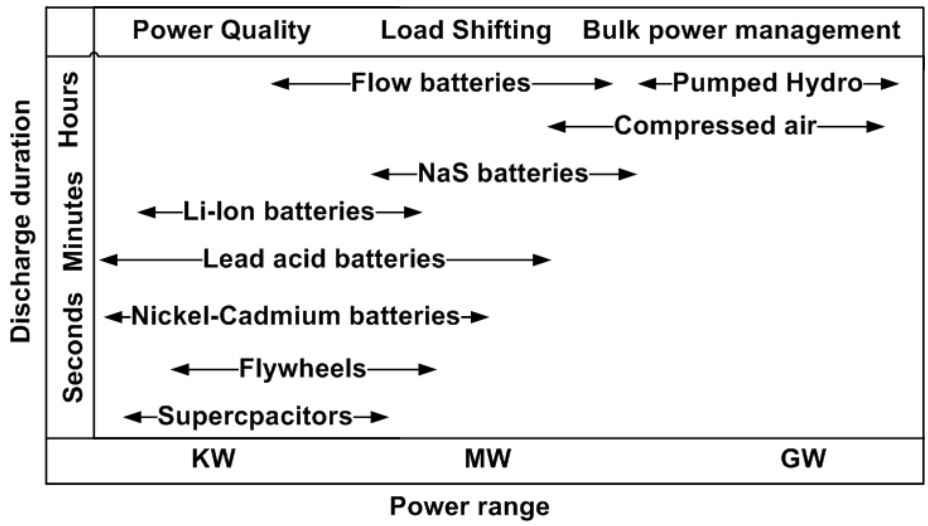


Fig.1. Categorization of ES technologies based on application

The capacities of the ESS (excluding pumped hydro) that are installed globally are shown in Table 3, in which the share of the electro-chemical based ESS is the highest. The United States tops the list with a cumulative installed capacity of ~570 MW distributed in 292 projects, followed by South Korea, Japan and Germany with 300, 250 and 120 MW, respectively [4][7]. The share of the different chemistries in the electro-chemical segment is shown in Fig.2.

Table.3. Global developments in ESS (non-pumped hydro) [7]

Technology	Number of projects	Combined capacity
Electro-chemical	1056	4GW
Thermal storage	225	3.7 GW
Electromechanical	74	2.6 GW
Hydrogen storage	14	21 MW
CAES	2	5 MW

Globally, Na-S, Li-Ion, Lead acid, Ni-Cd and flow chemistries share 59%, 21%, 13%, 5% and 2% of the electro-chemical based ESS capacities. However, the share of chemistries varies with the country based on the nature of the power system demand, domestic availability of the raw materials and prevailing policies. In China, Li-Ion, lead-acid and flow batteries share 74%, 17% and 9% respectively. In Japan, Na-S, Li-Ion, flow and lead-acid batteries share 48%, 38%, 8% and 4%, respectively. Li-Ion has a dominant position in China, whereas Na-S batteries are dominant globally, including Japan [8].

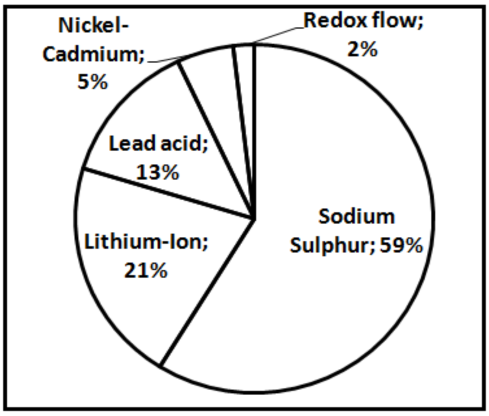


Fig.2. Share of different chemistries in electrochemical segment

In the Indian power sector, ~11% of the ESS is used for renewable firming up, 16% for power quality management and 73% for overcoming power blackouts and brownouts [9]. Under the determined effort scenario, (with a GDP growth rate, share of manufacturing in GDP and urbanization rate of 8.7, 1.13 and 0.7%/year, respectively), using NITI Aayog simulator IESS 2047, the cumulative renewable energy installed capacity, including wind and solar is expected to increase from ~60 GW in 2020 to 175 GW in 2030 (Fig.3) . Simulation results indicate that the cumulative ESS capacities of ~55 and 45 GW are required to bridge the gap in the energy and power requirements, caused by the increased integration of the stochastic renewable energy sources, including ~10,000 renewable distributed mini and micro-grids. Based on the predicted load profile, ~50GWh of energy balancing will be required by 2030 [10][11].

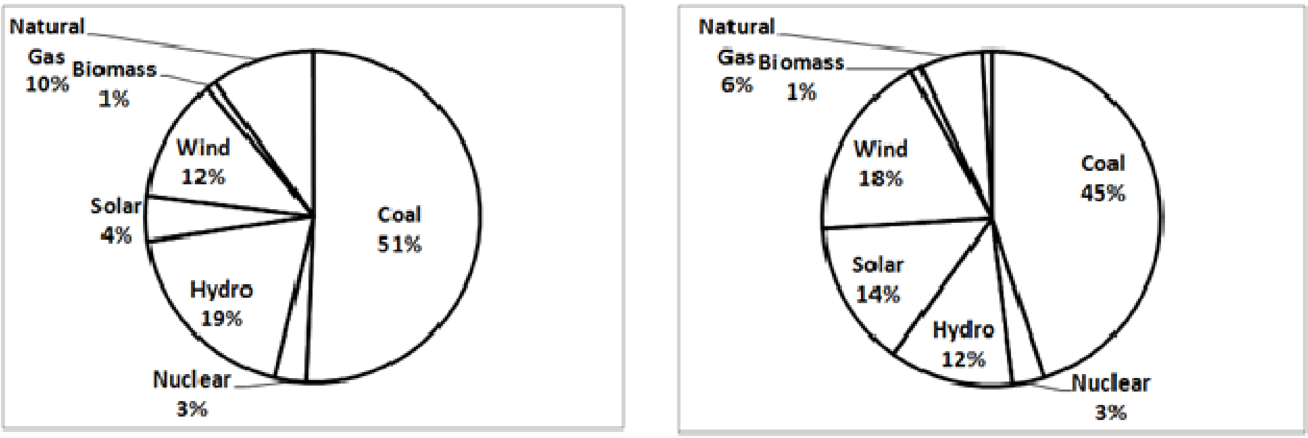


Fig.3. Electricity generation portfolio in 2019 and 2030

The cost-effective electro-chemical ESS is determined through, analysis using the World Energy Council cost model. The cumulative investments required till 2030 if the entire ESS is realized using specific electro-chemical batteries are plotted in Fig.4. The lead-acid batteries are found to be cost-effective, but lack efficiency, volume and weights. The Li-Ion chemistry is expected to be cost-effective compared to Na-S and Redox chemistries, till 2030.

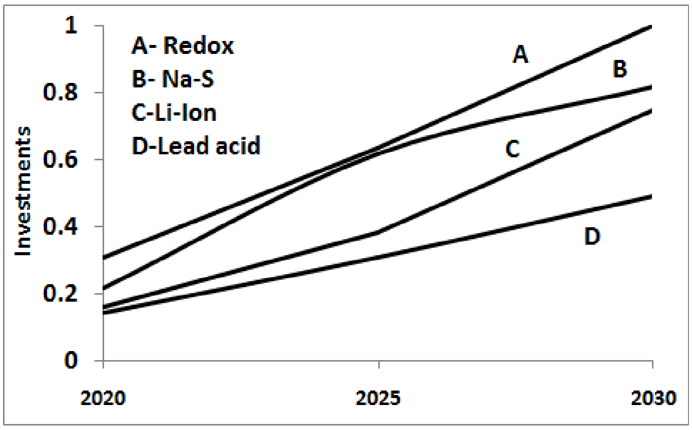


Fig.4.Cummulative investments for electro-chemical ESS

Lithium batteries in electric mobility

Considering the advantages of the electric mobility due to reduced emission, increased energy security and higher reliability because of reduced parts over ICE-based vehicles, the support and commitments from the policy makers and automotive industry is steadily increasing. Table.4 shows the share of the electric vehicles (EV) and the charging infrastructure in 2019. Further, promising growth could be expected from the prevailing zero emission vehicle (ZEV) mandates, fuel economy standards, fiscal incentives (upto 40% in several countries) and the regulations that are being enacted for establishing the charging infrastructure. The country-specific power generation mix and the carbon intensity of vehicle manufacturing determine the CO_2 intensity of the EV. According to the observations of the International Energy Agency (IEA) on the European automobile sector, the EV wheel-to-wheel (WTW) emissions were ~50% less than gasoline and ~40% less than diesel cars. Globally, in 2017, the EV-avoided emissions were ~30 $MtCO_2$ [12] Presently, the Shenzhen city in China has transformed its urban bus fleet of 16359 buses to all-electric models.

Tab.4. Electric mobility by country in 2019 [12]

Country	Percentage of global		
	Electric car stock (out of 3.1 million)	Slow chargers (out of 0.3 million)	Fast chargers (out of 0.11 million)
China	40 %	41 %	74 %
USA	24%	12%	6%
Japan	7 %	7 %	7 %
UK	4%	4%	2%
Germany	3%	7%	2%

In 2030, with the present EV policies in place, the projected share of the EV in China, Japan, US, Canada, India and global aggregate shall be 50, 37, 30,30 29 and 22 %, respectively. A number of local administrations have pledged to implement restrictions for prohibiting the access of Internal Combustion Engine (ICE-based) vehicles in certain areas. The global forecast for light duty EV, associated fuel saving, emission reduction and electricity demand by the battery charging systems on the electric grid, under the New Policy Scenario (NPS) and determined EV30 scenarios are shown in Table.5. By 2025, heavy duty electric trucks >15t that are announced for commercialization are expected to have a range of ~800 km [12].

Tab.5. Global forecast of light duty EV by 2030 [12]

Scenario	NPS	EV30
Sales	23 million	43 million
Stock	130 million	250 million
Fuel saving in 2030	2.5 MB/day	4.3 MB/day
Electricity demand	640 TWh	1110 TWh
Emission reduction	170 $MTCo_2$ eq	240 $MTCo_2$ eq

According to the World Health Organization (WHO), India is the home to 14 out of the 20 most polluted cities. Efforts to reduce the concentration levels pollutant to a safe level through the adoption of the EV has been initiated. The EV policies of India such as National Electric Mobility Mission Plan (NEMMP) 2020, Faster Adoption and Manufacturing of Hybrid & Electric Vehicles (FAME) and the National E-Mobility Programme targets 30% penetration of EV by 2030. The targets are defined considering the planned economic development, energy resource endowments, technological capabilities and political prioritization of responses to the climate change [13]. The forecast of the EV penetration in India and the battery capacity requirements in different modes of mobility are shown in Table.6.

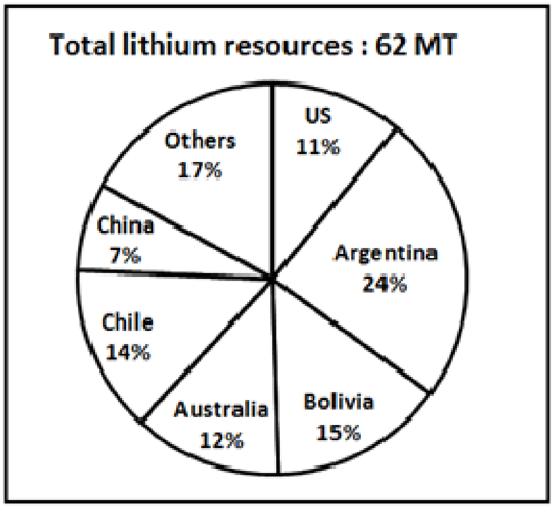
Tab.6. Forecast of electric mobility in India by 2030 [13]

Mode	Number of vehicles	Average Capacity/Vehicle	Total (GWh)
2 wheeler	200 million	1.8 kWh	360
4 wheeler	40 million	15 kWh	600
Bus	3 million	212 kWh	630
Total			**1590**

The key challenges for India in quick transition to electric mobility are the higher vehicle cost, lack of battery technology know-how, higher battery import cost, less local availability of the battery materials and the possible implication on the battery charging infrastructure in the electric grid. The establishment of charging infrastructure requires due attention for the existing conditions in India , which is evident from the global experiences, where 33% of all EV sales take place in only 14 cities where charging infrastructure are established. Accelerating the availability of necessary infrastructure for battery manufacturing and charging is reported to bring down the costs of ownership of the EV to be on par with ICE by 2025.

Strategic trends in lithium battery manufacturing

According to the global data on battery manufacturing, the raw materials, cell manufacturing and battery packaging contribute 40, 30 and 30%, respectively. In the electric mobility sector, as per the NPS, based on the most probable cell chemistry portfolio of 10% NCA, 40% NMC 622 and 50% 811, the global requirements of Cobalt, Lithium, Manganese and Nickel upto 2030 are estimated to be ~170, 155, 105 and 850 kt/year [14]. At present, the global nickel supply is ~2000 kt/year and is mainly used for high-grade steel production. Batteries forms a small fraction of the total demand mix. During 2018, ~ 6% the total demand of cobalt and 9% of the total demand of lithium has been reported from m the EV industry. The spot prices of the cobalt and lithium increased by 2.5 and 4 times since 4 years, which is mainly due to speculative stockpiling and strategic sourcing [14]. Lithium is called the "white petroleum" because of the growing economic importance. Moreover, lithium and cobalt resources are concentrated only in a few countries (Fig.5).



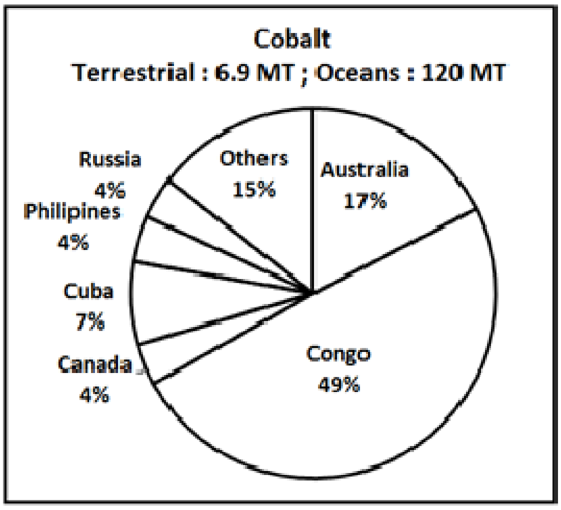


Fig.5. Global distribution of Li and Co resources [15]

Based on the lithium requirements of ~0.2 kg/kWh, till 2030, ~330 kilotons of lithium shall be required to realize 1650GWh of energy storage capacity. The existing battery factories have production capacities of up to 8 GWh/year, whereas factories announced to come online after 2025 are expected to have capacities of up to 35 GWh/year. The lithium battery technologies and manufacturing for the electricity and mobility applications target global investments up to US$ 125 billion, which includes establishment of 30 Giga factories for realizing cumulative battery capacities of 3.5 TWh by 2030 [16].

A feasibility study made for the Government of India indicate that for a Li-Ion battery production plant of 5 GWh/year capacity established in India with 66% of the battery cost towards raw materials, the battery production cost shall be US$ 148/kWh. The production facility requires an investment of US$ 5 billion and an establishment time of ~ 3 years. The battery production cost is reported to be as low as up to US$ 84 for a manufacturing capacity of 200GWh/year, indicating the economies of scale [17].

The spent lithium batteries, when left untreated in the ecosystem leads to health and environmental hazards. Moreover, the environmental and economic benefits of the li-Ion cell recycling are significant. According to global reports, recycled lithium and cobalt will reach 9 and 20 % of total lithium and cobalt used in the batteries supplied in 2025[17]. In India, li-ion battery recycling market is estimated to be ~US$ 1 billion by 2030 [18]. Efforts are underway to streamline and automate the recycling process, in which companies recycling lithium-ion batteries are to be tied up to work with the battery makers to adopt easily dismantled product designs, and uptake the recently developed recovery processes of all valued battery components.

Conclusion

Indications from the recent assessments on the battery technologies suggest that lithium-ion batteries are the preferred choice in the energy storage applications during the forthcoming decade. Ensuring conducive policies for the increased deployment of energy storage in the power sector and electric mobility by means of domestic manufacturing and innovation, incentives for bridging the price gap between conventional and electric vehicles, deployment of charging stations, standardisation, maximizing the economic value of the lithium batteries by recycling for environmental sustainability are essential for achieving India's ambitious climate goals. At the same time, a smooth transition with minimal impact on the present legacy internal combustion based supply chain is required from the economic and employability perspectives. The announced investment in large-scale battery manufacturing facilities confirms further reduction in the cost of the batteries. Surveying for lithium resources within India, and at the same time making strategic investments in the international mines are essential.

Acknowledgements

The authors gratefully acknowledge the support extended by the Ministry of Earth Sciences, Government of India for supporting this study.

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Best slogans for energy conservation

Save Today. Survive Tomorrow
Today's wastage is tomorrow's shortage.
Energy can't be created but it can be destroyed. Save it!
Spare a Watt; Save a Lot
Switch off to keep INDIA switched on
Energy conserved is energy produced.
Don't make your child ask… "What was oil ?"… Conserve today!0
More energy conserved, more the planet life is reserved.
Energy misused cannot be excused.