Role of Storage for Grid Integration/Round the Clock Supply from Renewable Energy Sources

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Presented by
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Decarbonizing the Global Energy Sector by 2050

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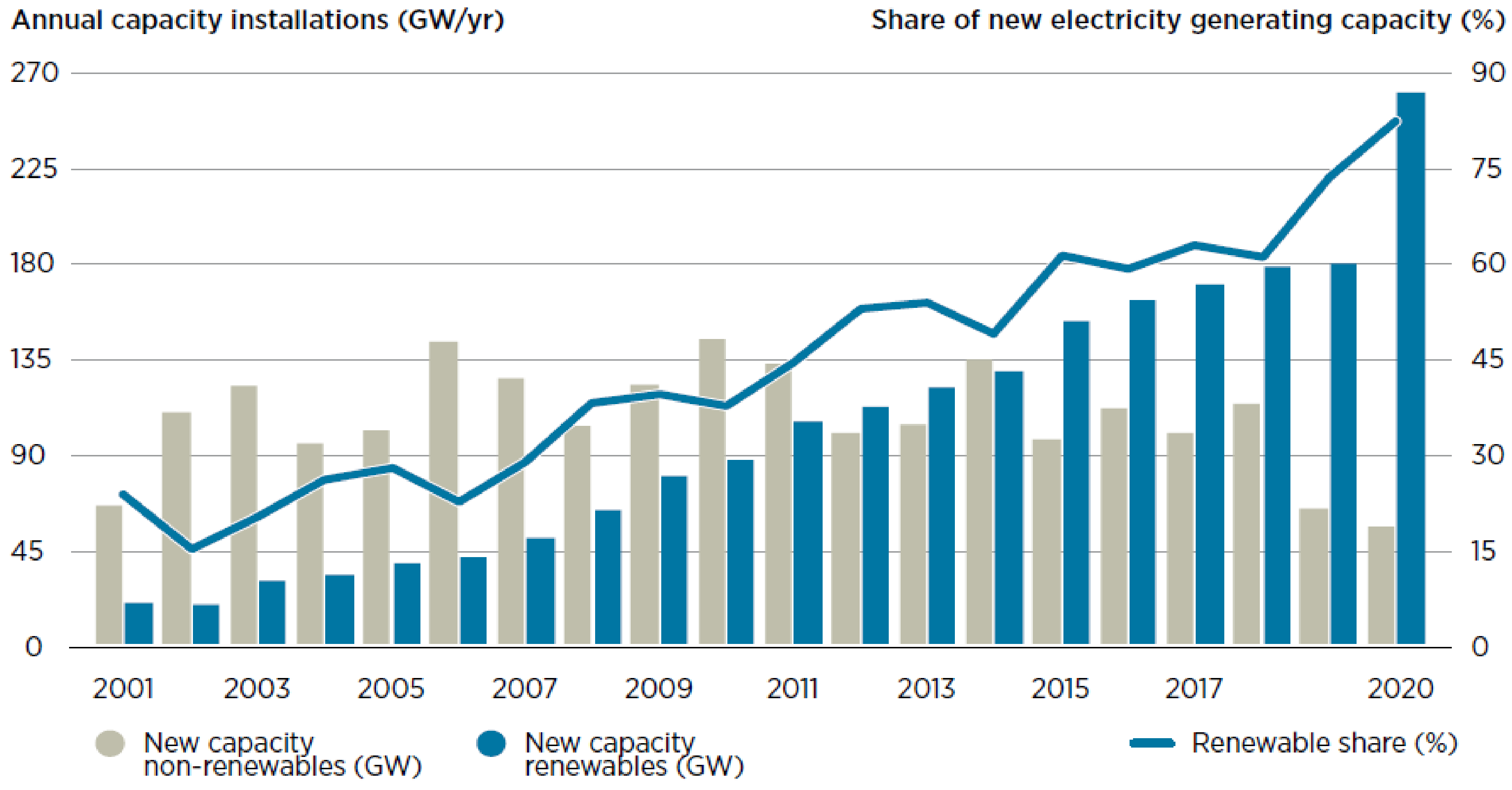
Annual addition of 630 GW of Solar and 390 GW of Wind by 2030 to give the planet a chance of achieving the emission reductions needed to limit global temperature rise to 1.5°C

- More than twice the record highest levels of **Solar addition of 280 GW in 2020**
- Almost FIVE TIMES the Wind capacity additions in 2020
- Net Zero energy sector would need 306 million-tons of green hydrogen per year by 2050
- 90% of the energy from RE by 2050 – compared to 20% presently
- Estimated US$ 5 trillion annual investment by 2030 onwards
- **One Terra-Watt (TW)+ a year of RE addition to the grid poses serious challenges!**

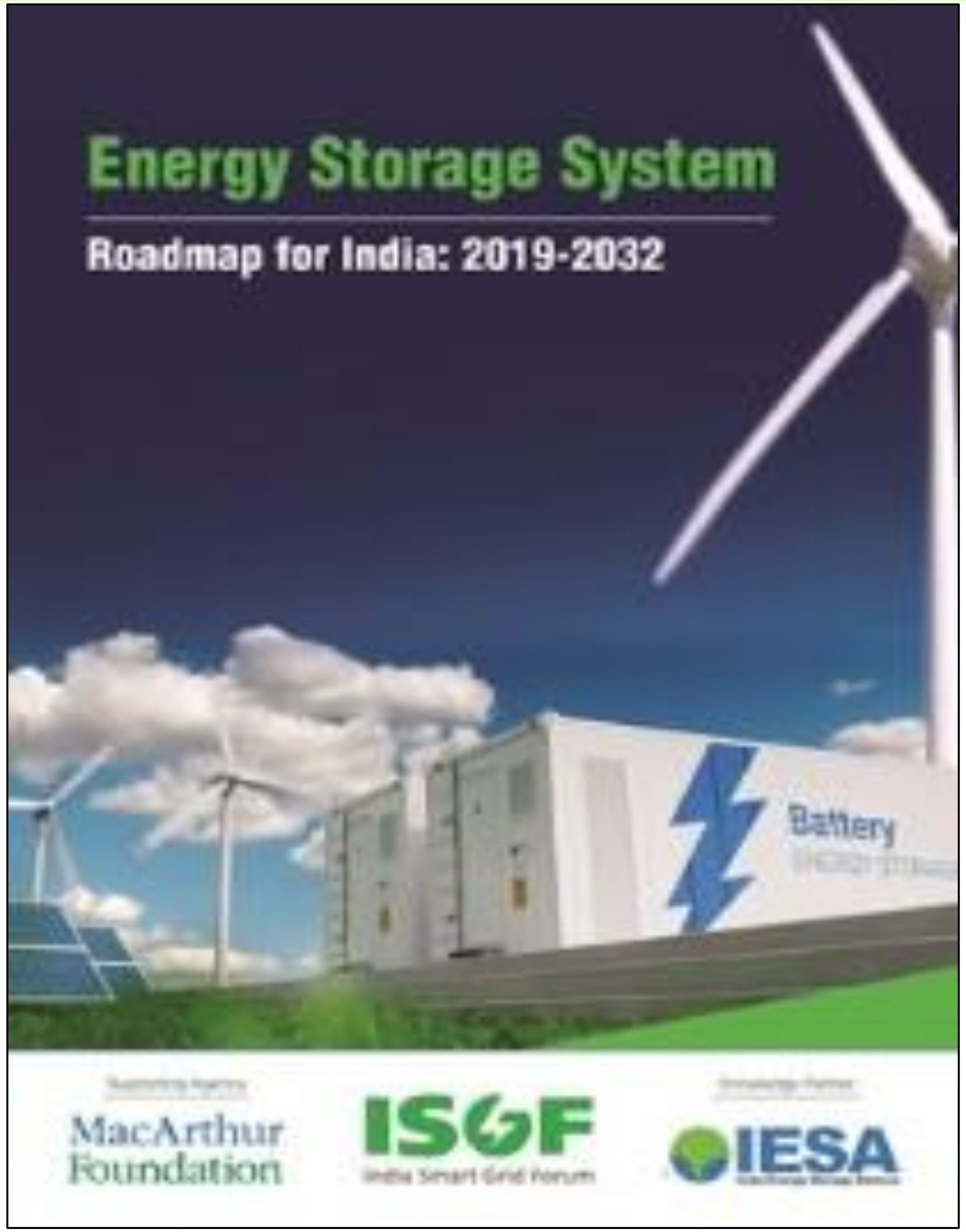
FIGURE S.1 **Share of capacity, 2001-2020**



Based on IRENA's renewable energy statistics.

Global Installed Power Generation Capacity is 7.78 TW of which 2.98 TW is RE share in 2020

Energy Storage System Roadmap for India 2019-2032



ESS Roadmap was prepared under the guidance of NITI Aayog in consultation with MoP, MNRE and CEA

Modelling Studies: Typical Analysis Urban Lightly Loaded Feeder

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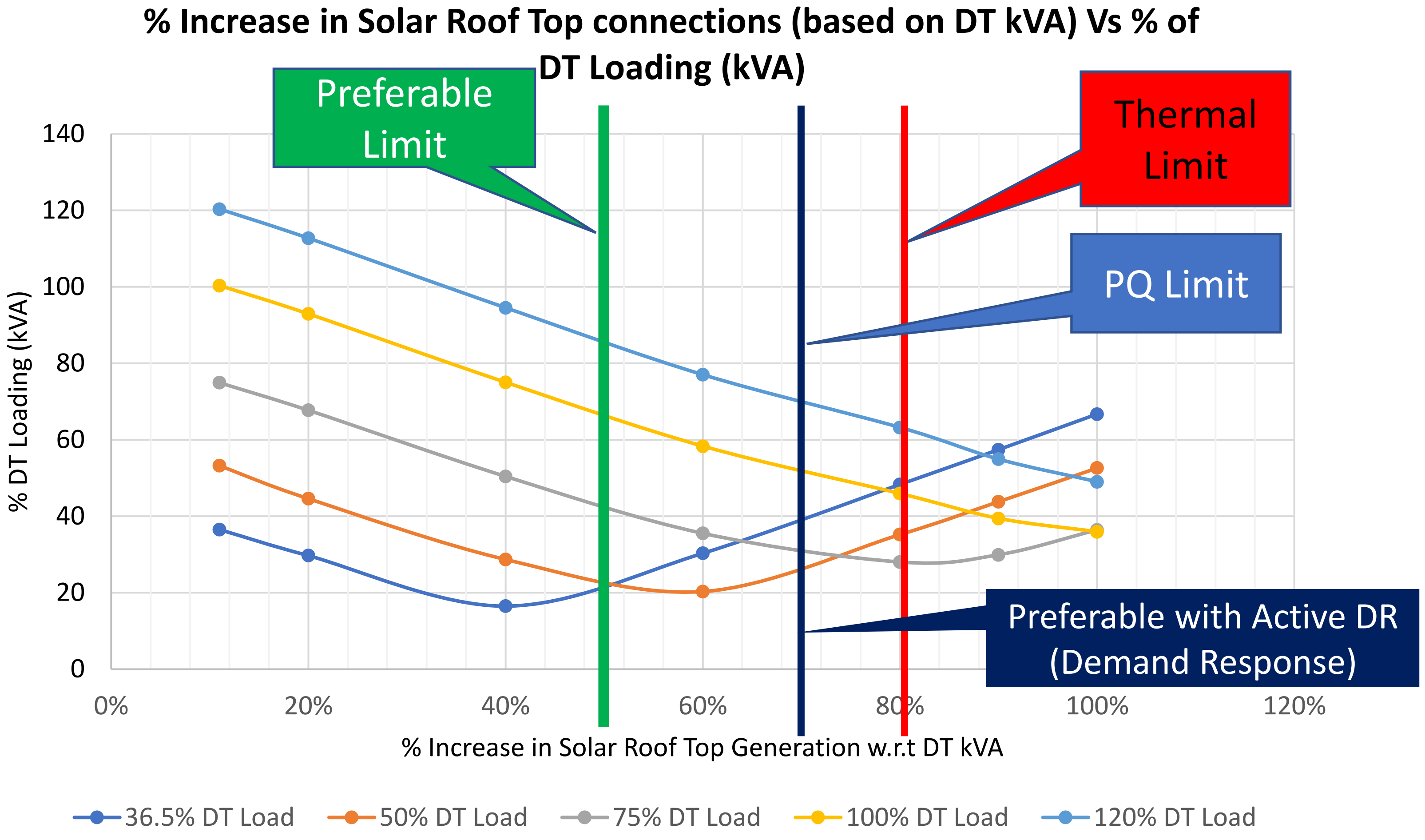
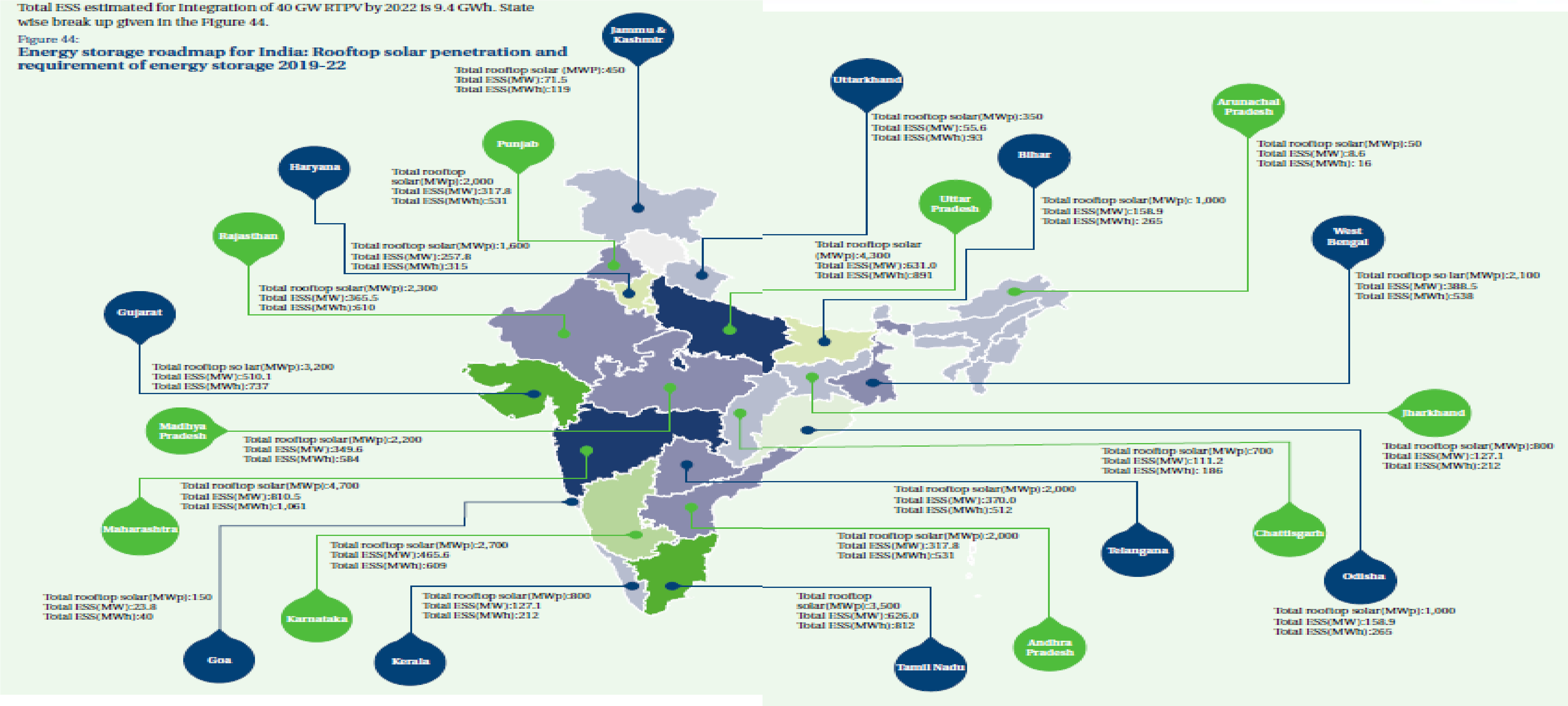
Observations

- Thermal Limit: 80% of RTPV connections
- PQ Limit: 75% of RTPV connections
- Considering harmonics and uncertainty of clouds, permissible limit for RTPV connections can be 50% of DT Capacity



Modelling Studies were conducted on Distribution Feeders in 6 States to determine the RTPV Hosting Capacity

Energy Storage Roadmap for India: 40 GW RTPV on MV/LV Grid by 2022



Energy Storage Roadmap for India: 100 GW RE on MV/LV Grid by 2027

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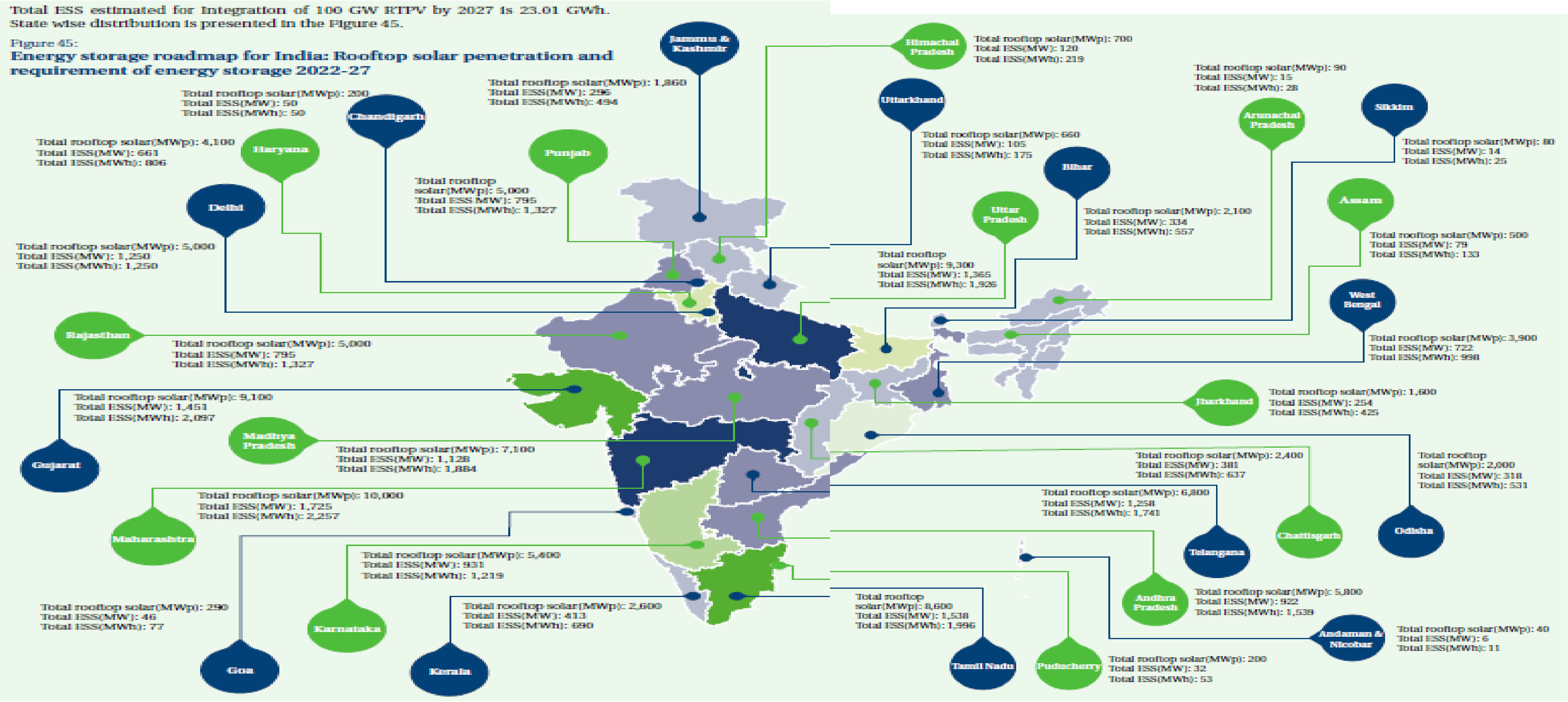
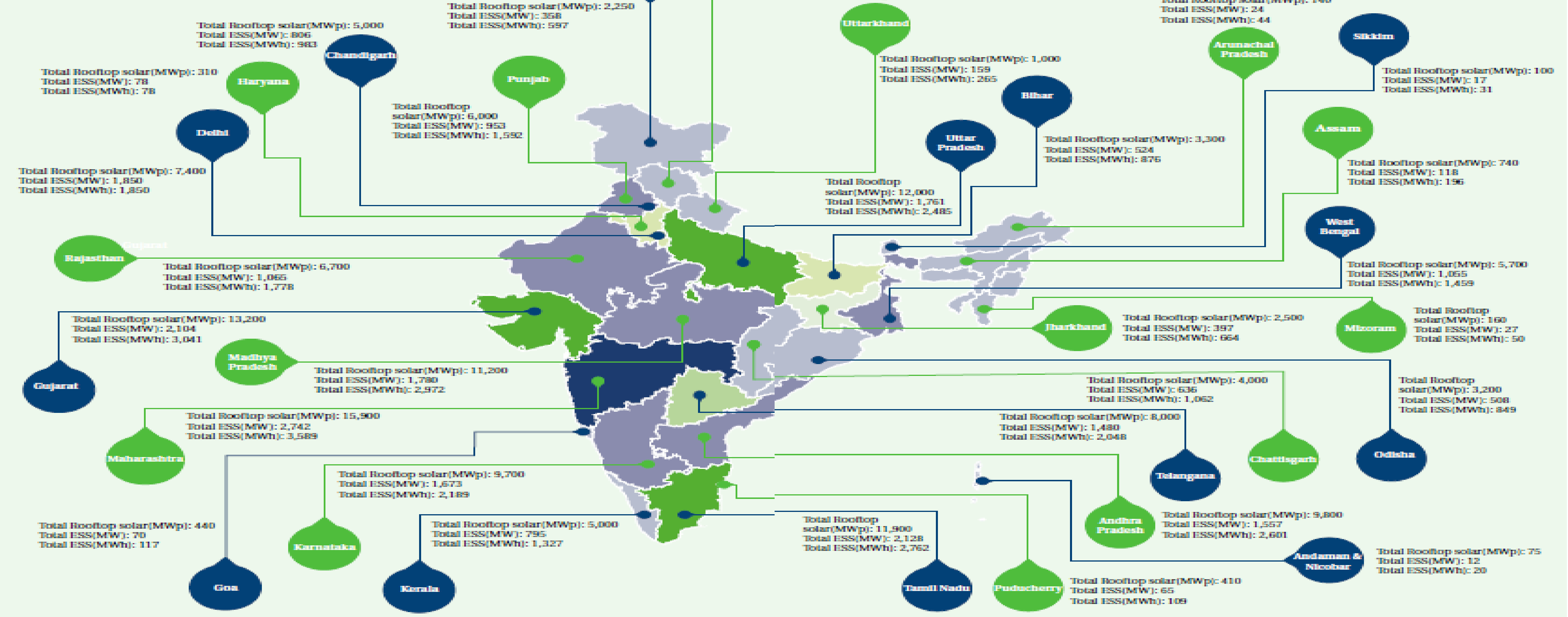


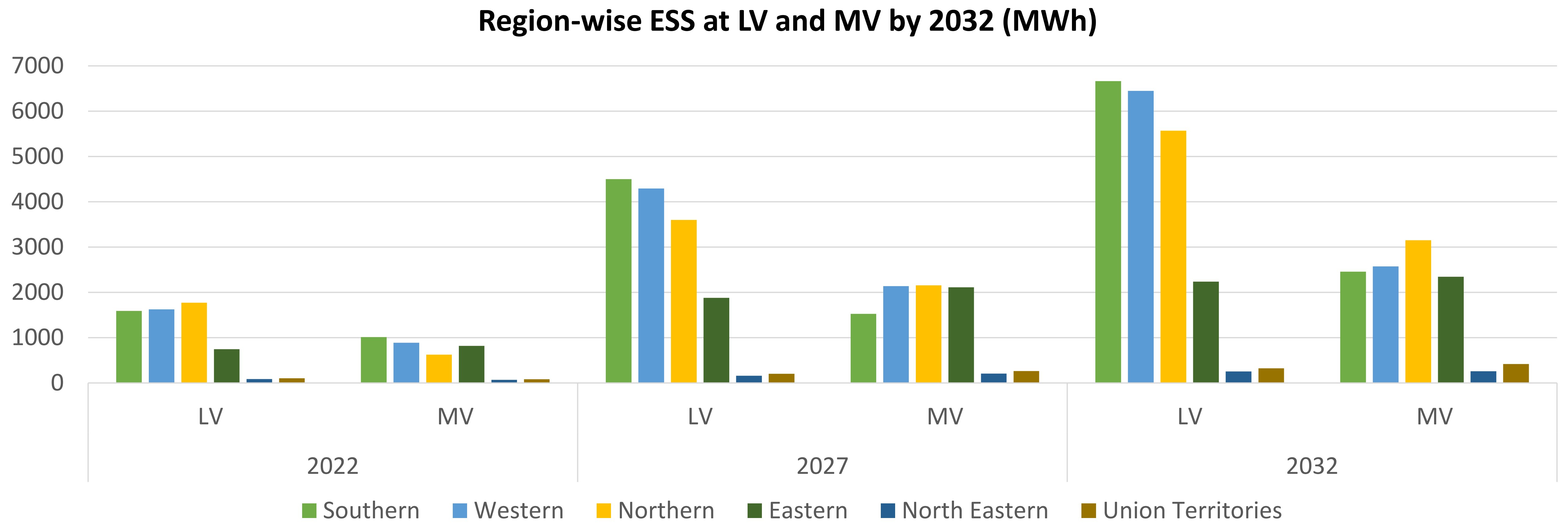
Energy Storage Roadmap for India: 150 GW RE on MV/LV Grid by 2032

Total ESS estimated for integration of 150 GW RTPV by 2032 is 32.675 GWh.
State wise details presented in the Figure 46.

Figure 46:
Energy storage roadmap for India: Rooftop solar penetration and requirement of energy storage 2027-32



Region wise ESS at LV and MV (MWh) by 2032



	2022		2027		2032	
	LV	**MV**	**LV**	**MV**	**LV**	**MV**
Total (MWh)	5908	3482	14617	8393	21484	11191

Energy Storage Roadmap for India: 2019 - 2032

Estimations	2018-19	2022	2027	2032
Generation (GW)				
Thermal	209	NA	NA	NA
Hydro	43	NA	NA	NA
Nuclear	6	NA	NA	NA
Solar	26	107	244	349
Ground Mounted Solar	24	68	148	206
RTPV	1.5	40	98	144
Connected to EHV	14	34	66	94
Connected to MV	11	35	84	112
Connected to LV	2	40	98	144
Wind	35	NA	NA	NA
Small Hydro	4.5	NA	NA	NA
Biomass & Biopower	10	NA	NA	NA
Peak Load (GW)	192	333	479	658
Energy (BUs)				
Annual Energy	1,192	1,905	2,710	3,710
Storage Recommended (MWh)				
Battery (LV)	241	5,908	14,617	21,484
Battery (MV)	1,054	3,482	8,393	11,191
Total (MWh)	**1,295**	**9,390**	**23,010**	**32,675**

Consolidated Energy Storage Roadmap for India: 2019-2032

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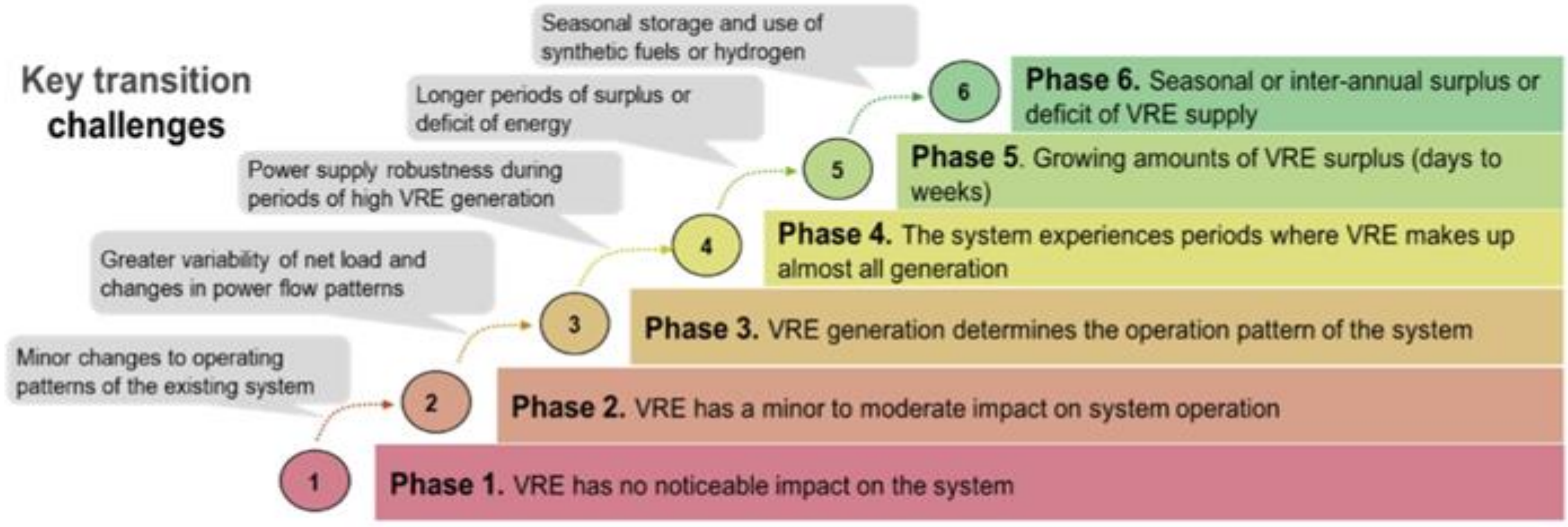
	Applications		Energy Storage (GWh)			
			2019-2022	2022-2027	2027-2032	Total by 2032
Stationary Storage	Grid Support	MV/LV	10	24	33	67
		EHV	7	38	97	142
	Telecom Towers		25	51	78	154
	Data Centres, UPS and inverters		80	160	234	474
	Miscellaneous Applications (Railways, rural electrification, HVAC application)		16	45	90	151
	DG Usage Minimization		0	4	11	14
Total Stationary (GWh)			**138**	**322**	**543**	**1,002**
Electric Vehicles	E2W		4	51	441	496
	E3W		26	43	67	136
	E4W		8	102	615	725
	Electric Bus		2	11	44	57
Total Electric Vehicles (GWh)			**40**	**207**	**1,167**	**1,414**
Total Energy Storage Demand (GWh)			**178**	**529**	**1,710**	**2,416**

ESIT Tool: General Overview

- ESIT tool is able to model the operation of ESS when given inputs related to the site and parameters of the project and derive the possible value benefits
- Some of the value benefits for ESS at feeder level are Loading Reduction, System peak shave benefits, Time shifting, Penalty Payment savings, Economic Adder, etc
- The value streams captured change based on the site of the ESS project: Feeder level, DT level or Customer level

Renewable Energy Integration – Different Phases

Phases of system integration of renewables



Source: IEA, Status of Power System Transformation 2019.

Renewable Energy Integration – Different Phases

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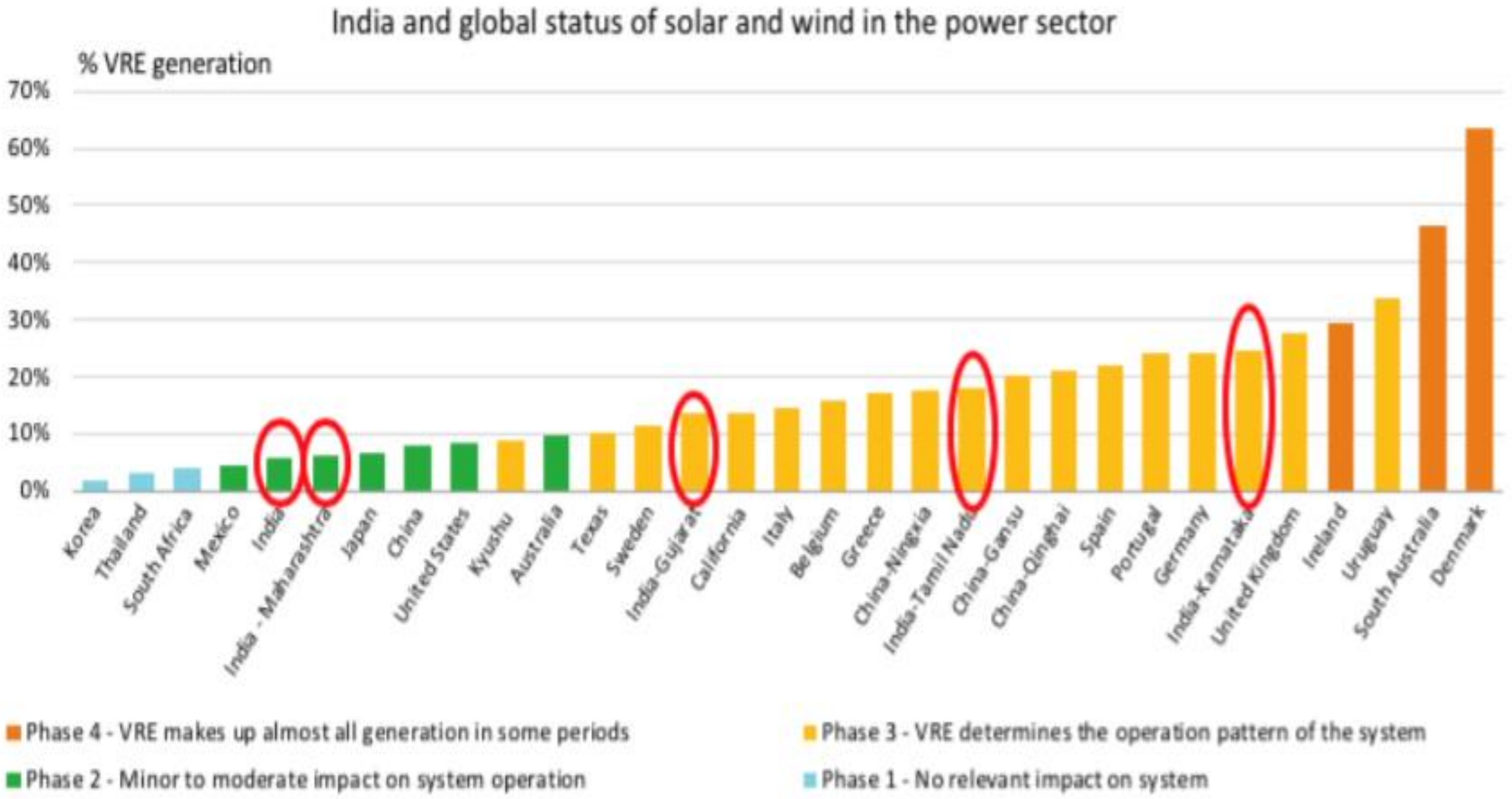
Karnataka, Tamil Nadu and Gujarat are already in Phase-3

Phases of RE Integration

Phase 1	• VRE has no noticeable impact on the power system
Phase 2	• VRE has a minor to moderate impact on system operation
Phase 3	• VRE generation determines the operation pattern of the power system
Phase 4	• Power system experiences periods where VRE makes up almost all generation
Phase 5	• Growing amounts of VRE surplus days to weeks
Phase 6	• Seasonal or inter annual surplus or deficit of VRE supply

Countries and Regions in Phases of RE Integration



RE Integration – Power System Flexibility

Flexibility at different time-scales and Phases

Flexibility type	Ultra short term flexibility	Very short term flexibility	Short term flexibility	Medium-term flexibility	Long-term flexibility
Timescale	Subseconds to seconds	Seconds to minutes	Minutes to days	Days to weeks	Months to years
Issue	Ensure system stability (voltage, transient and frequency stability) at high shares of non-synchronous generation	Short-term frequency control at high shares of variable generation	Meeting more frequent, rapid and less predictable changes on the supply/demand balance	Addressing longer periods of surplus or deficit of variable generation	Balancing seasonal and inter-annual availability of variable generation
Most relevant integration Phase and example regions	Phase 4 Several VRE rich states by 2025	Phase 3 Gujarat, Karnataka, Tamil Nadu in 2020	Phase 2 India as a whole, Maharasthra in 2020	Phase 4	Phase 5 Phase 6

Flexibility Resources For Different Timescales

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Flexibility Timescale / Flexibility Resource	Ultra Short Term (sub-seconds to seconds)	Very Short Term (seconds to minutes)	Short Term (minutes to hours)	Medium Term (hours to days)	Long Term (days to months)	Very Long Term (months to years)
State-of-the-art VRE	Controller to Enable Synthetic Inertia; Very Fast Frequency Response	Synthetic Inertial Response; Automatic Generation Control (AGC)	Downward/ Upward Reserves; AGC; Economic Dispatch (ED) including VRE	ED tools; Unit Commitment (UC) Tools; VRE Forecasting Systems	UC Tools; VRE Forecasting Systems	VRE Forecasting Systems; Power System Planning Tools
Demand-side Resources	Power electronics to enable Demand Response	Demand-side Options including Electric Water Heaters, EV Chargers, large Water Pumps, Electric Furnaces etc	ACs with Cold Storage and Heat Pumps; Equipment listed under Very-Short-Term Flexibility	Smart Meters for Time- Dependent Retail Pricing	Demand Forecasting Systems	Demand Forecasting Systems; Power-to-Gas (P2G)
Storage	Super Capacitor; Flywheels; Battery Storage; PSH Modern variable speed units	Battery Storage	Battery Storage; CAES; Pumped Storage Hydro (PSH)	PSH	PSH	PSH; Hydrogen Production; Ammonia or other P2G
Conventional Plants	Mechanical Inertia; Generation Shedding Schemes	Speed Droop Control; AGC	Cycling; Ramping; AGC	Cycling; Quick-Start; Medium-Start	Changes in Power Plant Operation Criteria	Retrofit Plants; Flexible Power Plants; Existing Generators as Reserve
Grid Infrastructure	Synchronous Condensers and other FACTS Devices	Special Protection Scheme (SPS); Network Protection Relays	Intra-regional Power Transfers; Cross-Border Transmission Lines	Inter-nodal Power Transfers; Cross-Border Transmission Lines	Control and Communication Systems to Enable Dynamic Line Ratings (DLR), WAMS, Static VAR Compensator	Transmission Lines/ Transmission Reinforcement

Source: IEA

Approach to Build Flexibility For the Indian Grid – 1/2

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- **Build Battery Energy Storage System (BESS)** at Solar and Wind Farms
- **Replace Diesel Generator (DG) sets with BESS -** the fastest and cheapest route to build flexibility for the Indian grid
  - Over 70 GW of large-size DG sets in India
  - With Diesel price at INR 95/liter, electricity from DG set costs INR 29.07/kWh
  - Power from BESS will be INR 15.40/kWh (if bought from grid @INR 8.00/kWh and stored in BESS)

ISGF White Paper on DG Replacement with Lithium-Ion Batteries in Commercial Buildings – www.indiasmartgrid.org

- **Promote Vehicle-Grid Integration:** Both EVs and Rooftop PV (RTPV) are connected to the low voltage distribution grid and V2G/V2B can help smoothen the intermittency of RTPV generation which could otherwise seriously affect power quality as the share of RTPV increases
- **Promote Smart Microgrids:** All large buildings, campuses, industrial parks, commercial and housing complexes with local generation and storage to be converted as Smart Microgrids that can island from the grid, buy and store electricity from the grid; and sell back to the grid during peak hours

Approach to Build Flexibility for the Indian Grid – 2/2

- **Promote GW-scale Electrolysers for Green Hydrogen:** Electrolysers can be flexible loads that can operate at varying PLF offering flexibility to the grid depending on the supply-demand scenario

- **Mandate District Cooling System (DCS) with Thermal Storage:** DCS distributes chilled water to multiple buildings through a network of underground insulated pipes for space cooling; Allow the system to produce ice/chilled water when the electricity is cheap on the grid or when solar plants are generating during the day; Thermal storage of DCS offers flexibility for the distribution grid – load as well as load relief

  ISGF White Paper on Sustainable Air Conditioning with District Cooling Systems – www.indiasmartgrid.org

- **Promote Electric Cooking:** Need of the hour as almost all households in the country are electrified and we have surplus electricity generation capacity – with smart plugs, cooking load can be made flexible – using RE

  ISGF White Paper on Electric Cooking – www.indiasmartgrid.org

- **Introduce Time of Use (ToU) Tariff for Electricity:** ToU or real-time tariff can motivate customers with interruptible loads to shift their usage (part or full load) from peak to off-peak hours through incentives and penalties

  ISGF Report on Design of Robust Time of Use (ToU) Framework for Electricity Tariff in Gujarat – www.indiasmartgrid.org

- **Create Dynamic Electricity Markets:** Encourage RE Buyers Associations, Promote Peer – to – Peer (P2P) Trading of Green Electricity ***ISGF implemented two pilot projects (Lucknow and Delhi) on P2P trading of solar RTPV energy amongst prosumers and consumers on a blockchain platform - www.indiasmartgrid.org***

Post Covid – Scenario has Changed

- Global EV penetration was just 2 to 3% and battery costs were following a path of 5 to 7% annual cost decreases
- The battery story is a global story and the amount of capital involved is 10 to 20x higher than it was pre-COVID – Industrialization of Battery Economy

	Pre-Covid	Today
Investment	Billions	Trillions
Geography	China/Tesla	Global
# of Companies	Few	Many
BEV Penetration	2%	7%
Policy	Fossil Fuels	ESG/Decarbonization
Chemistry	Cobalt/Nickel	Iron/Phosphoric Acid
OEM Strategy	Outsourcing	Insourcing

Source: Morgan Stanley Research

One Vision of the Battery Economy timeline…

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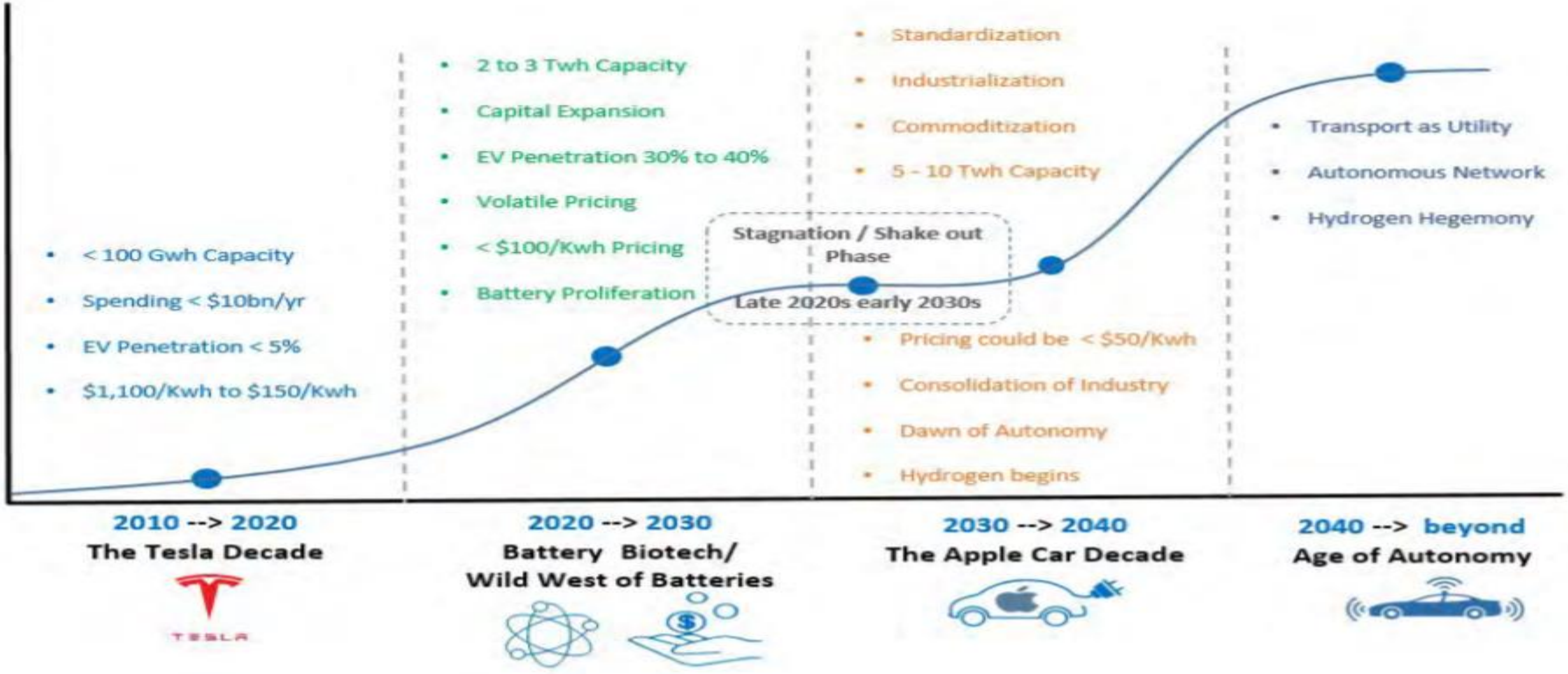
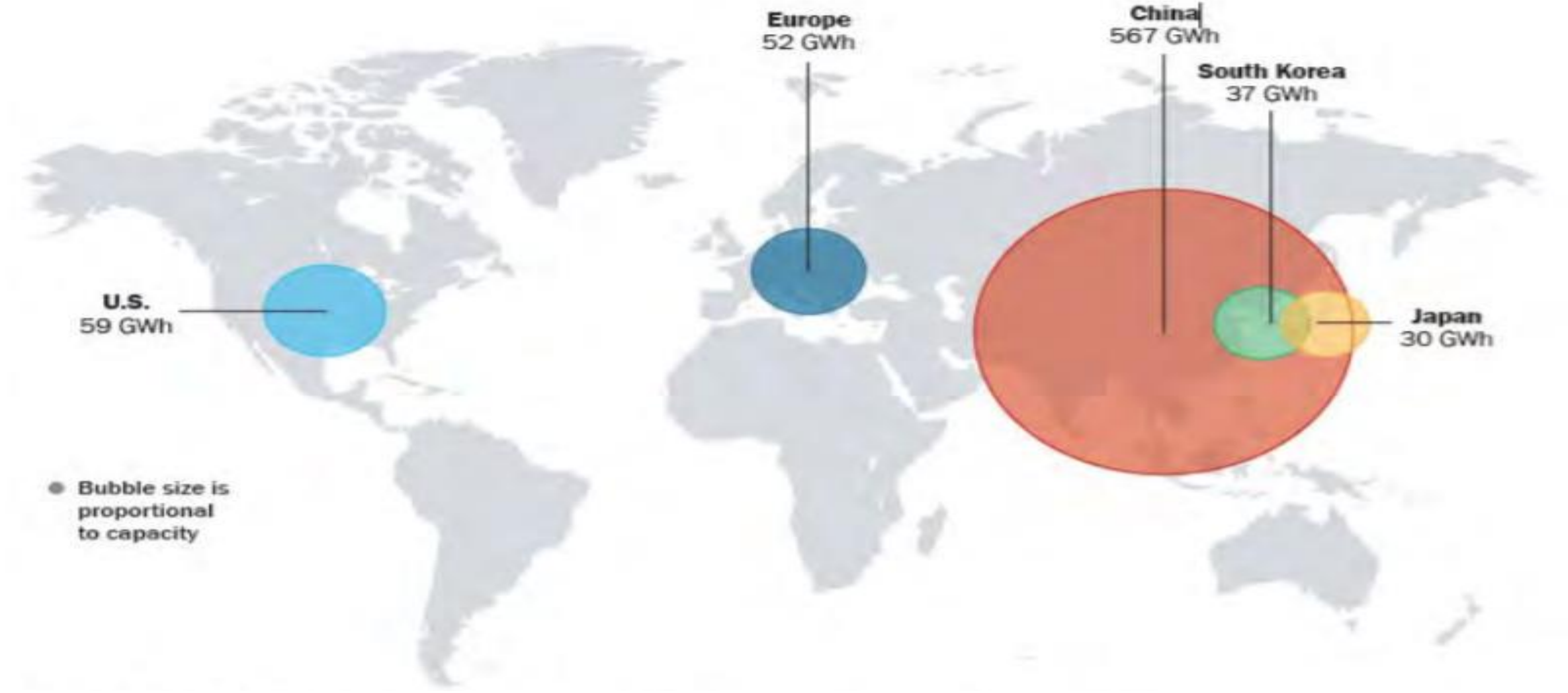


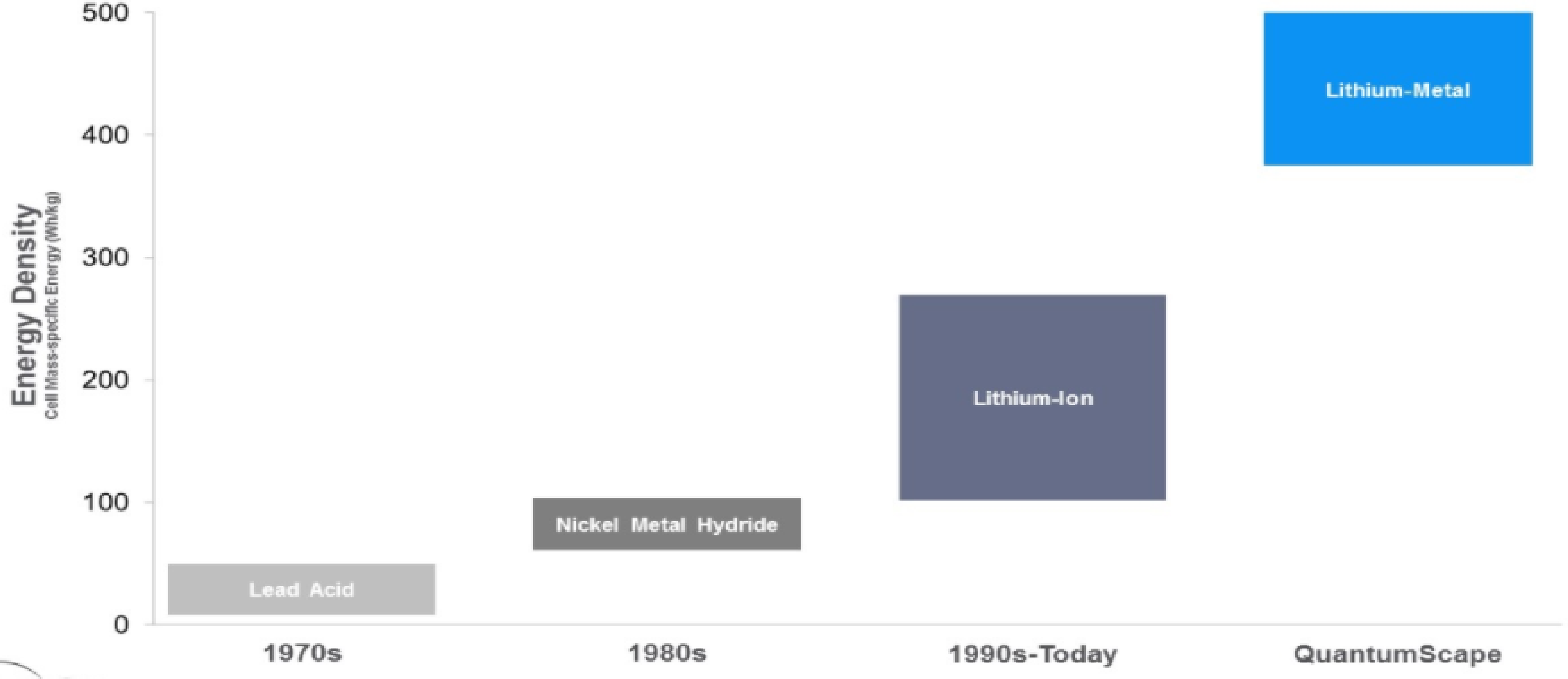
Source: Morgan Stanley Research

China Leads the World in Battery Manufacturing Capacity



567 GWh out of 745 GWh is in China – 76%

Lithium-metal : The Next Generation of Battery



QuantumScape Source: Cano et al (2018). Nature Energy, 3(4), 279–289; Ovshinsky Science 260 (1993) 176; Ding et al, Electrochem. Energ. Rev. 2, 1–28 (2019); Management analysis

Key Points in the LiB Journey

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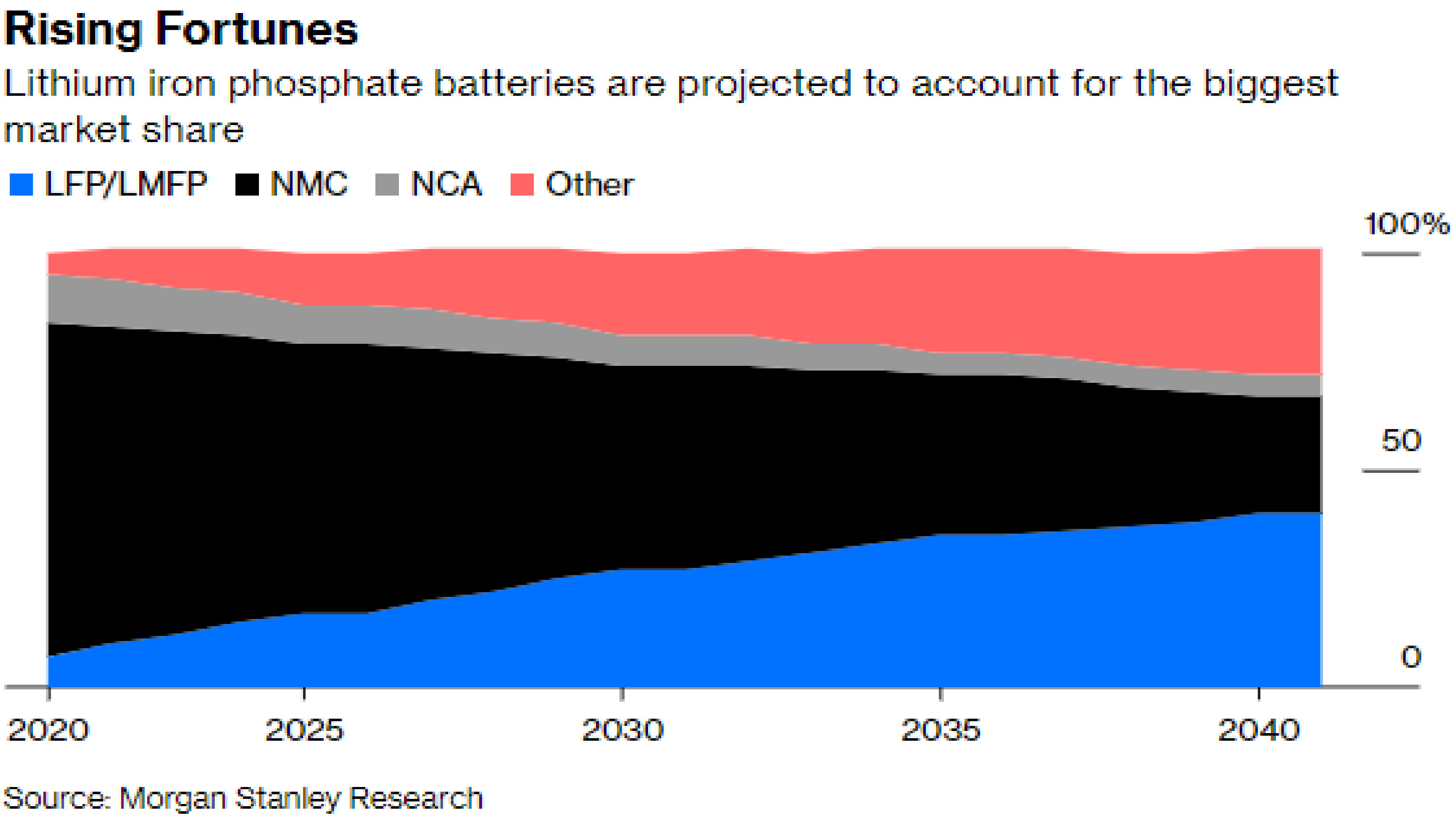
1. A decade ago, analysts did forecast the demise of LFP batteries owing to limitations in energy density – though cheaper and safer than other chemistries, LFP batteries were big, low-voltage and couldn't meet consumers' hunger for greater range
2. South Koreans companies were leading the LiB technology then and they focused on nickel, cobalt and manganese (NCM) in varying proportions to make it energy rich. ***Result: Expensive, more energy-dense but less safe batteries that are catching on fire from overcharging, overuse or while being parked***
3. Chinese companies CATL, BYD, Yutong Bus Company etc were able to finetune LFP chemistries and could drive down costs by around 20% and improve the performance
4. **LFP is cheaper and more appropriate for ESS applications for the grid – cooling load will be much less with LFP**
5. LFP batteries have critical safety advantage: If one of their cells failed, it generated far less heat than an NCM battery; it will **only smoke without actually catching fire in most thermal runaway scenarios**
6. Between 2018 and 2020, out of all **EV Battery Fire incidents NCM accounted for 60% and LFP accounted for 11%**
7. According to BNEF, the present market share of LFP batteries outpaced that of the NCM type - **Tesla's Model 3 in most parts of the world will house LFP batteries**

LFP Batteries are Projected for Biggest Market Share



ACC PLI Scheme – Evaluation Matrix in the RFP

INR Per KWh		Energy Density (Wh/Kg)				
		≥ 50	≥ 125	≥ 200	≥ 275	≥ 350
Cycle Life	≥ 1000	-	-	-	A	A*(1.2)
	≥ 2000	-	-	A	A*(1.2)	A*(1.2^2)
	≥ 4000	-	A	A*(1.2)	A*(1.2^2)	A*(1.2^3)
	≥ 10000	A	A*1.2	A*(1.2^2)	A*(1.2^3)	A*(1.2^4)

Note: It is expressly clarified that the ACCs manufactured shall have a minimum technical specifications viz. Energy Density and Cycle Life as provided in the shaded regions.

Best LFP Batteries today have 140-160 Wh/Kg and 3000 Cycles Life – so per above evaluation criteria LFP will not qualify for the PLI

THANK YOU

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Different Types of Lithium-ion Batteries

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Chemistry	Lithium Nickel Manganese Oxide	Lithium Nickel Cobalt Aluminum Oxide	Lithium Iron Phosphate	Lithium Cobalt Oxide	Lithium Manganese Oxide	Lithium Titanate Oxide
Short form	NMC	NCA	LFP	LCO	LMO	Li-titanate
Nominal voltage	3.60V (3.70V)	3.60V	3.20, 3.30V	3.60V	3.70V (3.80V)	2.40V
Specific Energy	150–220Wh/kg	200-260Wh/kg	90–120Wh/kg	150–200Wh/kg	100–150Wh/kg	70–80Wh/kg
Cycle life (ideal)	1000–2000	500	1000–2000	500–1000	300–700	3,000–7,000
Thermal runaway	210°C(higher when empty)	150°C (higher when empty)	270°C (safe at full charge)	150°C (higher when	250°C (higher when empty)	One of safest Li-ion batteries
Packaging (typical)	18650, prismatic and pouch cell	18650	26650, prismatic	18650, prismatic and pouch cell	prismatic	prismatic
History	2008	1999	1996	1991 (Sony)	1996	2008
Applications	E-bikes, medical devices, EVs, industrial	Medical, Industrial, Tesla's battery of choice	Stationary with high currents and endurance	Mobile phones, tablets, laptops, cameras	Power tools, medical devices, powertrains	UPS, EV, solar street lighting
Comments	High capacity and high power. Market share is increasing. Also NCM, CMN, MNC, MCN	Highest capacity with moderate power. Similar to Li-cobalt.	Flat discharge voltage, high power low capacity, very safe; elevated self-discharge.	High energy, limited power. Market share has stabilized.	High power, less capacity; safer than Li-cobalt; often mixed with NMC to improve performance.	Long life, fast charge, wide temperature range and safe. Low capacity, expensive.

Source: Battery University, Morgan Stanley Research

Global OEMs - Capital Investment and Electrification Goals

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	Electrification/Battery Plan	Battery Partner	Battery Capacity Guidance	Planned Investment Amount	Battery Timeframe
US OEM Coverage (Adam Jonas)					
Tesla	Announced at its 2020 Battery Day its vertical integration plans starting with its proprietary LMNO battery, announced in Oct 2021 plans to switch to LFP	Panasonic, CATL, Korean player	100 GWh by 2022, 3 TWh by 2030	~$233Bn (projected capex + R&D spend through 2030)	2021 through 2030
GM	JV partnership with Korean player to form battery business Ultium as well as announced recycling partnership with Li-Cycle and partnership with SES (hybrid lithium metal batteries)	Korean player	~30 GWh in Lordstown plant, ~30 GWh in Spring Hill plant	$35Bn for batteries ($5Bn already invested); $27Bn in electric/autonomous vehicles over next 5 years	2020 through 2025
Ford	JV partnership with SK Innovation on batteries through BlueOvalSK, partnership with Solid Power (solid state batteries)	SK Innovation	129 GWh across 3 plants in TN and KY	$30Bn; $11.4Bn battery investment in conjunction with SK Innovation	By 2025
EU OEM Coverage (Harald Hendrikse)					
Stellantis	JV with two Korean players to produce electric vehicle batteries with 2024-2025 SOP target as well as a 1/3 equity partnership with Automotive Cells Company (ACC)	Samsung SDI, ACC, Korean player	23 GWh with Samsung SDI, 120 GWh with ACC, aiming for a minimum of 130 GWh by 2025 & 260 Gwh by 2030	~30Bn EUR	Through 2025
Daimler	1/3 equity partnership in Automotive Cells Company (ACC), linked to construction of CATL facility in Germany	CATL, ACC	120 GWh with ACC	~$8Bn in battery venture; $47Bn in EVs between '22-'30	By 2030
Renault	Partnership with China's Envision AESC and France's Verkor (20% stake) for electric car battery manufacturing	Envision AESC, Verkor, Korean player	9 GWh by 2024, 24 GWh by 2030 with Envision AESC & 10 Gwh by 2026, 20 GWh by 2030 with Verkor	Renault/Envision to invest ~$2.5Bn in gigafactory; 10Bn EUR in car electrification over next 5 years	2021 through 2024
Volkswagen	Investment in EV platform for 70 all-electric models; investment in Quantumscape (solid state batteries); JV with Northvolt (holds 20% shares) to have six 40 Gwh battery cell production plants	CATL, Samsung SDI, Northvolt, SKI, Korean player, QS, Farasis, Gotion	240 GWh with Northvolt	$86Bn in electrification and automation by 2025; 10-year, $14Bn order for one out of six planned factories with Northvolt	Through 2030
Volvo	Exclusive partnership with Northvolt for battery manufacturing in Europe	CATL, Korean player, Northvolt	50 Gwh	$3.5Bn battery factory deal with Northvolt	50% of Volvo Cars' sales will be EV by 2025
BMW	Significant increase in battery cell contracts for i4 sedans, iX SUVs and other models based on demand with Samsung SDI, CATL, and Northvolt, partnership with Solid Power (solid state batteries)	Samsung SDI, CATL, Northvolt	60 GWh with CATL from 2026+	~$24Bn batteries; 30Bn EUR in EV/hydrogen before 2025	Through 2031
Japan OEM Coverage (Shinji Kakiuchi)					
Toyota	Broad investment plan for battery development and production with partners including CATL, BYD, GS Yuasa, Panasonic, and Toshiba	BYD, Panasonic, CATL, GS Yuasa, Toshiba	200 GWh by 2030	~$13Bn; $3.4Bn in batteries in the US through 2030	Through 2030
Honda	Investment into 100% electric vehicles by 2040, including R&D initiatives; partnership with CATL	Ultium (GM), CATL	56 GWh before 2027	~$46Bn for the company total R&D over the next 6 years	By 2040
Nissan	Investment in new EV battery plants in the U.K. and Japan; partnership with AESC	AESC	40 Gwh by 2024	$1.8Bn in EV battery plants; $460mm in AESC plant	By 2024
Korean OEM Coverage (Young Suk Shin)					
Hyundai/Kia	Investment into EV infrastructure in the US; JV partnership with Korean player for battery plant in Indonesia and SK Innovation; Partnership with SES (hybrid lithium metal batteries)	SK Innovation, CATL, Korean player	10 GWh by 2024 (up to 30 GWh)	~$8.5Bn batteries; $1.1Bn for Indonesian battery plant; $35Bn investment in mobility/other technologies by 2025	By 2025

Source: Company data, Morgan Stanley Research

Base, Bull & Bear Case Assumptions

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	Base	Bull	Bear
BEV+PHEV Sales Penetration			
2025	26%	30%	23%
2030	50%	59%	42%
2035	71%	78%	57%
2040	87%	96%	70%
BEV Capacity (kWh)			
2025	65	66	64
2030	68	71	66
2035	71	75	67
2040	74	80	69
Battery Price ($/kWh)			
2025	$ 88	$ 88	$ 88
2030	$ 83	$ 87	$ 73
2035	$ 79	$ 86	$ 61
2040	$ 75	$ 86	$ 51
Global Supply (GWh)			
2025	1,176	1,150	1,196
2030	2,849	2,530	3,119
2035	5,104	4,166	5,974
2040	6,974	5,419	8,495
Battery Characteristics			
Energy Density (Wh/kg)	300-500	700-1000	200-300
Efficiency (mi/kWh)	5-6	6-7	4-5

Source: Morgan Stanley Research; Note: battery characteristics are MS estimates for illustrative purposes

- **Base case:** Alongside supportive policy/ESG, base case assumes the global battery industry will improve on metrics such as energy density and cycle life, driving the BEV penetration acceleration required to achieve manufacturing scale
- **Bull case:** Supportive regulation and/or positive technology outcomes coincide, bringing high performing batteries to the market at scale on a faster timeline than base case and at a competitive cost for manufacturers. Bull case benefits upstream players like mining companies over downstream players like OEMs as they are able to capture the higher raw material prices
- **Bear case:** In a combination of unsupportive policy/ESG and a negative technology outcome, the battery industry struggles to produce a competitive battery that penetrates the market. EV penetration ramps slower than expectations while low-cost supply from Tesla and other battery makers results in an excess supply of batteries selling at or below cost

Commodity Outlook

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Commodity	Element	2021e forecast ($/ton)	Long term forecast ($/ton)	Comments
Lithium	Li	$10,293	$7,468	New supply brought in by higher prices is expected to outpace demand in the medium term due to new players in Argentina and Australia.
Cobalt	Co	$49,169	$37,475	Used in standard NMC and NCA chemistries, cobalt is the most expensive cathode material, comes almost entirely from the DRC and is mined in association with child labor.
Nickel	Ni	$18,472	$17,238	While EVs claim a low amount of global nickel demand, the general trend towards high nickel/lower cobalt chemistries implies that nickel may play role in the EV battery space in the medium term.
Copper	Cu	$9,180	$7,045	EVs may increase copper demand through both usage in the battery and for wiring in charging infrastructure.

Source: Morgan Stanley Research

Element	U.S. Reserves (1000 Metric tons)	World Reserves (1000 Metric tons)	Total Manufacturing Capacity with U.S. reserves (GWh)	Total Manufacturing Capacity with world reserves (GWh)
Lithium	750	21,000	7470	209,163
Cobalt	53	7100	703	94,164
Nickel	100	94,000	167	156,510
Manganese	230,000	1,300,000	3,271,693	18,492,176

Source: DOE US National Blueprint for Lithium Batteries