LITHIUM-ION VS ADVANCED LEAD CARBON VRLA BATTERIES FOR STATIONARY APPLICATIONS

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•TECHNICAL ASPECTS

Aspect	Lithium-ion Batteries (LiB)	LiB Score	Advanced Lead Carbon VRLA Batteries	VRLA Score
Energy Density	200-400 Wh/L	9	80-100 Wh/L	6
Cycle Life	3000-7000 cycles at 80% DoD	9	2000-4500 cycles at 70% DoD	8
Depth of Discharge (DoD)	Up to 90% regularly	9	Up to 70-80%	7
Charge/Discharge Efficiency	90-95%	9	75-85%	7
Self-Discharge Rate	2-3% per month	9	1-5% per month	8
Temperature Performance	-20°C to 60°C (requires thermal management)	7	-40°C to 60°C (better high-temp performance)	9
Scalability	Highly scalable	9	Moderately scalable	7
Response Time	Very fast (milliseconds)	10	Fast (milliseconds to seconds)	8
Calendar Life	10-20 years	9	5-10 years	7
Maintenance Requirements	Low	9	Low to moderate	8

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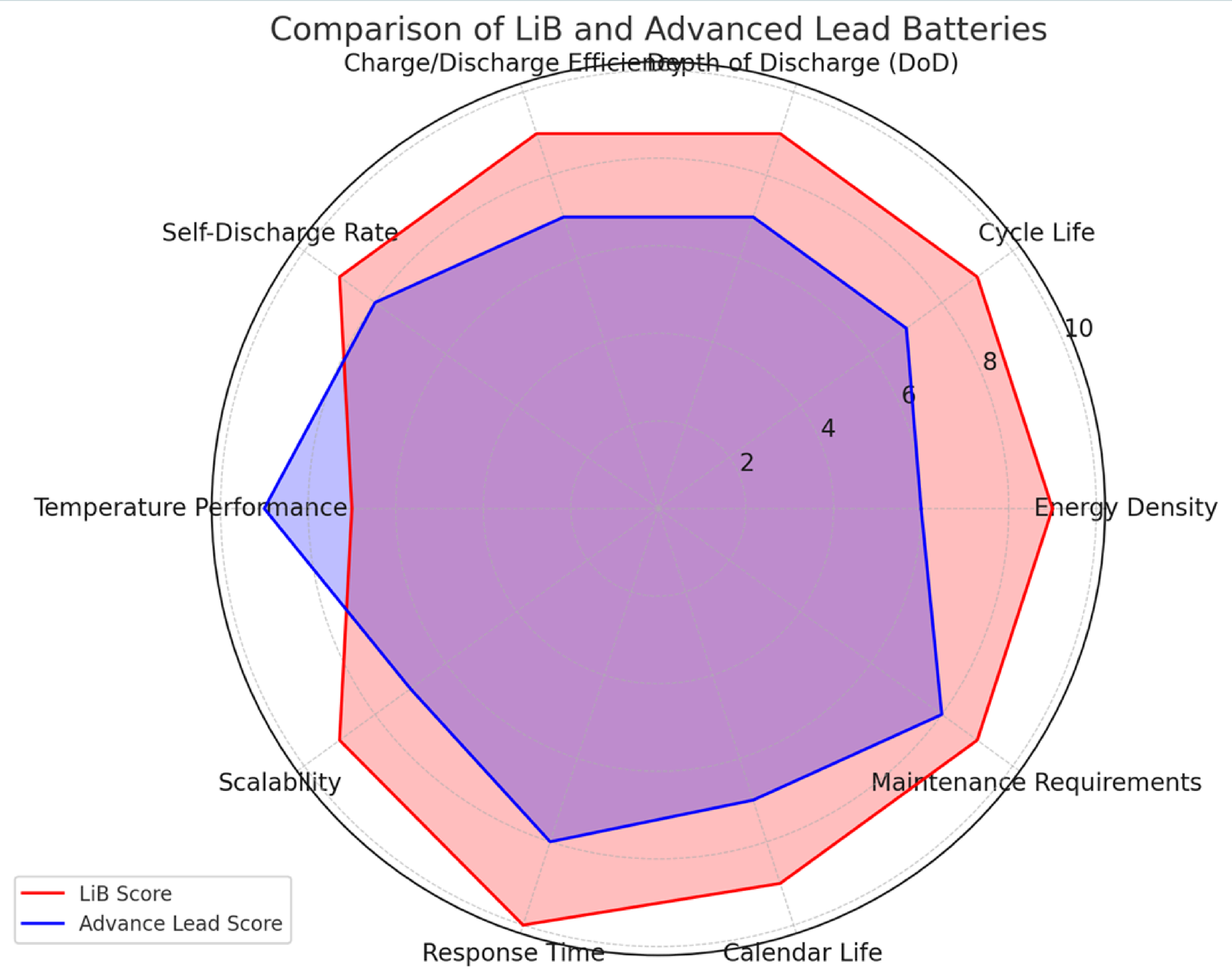
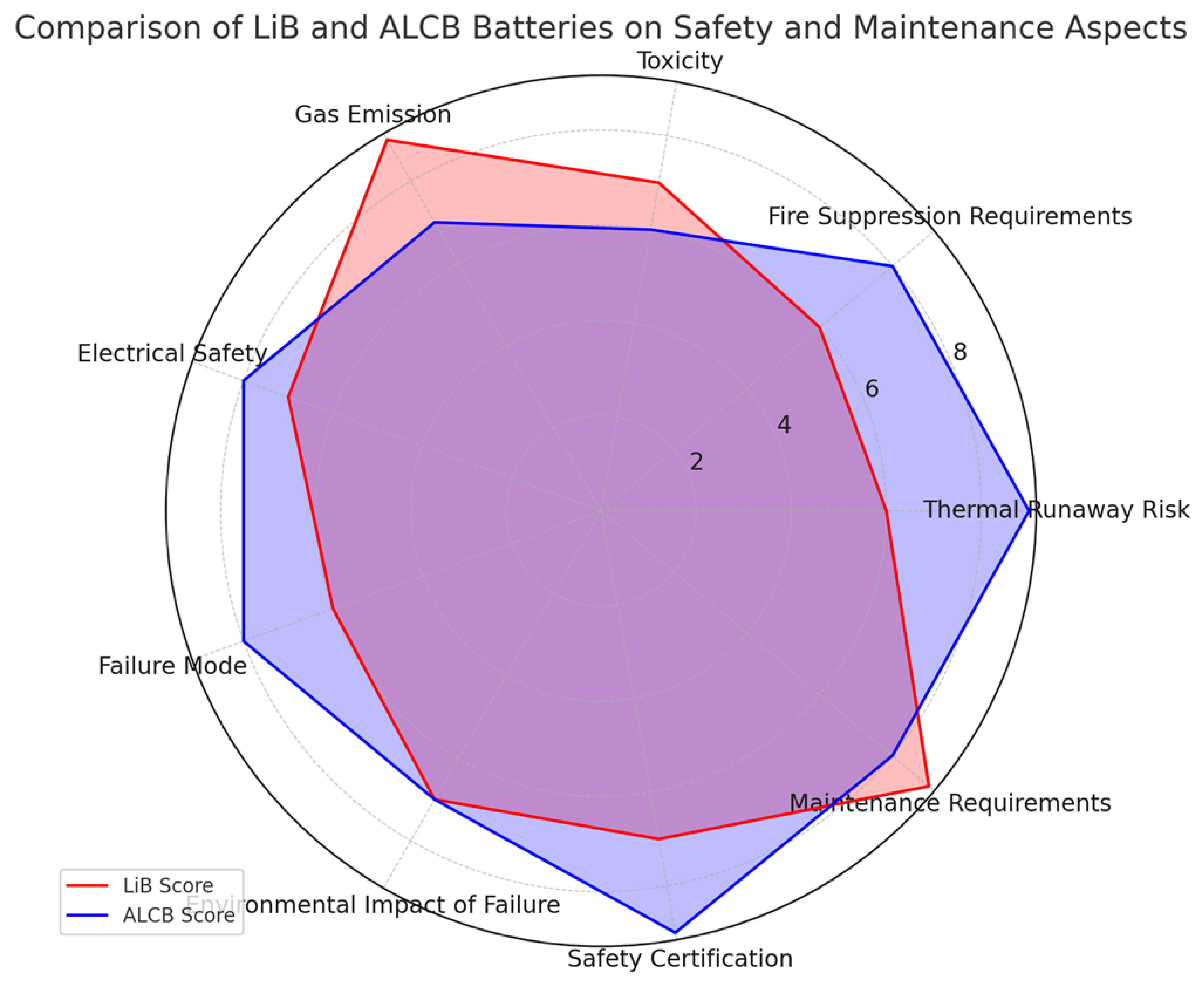
TECHNICAL ASPECTS



SAFETY ASPECTS

Aspect	Lithium-ion Batteries (LiB)	LiB Score	Advanced Lead Carbon VRLA Batteries	VRLA Score
Thermal Runaway Risk	Higher risk, requires active management	6	Lower risk, more stable chemistry	9
Fire Suppression Requirements	More complex, may need specialized systems	6	Simpler, standard fire suppression often sufficient	8
Toxicity	Low toxicity, but potential for toxic fumes if burning	7	Contains sulfuric acid, potential for acid spills	6
Gas Emission	Minimal under normal conditions	9	Some hydrogen gas emission possible, requires ventilation	7
Electrical Safety	Higher voltage systems, increased shock risk	7	Lower voltage systems, reduced shock risk	8
Failure Mode	Can be catastrophic if safety systems fail	6	Generally fails safe, less catastrophic failure modes	8
Environmental Impact of Failure	Potential for ground contamination	7	Potential for acid leakage, but more containable	7
Safety Certification	Often requires more rigorous certification	7	Well-established safety standards	9
Maintenance Requirements	Low	9	Low to moderate	8

SAFETY ASPECTS



ECONOMY ASPECTS

Aspect	Lithium-ion Batteries (LiB)	LiB Score	Advanced Lead Carbon VRLA Batteries	VRLA Score
Initial Capital Cost	Higher ($200-$400/kWh)	6	Lower ($150-$300/kWh)	8
Levelized Cost of Storage (LCOS)	Can be lower due to longer life	8	Competitive for short-duration storage	7
Installation Costs	Higher due to more complex BMS and safety systems	6	Lower, simpler installation requirements	8
Operational Costs	Lower due to higher efficiency	9	Slightly higher due to lower efficiency	7
Replacement Costs	Lower frequency, but higher cost per replacement	8	Higher frequency, but lower cost per replacement	7
Recycling Value	Higher, but less established infrastructure	7	Lower value, but well-established recycling process	8
Land Use Efficiency	Higher due to better energy density	9	Lower, requires more space for equivalent capacity	6
Grid Integration Costs	May require more advanced power electronics	7	Often simpler to integrate with existing infrastructure	8
Maintenance Requirements	Low	9	Low to moderate	8

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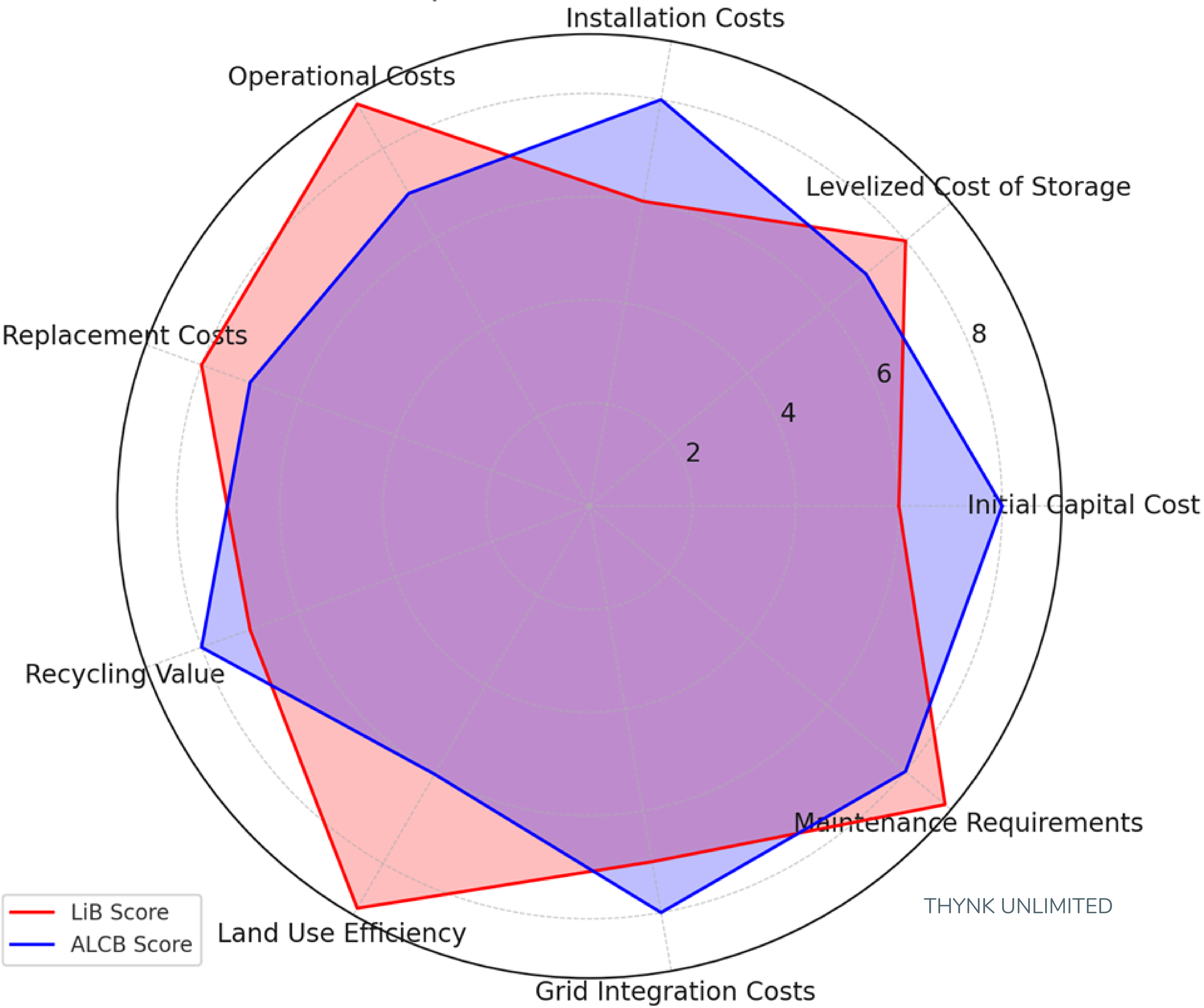
SIZE OF MARKET

Economic Comparison of LIB and ALCB Batteries



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•TECHNICAL ASPECTS

Application	Lithium-ion Batteries (LiB)	LiB Score	Advanced Lead Carbon VRLA Batteries	VRLA Score
Grid Frequency Regulation	Excellent (fast response)	10	Good	7
Peak Shaving	Very Good	9	Good	8
Load Shifting	Excellent	9	Good	7
Renewable Energy Integration	Excellent (scalable, long duration)	9	Good (especially for short-duration)	7
Backup Power	Very Good	8	Excellent (proven reliability)	9
Microgrids	Very Good (scalable, flexible)	9	Good (especially in harsh environments)	8
Telecom Towers	Good	8	Excellent (traditional choice, reliable)	9
Grid Integration Costs	May require more advanced power electronics	7	Often simpler to integrate with existing infrastructure	8
Maintenance Requirements	Low	9	Low to moderate	8

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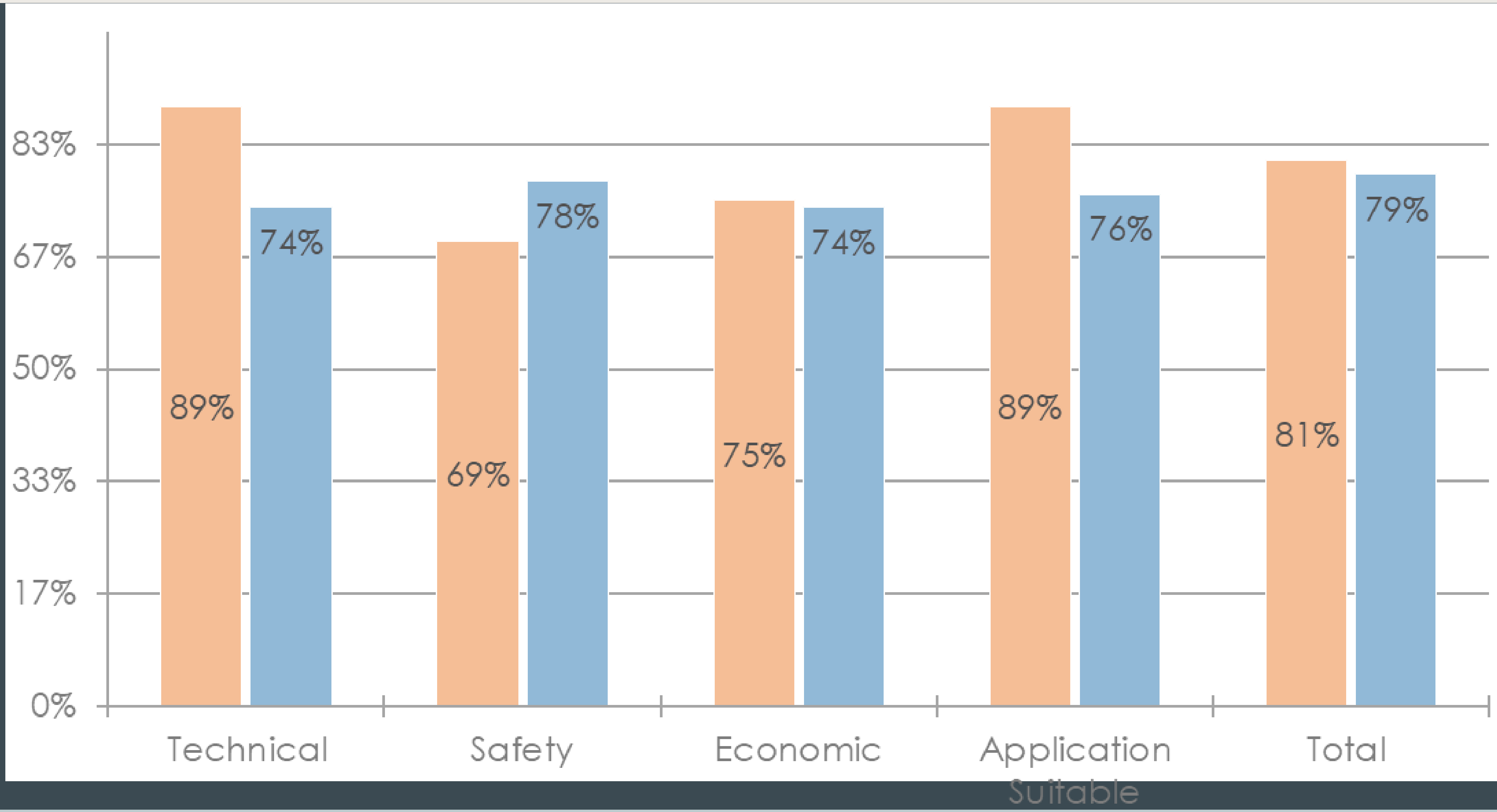
OVERALL VAULE

Category	Lithium-ion Batteries (LiB)	Advanced Lead Carbon VRLA Batteries (ALCB)
Technical	89%	74%
Safety	69%	78%
Economic	75%	74%
Application Suitability	89%	79%
Total Score	**81%**	**76%**



Lithium-ion vs Advanced Lead Carbon VRLA Batteries for Stationary Applications

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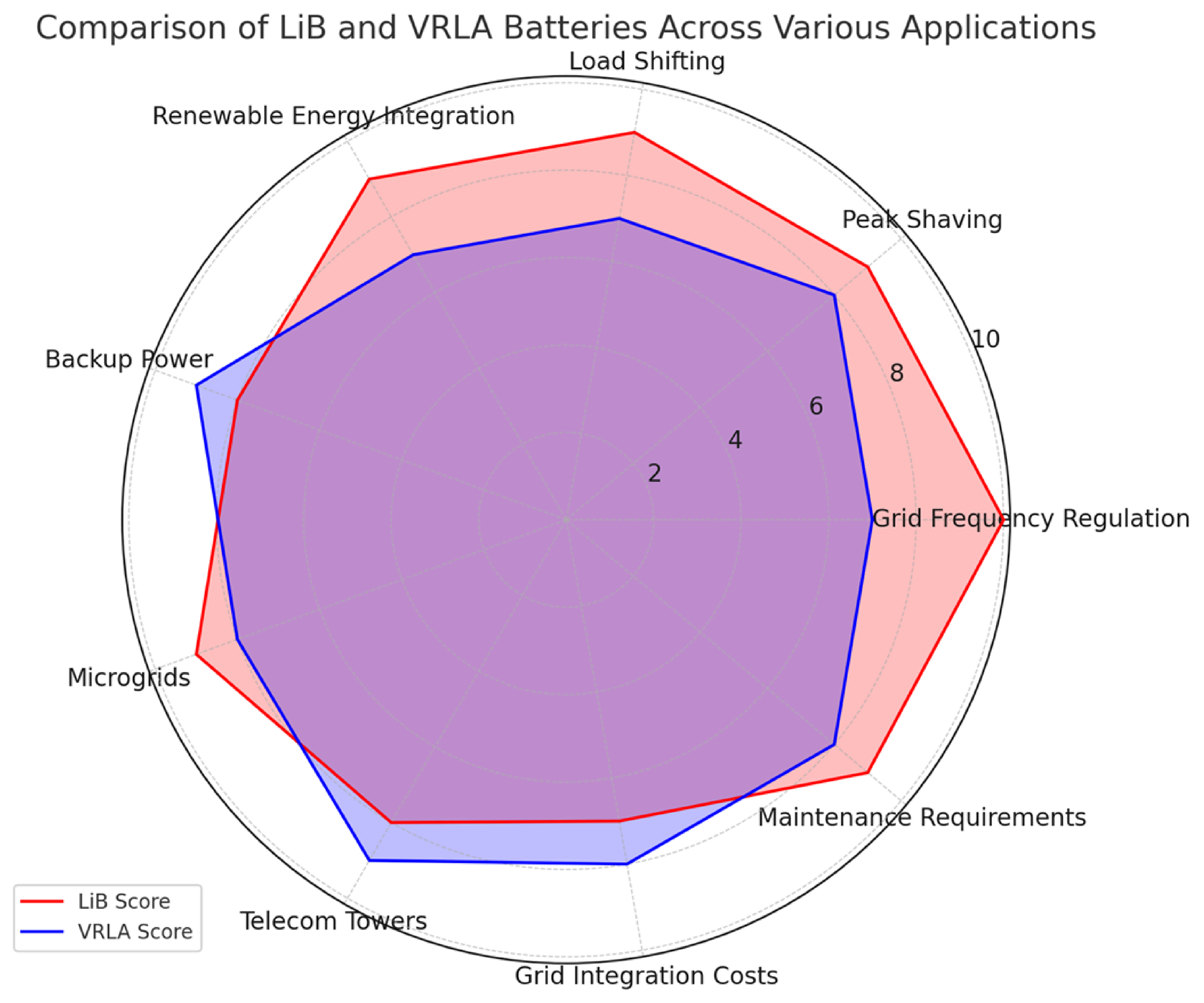
APPLICATION SUITABILITY IN STATIONARY USE CASES



BATTERY PERFORMANCE IN HARSH ENVIRONMENTS

Aspect	Advanced Lead Carbon	Lithium-ion	Traditional Lead-Acid	Notes
High Temperature Performance (>35°C)	8	6	5	Advanced Lead Carbon performs well at high temps. Li-ion needs thermal management. Traditional Lead-Acid suffers at high temps.
Low Temperature Performance (<0°C)	7	5	7	Both Lead-based technologies perform better at low temps than Li-ion.
Dust/Moisture Resistance	9	7	8	Advanced Lead Carbon's sealed design offers excellent protection. Li-ion requires additional enclosure for similar protection.
Maintenance Requirements in Remote Locations	8	9	6	Li-ion requires least maintenance. Advanced Lead Carbon needs minimal maintenance. Traditional Lead-Acid may need regular checks.
Safety in Extreme Conditions	9	6	8	Advanced Lead Carbon has lowest risk of thermal runaway. Li-ion has higher risks in extreme conditions.
Cycle Life in Harsh Conditions	8	7	6	Advanced Lead Carbon maintains better cycle life under stress. Li-ion degrades faster in extreme conditions.
Tolerance to Deep Discharge	7	8	5	Li-ion handles deep discharge better. Advanced Lead Carbon improved over Traditional Lead-Acid.
Resilience to Power Fluctuations	8	7	7	Advanced Lead Carbon handles irregular charging well. Li-ion and Traditional Lead-Acid are also fairly resilient.

BATTERY PERFORMANCE IN HARSH ENVIRONMENTS

Comparison of Battery Technology Under Various Conditions

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Resilience ในระบบไฟฟ้า หมายถึง

- การดูดกลืนหรือดูดซับ
- การรักษาตัว
- การฟื้นตัว

HARSH ENVIRONMENTS

PLANT EFFECIENCY

Aspect	Advanced Lead Carbon	Lithium-ion	Notes
Round-trip Efficiency (Normal Conditions)	75-85%	85-95%	Li-ion typically has higher efficiency
Efficiency in High Temperatures (>35°C)	70-80%	75-85%	Advanced Lead Carbon maintains efficiency better in high heat
Efficiency in Low Temperatures (<0°C)	65-75%	60-70%	Advanced Lead Carbon performs better in cold

CYCLE LIFE

Aspect	Advanced Lead Carbon	Lithium-ion	Notes
Cycle Life (Normal Conditions)	1,500-2,000 4,500 - 6,000 cycles	4,500-6,000 cycles	Li-ion typically has longer cycle life
Cycle Life (Harsh Environments)	1,200-1,800 3,600-4,800 cycles	2000-3500 cycles (more effected)	Both see reduced cycle life, but Li-ion more affected
Depth of Discharge (DoD)	Up to 70-80%	Up to 80-90%	Li-ion allows for deeper discharge

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HARSH ENVIRONMENTS :

LEVELIZED COST OF ENERGY (LCOE)

Factor	Advanced Lead Carbon	Lithium-ion	Impact on LCOE
Initial Capital Cost	Lower	Higher	Favors Advanced Lead Carbon
Replacement Frequency	Higher	Lower	Favors Lithium-ion
Auxiliary System Costs	Lower	Higher	Favors Advanced Lead Carbon
Efficiency Losses	Higher	Lower	Favors Lithium-ion
Maintenance Costs	Moderate	Low	Slightly favors Lithium-ion

ROUND TRIP EFFICIENCY

Real-World Performance Examples

01

Grid-Scale LiB Installation

- Location: Hornsdale Power Reserve, Australia
- Reported Round-Trip Efficiency: ~90%

02

Advanced Lead Acid Installation:

- Location: Notrees Wind Storage Demonstration Project, Texas, USA
- Reported Round-Trip Efficiency: ~75-80%

03

Recent Developments

- Some advanced LiB systems report up to 97% efficiencies in controlled conditions.
- Newer Advanced Lead Acid technologies are showing improvements, with some reaching efficiencies of up to 90% in optimal conditions.

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