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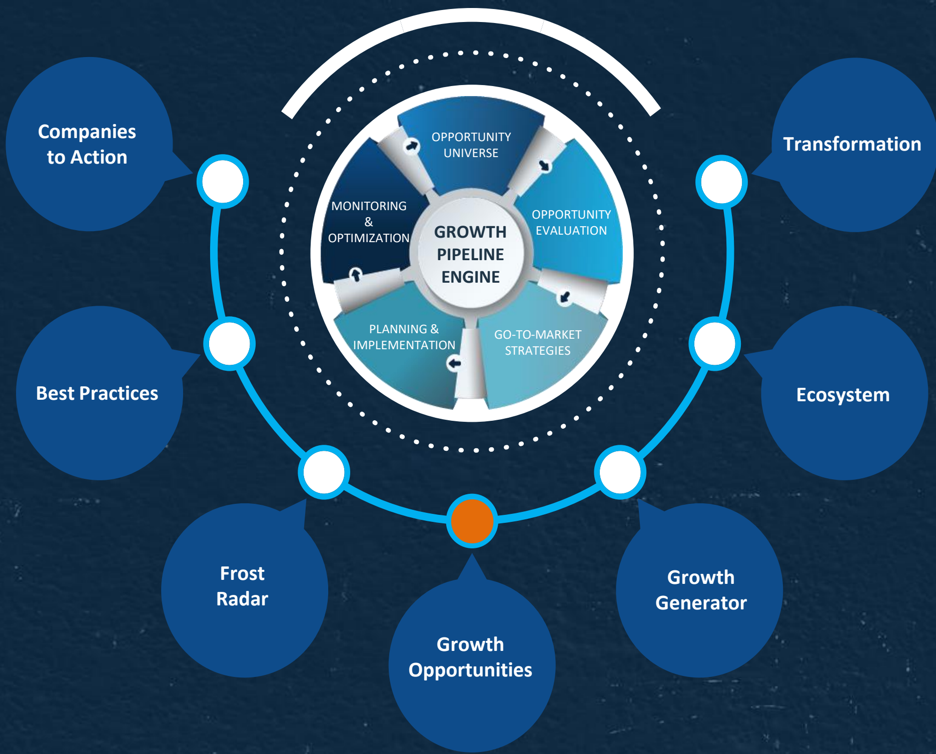

Growth Opportunities in Solid-state Batteries in Electric Vehicles, 2024–2030

Technological Advancements, Market Trends, and Future Roadmap for Sustainable EV Power Solutions

Global Automotive & Transportation Research Team at Frost & Sullivan

MH55-45

Contents

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Author: Sanchita Mendiratta

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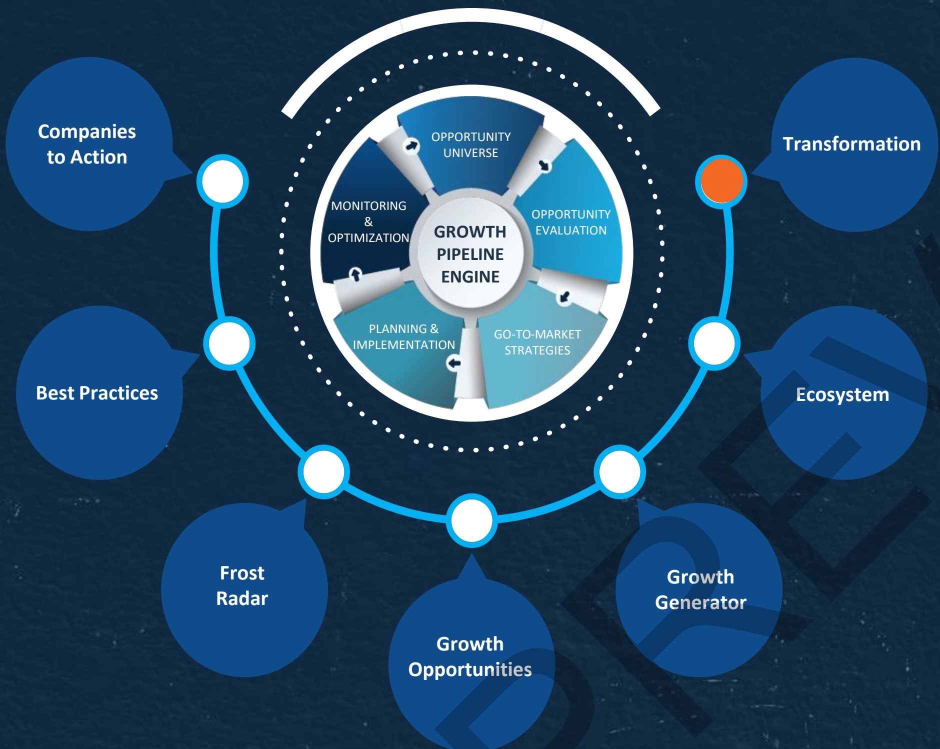
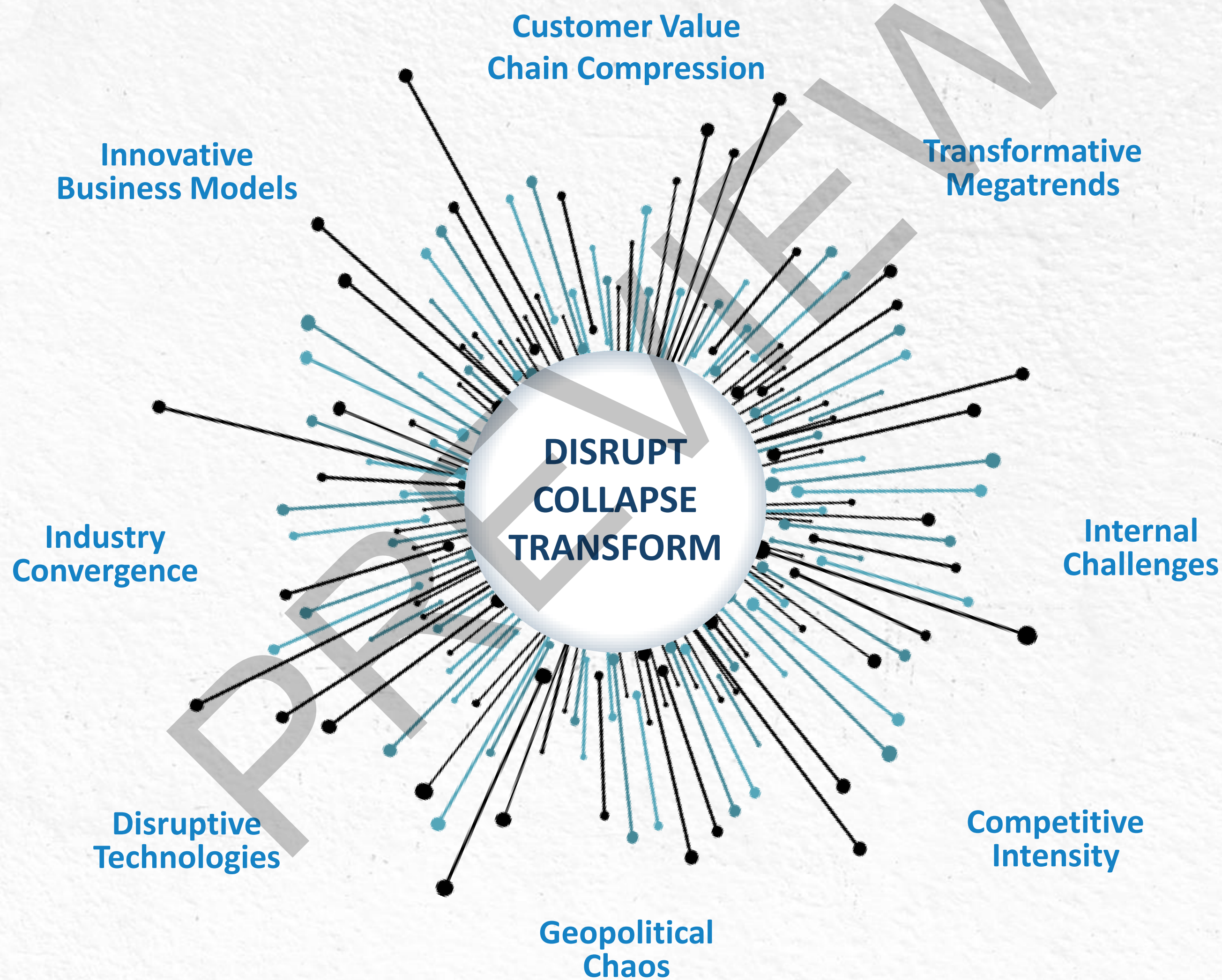


Strategic Imperatives

Urban mobility and autonomous vehicles driving progress in the SSB industry

Why is it Increasingly Difficult to Grow?

The Strategic Imperative 8™: Factors Creating Pressure on Growth



Source: Frost & Sullivan

The Strategic Imperative™

Innovative Business Models	Customer Value Chain Compression	Transformative Megatrends	Internal Challenges
A new revenue model that defines how a company creates and capitalizes economic value, typically impacting its value proposition, product offering, operational strategies, and brand positioning	Customer value chain compression as a result of advanced technologies, internet platforms, and other direct-to-consumer models that enables reduction in friction and the number of steps in customer journeys	Global forces that define the future world with their far-reaching impact on business, societies, economies, cultures, and personal lives	The internal organizational behaviors that prevent a company from making required changes

Competitive Intensity	Geopolitical Chaos	Disruptive Technologies	Industry Convergence
A new wave of competition from start-ups and digital business models that challenge the standing conventions of the past, compelling established industries to re-think their competitive stance	Chaos and disorder arising from political discord, natural calamities, pandemics, and social unrest that impact global trade, collaboration, and business security	New, disruptive technologies that are displacing the old, and significantly altering the way consumers, industries, or businesses operate	Collaboration between previously disparate industries to deliver on whitespace cross-industry growth opportunities

Source: Frost & Sullivan

The Impact of the Top 3 Strategic Imperatives on the Solid-state Battery (SSB) Market

SI8

Transformative Megatrends

Why

- **EV Revolution**: SSBs are driving the widespread adoption of EVs by offering higher energy densities and faster charging capabilities.
- **Autonomous Driving and Urban Mobility**: SSBs play a crucial role in powering the advanced sensors and computing systems necessary for autonomous vehicles and facilitating the development of sustainable urban mobility solutions, such as electric buses and taxis.

Frost Perspective

- Transformative megatrends underscore SSBs' pivotal role in revolutionizing mobility, driving the adoption of EVs, and powering advancements in autonomous driving and urban mobility solutions.
- These trends highlight the profound impact of SSB technology on shaping a cleaner, safer, and more efficient transportation future.

Competitive Intensity

Why

- Rivalry and competitive pressure exist among companies competing in the SSB sector. Factors contributing to competitive intensity include technological innovation, production scalability, cost efficiency, and market penetration strategies.
- This heightened competition drives innovation and pushes companies to continuously improve their offerings to gain a competitive edge in the rapidly evolving mobility market.

Frost Perspective

- The rivalry among established players and start-ups highlights the industry’s dynamic nature, where innovation and technological advancement are paramount.
- This competitive intensity fosters rapid SSB development and commercialization. Overall, the perspective underscores the significance of competition in shaping the future of mobility and accelerating the adoption of advanced battery technologies.

Industry Convergence

Why

- Collaboration between SSB and mobility companies represents an alliance between previously separate industries to capitalize on cross-industry growth opportunities, involving partnerships between battery manufacturers, automotive companies, technology firms, and renewable energy providers.
- Leveraging expertise from different sectors, such as material sciences and automotive engineering, will accelerate SSB development and adoption, driving progress toward a sustainable and interconnected mobility ecosystem.

Frost Perspective

- Industry convergence in SSB technology within the mobility market fosters collaboration between previously separate industries to capitalize on growth opportunities.
- This approach accelerates innovation, pooling expertise from the battery manufacturing, automotive, and technology sectors to develop cutting-edge solutions that align with the mobility market's evolving needs.

Source: Frost & Sullivan

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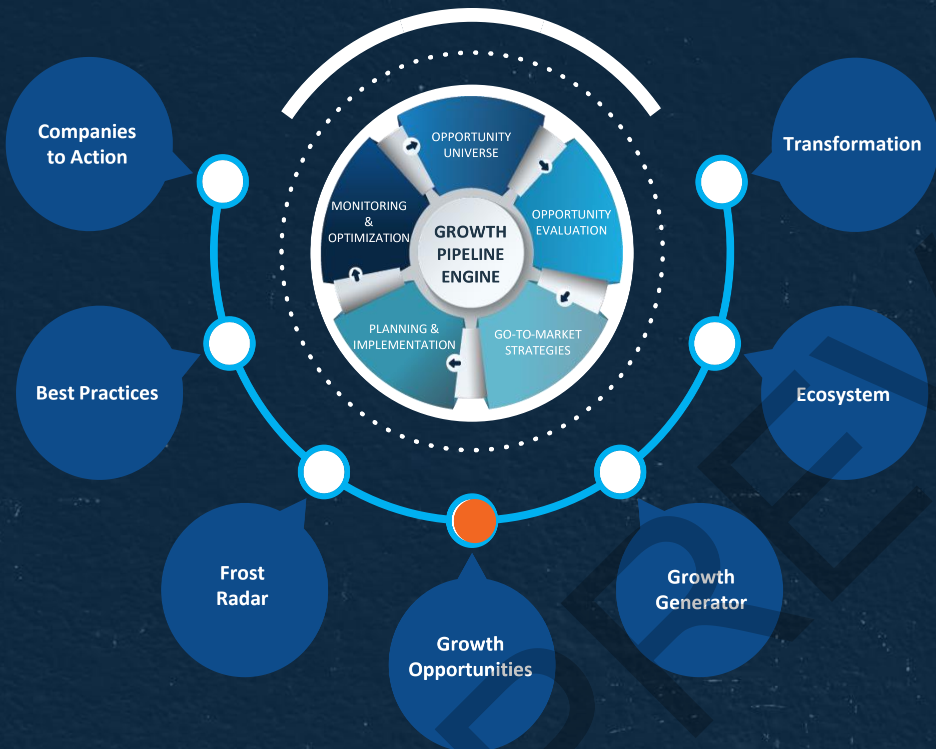

Growth Opportunity Analysis

Rapid progress and prospects in the global SSB industry

Scope of Analysis

Base Year	2023
Study Period*	2018–2030
Forecast Period	2024–2030
Market/Segment/ Program Area	Market Environment, Technology Trends, Market Participants and Collaborations and Partnerships
Geographic Scope*	North America, Europe and Asia-Pacific

* Unless the study indicates otherwise

Source: Frost & Sullivan

Research Aims and Objectives

Aim

Analyze the growth opportunities in SSBs globally in the electric vehicle (EV) market

Objectives

- Evaluate the critical adoption trends in SSBs for EVs
- Study the market landscape for SSBs and recognize the challenges the segment faces
- Understand the evolution of battery technologies and SSB’s place in the battery space
- Explore the role of OEMs in the SSB battery life cycle
- Breakdown the SSB market size among other battery technologies
- Define the global patent activity in SSB and related technologies
- Identify the companies active in the SSB space for EVs

Source: Frost & Sullivan

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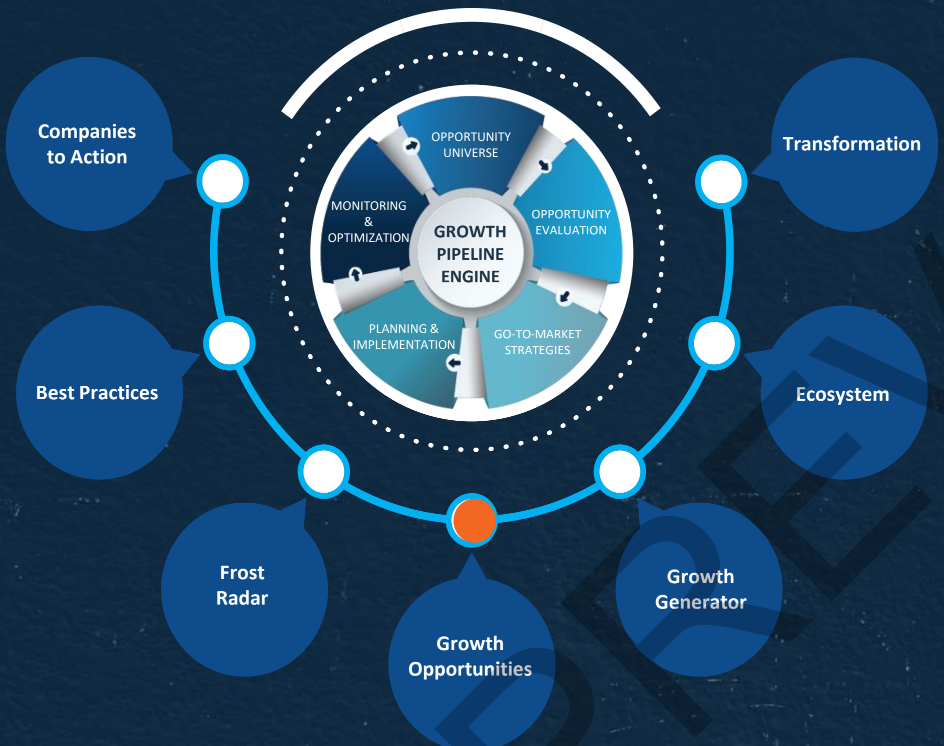


Growth Environment

SSBs promise environmentally friendly, cheaper, and safer technology compared to Li-ion batteries

Development of SSBs

SSBs represent a transformative leap in battery technology, relying on innovative materials, advanced manufacturing, and strategic collaborations. Concerted efforts in R&D and strategic partnerships are accelerating the path toward commercialization, promising a significant impact on the global EV market.

1 Material Selection and Development

Solid Electrolytes: Materials with high ionic conductivity (ceramic, sulfides, and polymers)
Anodes: Lithium metal (Li-metal) with suitable cathode material

2 Electrolyte-electrode Interface Engineering

Interfacial Layer: Resistance-lowering strategies; dendrite inhibition
Coating and Composite Methods: For improving interface compatibility and stability

3 Cell Design and Manufacturing Processes

Layer-by-layer Assembly: Precise layering of electrolytes and electrodes on one another
Manufacturing Streamlining: Assembly process automation and quality control

4 Performance Optimization and Testing

Cycle Life and Durability Testing: Evaluating charge-discharge cycles and capacity retention
Safety Testing: Ensuring reliability under various conditions (e.g., overcharging, high temperatures)

5 Collaborative Research and Development

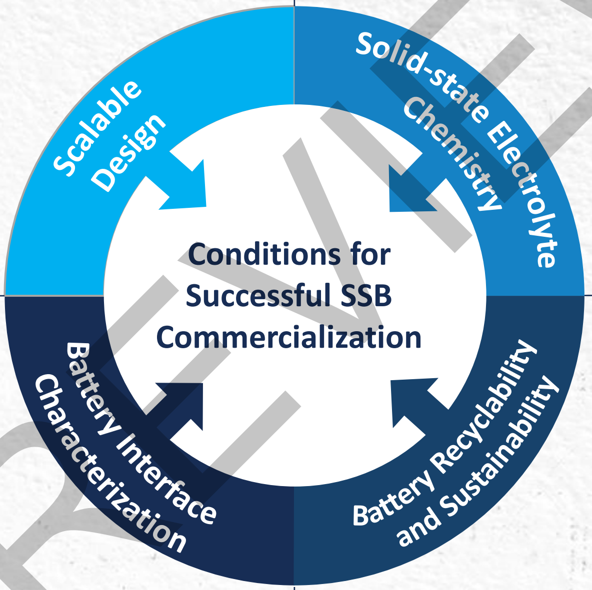
Industry-Academic Partnerships: Pooling resources and expertise (e.g., Toyota and Panasonic; Volkswagen [VW] and QuantumScape)
Government and Private Funding: Supporting R&D efforts and scaling up manufacturing

Source: Frost & Sullivan

Major Challenges to SSB Technology Development

The use of non-flammable solid-state electrolytes enables SSBs to effectively address battery safety concerns in EV applications.

SSBs in EVs: Barriers to Commercialization, Global, 2023

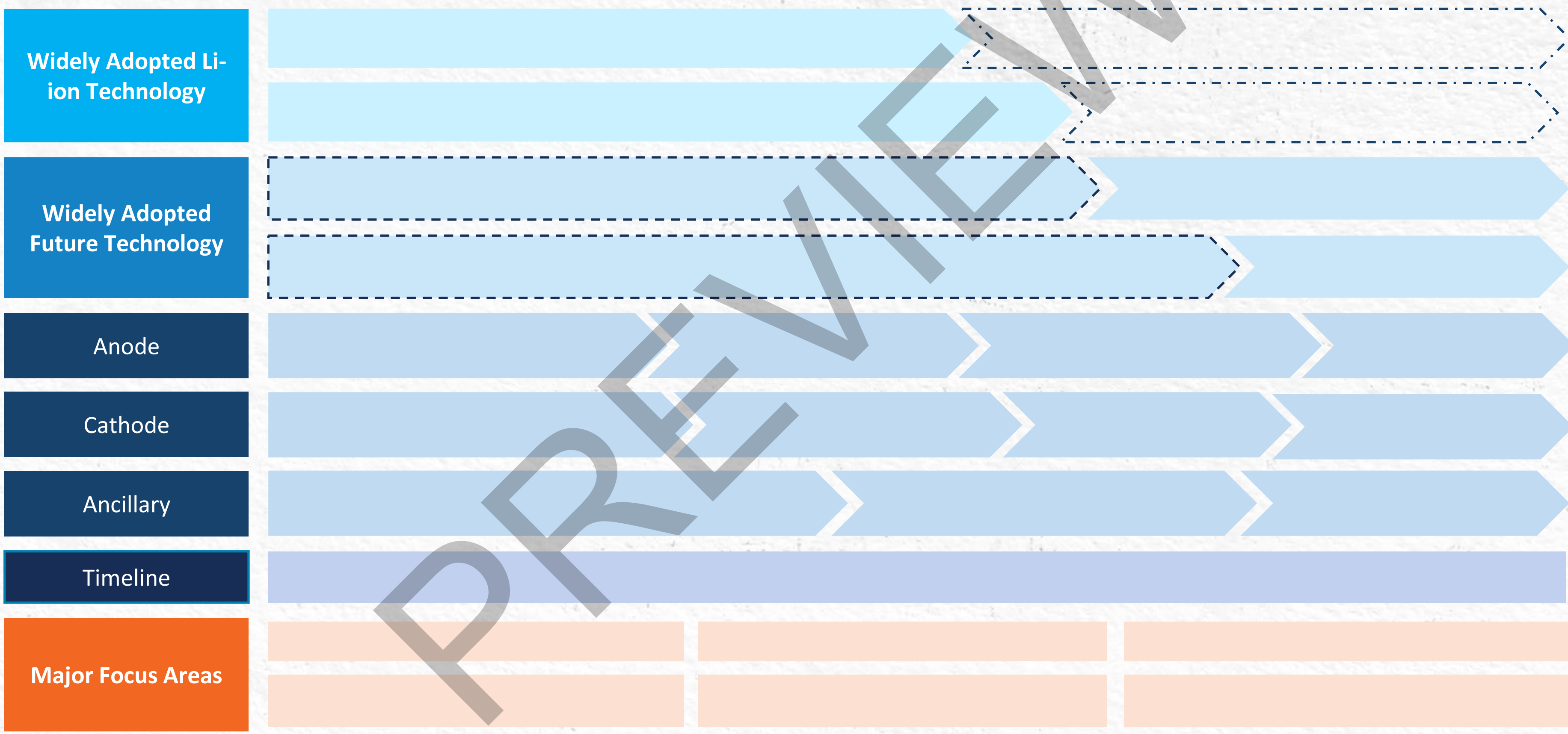


Source: Frost & Sullivan

Technology Roadmap for Evolving Battery Chemistries

SSBs and lithium-sulfur batteries will gain preference over other alternative chemistries primarily because of their high energy density, low cost, and reliability.

SSBs in EVs: Technology Roadmap for Evolving Battery Chemistries, Global, 2023



Source: Frost & Sullivan

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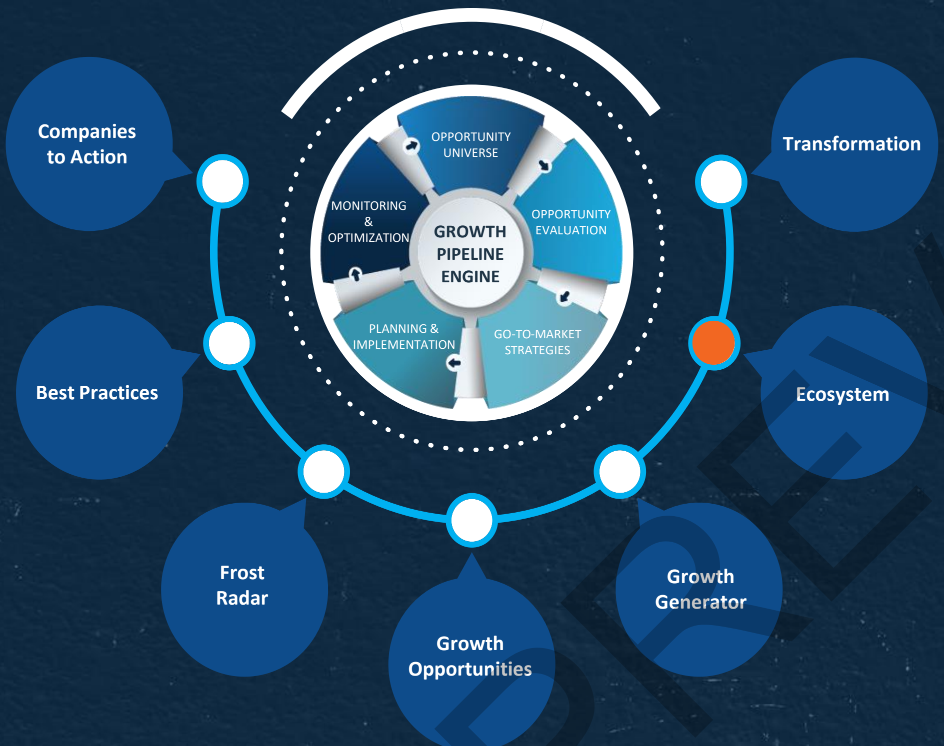


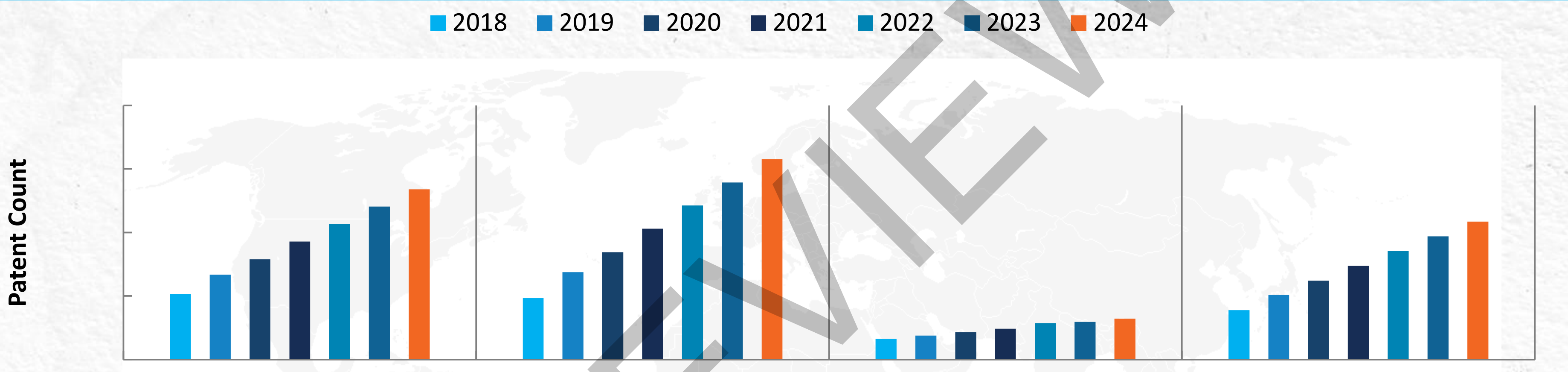
Patent Activity

China leads growing SSB patent filings globally

SSB Patent Activity by Geography

The increase in SSB patents globally signals growing interest and investment in these safer and more efficient technologies, which are imperative for advancing industries and addressing requirements such as sustainability and energy.

SSBs: Published Patents by Patent Office, Global, 2018–2024*



* 2021–2024 are projected figures.

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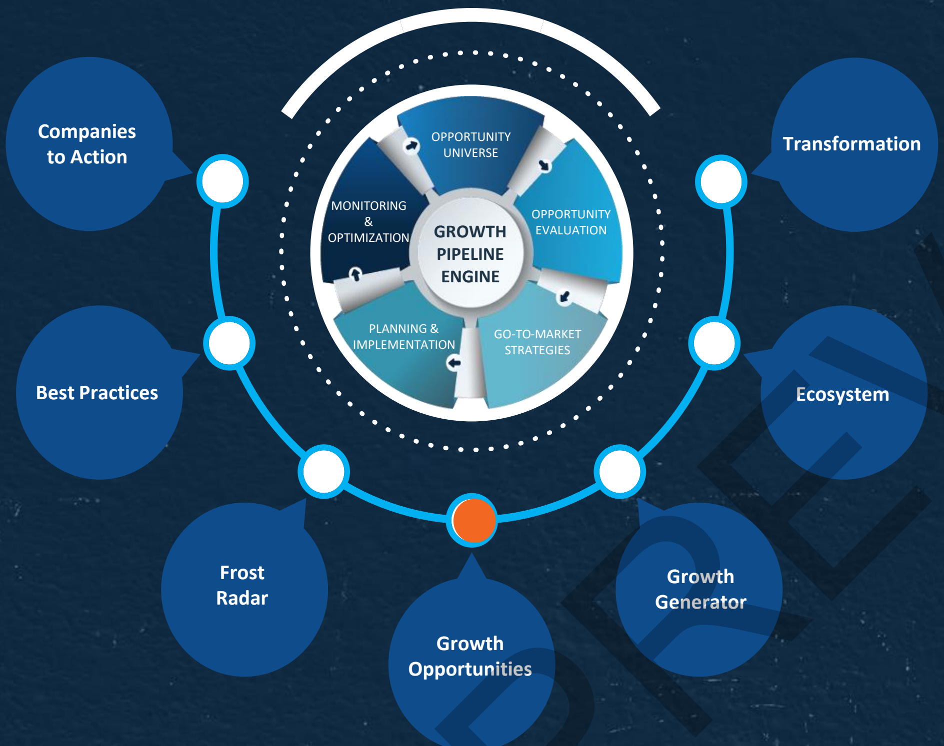

Growth Opportunity Universe

What Growth Strategies have you embraced to maximize your Growth Potential?

Growth Opportunity 1: Mass Manufacturing to Drive SSB Technology Implementation

Opp. Size in 5 Years	$100 M–$500 M
Timeline for Action	Over 3 to 5 Years
GO Base Year	2024

Relevant End-User Industries for this Growth Opportunity

Manufacturing	Mobility	Metal & Mining
Energy & Environment	Chemicals & Materials	Information & Communications Technologies
Electronics & Semiconductors	Agriculture, Food & Nutrition	Govt and Public Sector
Construction	Education	Healthcare & Lifesciences
Consumer	Aerospace	Hospitality
Retail	Defense	Banking & Financial Services

Applicable Regions

- Central & East Europe
- South Asia
- Western Europe
- CIS
- North America
- Latin America
- Africa
- Middle East
- Asia-Pacific

Frost & Sullivan has identified 10 Growth Processes that serve as levers for determining and evaluating new Growth Opportunities.

Growth Processes

- Customer & Branding
- Distribution Channel
- Geographic Expansion
- Vertical Market Expansion
- Competitive Strategy
- Strategic Partnering
- Product Development
- Mergers & Acquisitions
- Product Launch
- Technology & IP

Source: Frost & Sullivan

Growth Opportunity 2: R&D Focus Areas

Opp. Size in 5 Years	$100 M–$500 M
Timeline for Action	Over 3 to 5 Years
GO Base Year	2024

Relevant End-User Industries for this Growth Opportunity

Manufacturing	Mobility	Metal & Mining
Energy & Environment	Chemicals & Materials	Information & Communications Technologies
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- Strategic Partnering
- Product Development
- Mergers & Acquisitions
- Product Launch
- Technology & IP

Source: Frost & Sullivan

Growth Opportunity 3: Regulatory and Standardization Focus Areas

Opp. Size in 5 Years	$100 M–$500 M	Relevant End-User Industries for this Growth Opportunity			Applicable Regions
		Manufacturing	Mobility	Metal & Mining	Central & East Europe
					South Asia
Timeline for Action	Over 3 to 5 Years	Energy & Environment	Chemicals & Materials	Information & Communications Technologies	Western Europe
		Electronics & Semiconductors	Agriculture, Food & Nutrition	Govt and Public Sector	CIS
					North America
		Construction	Education	Healthcare & Lifesciences	Latin America
GO Base Year	2024	Consumer	Aerospace	Hospitality	Africa
					Middle East
		Retail	Defense	Banking & Financial Services	Asia-Pacific

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Source: Frost & Sullivan

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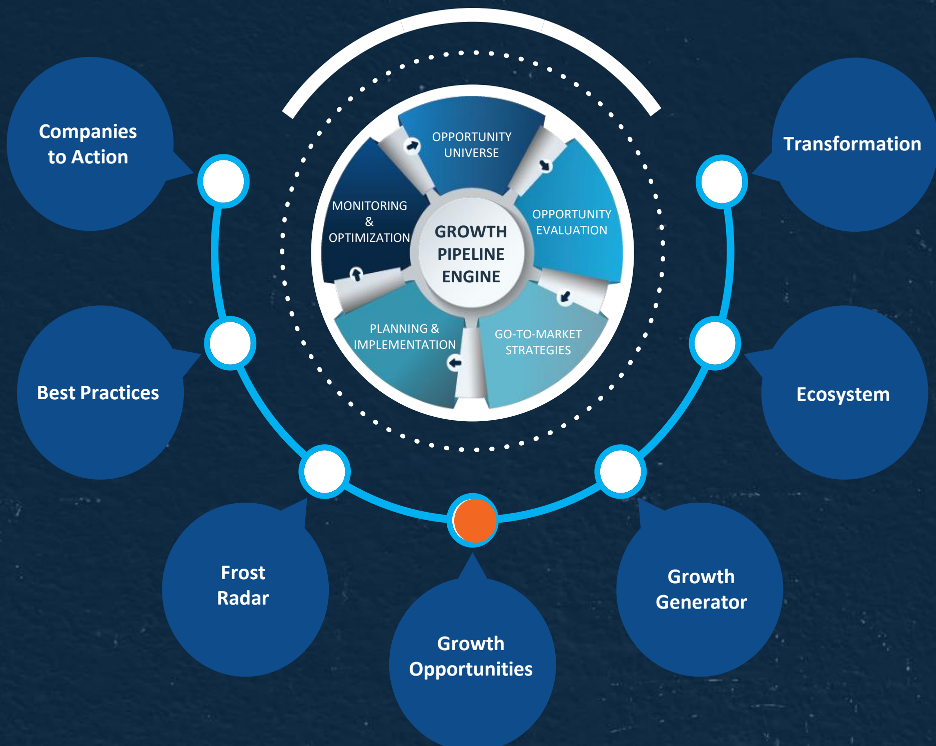

Appendix & Next Steps

How does your organization identify and prioritize Growth Opportunities?

Benefits and Impacts of Growth Opportunities

1

Survive & Thrive:

The Coming Transformation

2

Maximize:

Future Growth Potential

3

One Team:

CEO's Growth Team is inspired & unified

4

Implementation:

Align with Growth Opportunities

5

Brand Power:

Investor-Customer-Employee

Which of these benefits would be most important to your Investor-Customer-Employee?

Source: Frost & Sullivan

Next Steps

JOIN:
Growth Council

APPLY:
Companies to Action

ENGAGE:
Growth Dialog

PARTICIPATE:
Growth Council Think Tank

Does your current system support rapid adaptation to emerging opportunities?

List of Exhibits

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