Research Sample

The Next-Generation Battery Roadmap: Quantifying How Solid-State, Lithium-Sulfur, and Other Batteries Will Emerge After 2020

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Coverage Area: Energy Storage

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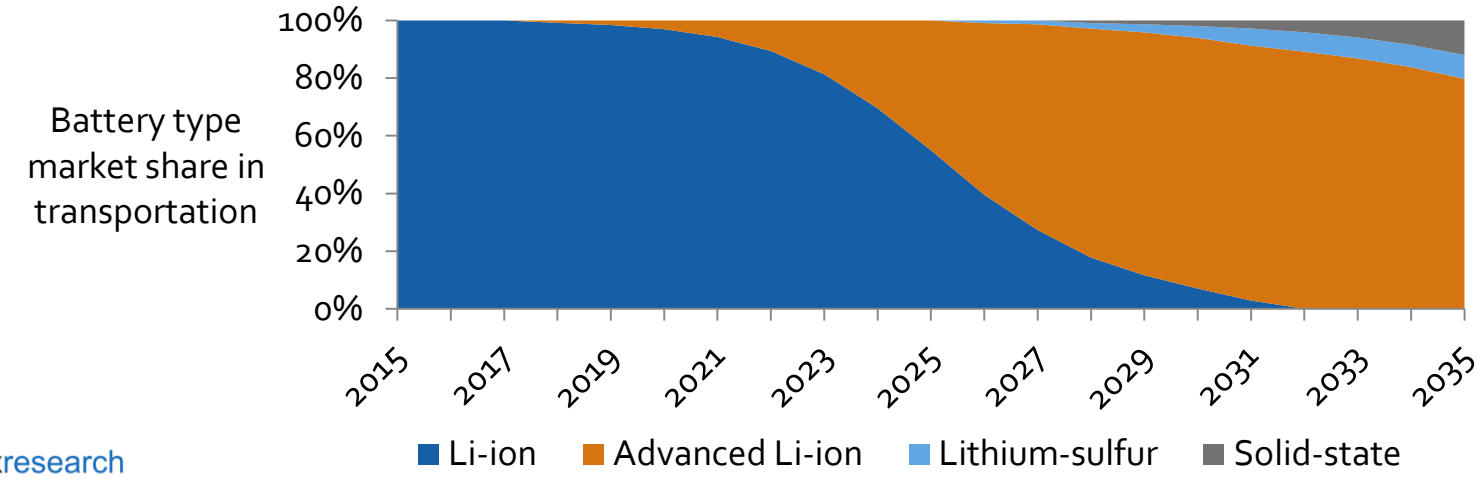
Executive Summary

- Today's Li-ion batteries are under intense pressure to evolve, leading to longer-running electronics, cheaper electric vehicles, and a market for stationary storage; through our analysis, we find that:
  - The biggest growth in batteries will actually come from gradually evolving Li-ion batteries, through incremental innovations like higher-voltage cathodes and electrolytes, paired with higher-capacity active materials like silicon-containing composites
  - Next-generation batteries must wait until nearly 2030 to gain noteworthy market share – around then, solid-state batteries will win about $3 billion in transportation and $2 billion in electronics; lithium-sulfur will capture market share, too, though its growth will be slower
  - Early adopter markets will be key – we recommend focusing on military, wearables, IoT



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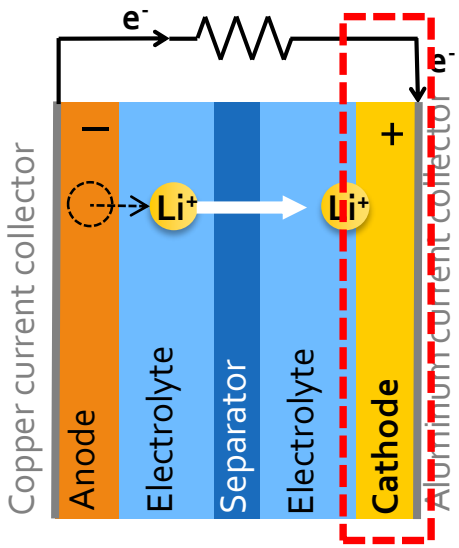
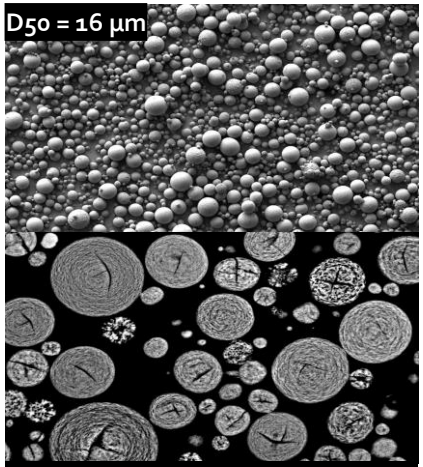
Li-ion will remain a moving target, with one of key improvements being better cathodes

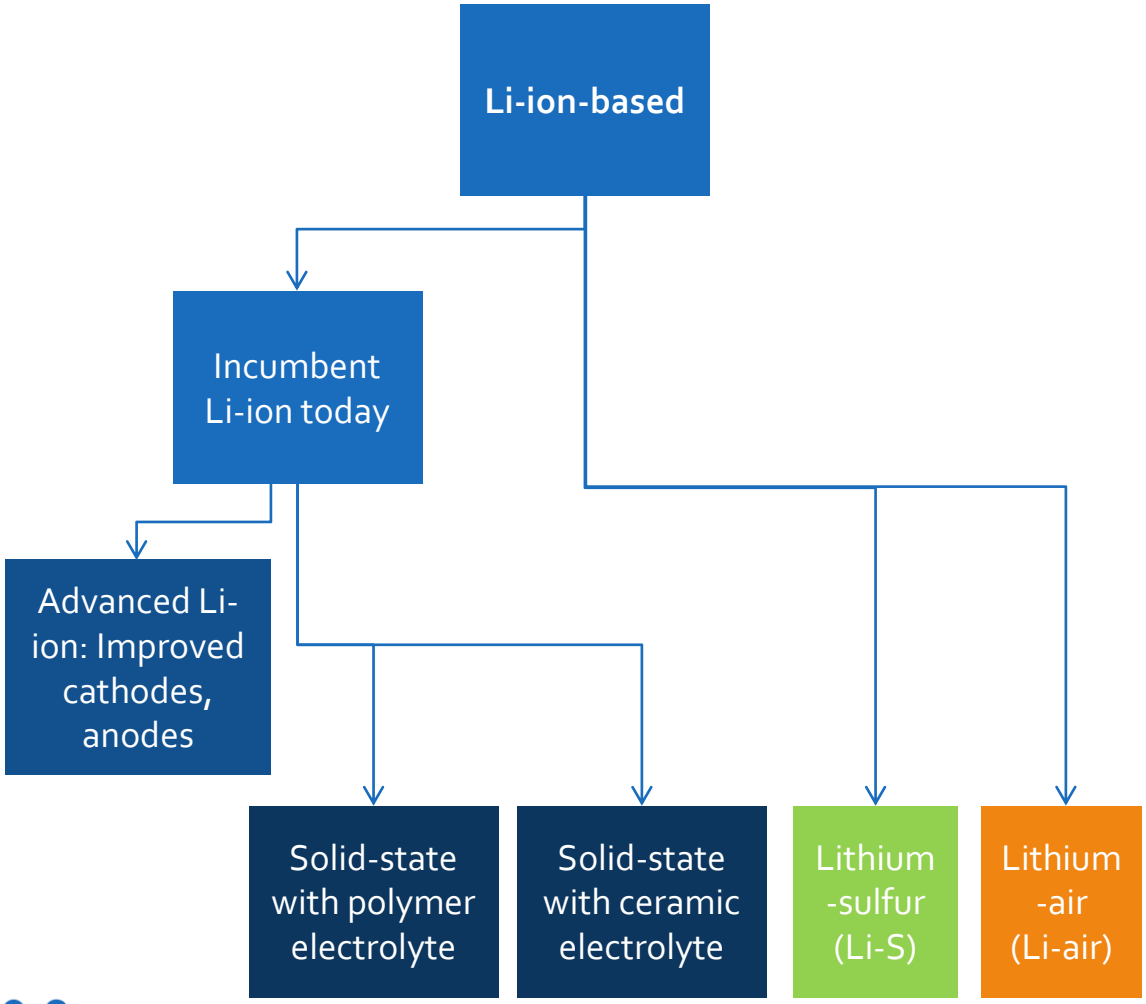
- Today's Li-ion batteries still enjoy incremental improvements every year, boosting performance within established design and manufacturing process, via better cathodes (this slide) and anodes, electrolytes, separators (next slides)
- **Incumbent Li-ion cathodes**: Li-containing transition metal oxides, at < 4.1 V:
  - Lithium cobalt oxide ($LiCoO_2$, LCO)
  - Lithium nickel manganese cobalt oxide ($Li(Ni_xMn_yCo_{1-x-y})O_2$, NMC)
  - Lithium manganese oxide ($LiMn_2O_4$, LMO; spinel-type)
  - Lithium iron phosphate ($LiFePO_4$, LFP)
- **Advanced Li-ion cathodes**:
  - Higher-voltage and higher-capacity materials, including:
    - "Layered-layered" oxide materials, such as BASF's high-energy NMC (see the report "The Li-ion NMC Patent Lawsuit and Its Fallout: Waging Billion-dollar War over Crystal Phases")
    - Spinel-type oxides (such as $LiNi_{0.5}Mn_{1.5}O_4$)
    - Polyanion materials (such as $LiCoPO_4$)
  - **Advantages**: Greater volumetric and gravimetric energy density, potentially reaching or exceeding the 300 Wh/kg to 350 Wh/kg level
  - **Challenges**: Low cycle life due to material degradation upon cycling (commonly less than 100 cycles), capacity fade, safety concerns

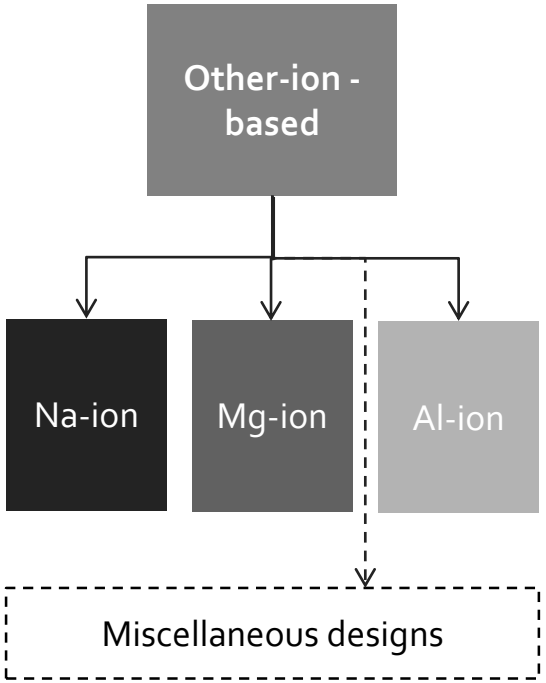




High-energy NMC cathode material from BASF

Beyond today's incumbent Li-ion and advancing Li-ion, there are many next-generation battery options





Major players are already betting big on next-generation batteries, but many questions remain

- In late 2015, the next-generation battery race officially kicked into gear, with two landmark acquisitions being the first-ever buys by major corporations of solid-state battery start-ups:
  - Automotive supplier **Bosch** bought California-based **Seeo**, a developer of polymer solid-state batteries, to help with Bosch's ambitious goals to cut energy storage costs by 75% (see the September 1, 2015 LRESJ)
  - Electronics maker **Dyson** bought Michigan-based **Sakti3**, another developer of solid-state batteries, for $90 million, and is considering investing a further $1 billion to scale up its technology towards mass-production
- Despite other examples abound – including BASF investing $50 million into lithium-sulfur developer Sion Power, and Toyota Motor running of the world's largest solid-state battery research laboratories – many questions remain unanswered:
  - When will next-generation batteries really begin to impact the market, and to what extent?
  - Who are the leading developers of next-generation battery technology?
  - What applications should developers target to maximize chances of success?

2015's first landmark buy in solid-state batteries

BOSCH

SEEO

2015's second landmark buy in solid-state batteries

dyson

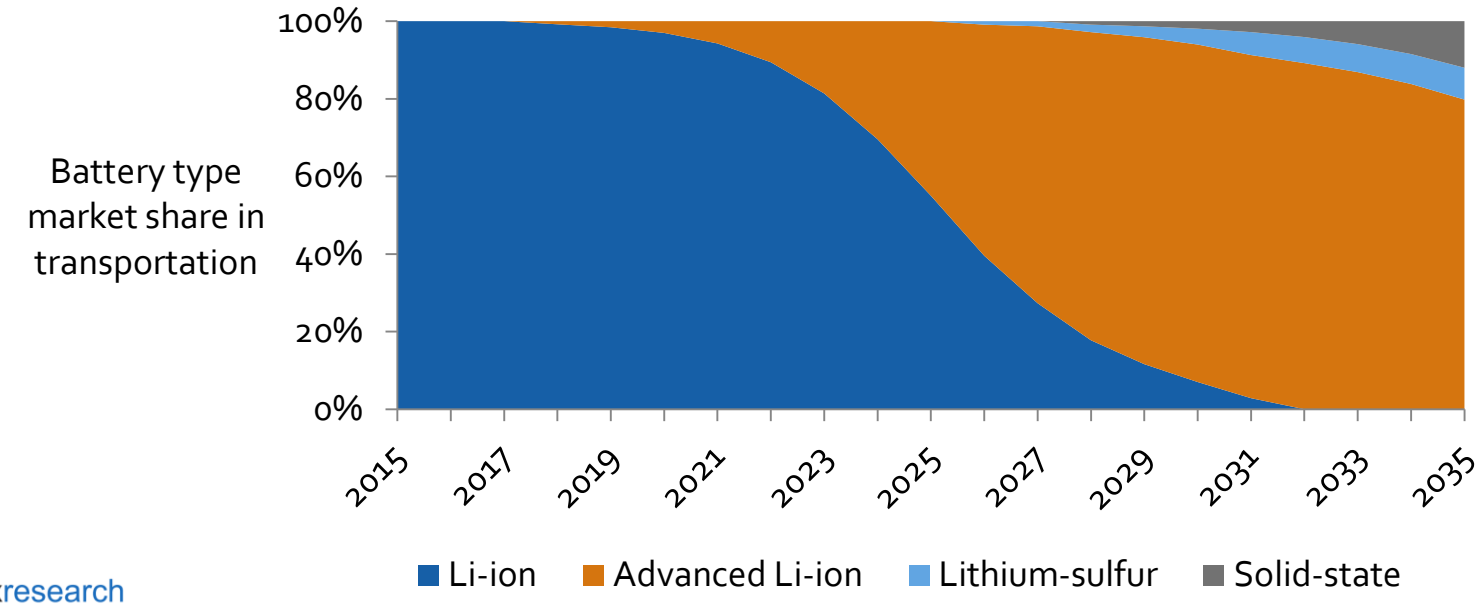
SAKTI3

Our methodology sizes the next-generation battery market, ranks developers, and identifies early adopters

- This report's analysis is in three parts:
  1. We forecast the adoption roadmap for battery technology, quantifying how evolving Li-ion will lose some market share to next-generation energy storage, and how that varies by application
  2. We rank next-generation battery developers using primary research, comparing them through our proprietary Lux Innovation Grid framework
  3. We study how to best bring next-generation batteries to market, analyzing the strategies of developers as they target niches and early adopters
- This analysis is based on a mixture of primary and secondary research, based on interviews with technology developers – both start-ups and large corporations – along with interviews with customers in various applications, including transportation, stationary, and electronics
- Because of the long timeframe involved – our analysis goes out to 2035 – clients are urged to view these figures as directionally indicative of order-of-magnitude market trends, rather than focusing on the exact figures associated with this 20-year forecasted view

We forecast no significant next-generation battery adoption until the late 2020s in transportation

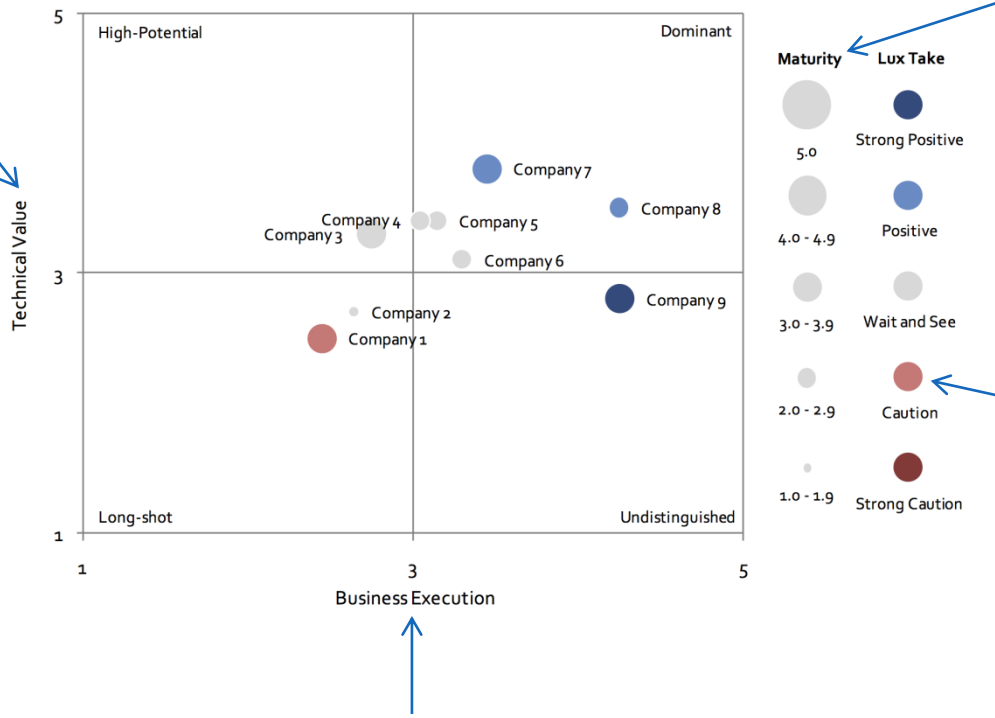
- Transportation will see no significant adoption of next-generation batteries before the late 2020s – until then, Li-ion will dominate, evolving to become advanced Li-ion:
  - We define advanced Li-ion as a varied mix of higher-voltage and higher-capacity materials, but a step beyond today's NMC or NCA paired with graphite
  - We forecast lithium-sulfur and solid-state batteries to reach 4% and 2% market penetration in 2030 in transportation, respectively, rising to 8% and 12% in 2035
  - Lithium-sulfur's slight lead in market entry will be due to initially simpler manufacturing, lower costs, and good performance, although solid-state will catch up and pass it by 2035



The Lux Innovation Grid compares companies on their technical value, business execution, and maturity

- We now turn to look at specific start-ups currently offering next-generation batteries:
  - Drawing from our interviews with executives at these companies and in the industry, we plot their potential on the Lux Innovation Grid (LIG):

The strength and value of a company's technology determines its **Technical Value** score. Companies with useful products and services that lower cost, boost performance, or increase revenue are valuable to customers, partners, and investors. The Technical Value score not only takes into account the absolute performance level of a certain solution, but also how it fits with the requirements of the target application.



The completeness of a company's development reflects its **Maturity**. Mature companies have secured a place and built a presence in the market. Dot size indicates the company's maturity on a scale from 1 (immature) to 5 (developed).

A company's success is measured holistically by the **Lux Take**. The Lux Take is an overall ranking mechanism based on the considerations taken in the above areas, placing companies into five categories indicated by dot color.

A company's ability to perform and achieve success determines its **Business Execution** score. Business execution is a measure of the company's ability to run a viable organization, growing sales, managing costs, and making customers and investors happy.

Details of the methodology behind the Lux Innovation Grid's scoring metrics

Technical Value Criteria	Description
Technology/Solution Value	Qualitative measure of the value of a company's offering, in terms of performance and cost
Market Size	Size of the addressable market for a company's technology
IP Position	Qualitative measure of the value of the company's patents or trade secrets and considers defensibility
Competitive Landscape	Qualitative ranking of the strength and amount of competition that a company faces in its part of the health care markets
Key Metrics	Qualitative score based on capital costs, operating or recurring costs, and energy use

Business Execution Criteria	Description
Momentum	Qualitative measure of the rate of a company's progress
Partnerships	Qualitative measure of the strength and number of a company's partnerships
Revenue/Employees	Company's revenue divided by the number of employees; measure of profitability
Barriers to Growth	Qualitative ranking of the barriers that the organization has to overcome to achieve growth
Cash Position	Company's cash on hand; measure of company's livelihood

Maturity Criteria	Description
Employee Count	Number of employees
Stage of Development	Qualitative score based on the company's primary product's stage of development
Revenue	Amount of yearly revenue
Age	Number of years since company was founded

Battery incumbents continue to invest billions into Li-ion improvements – sums that next-generation battery developers should aim to match

- Major Li-ion developers are scaling up manufacturing capacity aggressively, even in the face of existing overcapacity (the U.S. DOE estimated global utilization at 22% in 2014)
  - Developers will face continuing overcapacity if plug-in vehicle sales do not grow rapidly
  - Excess Li-ion capacity will encourage cell makers to keep iterating on designs that can use the same manufacturing techniques as Li-ion
- Disruptive next-generation companies (both in new technologies and manufacturing processes) will most likely *not* be today's incumbent Li-ion players, since these incumbents are focused on more incremental efforts – but next-generation developers can hope to learn from them:

Company	Anticipated new capacity	Year fully operational	Investment	Location
Tesla Motors, Panasonic	35 GWh	2020	$4 billion to $5 billion	United States
BYD	18 GWh to 30 GWh	2020	$2 billion to $4 billion	China, Brazil, United States
Boston Power	8 GWh	2018	$0.3+ billion	China
Samsung SDI	5 GWh	2016	$0.6 billion	China
LG Chem	3 GWh	2016	$0.3+ billion	China

Thank you for downloading this Lux Research Energy Storage Intelligence research sample, which contains selected pages from **our 49-page** research document "The Next-Generation Battery Roadmap: Quantifying How Solid-State, Lithium-Sulfur, and Other Batteries Will Emerge After 2020."

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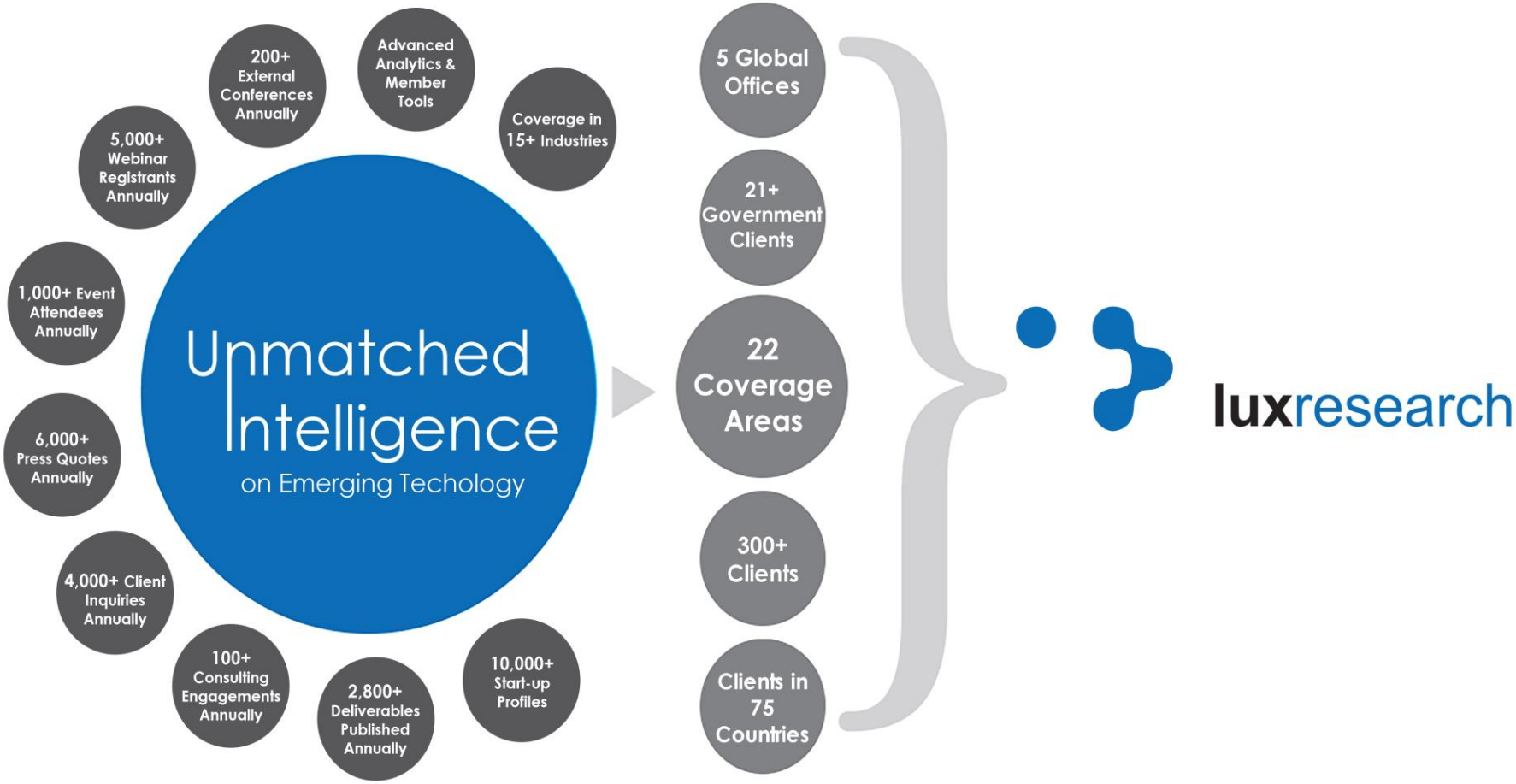

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