



2018 North American Lithium-ion Industrial and Electric
Vehicle Battery Technology Innovation Award



2018
BEST PRACTICES
AWARDS

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Background and Company Performance

Industry Challenges

The demand for energy-intensive batteries is rapidly increasing with the rise of grid energy storage systems, electric vehicles (EVs), and smart consumer electronics. The primary requirements for lithium-ion battery storage include increasing the cost-to-performance ratio and safety features in EV and grid storage applications. The principal challenge in the EV market is the relatively higher cost of the vehicles, which is a direct outcome of the pricey battery pack. On the other hand, the challenges associated with the grid energy storage market involve delivering high capacity while simultaneously lowering cost of the lithium-ion cell for peak energy demand.

Safety

Despite its superior performance characteristics such as high energy density and long cycle life, lithium-ion batteries have acquired the reputation of having high pricing points, aging, and thermal runaway problems. Safety is a primary criterion in mission-critical applications such as those within the grid storage and transportation industries where compromising safety features could prove fatal. The high-profile safety incidents associated with lithium-ion batteries, such as fire hazards in passenger aircraft, have caused apprehension among end users concerning inclusion of these batteries in consumer electronics and industrial applications.

Energy Density

High energy density, safety, and cost must be balanced to address the unmet market needs of utility-scale energy storage and battery use in EVs. In particular, energy density plays a vital role in dictating the weight, power output, and efficiency of a battery pack. Although the current energy density of lithium-ion batteries is competitive in smaller cells, there is still scope to increase it in a larger architectural footprint to change the energy paradigm.

Pricing

Pricing pressure is acute across several industrial and automotive applications. Compared to traditional cost-competitive lead-acid and nickel-cadmium batteries, the current average cost of \$350 per kilowatt hour for lithium-ion batteries is high. Therefore, pricing remains a major barrier to large-scale adoption of lithium-ion technologies in industrial and automotive applications. In addition, there is a substantial challenge to lower the production costs associated with manufacturing lithium-ion batteries for mass production. The battery market is price sensitive with constant pricing pressure. Therefore, companies are bombarded with challenges as they aim to strike a balance between leveraging innovative products with economic feasibility for broader market acceptance. At \$100/kWh EV's become more cost effective than traditional internal combustion engine (ICE) vehicles.

Packaging

The existing packaging techniques for the deployment of lithium-ion batteries in the EV space have certain drawbacks. The major issues associated with the design include uneven current distribution and active material distribution, which causes significant deterioration in the performance of the batteries and the cycle life. The only practical solution to improve the energy density of lithium-ion batteries is by closely packing the jelly-rolls in a module. Typically, the standard modules utilizing industry-available cylindrical cells (18650) have a 50 to 250% higher separation spacing between electrode assemblies, thereby resulting in unused potential space for improving the energy density.

In a nutshell, increasing battery capacity to satisfy the energy-intensive applications usually increases the system cost and safety risks. Safety standards are then met by increasing cost and complexity of the end product. The practical approach manufacturers must take to operate commercially is continuously innovating and providing world-class products with features and price points that make it difficult for other market players to match.

Technology Attributes and Future Business Value

Product Impact

Cadenza Innovation (Cadenza) is pioneering the lithium-ion power revolution by developing a low-cost lithium-ion cell with superior packing technology that breaks existing cost and safety barriers. Cadenza has received two patents for its multi-core lithium-ion battery cell structure, referred to as the supercell. Independent testing by government research laboratories, as well as economic assessment by DNV-GL, has validated the safety and benefits of this new battery system. The company's breakthrough innovations dramatically improve performance, reduce costs, and boost safety through the following elements:

- i. A technology platform that employs the existing typical lithium-ion cell chemistry in a multi-jelly roll configuration
- ii. A ceramic housing material which includes a fire retardant and allows for maximizing energy density and restricts thermal runaway to a single cell in case of any fire event
- iii. An architecture which utilizes low-cost electrode assemblies with packaging arrangement flexibility to obtain different geometric sizes and shapes that drastically increase the battery capacity in a smaller footprint

As a result of these innovative features, the following performance characteristics have been achieved:

- i. 30% higher energy density (close to 350Wh/L in a module and over 500Wh/L in a near future)
- ii. Higher safety capabilities (limited thermal runaway)

- iii. Enhanced environmental friendliness, scalability, and sustainability
- iv. Simplified production and manufacturing (simplified battery architecture by eliminating unnecessary parts)
- v. 30% reduced price points (by utilizing commonly available materials such as cylindrically wound jelly rolls and established manufacturing techniques)
- vi. Smaller footprint and ease of integration

The current large cell batteries are easier to assemble via an expensive manufacturing process. On the other hand, small cells have established manufacturing methods but do not meet the energy and power requirements for challenging end-user applications. Cadenza has addressed the gaps left by existing lithium-ion batteries through the introduction of its supercell lithium-ion battery platform architecture designed with enhanced features and functionalities. The battery structure and unique packaging allow it to utilize the advantages of both large and small cell formats by assembling the battery pack in any desired form to deliver an unrivaled combination of energy demand, safety, and cost required for industrial energy storage and EV applications. Moreover, the non-expanding cells and avoidance of thermal runaway results in a space-efficient and low-cost module design. The meticulous focus on improving the safety features by avoiding the thermal runaway is the major driving force enabling performance, cost, and safety.

As an outcome of its product impact, Cadenza has been selected as an innovative solution source for New York State Energy Research and Development Authority (NYSERDA) as part of the Advanced Clean Power Program to develop a low-cost lithium-ion cell in the grid storage segment. It has also partnered with several leading companies in EV and grid storage including ABB, Alcoa, and Fiat Chrysler, which is a testament to its innovation capabilities and product impact. Frost & Sullivan has analyzed the competitors' offerings and concludes that this company's superior performance characteristics and attention to safety aspects outshine all others and will result in massive adoption in the EV and grid storage markets.

Industry Impact

Today, the grid storage and EV industries are dominated by the lithium-ion technology because of its inherent features, despite the high pricing drawback. Lithium-ion batteries have a record of safety issues, most notably displayed in the lithium-ion battery powered electrical system explosion in the Boeing Dreamliner aircraft. Therefore, the primary requirement in the EV and grid storage spaces for broader adoption is harmonizing the high energy density with low cost and uncompromising safety features.

Cadenza, with its innovative patented packaging of the lithium-ion battery, has worked from scratch to develop a high-performance, cost-effective, and safe battery solution. Frost & Sullivan estimates the combined market value for EV and grid battery storage will total \$60

billion by 2020 and experience an explosive growth rate. The lithium-ion battery market is projected to increase its market share significantly considering the growing adoption of EVs and augmentation of grid storage applications.

In particular, Cadenza's battery architecture is chemistry agnostic but allows all transition metal oxides to be leveraged for the platform. The precise focus on the cell/platform design and established mass production techniques have enabled the company to offer a lithium-ion battery at 30% fewer price points than the existing available battery price. Cadenza's technology innovation has the potential to disrupt the multi-billion dollar EV and grid storage markets with its excellent combination of high performance, safety, and low-cost offering.

The company also has the early-mover advantage in its proprietary battery architecture and shows tremendous potential in setting new standards for lithium-ion battery manufacturing and design. Frost & Sullivan believes the company's ability to achieve 30% more energy density and 30% less cost when compared to the traditional lithium-ion battery positions it to cause a major disruption in the battery industry.

Visionary Innovation

Cadenza's deep understanding of end-user needs and specific requirements is the pillar of its product development process that led to the groundbreaking packaging techniques, specifically a low-cost approach to packaging lithium-ion chemistries for a range of end-user applications.

Cadenza has worked on the cell-level architecture and packaging of lithium-ion batteries to create a revolutionary battery technology. The company uses readily available materials for mass production which can be manufactured using traditional jelly-roll production machinery that significantly reduces cost barriers. Production techniques combine the best properties of wound jelly rolls and large prismatic cells that can be packaged in a compact, lightweight case. Frost & Sullivan finds that the company's meticulous focus on energy density and safety is second to none in the industry. The cells' proprietary ceramic fiber material and unique matrix arrangement allow them to be thermally insulated from each other, thereby preventing thermal runaway if a single cell experiences a malfunction. In addition, the patented fire retardant thermal ceramic material used to avoid cascade runaway provides a safe cell structure that can be shipped anywhere in the world without fire hazard concerns.

Standard modules deploying standardized 18650 cylindrical cells have spacing between electrode assemblies of 50 to 250% wider separation than modules using the Cadenza packaging concept. By contrast, Cadenza's arrangement allows a tighter jelly roll array (1.5 to 2mm apart) than is typically found in modules of standard cylindrical cells (3 to 5mm apart). Such a packing arrangement enables more energy per unit volume while still ensuring safety. The above aspects set this technology apart from competitors whose

attempts have been primarily directed towards improving lithium-ion batteries by changing the chemistry or components of a cell. Frost & Sullivan resolutely believes that Cadenza's unparalleled commitment to manufacturing innovation in more space-efficient products offered at industry-leading price points will find greater acceptance in the battery industry.

Application Diversity

Cadenza's vision to develop a superior lithium-ion battery packaging architecture that caters to diverse end-user requirements and its scrupulous efforts to provide superior customer value are highly commendable. The company's staunch commitment to provide an environmentally-friendly solution that will contribute to mitigating climate change exemplifies market leadership initiative. And, most importantly, the patented technology has decoded the solution for application in the EV and grid storage markets.

The major hurdles to mass adoption of EVs have been the limited driving range, battery safety, and high cost. The Cadenza battery technology's high energy density obtained from the tighter packaging of the electrochemical unit results in increased vehicle range within a smaller footprint and price reduction up to 30% compared to existing lithium-ion batteries, thus facilitating more realistic widespread adoption.

In addition, the technology can be applied to the multi-hour grid and residential storage as well as peak shaving applications owing to its higher energy density while the decreased system costs generate a higher return on investment (ROI) across a wider range of use cases. The enhanced safety features and the ability for flexible placement of battery packs are opening up new market opportunities including consumer electronics, aerospace and defense, and lawn and garden equipment, to name a few. Frost & Sullivan's competitive analysis reveals that Cadenza's unique combination of safety features and cost-competitiveness, with high energy density, overshadows competing technologies, which will facilitate faster adoption over similar products in the market.

Customer Acquisition/Penetration Potential

The company is gradually gaining a reputation for delivering solutions that cater to the markets' exact needs, both current and upcoming. It is raising the bar in terms of innovation by leveraging its immense intellectual property, massive industry experience, and mass production expertise to deliver what it promises. Its technology is so effective that even during the demonstration stage the company has been able to secure pilot projects with FIAT Chrysler, an automotive giant, and ABB, the technology leader in electrification products. This is a precursor to the potential of Cadenza's technology innovation in the EV and grid energy storage markets.

With the positive results obtained so far from the pilot installations, the company has drawn substantial interest from major industrial and automotive companies across the globe for its technology. It has partnered with several major global players for rapid integration into exceptional global market opportunities. Ultimately, the global EV revolution and the need

for safe and emission-free battery energy storage solutions offer substantial penetration potential for the company to provide innovative products.

Cadenza has all the attributes needed to penetrate multiple markets by leveraging its innovative packaging technology, collaborating with global technology partners, and nurturing well-established global sourcing partnerships throughout the United States and Asia. It is Frost & Sullivan's finding that Cadenza's technology excellence combined with its pursuit for constant innovation will significantly increase its customer acquisition potential.

Technology Licensing/Positioning

Cadenza is in a solid position to capitalize on the trends sweeping through utility grid storage and automotive electrification. The company is flexing its muscles by negotiating licensing its technology to multiple global battery manufacturers to leverage its technological application. Cadenza's technology platform architecture uses readily available components and established mass production techniques to achieve cost reduction. The major advantage of this platform is that the manufacturers can source the jelly rolls from anywhere on the globe and store the dry roll for a year. A licensee can then utilize Cadenza's prefabricated novel housing to produce disruptive, high-performance batteries, thereby shifting the established paradigm that requires significant vertical integration to succeed as a battery manufacturer.

The company's licensing strategy does not involve offering new lithium chemistry or adding new material into the traditional lithium sealed cell. Instead, the technology innovation is focused on novel packaging of the platform that will enable any manufacturer to maximize the utilization of its proprietary lithium cells to drive cost even lower than what is possible from their initial designs. Cadenza takes advantage of this major benefit as a vital benchmarking criterion to differentiate itself from its competitors.

The company is further solidifying its position by working closely with a major global partner network to facilitate fast commercialization. The collaboration partners include Fiat Chrysler, vehicle integration; Alcoa (now Arconic), metal components; Karotech, metal component design and fast prototyping; Morgan Thermal Ceramics, housing material; ABB, grid system integration; NREL and Impact Design (MIT), thermal and mechanical modeling; and multiple US and Asian supply chain sources. It has also been rewarded with several government contracts such as US Department of Energy/Advanced Research Projects Agency-Energy (DOE/ARPA-E) and NYSERDA to validate the technology for large-scale adoption.

The company is working resolutely towards achieving \$125/kWh by 2018, which will drive the industry-leading cost reduction. In comparison to Cadenza, competitor 2 and competitor 3's products are priced higher. Frost & Sullivan believes that Cadenza's technology architecture and its competitive pricing have the potential to become the next global industry standard.

Conclusion

Cadenza Innovation's breakthrough packaging architecture for lithium-ion battery technology has overcome the relevant battery technology challenges; the company has developed a novel low-cost, safe, high-performance, scalable, and environmentally-friendly solution. Frost & Sullivan's independent analysis reveals that this innovation has sufficient potential to replace the commercially available lithium-ion and lead-acid batteries across different industry verticals including electric vehicle, grid storage, and military applications.

Cadenza Innovation has etched a strong mark in the industry with its innovative product and fastidious focus on delivering value to customers. This groundbreaking product is already witnessing tremendous interest, and customers will derive significant benefits going forward.

With its commitment to cutting-edge innovation, technical excellence, and overall industry impact, Cadenza Innovation earns Frost & Sullivan's 2018 Technology Innovation Leadership Award in the lithium-ion industrial and EV battery technology industry.

Significance of Technology Innovation

Ultimately, growth in any organization depends upon finding new ways to excite the market and upon maintaining a long-term commitment to innovation. At its core, technology innovation, or any other type of innovation, can only be sustained with leadership in three key areas: understanding demand, nurturing the brand, and differentiating from the competition.



Understanding Technology Innovation

Technology innovation begins with a spark of creativity that is systematically pursued, developed, and commercialized. That spark can result from a successful partnership, a productive in-house innovation group, or a bright-minded individual. Regardless of the source, the success of any new technology is ultimately determined by its innovativeness and its impact on the business as a whole.

Key Benchmarking Criteria

For the Technology Innovation Award, Frost & Sullivan analysts independently evaluated two key factors—Technology Attributes and Future Business Value—according to the criteria identified below.

Technology Attributes

- Criterion 1: Industry Impact
- Criterion 2: Product Impact
- Criterion 3: Scalability
- Criterion 4: Visionary Innovation
- Criterion 5: Application Diversity

Future Business Value

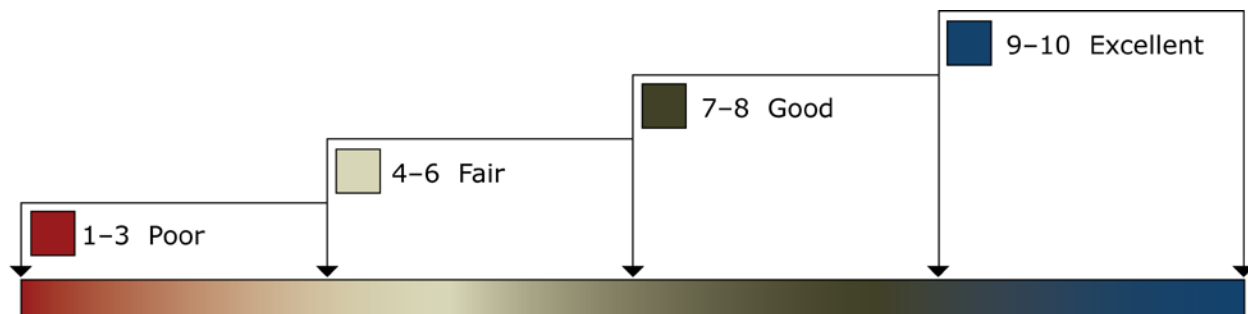
- Criterion 1: Financial Performance
- Criterion 2: Customer Acquisition
- Criterion 3: Technology Licensing
- Criterion 4: Brand Loyalty
- Criterion 5: Human Capital

Best Practices Award Analysis for Cadenza Innovation

Decision Support Scorecard

To support its evaluation of best practices across multiple business performance categories, Frost & Sullivan employs a customized Decision Support Scorecard. This tool allows our research and consulting teams to objectively analyze performance, according to the key benchmarking criteria listed in the previous section, and to assign ratings on that basis. The tool follows a 10-point scale that allows for nuances in performance evaluation. Ratings guidelines are illustrated below.

RATINGS GUIDELINES



The Decision Support Scorecard is organized by Technology Attributes and Future Business Value (i.e., these are the overarching categories for all 10 benchmarking criteria; the definitions for each criterion are provided beneath the scorecard). The research team confirms the veracity of this weighted scorecard through sensitivity analysis, which confirms that small changes to the ratings for a specific criterion do not lead to a significant change in the overall relative rankings of the companies.

The results of this analysis are shown below. To remain unbiased and to protect the interests of all organizations reviewed, we have chosen to refer to the other key participants as Competitor2 and Competitor3.

<i>Measurement of 1–10 (1 = poor; 10 = excellent)</i>			
Technology Innovation	Technology Attributes	Future Business Value	Average Rating
Cadenza Innovation	9	9	9
Competitor2	8	8	8
Competitor3	7	7	7

Technology Attributes

Criterion 1: Industry Impact

Requirement: Technology enables the pursuit of groundbreaking ideas, contributing to the betterment of the entire industry.

Criterion 2: Product Impact

Requirement: Specific technology helps enhance features and functionalities of the entire product line for the company.

Criterion 3: Scalability

Requirement: Technology is scalable, enabling new generations of products over time, with increasing levels of quality and functionality.

Criterion 4: Visionary Innovation

Requirement: Specific new technology represents true innovation based on a deep understanding of future needs and applications.

Criterion 5: Application Diversity

Requirement: New technology serves multiple products, multiple applications, and multiple user environments.

Future Business Value

Criterion 1: Financial Performance

Requirement: Potential is high for strong financial performance in terms of revenues, operating margins, and other relevant financial metrics.

Criterion 2: Customer Acquisition

Requirement: Specific technology enables acquisition of new customers, even as it enhances value to current customers.

Criterion 3: Technology Licensing

Requirement: New technology displays great potential to be licensed across many sectors and applications, thereby driving incremental revenue streams.

Criterion 4: Brand Loyalty

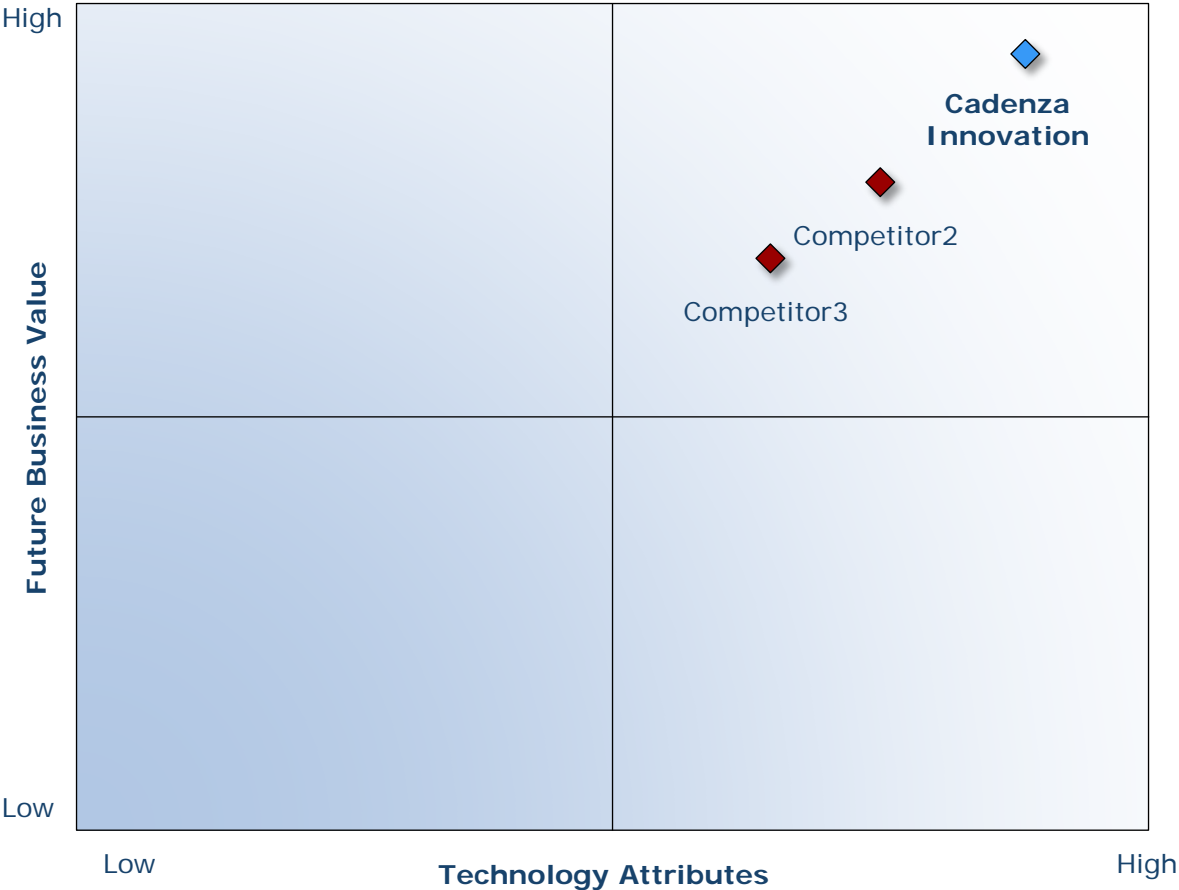
Requirement: New technology enhances the company’s brand, creating and/or nurturing brand loyalty.

Criterion 5: Human Capital

Requirement: Customer impact is enhanced through the leverage of specific technology, translating into positive impact on employee morale and retention.

Decision Support Matrix

Once all companies have been evaluated according to the Decision Support Scorecard, analysts then position the candidates on the matrix shown below, enabling them to visualize which companies are truly breakthrough and which ones are not yet operating at best-in-class levels.



Best Practices Recognition: 10 Steps to Researching, Identifying, and Recognizing Best Practices

Frost & Sullivan analysts follow a 10-step process to evaluate Award candidates and assess their fit with select best practice criteria. The reputation and integrity of the Awards are based on close adherence to this process.

STEP	OBJECTIVE	KEY ACTIVITIES	OUTPUT
1 Monitor, target, and screen	Identify Award recipient candidates from around the globe	<ul style="list-style-type: none"> • Conduct in-depth industry research • Identify emerging sectors • Scan multiple geographies 	Pipeline of candidates who potentially meet all best-practice criteria
2 Perform 360-degree research	Perform comprehensive, 360-degree research on all candidates in the pipeline	<ul style="list-style-type: none"> • Interview thought leaders and industry practitioners • Assess candidates' fit with best-practice criteria • Rank all candidates 	Matrix positioning of all candidates' performance relative to one another
3 Invite thought leadership in best practices	Perform in-depth examination of all candidates	<ul style="list-style-type: none"> • Confirm best-practice criteria • Examine eligibility of all candidates • Identify any information gaps 	Detailed profiles of all ranked candidates
4 Initiate research director review	Conduct an unbiased evaluation of all candidate profiles	<ul style="list-style-type: none"> • Brainstorm ranking options • Invite multiple perspectives on candidates' performance • Update candidate profiles 	Final prioritization of all eligible candidates and companion best-practice positioning paper
5 Assemble panel of industry experts	Present findings to an expert panel of industry thought leaders	<ul style="list-style-type: none"> • Share findings • Strengthen cases for candidate eligibility • Prioritize candidates 	Refined list of prioritized Award candidates
6 Conduct global industry review	Build consensus on Award candidates' eligibility	<ul style="list-style-type: none"> • Hold global team meeting to review all candidates • Pressure-test fit with criteria • Confirm inclusion of all eligible candidates 	Final list of eligible Award candidates, representing success stories worldwide
7 Perform quality check	Develop official Award consideration materials	<ul style="list-style-type: none"> • Perform final performance benchmarking activities • Write nominations • Perform quality review 	High-quality, accurate, and creative presentation of nominees' successes
8 Reconnect with panel of industry experts	Finalize the selection of the best-practice Award recipient	<ul style="list-style-type: none"> • Review analysis with panel • Build consensus • Select recipient 	Decision on which company performs best against all best-practice criteria
9 Communicate recognition	Inform Award recipient of Award recognition	<ul style="list-style-type: none"> • Present Award to the CEO • Inspire the organization for continued success • Celebrate the recipient's performance 	Announcement of Award and plan for how recipient can use the Award to enhance the brand
10 Take strategic action	Upon licensing, company is able to share Award news with stakeholders and customers	<ul style="list-style-type: none"> • Coordinate media outreach • Design a marketing plan • Assess Award's role in future strategic planning 	Widespread awareness of recipient's Award status among investors, media personnel, and employees

The Intersection between 360-Degree Research and Best Practices Awards

Research Methodology

Frost & Sullivan's 360-degree research methodology represents the analytical rigor of our research process. It offers a 360-degree-view of industry challenges, trends, and issues by integrating all 7 of Frost & Sullivan's research methodologies. Too often companies make important growth decisions based on a narrow understanding of their environment, leading to errors of both omission and commission. Successful growth strategies are founded on a thorough understanding of market, technical, economic, financial, customer, best practices, and demographic analyses. The integration of these research disciplines into the 360-degree research methodology provides an evaluation platform for benchmarking industry participants and for identifying those performing at best-in-class levels.



About Frost & Sullivan

Frost & Sullivan, the Growth Partnership Company, enables clients to accelerate growth and achieve best-in-class positions in growth, innovation and leadership. The company's Growth Partnership Service provides the CEO and the CEO's Growth Team with disciplined research and best practice models to drive the generation, evaluation and implementation of powerful growth strategies. Frost & Sullivan leverages more than 50 years of experience in partnering with Global 1000 companies, emerging businesses, and the investment community from 45 offices on six continents. To join our Growth Partnership, please visit <http://www.frost.com>.