PARAGRAF

2025 TECHNOLOGY INNOVATION LEADER

Enhancing Customer Impact Through Powerful Technology Integration

RECOGNIZED FOR BEST PRACTICES IN THE EUROPEAN GRAPHENE-BASED ELECTRONICS MANUFACTURING INDUSTRY

FROST & SULLIVAN

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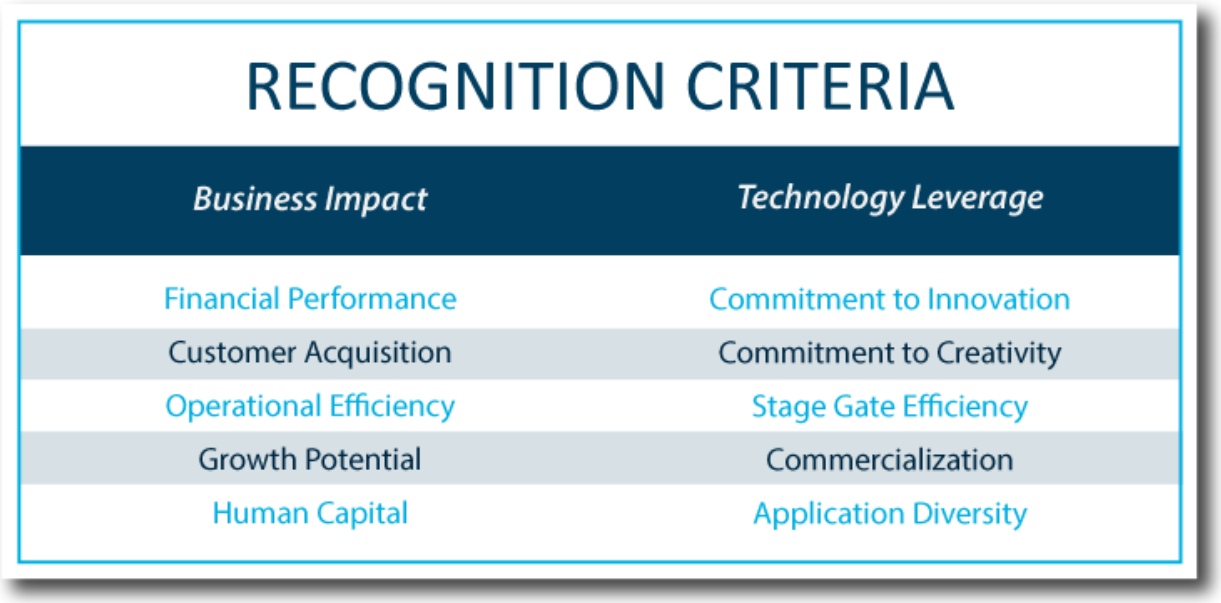
Best Practices Criteria for World-class Performance

Frost & Sullivan applies a rigorous analytical process to evaluate multiple nominees for each recognition category before determining the final recognition recipient. The process involves a detailed evaluation of best practices criteria across two dimensions for each nominated company. Paragraf excels in many of the criteria in the graphene-based electronics manufacturing space.



The Transformation of the Graphene-based Electronics Manufacturing Industry

Graphene-based electronics manufacturing is an emerging field with immense potential to reshape the future of electronic devices because of graphene's exceptional electrical, thermal, and mechanical properties. Researchers and industry pioneers are leveraging graphene's high electron mobility to develop high-speed transistors that could outperform traditional silicon components, opening doors for faster and more energy-efficient chips. At the same time, graphene's remarkable flexibility and strength make it ideal for next-generation flexible electronics, enabling the development of smartphones, wearable sensors, and smart textiles that can bend and stretch without compromising performance. In addition, companies use graphene-based conductive inks to print circuits directly onto various substrates, revolutionizing how they design and manufacture electronic devices.

Beyond these advancements, graphene's superior conductivity and transparency enhance touch screens, improving their durability and performance for phones, tablets, and other interactive displays. The material's versatility also extends to the development of highly sensitive sensors, from gas detectors to biosensors, which hold promise for applications in healthcare, environmental monitoring, and the Internet of Things. Meanwhile, interest in energy storage solutions is driving exploration of graphene's unique structure, boosting the efficiency of batteries and supercapacitors. However, challenges such as large-scale production, integration with Complementary Metal-Oxide-Semiconductor (CMOS) processes, and addressing graphene's lack of an inherent bandgap remain key hurdles. To overcome these, researchers are exploring techniques like bandgap engineering through bilayer graphene and graphene nanoribbons. As the industry works to scale up production and make graphene-based electronics cost-

competitive, ongoing research and development efforts in materials science and semiconductor integration are vital in unlocking the full potential of graphene in mainstream electronics.

Pioneering Graphene Electronics from Cambridge to the World

Founded in 2017 and headquartered in Somersham, Cambridgeshire, United Kingdom (UK), Paragraf emerged as a pioneering spin-out from the University of Cambridge with the mission to unlock the extraordinary potential of graphene in the electronics industry. Since its inception, the company has spearheaded the commercialization of graphene-based electronics, becoming the first company globally to mass-produce graphene-based electronic devices using standard semiconductor manufacturing processes. Its flagship products, such as the Graphene Hall Sensors (GHS) and Graphene Field-Effect Transistors (GFET), showcase Paragraf's proprietary graphene growth technology, delivering exceptional sensitivity, durability, and energy efficiency across various sectors, including automotive, industrial automation, cryogenics, healthcare, and agricultural technology.

> *"Frost & Sullivan recognizes Paragraf for its pioneering approach to redefining semiconductor performance through unmatched creativity in harnessing graphene's full potential for scalable, high-performance electronics."*
>
> ***- Natalia Casanovas, Best Practices Research Analyst***

Paragraf has achieved remarkable milestones. Its graphene-based Hall effect sensors, among the first of their kind, are globally available through its online platform, broadening access to cutting-edge sensing solutions. To strengthen its global presence and scale up production capabilities, the company acquired an American-based graphene technology company in 2023 and commissioned a new manufacturing facility in the UK. These strategic expansions align with the rapid evolution of edge artificial intelligence and quantum computing, positioning Paragraf as a critical enabler for next-generation electronics. Backed by $140 million[1] raised over four funding rounds, the company remains committed to driving a two-dimensional (2D)-material revolution in the semiconductor industry, aiming to address critical global challenges and advance technological performance across all aspects of life.

Redefining Semiconductor Performance

While silicon will remain a cornerstone of the semiconductor industry for years to come, Paragraf is committed to pushing the boundaries by harnessing the transformative potential of graphene and other 2D materials. By overcoming the physical limitations that silicon increasingly faces, graphene opens the door to developing electronic devices that are smaller, faster, and more energy efficient. With this vision, Paragraf positions itself at the vanguard of the next wave of semiconductor innovation, addressing the industry's pressing need for higher-performance components that conventional materials no longer deliver.

To bridge these critical technology gaps, Paragraf successfully commercializes pioneering products that showcase the real-world benefits of graphene. Its GHS, which uses the Hall effect to detect magnetic fields reinvents well-established technology by offering superior sensitivity, lower power consumption, and a

[1] https://www.paragraf.com/about-paragraf/, accessed July 2025

wider thermal range than traditional alternatives, making it an attractive solution for automotive, industrial, and precision measurement applications. Meanwhile, the company's GFET is unlocking new frontiers in sectors such as medical diagnostics, agritech, and industrial gas sensing, where demand for highly responsive, low-energy sensors continues to grow. Complementing its product portfolio, Paragraf's custom foundry services provide industry partners with a pathway to integrate graphene into their own advanced designs, accelerating the adoption of 2D materials across the wider electronics ecosystem. By combining breakthrough products with collaborative innovation, the company drives the transition toward a future where graphene-enabled devices redefine the limits of semiconductor performance.

Much of the early commercial adoption of graphene focused on its use as a composite additive, an impressive way to make plastics lighter and stronger or to boost thermal conductivity in batteries and heat sinks; but this falls short of realizing graphene's full potential as an advanced electronic material. Its most transformative value lies in its extraordinary electrical properties, which remained largely untapped in real-world semiconductor devices for years. Determined to change that, Paragraf set out with a clear mission: to unlock graphene's true potential as a core electronic material and prove that it can be manufactured at scale using standard semiconductor industry techniques, a critical milestone that others struggle to achieve reliably. The company's manufacturing process is built on proprietary technology that distinguishes it in the graphene electronics industry.

The company's core innovation is its direct graphene deposition method, developed by its founders at the University of Cambridge. This technique grows graphene directly onto substrates like sapphire using Metal-Organic Chemical Vapor Deposition reactors. in conjunction with precise growth recipes to ensure high-quality, contamination-free graphene layers for semiconductor devices.

Unlike other methods that transfer graphene from metal onto substrates, causing impurities and damage, Paragraf integrates graphene growth directly onto wafers of semiconductor substrate materials. This seamless approach delivers consistent device performance and scalable mass production without sacrificing quality. The proprietary process sets the company apart from other foundries and underpins its vision to bring graphene-enabled semiconductors into mainstream electronics by combining cutting-edge materials science with established manufacturing infrastructure.

Frost & Sullivan recognizes Paragraf for its pioneering approach to redefining semiconductor performance through unmatched creativity in harnessing graphene's full potential for scalable, high-performance electronics.

From GHSs to Molecular Sensing: Expanding Graphene Applications

Paragraf's first breakthrough came with its GHS, a product that demonstrated both the feasibility and commercial value of graphene's unique electrical behavior. In just five years, the GHS evolved dramatically, shrinking from an early two-centimeter prototype to a highly compact, highly precise three-millimeter, commercially available device (with a 0.7mm device in development). This leap was possible thanks to Paragraf's proprietary Metal-Organic Chemical Vapor Deposition process, which grows graphene directly on the substrate without the contamination risks of traditional transfer techniques. This method ensures a cleaner, more uniform graphene layer and, as a result, more stable and predictable

device performance, an achievement that sets Paragraf apart in an industry where purity and consistency are non-negotiable.

Building on this foundation, Paragraf expanded its portfolio with the GFET, proving that its core process adapts to advanced molecular sensing. By introducing a liquid analyte onto the transistor's surface alongside specific chemistry for the target, researchers can detect minute changes in electrical characteristics, enabling precise identification of specific molecules. This versatility opens new frontiers in applications ranging from medical diagnostics and environmental monitoring to industrial process control, all from the same robust graphene technology that underpins the company's sensors. To lower the barriers for researchers and developers globally, Paragraf makes its GHS and GFET products available through a dedicated online store, helping accelerate the adoption of practical, production-ready graphene electronics.

Sensors are just the beginning. Paragraf's long-term ambition is far more transformative: to integrate graphene into the very architecture of tomorrow's semiconductors, from high-performance transistors to next-generation memory devices. As the semiconductor industry faces the physical limits of silicon's horizontal scaling, a reality driving a pivot toward vertical stacking, chiplets, and other complex architectures, new problems, like heat concentration, emerge. Here, graphene's exceptional thermal and electrical conductivity offers a game-changing advantage, enabling higher transistor densities without the heat bottlenecks that threaten Moore's Law.

However, bridging the gap between this potential and commercial-scale reality demands overcoming significant technological and operational hurdles. Integrating graphene deposition into CMOS processes remains a critical challenge, as high deposition temperatures can damage sensitive circuit layers if not precisely sequenced. Paragraf's strategy of direct, catalyst-free graphene growth is a key differentiator in solving this puzzle, but success also relies on continuous innovation and close collaboration with semiconductor partners. Beyond the lab, scaling deep-tech manufacturing in the UK adds further complexity, from securing suitable infrastructure and attracting world-class technical talent (much of which comes from overseas) to navigating funding and regulatory constraints. Despite these challenges, the company's investment in its new UK manufacturing facility underscores its commitment to scaling up production and delivering graphene's long-promised revolution in mainstream electronics.

Complementing its product offerings, Paragraf provides Custom 2D Foundry Services, working closely with partners to develop bespoke solutions that integrate graphene seamlessly into next-generation electronic devices. By refining deposition techniques and device processing, the company eliminates the need for metal catalysts and complex transfer steps, instead growing graphene directly on wafers using industry-standard methods. This capability empowers Paragraf's partners to develop innovative products such as memory devices tailored to AI datacenters and graphene radio-frequency electronics. With a clear vision to expand the role of 2D materials in future computing technologies, the company continues to redefine what is possible in the semiconductor landscape.

Certified for Excellence: Paragraf's Path through Compliance and Scale

Paragraf's GHS have been commercially available for over five years, yet their adoption journey reflects the inherently long certification and regulatory cycles typical of highly regulated industries such as

automotive and medical devices. For instance, integrating these sensors into electric vehicle batteries demands multiple manufacturing facilities, extensive testing, and stringent compliance with automotive safety standards, a process that spans several years. Currently, the company operates three sites including one newer facility focused on manufacturing. The companies holds International Organisation for Standardisation (ISO) certification for quality and health and safety. However, scaling production to meet high-volume market demands necessitates establishing additional manufacturing sites, securing further investments, and successfully navigating complex certification processes. Meanwhile, Paragraf's GHSs have traction in specialized, high-performance sectors including quantum computing, cryogenics, magnetic resonance imaging, and particle accelerators. These demanding markets highly value the sensors' exceptional reliability and functionality in extreme environments, despite their higher cost relative to mass-market alternatives.

In contrast, Paragraf's GFETs, engineered for molecular sensing, represent a more-recent and rapidly growing commercial opportunity. Introduced via the company's online store in 2024, these devices enable users to detect specific molecules by applying liquid analytes that interact with a functional layer applied to the graphene surface, causing measurable electrical changes. Early adopters, including universities and specialized companies, test Paragraf's GFETs and favor them over alternative graphene sensors due to their enhanced purity, stability, and reproducibility. Notable collaborations with companies like TachMed and Archer highlight increasing commercial interest, especially within the medical diagnostics field. These sensors hold the promise of facilitating rapid, at-home testing for conditions such as diabetes or kidney disease by detecting key biomarkers in small liquid samples. This advancement significantly reduces dependency on centralized laboratories, accelerates clinical decision-making, and broadens access to diagnostic testing in remote and underserved regions globally.

> *"Frost & Sullivan praises Paragraf for its strategic approach to expanding global reach while maintaining a clear, disciplined focus on sustainable growth and lasting customer impact."*
>
> ***- Jabez Mendelson, Research Manager***

Looking forward, Paragraf is broadening its focus beyond sensors and toward developing advanced semiconductor components, aiming to integrate graphene and other 2D materials directly into transistors and memory devices. This strategic shift aligns with broader industry trends as silicon technology approaches its physical limits, and demand surges for higher performance, energy-efficient materials. The company is also actively exploring applications in high-frequency filters for emerging 6G (i.e., sixth generation) communications technologies and radiation-hardened electronics suitable for space environments. While mass-market adoption timelines in these cutting-edge sectors remain uncertain, Paragraf's leadership in scalable, high-quality graphene manufacturing positions it at the forefront of innovation across multiple high-value and emerging markets.

Expanding Reach

Paragraf makes significant strides, particularly with the launch of its online store, which coincided with the introduction of its GFET molecular sensors. This platform enables global customers to order sensors directly, dramatically expanding the company's reach without the need for extensive global sales efforts. Recently, Paragraf added its GHSs to the store, boosting visibility and customer engagement further. This

accessibility led to key partnerships, including Archer,[2] which recognized the superior performance of the company's sensors and continues to collaborate closely with the company. Although high-volume sales through the store remain modest, this channel acts as a critical gateway to new markets and commercial opportunities. On the commercial front, Paragraf is deliberately cautious in its public communications. After several years of confidential work with partners like Rolls-Royce,[3] CERN,[4] and other automotive and high-tech players, recent announcements from collaborators like TachMed[5] and Archer mark the first public acknowledgments of the company's technology gaining traction. Paragraf prioritizes managing expectations realistically, focusing on steady progress over hype, knowing that advancing cutting-edge graphene technology and scaling production is a complex and time-intensive process. Despite significant global investments in graphene semiconductor manufacturing, the company remains a leader in commercially viable, mass-production-capable graphene technology.

This leadership and distinctive position in the industry strengthen Paragraf's brand and reputation significantly. As the only graphene technology developer to demonstrate proven mass manufacturing capabilities, the company cements its credibility and sharpens its market visibility at a global scale. Its compelling story, rooted in breakthrough innovation and a clear mission to unlock graphene's full potential, continues to capture the imagination of media, investors, and industry stakeholders alike, all eager to see the company deliver on the promise that has long surrounded this remarkable material. With a growing roster of satisfied customers and high-profile endorsements from partners such as Archer, Paragraf's commercial team remains committed to sharing success stories that highlight the real-world impact of its technology and further reinforce its reputation as a trusted pioneer in advanced materials innovation.

As Paragraf scales its manufacturing and commercial operations, it is also expanding its team, fostering a culture that blends deep scientific expertise with a dynamic entrepreneurial spirit. This human capital is essential to navigating the challenges of pioneering new materials technology while maintaining close collaboration with partners and customers. The company's culture encourages innovation, resilience, and a long-term vision focused on transforming graphene from a scientific breakthrough into a mainstream semiconductor material with broad industrial value.

Frost & Sullivan praises Paragraf for its strategic approach to expanding global reach while maintaining a clear, disciplined focus on sustainable growth and lasting customer impact.

[2] https://www.paragraf.com/press-release-archer-enters-partnership-with-paragraf-for-biochip-development/, accessed July 2025

[3] https://www.paragraf.com/paragraf-rolls-royce-tt-electronics-and-the-compound-semiconductor-applications-catapult-drive-electric-transport-revolution-with-first-ever-supply-chain-for-graphene-hall-effect-sensors/, accessed July 2025

[4] https://www.paragraf.com/paragraf-partners-with-cern-to-demonstrate-unique-properties-of-paragrafs-new-graphene-hall-effect-sensor/, accessed July 2025

[5] https://med-techinsights.com/2025/05/28/tachmed-and-paragraf-team-to-scale-graphene-powered-diagnostics/, accessed July 2025

Conclusion

Paragraf stands at the forefront of a graphene revolution that promises to reshape the semiconductor industry and beyond. With a proven ability to scale mass production of high-quality graphene devices and a clear vision to extend its technology into next-generation electronics, the company is uniquely positioned to overcome longstanding material limitations and meet growing demands for performance and efficiency. Its strategic expansions, deep partnerships, and commitment to rigorous quality and certification processes underscore Paragraf's dedication to transforming groundbreaking research into impactful, real-world solutions. As it continues to grow its manufacturing footprint and broaden its product portfolio, the company exemplifies how innovative materials science, combined with commercial rigor, drives the future of electronics toward previously unattainable heights.

Paragraf earns Frost & Sullivan's 2025 European Technology Innovation Leadership Recognition for its strong overall performance in the graphene-based electronics manufacturing industry.

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What You Need to Know about the Technology Innovation Leadership Recognition

Frost & Sullivan's Technology Innovation Leadership Recognition is its top honor and recognizes the market participant that exemplifies visionary innovation, market-leading performance, and unmatched customer care.

Best Practices Recognition Analysis

For the Technology Innovation Leadership Recognition, Frost & Sullivan analysts independently evaluated the criteria listed below.

Technology Leverage

Commitment to Innovation: Continuous emerging technology adoption and creation enables new product development and enhances product performance

Commitment to Creativity: Company leverages technology advancements to push the limits of form and function in the pursuit of white space innovation

Stage Gate Efficiency: Technology adoption enhances the stage gate process for launching new products and solutions

Commercialization: Company displays a proven track record of taking new technologies to market with a high success rate

Application Diversity: Company develops and/or integrates technology that serves multiple applications and multiple environments

Business Impact

Financial Performance: Strong overall business performance is achieved in terms of revenue, revenue growth, operating margin, and other key financial metrics

Customer Acquisition: Customer-facing processes support efficient and consistent new customer acquisition while enhancing customer retention

Operational Efficiency: Company staff performs assigned tasks productively, quickly, and to a high-quality standard

Growth Potential: Growth is fostered by a strong customer focus that strengthens the brand and reinforces customer loyalty

Human Capital: Leveraging innovative technology characterizes the company culture, which enhances employee morale and retention

Best Practices Recognition Analytics Methodology

Inspire the World to Support True Leaders

This long-term process spans 12 months, beginning with the prioritization of the sector. It involves a rigorous approach that includes comprehensive scanning and analytics to identify key best practice trends. A dedicated team of analysts, advisors, coaches, and experts collaborates closely, ensuring thorough review and input. The goal is to maximize the company's long-term value by leveraging unique perspectives to support each Best Practice Recognition and identify meaningful transformation and impact.

		VALUE IMPACT	
STEP		WHAT	WHY
1	**Opportunity Universe**	Identify Sectors with the Greatest Impact on the Global Economy	Value to Economic Development
2	**Transformational Model**	Analyze Strategic Imperatives That Drive Transformation	Understand and Create a Winning Strategy
3	**Ecosystem**	Map Critical Value Chains	Comprehensive Community that Shapes the Sector
4	**Growth Generator**	Data Foundation That Provides Decision Support System	Spark Opportunities and Accelerate Decision-making
5	**Growth Opportunities**	Identify Opportunities Generated by Companies	Drive the Transformation of the Industry
6	**Frost Radar**	Benchmark Companies on Future Growth Potential	Identify Most Powerful Companies to Action
7	**Best Practices**	Identify Companies Achieving Best Practices in All Critical Perspectives	Inspire the World
8	**Companies to Action**	Tell Your Story to the World (BICEP*)	Ecosystem Community Supporting Future Success

*Board of Directors, Investors, Customers, Employees, Partners

About Frost & Sullivan

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The Growth Pipeline Generator™

Frost & Sullivan's proprietary model to systematically create ongoing growth opportunities and strategies for our clients is fuelled by the Innovation Generator™.

Learn more.

Key Impacts:

- **Growth Pipeline:** *Continuous Flow of Growth Opportunities*
- **Growth Strategies:** *Proven Best Practices*
- **Innovation Culture:** *Optimized Customer Experience*
- **ROI & Margin:** *Implementation Excellence*
- **Transformational Growth:** *Industry Leadership*



The Innovation Generator™

Our 6 analytical perspectives are crucial in capturing the broadest range of innovative growth opportunities, most of which occur at the points of these perspectives.

Analytical Perspectives:

- Megatrend (MT)
- Business Model (BM)
- Technology (TE)
- Industries (IN)
- Customer (CU)
- Geographies (GE)

