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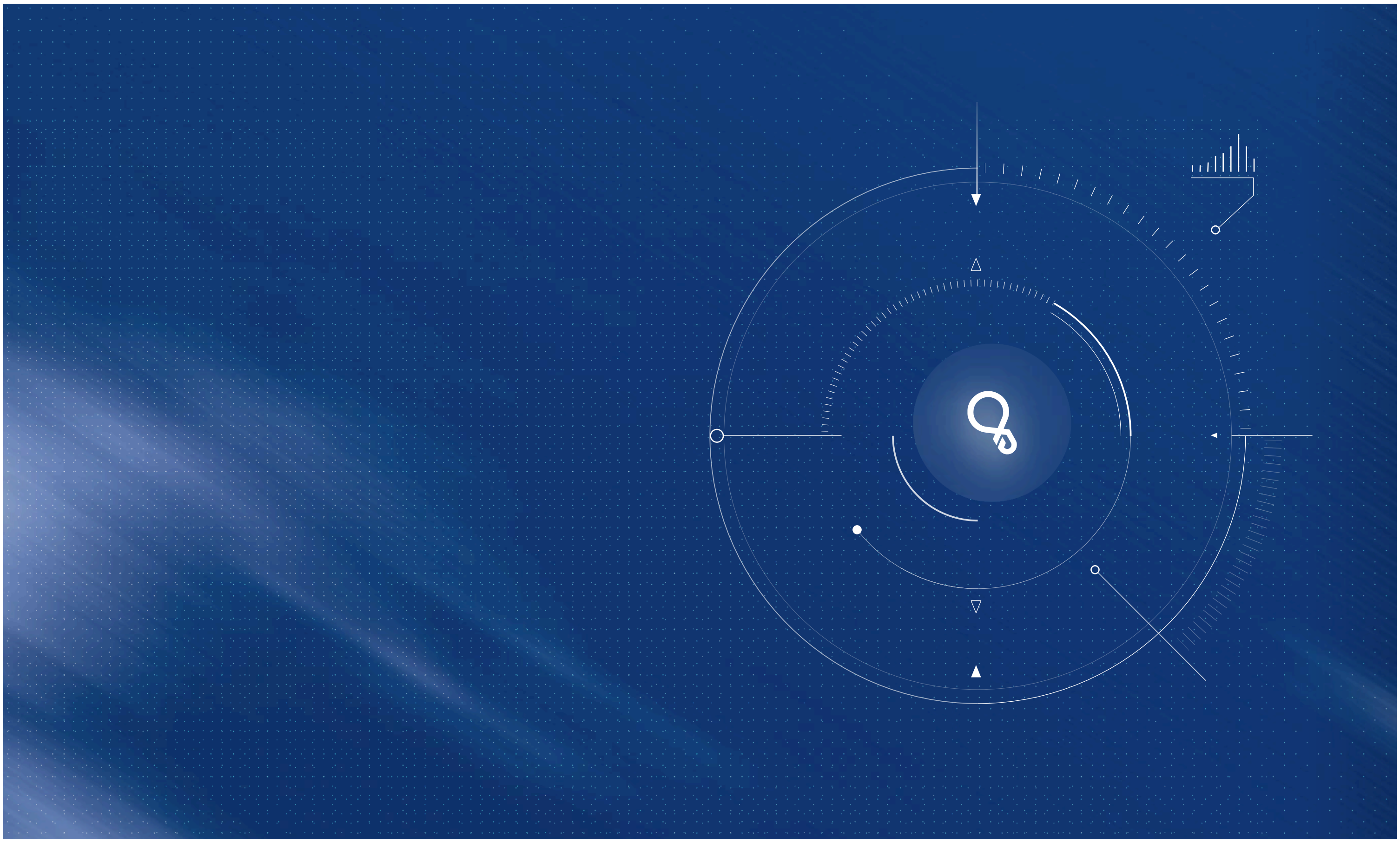

RESEARCH BRIEF

High Temperature Paperboard

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Executive Summary

This Insight Brief aims to examine and showcase the latest state of the art technologies that may be used to create a food-safe paperboard product that can withstand high-temperatures (up to 550 degrees F) in confined spaces (e.g., air fryers). The brief will explore the latest coatings and other technologies that can be used to create food-safe paperboard packaging to withstand high-temperatures. The identified potential technology solutions should (1) not degrade the structural integrity of the paperboard, (2) be compliant with 21 CFR 176.170 and conditions of use A-H, (3) must mitigate fire risk of the paperboard product.

Analyst Opinion

Recent advancements in high-temperature coating technologies, including polymeric, silicone-based, and ceramic coatings, emphasize their suitability for confined high-heat environments. These innovations focus on maintaining structural integrity, ensuring safety compliance, and introducing multi-functional properties such as fire resistance, moisture resistance, and heat durability. Breakthroughs in composite materials and nanotechnology further extend the capabilities of coatings for elevated temperatures.

Key products and solutions from industry leaders such as Holmen Iggesund and Graphic Packaging International highlight the potential for high-performance coatings and paperboard applications in extreme-temperature environments. Advanced solutions like **TopScreen™ coatings** and **Trayforma™ PET** demonstrate adaptability for applications requiring durability, food safety compliance, and resistance to heat and moisture. Furthermore, alternative technologies such as food-grade high-temperature pouches and non-stick coatings provide additional inspiration for developments in this market, offering insights into creating solutions tailored to high-temperature food-safe paperboard packaging.

Our analysis ranks Silicone-Modified UV-Cured Polyurethane-Acrylate Coatings as the most feasible option due to their demonstrated high-temperature stability, scalability, and track record in similar applications, albeit with some adaptation needed for food safety. High-Performance Polymer Coatings follow closely, with proven industrial applications but higher adaptation costs. In contrast, Nanocomposite Coatings and Ceramic-Based Coatings rank lower due to high costs, early-stage development, and challenges in scaling or meeting food safety standards.

Patent activity reveals a focus on high-temperature-resistant materials, with significant whitespace in food-safe paperboard applications for extreme-temperature environments. Promising technologies such as polyester-modified silicone resins and fluoropolymer-based solutions show potential for adaptation but require targeted R&D.

Overall, specific technologies addressing food-safe paperboard products for extreme temperatures in confined spaces are scarce, indicating a niche, emerging market ripe for innovation.

Research Methodology

Our research primarily utilized the Cypris platform as a foundation, leveraging its extensive database to gather relevant insights. We began with a broad query (linked below) aligned with the project's objectives, refining it further with targeted keywords to narrow down and source the specific research papers highlighted in this brief, which provided the foundational direction for this report. To supplement these findings, we explored secondary sources, including company websites, recent news, industry reports, and articles, adding depth and current context to our analysis of the multi-phase flow metering market.

Foundational Query: Semantic Search | "latest coatings and other technologies that can withstand high-temperatures up to 550 degrees f in confined spaces such as air fryers food-safe paperboard product"

Coatings and Technologies Overview

Developing food-safe paperboard packaging capable of withstanding extreme temperatures is a challenging yet feasible goal, with recent innovations showing promise. The technologies outlined below—ranging from advanced silicone coatings to hybrid materials and composite paperboards—represent some of the best-fit approaches currently in research and development. Each offers unique potential to address the thermal and structural demands of high-heat food packaging, though further adaptation and testing are essential to ensure they meet both regulatory and performance requirements.

Advanced Silicone and Nanocomposite Coatings

- Recent work on multifunctional silicone-based coatings incorporating $Ti_3C_2T_x$ MXene nanocomposites has shown promising high-temperature stability and thermal resistance. These coatings exhibit photothermal de-icing capabilities, achieving surface temperatures above 200°F in specific applications. While further development is required to reach the 550°F threshold, the initial findings suggest a path forward for high-heat applications.
    - **Structural Integrity:** Silicone-based coatings are known for maintaining flexibility and durability under heat, supporting paperboard structure. Nanocomposites could further enhance strength.
    - **Regulatory Compliance:** Silicone can be modified to meet FDA food safety requirements, but nanocomposites will require additional testing for compliance with 21 CFR 176.170 and use conditions A-H.
    - **Fire Risk Mitigation:** Silicone inherently resists combustion, making it a safer option for high-temperature applications, but the fire risk of nanocomposites needs further validation.
    - **Best Fit:** Suitable for applications requiring moderate to high-temperature resistance and surface non-stick qualities. Promising for direct food contact packaging if thermal tolerance can be further enhanced.
    - **Technology Readiness Level:** TRL 3-4 (Early prototype stage) – Functional coatings are being developed but require significant adaptation to achieve consistent high-temperature and food-safe applications at 550°F.

Silicone-Modified UV-Cured Polyurethane-Acrylate Coatings

- Silicone-modified UV-cured polyurethane-acrylate coatings have demonstrated excellent thermal stability, with decomposition temperatures reaching around 300°C (572°F). This type of coating, with its non-stick and scratch-resistant properties, holds potential for food-safe packaging in high-temperature environments, though further food-safety-specific adaptations may be needed.

- **Structural Integrity:** UV-cured coatings form a strong, resilient layer on paperboard, with high scratch resistance that could protect structural integrity even at high temperatures.
- **Regulatory Compliance:** Polyurethane acrylates can be formulated to meet FDA food-contact standards; further testing is required to ensure these coatings comply with 21 CFR 176.170 at high temperatures.
- **Fire Risk Mitigation:** Silicone-modified components can offer flame resistance; however, additional testing is needed to ensure the coating doesn't compromise fire safety in confined spaces like air fryers.
- **Best Fit:** Ideal for ovenable food trays or liners where scratch resistance and non-stick properties are advantageous, especially in moderate-to-high temperature uses where silicone provides structural integrity.
- **Technology Readiness Level:** TRL 4-5 (Lab-scale testing, with some prototyping) – Demonstrated thermal stability up to 572°F in lab settings; further testing is needed for consistent performance in food-safe applications under high heat.

Waterborne Coatings for Barrier Properties

- Alkali-soluble waterborne resin coatings have been shown to be effective barriers against water and oils, making them a viable option for food packaging applications. While current versions are not designed for temperatures as high as 550°F, adjustments to their formulation and layering could improve their temperature resistance, making them more suited for high-heat applications.
  - **Structural Integrity:** Effective as a water and oil barrier, these coatings help maintain structural integrity against moisture but need further enhancement to withstand high temperatures without degrading.
  - **Regulatory Compliance:** Many waterborne coatings are already approved for food contact, but modifications for high heat could require further compliance testing under conditions A-H.
  - **Fire Risk Mitigation:** Waterborne coatings offer some fire resistance due to their moisture content, but their performance at 550°F would need validation to ensure minimal flammability.
  - **Best Fit:** Best suited for packaging requiring strong moisture and grease barriers; suitable for lower-temperature cooking applications unless further modified for extreme heat.
  - **Technology Readiness Level:** TRL 5-6 (Transitioning to pilot scale) – Well-established as a barrier in food packaging; further adaptations are required to enhance thermal resistance to reach the 550°F target.

High-Performance Polymer Coatings

- Polymers like polyimide and certain fluoropolymers offer high-temperature stability, typically up to 400-500°F. These polymers are often used in high-heat industrial applications and show potential for adaptation in food-safe paperboard packaging. Polyimide coatings, in particular, could provide stability at extreme temperatures while offering some flexibility for paperboard surfaces.
  - **Structural Integrity:** Known for excellent thermal stability, high-performance polymers like polyimides can maintain structure up to 500°F, although further adaptation is required for 550°F and to avoid structural weakening.
  - **Regulatory Compliance:** High-performance polymers can potentially meet food-contact standards but would need testing to align with 21 CFR 176.170 at higher temperatures.

- **Fire Risk Mitigation:** Some high-performance polymers are flame-retardant, making them viable for fire risk mitigation, though each polymer type will need specific testing for air fryer safety.
- **Best Fit:** Ideal for applications involving prolonged or high-temperature exposure; potentially useful in confined cooking appliances like air fryers if food-safe versions can be formulated.
- **Technology Readiness Level:** TRL 4-5 (Prototype development) – Existing polymers show potential, but food-safe versions require additional testing for temperature performance and regulatory compliance at high temperatures.

Ceramic-Based Coatings

- Ceramic coatings provide excellent thermal stability and could theoretically sustain temperatures up to 800°F in thin applications. Although ceramics are traditionally used in metal and industrial settings, they show promise for high-temperature food packaging. Research is ongoing to explore methods for applying thin, ceramic layers on paperboard to achieve the necessary heat resistance without compromising food safety.
  - **Structural Integrity:** Ceramics provide robust structural support at high temperatures, though their brittleness can challenge paperboard flexibility, possibly compromising structural integrity in flexible applications.
  - **Regulatory Compliance:** Ceramics are chemically inert, but compliance with food safety standards for direct contact is still limited; additional testing for 21 CFR 176.170 would be necessary.
  - **Fire Risk Mitigation:** Ceramics are highly flame-resistant and can effectively reduce fire risks, especially at temperatures over 500°F, making them ideal for confined cooking environments.
  - **Best Fit:** Suitable for high-heat applications where structural integrity and fire resistance are priorities, such as disposable baking trays, but less ideal for direct food contact without further testing.
  - **Technology Readiness Level:** TRL 3-4 (Concept proven in limited settings) – Thermal stability of ceramics is well-documented; however, adapting ceramic coatings for food-safe paperboard is in the early stages of testing and application.

Nanocomposite Coatings

- Incorporating nanoparticles like MXene or other advanced nanomaterials into coatings can enhance thermal resistance. While current applications for these nanocomposites are still in early stages, they have shown photothermal stability up to 250-300°C. With continued advancements, these coatings could offer food-safe, high-temperature capabilities suitable for paperboard applications.
  - **Structural Integrity:** Nanocomposites strengthen the coating layer, potentially enhancing the overall durability of the paperboard; however, structural integrity at high heat still requires extensive testing.
  - **Regulatory Compliance:** Nanomaterials face strict scrutiny under food safety regulations and would need to comply with 21 CFR 176.170 and further safety testing for high-heat applications.
  - **Fire Risk Mitigation:** Some nanomaterials exhibit flame-retardant properties, but each formulation would need rigorous evaluation to confirm fire resistance and safety in air fryer-like environments.
  - **Best Fit:** Suitable for high-heat applications if scaled and adapted for food safety; promising for paperboard requiring an ultra-thin, durable, and high-temperature-resistant barrier.

- **Technology Readiness Level:** TRL 3 (Proof of concept) – Nanocomposites show promise for thermal and barrier properties, but they are in early experimental stages for food-safe, high-temperature applications on paperboard.

Hybrid Coating Systems (e.g., Silicone-Ceramic Blends)

- By combining materials such as silicone and ceramic, hybrid coatings leverage the high-temperature stability of ceramics with the flexibility of silicone. This hybrid approach could create durable, heat-resistant coatings capable of tolerating 450-600°F, though further research is required to confirm food-safe adaptations.
  - **Structural Integrity:** Hybrid systems could leverage the structural benefits of both silicone and ceramics, supporting paperboard strength at elevated temperatures with enhanced flexibility.
  - **Regulatory Compliance:** Combining materials could complicate regulatory approval; both silicone and ceramic components would need to comply with food safety standards under conditions A-H.
  - **Fire Risk Mitigation:** Silicone-ceramic hybrids are likely to be flame-retardant, as both materials resist combustion, reducing fire risks in high-heat applications like air fryers.
  - **Best Fit:** Well-suited for high-heat applications in confined spaces, like air fryer liners, where both flexibility and thermal resistance are essential. Effective for uses where both moisture and fire risk need to be controlled.
  - **Technology Readiness Level:** TRL 3-4 (Initial feasibility studies) – Hybrid systems combining silicone and ceramic materials have been tested individually but require further integration and testing to meet high-temperature food-safe standards.

Innovative Paperboard Composites

- Developing composite paperboard materials with inherent high-temperature resistance is another research direction. Integrating heat-resistant fibers or additives directly into the paperboard itself could produce materials capable of withstanding up to 500°F, eliminating the need for separate coatings and potentially simplifying the manufacturing process.
  - **Structural Integrity:** By embedding heat-resistant fibers directly into the paperboard, these composites could maintain structural integrity without requiring separate coatings, enhancing overall strength at high temperatures.
  - **Regulatory Compliance:** Compliance with 21 CFR 176.170 may be achievable depending on the fibers and additives used, though regulatory approval would be necessary for any embedded materials.
  - **Fire Risk Mitigation:** Heat-resistant fibers can inherently mitigate fire risk by improving thermal stability, making this solution promising for reducing flammability in confined cooking spaces.
  - **Best Fit:** Ideal for sustainable, high-heat packaging applications, especially where eliminating separate coatings is preferred. Best for applications needing a stable structure in extreme heat while retaining compostability or recyclability.
  - **Technology Readiness Level:** TRL 3-4 (Experimental design and early prototype) – Embedding heat-resistant fibers within paperboard is a promising approach but is still largely in the research phase for food-safe, high-temperature applications.

Summary of Coatings and Technologies- Chart

Shown below is a chart summarizing the above section.

Technology	Benefits	Best Fit Applications	TRL
Advanced Silicone and Nanocomposite Coatings	High thermal resistance, flexibility, and durability. Nanocomposites enhance structural strength.	Moderate-to-high temperature resistance; surface non-stick qualities.	TRL 3-4 (Early prototype stage)
Silicone-Modified UV-Cured Polyurethane-Acrylate Coatings	High scratch resistance, thermal stability (up to 572°F), strong structural integrity.	Ovenable food trays; high-temperature liners.	TRL 4-5 (Lab-scale testing)
Waterborne Coatings for Barrier Properties	Effective water and oil barriers, sustainable and eco-friendly.	Moisture and grease barriers; lower-temperature applications.	TRL 5-6 (Transitioning to pilot scale)
High-Performance Polymer Coatings	Excellent thermal stability (up to 500°F), flame-retardant properties, durable for industrial use.	Prolonged high-temperature exposure; confined cooking appliances.	TRL 4-5 (Prototype development)
Ceramic-Based Coatings	Exceptional thermal stability (up to 800°F), highly flame-resistant.	Disposable baking trays; high-heat, confined environments.	TRL 3-4 (Concept proven in limited settings)
Nanocomposite Coatings	Enhanced durability, flame-retardant properties, ultra-thin application potential.	Ultra-thin, high-temperature-resistant barriers.	TRL 3 (Proof of concept)
Hybrid Coating Systems (e.g., Silicone-Ceramic Blends)	Combines flexibility of silicone with ceramic's heat resistance, supports multifunctionality.	High-heat applications in confined spaces; moisture and fire control.	TRL 3-4 (Initial feasibility studies)
Innovative Paperboard Composites	Integrates heat-resistant fibers, eliminating need for separate coatings.	Sustainable high-heat packaging with inherent thermal stability.	TRL 3-4 (Experimental design)

Feasibility Analysis of High-Temperature Coating and Paperboard Technologies

Listed below is a ranked feasibility analysis of the technologies and coatings previously discussed as they relate to innovation in creating food-safe paperboard packaging capable of withstanding high temperatures (up to 550°F) in confined spaces such as air fryers. These rankings are based on three primary criteria: cost, challenges associated with adapting the technology to this specific use case, and the previous track record of success in high-temperature or food-safe applications.

Silicone-Modified UV-Cured Polyurethane-Acrylate Coatings

- **Cost:** Medium. These coatings are cost-effective due to the efficiency of the UV-curing process, but flame-retardant modifications would increase expenses.
- **Challenges:** Requires additional development to meet stringent FDA food safety standards and integrate flame resistance for confined spaces like air fryers.
- **Previous Successes:** Demonstrated thermal stability up to 572°F and proven durability in industrial applications.
- **Overall Feasibility:** High. Its scalability, durability, and performance at elevated temperatures make it one of the most feasible solutions.

High-Performance Polymer Coatings

- **Cost:** High. Polymers like polyimide and fluoropolymers are expensive due to their specialized synthesis and application processes.
- **Challenges:** Adapting these materials to flexible paperboard substrates and ensuring food safety compliance would require significant engineering efforts.
- **Previous Successes:** Widely used in high-heat industrial applications, showcasing durability and thermal stability close to 550°F.
- **Overall Feasibility:** Medium-High. Proven performance in other applications makes them a strong contender, but adaptation costs could be prohibitive.

Advanced Silicone and Nanocomposite Coatings

- **Cost:** High. Incorporating nanomaterials like MXene significantly increases production costs.
- **Challenges:** Scaling production, regulatory approvals for food-safe nanoparticles, and ensuring consistent thermal performance.
- **Previous Successes:** Initial success in combining flexibility with enhanced heat resistance, showing potential for achieving 550°F tolerance.
- **Overall Feasibility**: Medium. Early-stage technology with promising features but significant regulatory and cost barriers.

Innovative Paperboard Composites

- **Cost**: Medium-High. Embedding heat-resistant fibers increases raw material and production costs, particularly in experimental stages.
- **Challenges**: Balancing flexibility, thermal performance, and food safety while maintaining recyclability and compostability.
- **Previous Successes**: Demonstrated potential to integrate heat-resistant fibers directly into paperboard, simplifying manufacturing processes.

- **Overall Feasibility**: Medium. A sustainable and innovative approach, but high development costs and recyclability challenges limit immediate feasibility.

Waterborne Coatings for Barrier Properties

- **Cost**: Low-Medium. Existing formulations are inexpensive, but enhancing thermal resistance would require additional investment.
- **Challenges**: Current thermal resistance is insufficient for extreme high-heat applications; requires significant reformulation for 550°F tolerance.
- **Previous Successes**: Widely used for moisture and grease barriers in food packaging, indicating proven adaptability.
- **Overall Feasibility**: Medium-Low. A cost-effective option for moderate heat but lacks the necessary thermal performance for air fryers.

Hybrid Coating Systems (Silicone-Ceramic Blends)

- **Cost**: Medium-High. Blending materials increases costs due to specialized production processes.
- **Challenges**: Achieving a uniform, durable bond between silicone and ceramic and ensuring food safety compliance.
- **Previous Successes**: Theoretically capable of tolerating temperatures up to 600°F, offering a combination of flexibility and thermal resistance.
- **Overall Feasibility**: Medium. Promising for high-heat applications but still in experimental stages, requiring further testing and refinement.

Ceramic-Based Coatings

- **Cost**: Very High. Ceramics are costly due to raw material prices and specialized application methods.
- **Challenges**: Brittle nature and difficulty adhering to flexible substrates limit adaptability for disposable food packaging.
- **Previous Successes**: Proven exceptional thermal stability exceeding 800°F in industrial applications.
- **Overall Feasibility**: Low. High costs and lack of flexibility make them impractical for food-safe paperboard applications.

Nanocomposite Coatings

- **Cost**: Very High. Advanced materials like graphene or MXene are expensive to produce and scale.
- **Challenges**: Regulatory hurdles for nanoparticles in food-safe applications and consistency in large-scale production.
- **Previous Successes**: Experimental success in enhancing thermal and structural properties, but limited to lab-scale testing.
- **Overall Feasibility**: Low. While innovative, high costs and early-stage development limit immediate applicability for the project.

Relevant Companies and Products Snapshot

Listed below is a snapshot of some of the currently commercialized technologies and products in this field that could potentially be relevant to this topic. **However, it is important to note that these offerings are not exact matches to the project's requirements, particularly in terms of their ability to withstand extreme temperatures or their specific application to food-safe paperboard packaging.**

Instead, the below companies and products represent the latest commercialized state of the art. The below entities have been identified as leaders in this technology space who may be best positioned to launch innovative products within this space.

Graphic Packaging International

The **Fortress™ PET Ovenable Paperboard** offers a durable, food-safe packaging solution designed for frozen food applications intended for baking or microwaving. With a PET coating, this paperboard performs well across a temperature range from below freezing to 400°F (204°C), making it suitable for moderate-temperature applications.

Key Product Features:

- **Structural Integrity**: Fortress™ PET Ovenable Paperboard is engineered for durability in food applications. It maintains structural integrity during manufacturing processes such as folding, die-cutting, and forming. Additionally, it holds up under heat and moisture exposure in microwaves and conventional ovens, though its heat tolerance caps at 400°F.
- **Food Safety Compliance**: The paperboard complies with FDA 21 CFR 176.170 and 21 CFR 176.180 for direct contact with aqueous, fatty, and dry foods, and also meets EU food-contact regulations. The PET coating is FDA and EU-compliant, making it a safe choice for direct food contact across various packaging applications.
- **Fire Risk Considerations**: Although the PET coating provides a degree of heat resistance, Fortress™ PET Ovenable Paperboard lacks inherent flame-retardant properties. Its design is tailored for moderate heat exposure rather than high-temperature use in confined spaces, such as air fryers, where temperatures may reach 550°F.
- **Sustainability**: Made from up to 90% renewable resources and certified by sustainability standards (FSC, SFI, PEFC), Fortress™ PET Ovenable Paperboard is a sustainable choice for environmentally conscious food packaging solutions.
- **Applications:** Fortress™ PET Ovenable Paperboard is ideal for food packaging where moderate heat exposure is expected, including frozen foods, limited-service restaurant trays, and other applications requiring moisture and fat resistance.
- **Relevance:** The PET coating **is heat-resistant only up to 400°F**, falling short of the 550°F requirement for confined high-temperature applications like air fryers. While its food-safe and durable properties are relevant to moderate-temperature applications, it lacks the structural integrity and fire resistance needed for extreme heat environments. The coating lacks flame-retardant properties and has not been tested for use in confined spaces at 550°F.

Holmen Iggesund

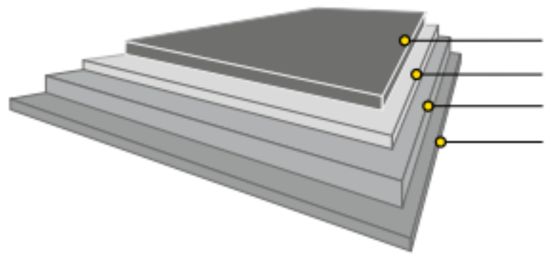
Inverform + PET is a formable, multi-layered solid bleached board (SBB) product developed by Holmen Iggesund specifically for ready-made food packaging applications. Constructed entirely from fresh fibers, it combines an outer layer of hardwood fibers for smoothness and printability with a middle layer of softwood fibers for strength, flexibility, and formability. This unique structure enables it to support the demands of press-forming and dual-ovenable tray manufacturing.

Key Features:

- **Structural Integrity**: Inverform + PET maintains high structural integrity through a PET extrusion coating that provides durability and flexibility. This makes it ideal for trays that need to withstand microwave and conventional oven temperatures while preserving shape and form. The fiber construction further supports strength and formability, making it resistant to deformation during food packaging processes.
- **Food Safety Compliance**: The product is compliant with FDA 21 CFR 176.170 and other international food safety standards, making it suitable for direct food contact. The PET coating acts as a barrier against moisture and fat, ensuring that food remains safe and packaging integrity is maintained.
- **Fire and Heat Resistance**: The PET coating on Inverform provides heat resistance and is designed for high-performance oven and microwave applications, though the temperature limit may not extend to 550°F. Its fire resistance for extreme heat in confined spaces like air fryers would require further testing to confirm suitability.
- **Sustainability**: Inverform is manufactured using renewable wood fibers from sustainably managed forests and is fully recyclable. Its production aligns with environmental standards, and it has a significantly lower carbon footprint than plastic trays, supporting eco-conscious food packaging needs.
- **Applications:** Inverform + PET is suitable for a variety of food packaging applications, including press-formed trays, cutlery, plates, and containers that require heat tolerance and food safety.
- **Relevance:** Designed for microwave and oven applications, **the PET coating does not extend beyond 400°F**, making it unsuitable for air fryers and other extreme heat environments. The multi-layer structure and food safety compliance make it relevant for general high-heat packaging but not for the extreme conditions specified in the project. It requires additional fire-resistant and high-temperature testing to determine its viability for air fryers.

Stora Enso

Trayforma™ PET is a high-quality, bleached virgin-fiber board designed for pressed and folded trays focused on creating food-safe, durable, and sustainable high-temperature packaging. While it does not meet the extreme temperature threshold of 550°F, its features align closely with several key requirements for food packaging that needs to withstand moderate heat exposure.



Key Features:

- **Structural Integrity**: Trayforma™ PET's three-layer construction, featuring a core of chemi-thermomechanical pulp (CTMP), enhances its formability and strength, allowing it to retain structural integrity in both microwave and conventional oven settings. This is essential for maintaining the shape and durability of food trays during heating, aligning well with requirements for packaging that must withstand temperature fluctuations without degrading.
- **Food Safety Compliance**: Trayforma™ PET meets FDA food safety standards, including 21 CFR 176.170 and other essential food-contact certifications (ISO 9001, FSSC 22000, PEFC). Its PET coating serves as a functional barrier against moisture, grease, and oxygen, providing effective food protection that aligns with compliance needs for packaging in direct contact with various food types, including chilled and heated meals.
- **Fire and Heat Resistance**: While designed for moderate oven and microwave temperatures, Trayforma™ PET does not reach the required 550°F tolerance, which is critical for confined high-temperature environments like air fryers. However, its PET coating can withstand typical oven and microwave use, making it suitable for conventional food heating applications. Additional development or alternative coatings would be needed to meet extreme heat resistance.
- **Sustainability**: Composed of over 90% renewable wood fibers and capable of reducing plastic content by up to 80%, Trayforma™ PET offers a significant sustainability advantage. It reduces the carbon footprint of trays by two-thirds compared to traditional PET, providing an eco-friendly option for brands prioritizing plastic reduction and lower environmental impact—key considerations for environmentally conscious packaging projects.
- **Printing and Convertibility**: The board is highly formable and supports flexographic and offset printing, making it suitable for customized branding and efficient tray production. Its smooth surface allows for high-quality print results, essential for packaging that requires both functional durability and strong shelf appeal.
- **Applications:** Trayforma™ PET is well-suited for moderate-temperature food tray applications, including ready-made meals, microwavable dishes, and freezer-to-oven packaging. Although it does not meet the high-heat requirements of air fryers, it offers a sustainable, food-safe, and durable solution for other heating environments, contributing valuable features for companies aiming to reduce plastic use in high-performing food packaging.
- **Relevance:** The PET coating supports moderate oven and microwave temperatures but **fails to meet the 550°F threshold critical for air fryers**. Trayforma™ PET aligns with the need for food-safe, durable packaging but is limited to moderate heating applications, falling short for extreme-heat conditions. It lacks the required flame resistance and structural stability for confined high-heat environments.

Solenis

TopScreen™ Oil & Grease Resistant Barrier Coatings by Solenis offers a sustainable, food-safe barrier coating technology designed for paperboard and molded fiber packaging. These water-based coatings are engineered to replace traditional polyethylene (PE) and per- and polyfluoroalkyl substances (PFAS), providing a highly effective solution for packaging greasy and oily foods. This innovative coating aligns with the goals of maintaining structural integrity, meeting food safety standards, and reducing environmental impact, making it highly relevant for high-temperature packaging applications.

Product Name	Fast Food/ Short Term*	Long Term Barrier†	Water Repellency	Heat Sealability	Non-fossil Content (%)	Styrene-Free
TopScreen GR 61-300	◒	●		●	0	No
TopScreen GR 393	●	◒	○	○	50	No
TopScreen DL 102	◒	●			55	No
TopScreen SP 200-F	●	○	●	○	30	Yes
TopScreen BW 200	◒		◒		90	No

● very good | ◒ good | ○ sufficient *Barrier duration of hours/days †Barrier duration of several weeks/months

Key Features:

- **Structural Integrity**: TopScreen™ coatings maintain the durability and strength of paper-based packaging, supporting structural integrity under various conditions. The coating is applied seamlessly to fiber-based substrates, enabling food packaging to remain robust, even with greasy and moist foods, although specific extreme heat resistance would need testing.
- **Food Safety Compliance**: TopScreen™ is compliant with FDA 21 CFR § 176.170 and BfR XXXVI standards, ensuring it meets food safety regulations for direct contact with a wide range of food types. This makes it suitable for use in food packaging applications where maintaining food safety in high-temperature environments, such as oven use, is critical.
- **Fire and Heat Resistance**: While TopScreen™ is primarily designed for oil and grease resistance, its water-based nature and ability to handle heat sealing make it versatile. However, like other coatings in this market, it may not fully meet the 550°F threshold for air fryer conditions without additional testing or modification.
- **Sustainability**: TopScreen™ coatings are compostable, recyclable, and repulpable, providing an eco-friendly alternative to traditional plastic-based coatings. This aligns with the trend of reducing reliance on fossil-fuel-based materials in food-safe packaging. By replacing PE and PFAS, TopScreen™ also reduces the environmental footprint and increases the recyclability of the packaging.
- **Application Flexibility**: These coatings can be applied using conventional equipment with minimal modifications, making them adaptable for widespread use. TopScreen™ supports multiple application techniques (e.g., rod coaters, curtain coaters), allowing easy integration into various packaging designs.
- **Applications:** TopScreen™ Oil & Grease Resistant Barrier Coatings are ideal for food packaging applications that require moisture, grease, and moderate heat resistance, such as fast-food wrappers, food trays, and containers. This makes it suitable for moderate-temperature packaging where food safety, durability, and sustainability are paramount, aligning with goals to create robust and eco-friendly food-safe paperboard solutions.
- **Relevance:** These coatings are engineered for oil and grease resistance but have not been tested or proven to withstand temperatures up to 550°F in confined spaces. The water-based, food-safe design is relevant for food packaging applications but lacks specific applicability to extreme heat scenarios. The coating has no demonstrated capability to mitigate fire risk or maintain performance at the temperatures required for air fryers.

PPG (formerly Whitford Worldwide)

PPG Xylan Coating is an advanced fluoropolymer-based coating originally developed by Whitford and now owned by PPG. Known for its extreme performance, Xylan provides a highly durable, non-stick, and heat-resistant solution that withstands temperatures from -420°F to +550°F. This coating offers unique benefits, including low friction, wear resistance, and robust protection against corrosion and chemicals, making it a versatile choice for industrial, automotive, and food-safe applications.

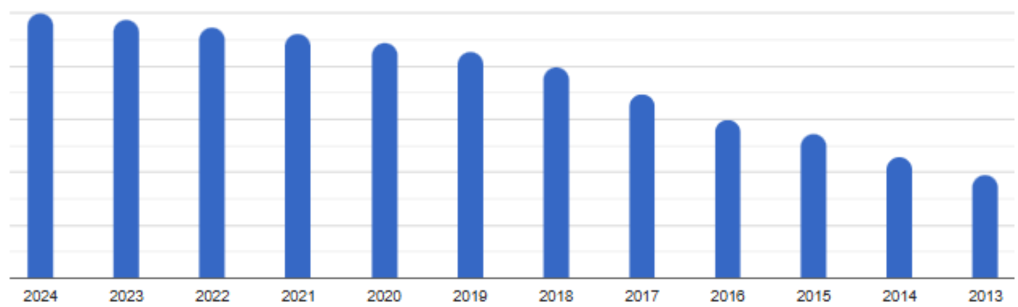
- **Xylan 1000 Series** – Best suited to sliding mechanisms, bearings, large fasteners, power screws, valves, machine parts, and pistons.
- **Xylan 1400 Series** – Typical applications include large fasteners and automotive components.
- **Xylan 1500 Series** – Protective and decorative enamels available in virtually any color.
- **Xylan 8000 Series** – Utilizing materials approved by the FDA for use in the food and beverage industries.
- **Xylan PFA Plus** – Most commonly used for plastic and urethane molds, bakery products, and chemical storage tanks.

- **Structural Integrity**: Xylan coatings are formulated for extreme durability, maintaining structural integrity across a wide temperature range (-420°F to +550°F). This high heat tolerance could support the development of a protective coating layer for paperboard packaging that must withstand elevated temperatures without degrading.
- **Food Safety Compliance**: Some variants of Xylan, such as the **Xylan 8000 Series**, use FDA-approved materials for food-related applications, suggesting that it could potentially meet FDA 21 CFR 176.170 standards for direct food contact.
- **Fire and Heat Resistance**: Xylan coatings offer both heat and chemical resistance and are engineered for demanding conditions, such as automotive and industrial settings, where both high temperatures and pressure are common. Although originally intended for metal and industrial applications, the adaptation of Xylan's non-stick, heat-tolerant properties could mitigate fire risk in high-temperature environments (e.g., air fryers).
- **Applications**: Xylan coatings are used in a variety of high-temperature applications, including bakeware, food processing equipment, and cookware, making it versatile in food-safe environments. Its application as a thin, durable film that resists wear, corrosion, and high temperatures suggests potential for use as a coating for fiber-based packaging that would maintain heat tolerance, durability, and food-safe standards.
- **Relevance:** Xylan coatings can withstand up to 550°F, making them one of the few options potentially suitable for this project. **However, their application to paperboard substrates remains unproven.** The extreme heat resistance and FDA-approved variants for food applications make Xylan coatings highly relevant, but adaptation for paperboard use is necessary. Requires further testing to confirm compatibility with paperboard and ability to maintain structural integrity under the project's specific conditions.

IP Snapshot

Recent patent activity in the field of high-temperature resistant coatings in confined spaces indicates a niche but emerging area of development. However, **most patents in this field do not explicitly specify food-safe or paperboard applications**, nor do they consistently disclose exact temperature thresholds, making it an evolving area of research.

Patents Filed Over Time



Key Trends

- **Food Safety Compliance**: There is an emerging focus on ensuring high-temperature coatings meet food safety standards, but many patents still lack specific references to regulatory compliance, highlighting a potential area for further innovation.
- **Eco-Friendly Materials**: Sustainable and non-toxic coating options are becoming more prominent, with some patents exploring materials that reduce environmental impact.
- **Multi-Functionality**: Research increasingly incorporates multifunctional properties into coatings, such as combining heat resistance with anti-stick or fire-resistant features, aiming for broader applications.
- **Confined Space Applications**: Several patents emphasize coatings for confined, high-temperature environments, indicating a demand for solutions that perform well under restricted airflow and higher heat exposure.
- **Technological Enhancements**: Innovations in nanotechnology and polymer engineering are frequently used to enhance coating durability, temperature resistance, and application versatility.

Examples of IP

Title: A food-grade high-temperature resistant thin-coated high-temperature powder coating for ovens
Publication Number: CN117820962A
Publication Date: April 4, 2024
Applicant: Changzhou Carbonsuo New Material Technology Co., Ltd.
Summary: This invention introduces a specialized powder coating designed for use in ovens, which is safe for food contact and can withstand high temperatures. The coating is made from a carefully calculated mix of materials, including silicone resin, epoxy resin, a curing agent, pigment, mixed glass powder, and a flame retardant, each measured in specific parts by mass. The unique formulation of this coating ensures that it not only adheres to safety standards for food contact but also provides excellent temperature resistance. Additionally, it is designed to be a thin coating, which helps reduce costs and extends the lifespan of the product, making it a practical choice for oven manufacturers and users alike.
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Title: A kind of high-temperature resistant coating polyester modified silicone resin inside the air fryer and its preparation method
Publication Number: CN117487170A
Publication Date: February 1, 2024
Applicant: Jiangsu Sanmu Chemical Co., Ltd. , Jiangsu Sanmu Group Co., Ltd.
Summary: This invention introduces a new type of coating made from a polyester-modified silicone resin specifically designed for use inside air fryers. The coating is created using a variety of raw materials, including neopentyl glycol and different types of acids and anhydrides, which are combined

through a specialized high-temperature melt polymerization process. This method allows for the careful adjustment of the chemical components to achieve the best performance characteristics. The resulting polyester-modified silicone resin boasts several impressive qualities, including high wear and scratch resistance, the ability to withstand high temperatures, strong adhesion, and high hardness. These properties make it particularly suitable for the demanding environment of an air fryer, ensuring durability and effectiveness in cooking applications.

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Title: Food grade high temperature resistant baking paper
Publication Number: CN221142315U
Publication Date: June 13, 2024
Applicant: Zhejiang Senyao New Materials Co., Ltd.
Summary: This utility model focuses on a new type of baking paper designed for high-temperature cooking. It features a multi-layered structure that includes various layers such as an anti-adhesion layer, heat insulation layers, and a waterproof base, all aimed at enhancing its performance in the kitchen. The baking paper is constructed with materials that provide both heat resistance and tensile strength, making it durable and effective for baking purposes. The innovative design incorporates bamboo pulp and carbon fiber, which contribute to its ability to withstand high temperatures while preventing food from sticking, thus making it a practical choice for both home and commercial use.

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Title: A high temperature resistant non-stick coating
Publication Number: CN107641426B
Publication Date: January 9, 2020
Applicant: N/A
Summary: This invention introduces a new type of coating that can withstand high temperatures while also being non-stick. The coating is made from a specific combination of materials, including modified epoxy resin, organic silicone resin, and various other resins and additives, each measured in precise amounts to ensure optimal performance. The resulting coating is designed to be safe for food use, as it is non-toxic and complies with food hygiene standards. It boasts strong adhesion, making it durable and effective for various applications, while also providing excellent resistance to high temperatures and non-stick properties, making it suitable for cooking and other high-heat environments.

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Title: High temperature-resistant and non-sticking coating
Publication Number: CN107641426A
Publication Date: January 29, 2018
Applicant: ZHEJIANG GENYUAN PAINT SCIENCE AND TECH CO LTD
Summary: This invention introduces a new type of coating that can withstand high temperatures and prevents sticking. The coating is made from a specific mixture of various materials, including modified epoxy resin, organosilicone resin, and several other components that enhance its properties. The key benefits of this coating include its ability to resist high temperatures while remaining non-sticky, making it suitable for food-related applications. It is designed to meet food safety standards, ensuring that it does not contain harmful substances. Additionally, the coating exhibits strong adhesion and good mechanical properties, making it effective for various uses.