To achieve greater impact, the industry must embrace a more ambitious and transparent trajectory, recognizing both its privilege and its duty to leave a legacy that inspires and uplifts future generations.

Fragrances and Flavors at a Crossroads: From Fossils to the Future

Strengthening sustainability and resilience in a fossil-dominated industry.

BY ALAIN FRIX

Alain Frix founded Allchemix in 2020, as an independent consultancy focused on natural and synthetic ingredients for fragrances and flavors.

Although the global flavors and fragrances (F&F) industry represents a small fraction of global economic output, it plays a critical role in consumer perception, product differentiation and cultural expression. Beneath its creative image, the industry relies on a narrow and increasingly imbalanced set of feedstocks, dominated by fossil-derived petrochemicals. This article examines the historical evolution, current structure, and future trajectories of F&F feedstocks, integrating environmental, socioeconomic and geopolitical dimensions. By analyzing petrochemical dominance, the decline of natural ingredients, the geographic relocation of chemical production, and the limits of carbon-centric sustainability metrics, the article highlights systemic risks and identifies emerging building blocks for a more resilient and responsible F&F industry.

An Industry of Disproportionate Influence

The global F&F industry accounts for less than 0.04% of global GDP[1] and is valued at approximately $40 billion[2]. Despite its modest economic size, the industry exerts a disproportionate influence on everyday life. F&F ingredients shape sensory perception across food, personal care, household products and fine perfumery, deeply influencing consumer preference and brand identity.

This paradox—limited economic scale paired with significant cultural and sensory impact—makes the sustainability of the F&F industry particularly relevant. Sustainability claims are increasingly prominent. Yet, structural dependencies remain largely unchanged: petrochemical feedstocks dominate both volume and innovation pathways, while renewable and natural materials occupy a declining share.

Image by Petro at Adobe Stock; Courtesy of Alain Frix

Petrochemical feedstocks continue to dominate both volume and innovation pathways, while renewable and natural materials occupy a declining relative share. At the same time, the relocation of chemical production from Western countries to Asia has reduced operational costs and expanded access, but has also intensified environmental burdens and geopolitical dependencies.

This article explores how feedstocks shape the modern F&F industry, examining past dependencies, present imbalances, and the emerging building blocks that may define its future.

Feedstock Foundations of the F&F Industry

At its core, the F&F industry transforms raw materials into olfactory and gustatory experiences. Although perfumers and flavorists work with more than 3,000 commercial ingredients [3], these materials originate from a limited number of primary feedstock categories. Broadly, F&F ingredients derive from four main sources: petrochemicals, turpentine derivatives, essential oils and natural extracts, and a diverse group of other natural or emerging inputs (**F-1**).

Together, these feedstocks supply approximately 800,000 metric tons of aromatic materials annually, excluding solvents[3].

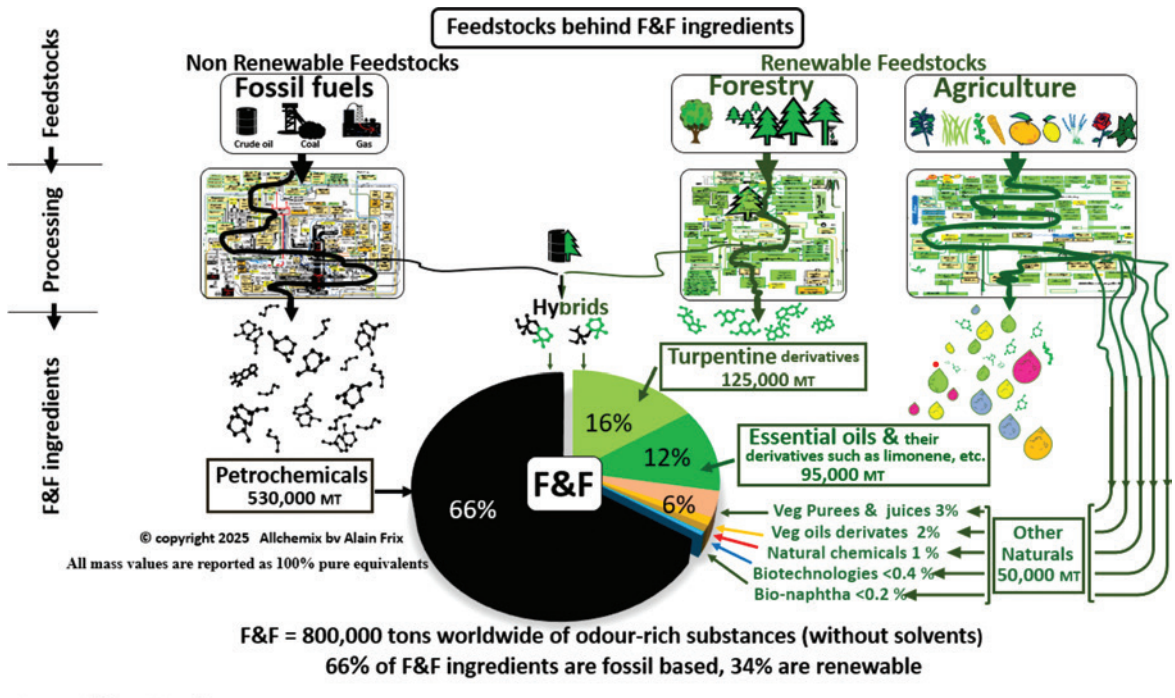
Petrochemicals dominate this volume, accounting for roughly 530,000 tons per year. Their prevalence reflects chemical versatility, reliable supply, and cost efficiency, enabling access to a broad spectrum of functional structures essential to modern fragrance and flavor creation.

Turpentine derivatives, contributing around 125,000 tons annually, originate from forestry by-products associated with cellulose and paper production. Although renewable in origin, these materials are extensively modified through chemical synthesis and are therefore classified as synthetic.

Essential oils and natural extracts, totaling approximately 95,000 tons per year, are sourced from more than 300 plant species and form the backbone of the industry's natural ingredient segment[3,4]. A final category of other natural ingredients includes fruit derivatives, botanical extracts and limited contributions from biotechnology.

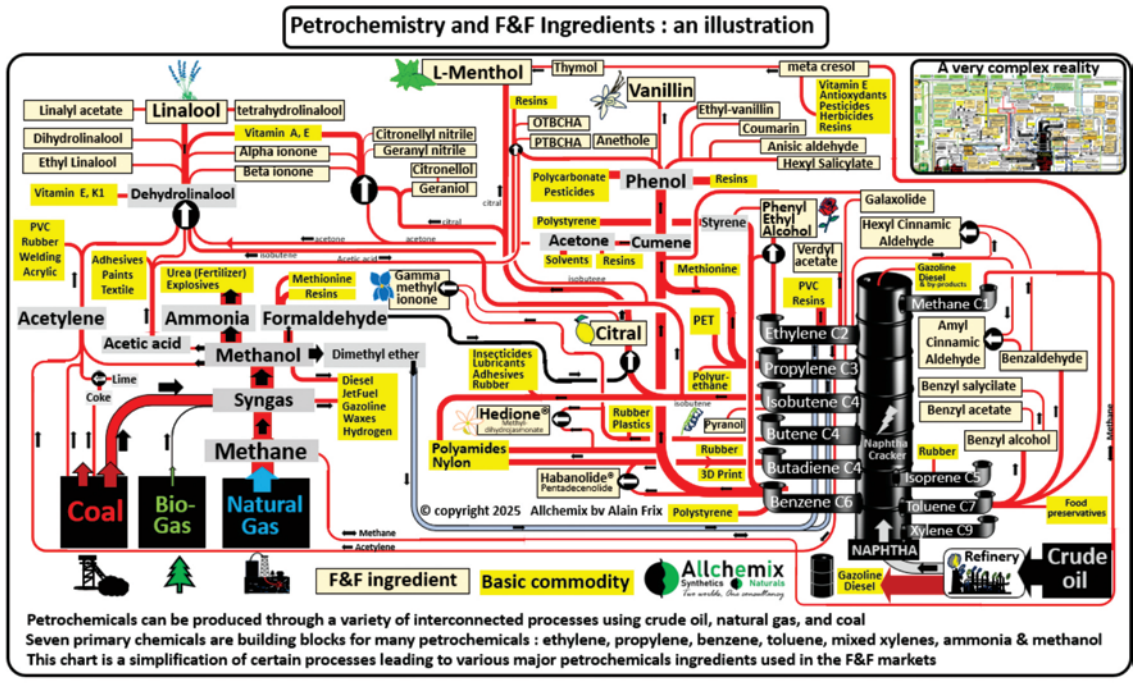
This distribution underscores a fundamental imbalance: while natural ingredients are central to industry narratives, fossil-derived materials remain structurally dominant.

F-1 **Broadly, F&F ingredients derive from four main sources: petrochemicals, turpentine derivatives, essential oils and natural extracts, and a diverse group of other natural or emerging inputs**



Courtesy of Alain Frix

F-2 **Petrochemical F&F ingredient supply chain outline**



Petrochemicals can be produced through a variety of interconnected processes using crude oil, natural gas, and coal
Seven primary chemicals are building blocks for many petrochemicals : ethylene, propylene, benzene, toluene, mixed xylenes, ammonia & methanol
This chart is a simplification of certain processes leading to various major petrochemicals ingredients used in the F&F markets

Source : Allchemix Consultancy

Petrochemicals as the Structural Backbone

Petrochemical derivatives account for more than 2,000 individual aromatic molecules used in the F&F industry[3,4]. All are derived from fossil fuels—crude oil, gas and coal—which still provide approximately 80% of global primary energy[5]. Contrary to expectations of rapid decarbonization, global fossil fuel consumption reached record levels in 2023, driven largely by demand growth in Asia[6], with petrochemicals expected to become the main driver of this demand in the long term[7,8] (**F-2**).

Petrochemicals benefit from mature, extreme complex global infrastructure, economies of scale and well-established synthesis pathways. Recycling generally remains limited, as recycled petrochemical intermediates are often more expensive than virgin materials derived from fossil sources[9,10].

From an industrial perspective, petrochemistry offers high predictability and cost stability—attributes that strongly influence ingredient selection in high-volume applications. While petrochemicals are sometimes treated as a monolithic category, there is an extreme variability in feedstock origin, energy mix and process efficiency, and one could even argue about high petrodiversity.

However, these advantages mask significant externalities. Fossil fuel extraction and processing involve land disruption, water contamination risks, air pollution and greenhouse gas (GHG) emissions that are not fully reflected in product-level sustainability metrics. Moreover, fossil resources are finite. At current consumption rates, crude oil reserves may be depleted within one century, a reality seldom integrated into long-term industry planning.

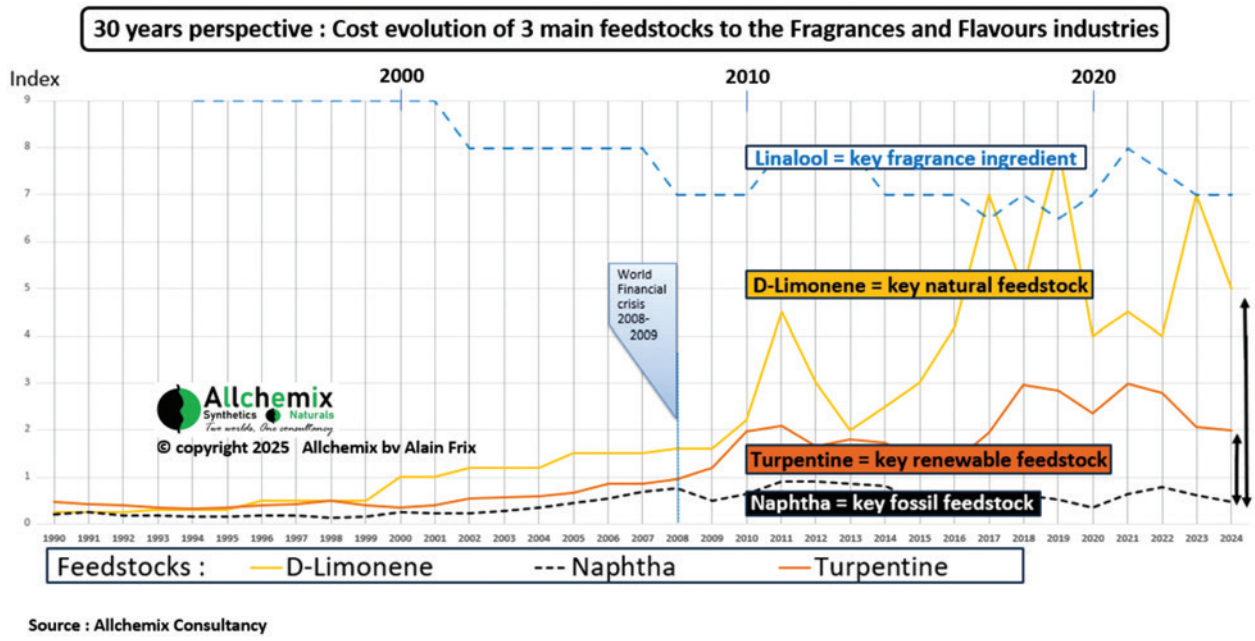
Economic Pressures and the Decline of Natural Ingredients

Natural ingredients play a unique role in the F&F industry, extending beyond their functional properties. Although global essential oil production is small compared with petrochemicals 4, natural ingredient supply chains have a unique socioeconomic impact, supporting millions of rural livelihoods and contributing significantly to local economies.

Over the past three decades, however, the price gap between natural feedstocks and petrochemical alternatives has widened considerably. Since the late 1990s—and particularly following the 2008 financial crisis—petrochemical intermediates have consistently

Courtesy of Alain Frix

F-3 The cost evolution of three F&F industry feedstocks



outperformed renewable alternatives in terms of price stability. This divergence has redirected investment toward fossil-based chemistry and accelerated the substitution of natural ingredients in cost-sensitive markets (**F-3**).

The case of L-menthol illustrates this shift.

L-menthol, prized for its cooling effect in oral care products such as toothpaste, exemplifies the shift from natural to petrochemical ingredients, driven primarily by price competition. Historically, L-menthol was extracted from *Mentha arvensis* oil (cornmint oil), whose global production exceeded 50,000 tons in 2013[11,12]. Mint cultivation, mostly in India, supports several million workers and is intercropped with staple food crops, providing critical diversification for farmers facing climate uncertainty[13].

Recent investments have significantly increased global production capacity for the petrochemical version of L-menthol. In 2022, Symrise AG and, separately, Shengyuan expanded their production of toluene-based L-menthol[14,15], while Zhejiang NHU Co. launched a citral-based version, another intermediate used for menthol[16]. In 2024, Wanhua Chemical Group inaugurated a citral plant in China with an annual capacity of 48,000 tons[17], while BASF AG plans to increase its production of citral to 118,000 tons this year[18]. This increase in petrochemical supply and its cheaper and more abundant precursors directly threatens the natural menthol market. In just two decades, the oral segment has shifted from a predominantly natural L-menthol to a predominance of fossil-derived L-menthol, bringing significant negative socioeconomic consequences.

Over the last three decades, while large F&F compounders have been consolidating at a fast pace, often incorporating family driven businesses into the stronghold of public rated companies, many F&F houses have been increasingly looking to replace dozens of sizeable renewable ingredients with petrochemical alternatives, purely driven by cost.

Delocalization of the Chemical Industry from the West to Asia: A Cost-Driven Shift

Since the 1990s, F&F ingredient production has gradually shifted from the West to Asia—primarily China and India—driven by a combination of cost considerations and regulatory pressures over past decades. Plant closures in Europe released skilled labor and equipment, which Asian investors effectively adopted and integrated, accelerating this transition. Stricter Western environmental regulations further encouraged outsourcing by companies seeking cost-effective compliance solutions, initially transferring their hazardous processes to Asia and later extending to broader manufacturing activities.

Today, following this cost-driven transition, Asia is a major global hub for chemicals, combining advanced technology, high production capacity, and a skilled workforce (**F-4**).

Courtesy of Alain Frix

In some perfumery materials, global dependence on Chinese petrochemistry exceeds 90%. Asia now leads not only in production but increasingly in innovation and is likely to drive future sustainable F&F solutions as it gradually transitions away from coal.

As illustrated by Ronald Piech in his historical account of fragrance chemistry in Germany[19], the modern fragrance industry has always been intrinsically linked to the chemicals sector. The ongoing relocation of global chemical production from West to East is moving the center of gravity for fragrance chemicals to Asia, significantly reshaping the global fragrance industry. Mirroring events in the textile industry, Asia is poised to become the world's leading producer of finished fragrances in the coming decades, in particular for personal care and household products.

Systemic Environmental Impact of Petrochemical Production Shifting to Asia

The relocation of F&F ingredient production to Asia has delivered undeniable economic benefits, but it has also reshaped the environmental profile of the industry in ways that are often underestimated. As compounders and consumer goods companies refine formulations and reduce ingredient costs, the upstream environmental burden of feedstock production has increased significantly.

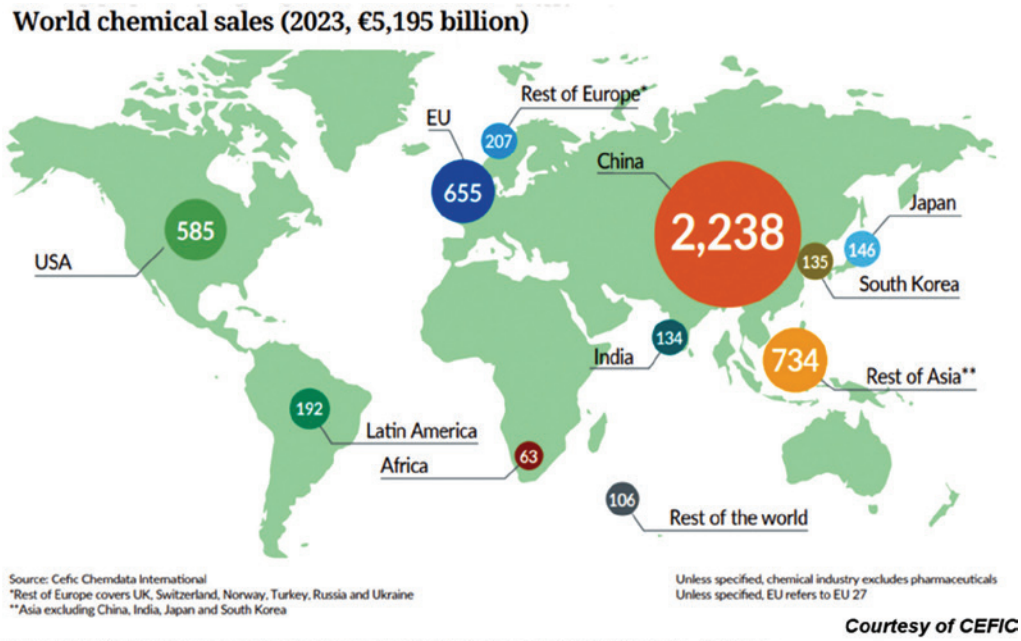
One of the primary drivers of this trend is energy. In many Asian countries—including China, India, Indonesia and Vietnam—chemical production continues to rely significantly on coal, which remains a major energy source. Although substantial investments in renewable energy are underway, electricity demand in the region is growing faster than clean energy deployment can currently meet[20,21].

Coal is both an energy source and chemical feedstock. In China, coal-to-chemicals pathways are central to methanol production, later converted into olefins like ethylene and propylene via methanol-to-olefins (MTO) technology. While technically efficient and strategically attractive in coal-rich regions, these processes generate substantially higher GHG emissions than steam cracking routes based on oil or natural gas, which remain dominant in Western countries[22,23]. Not all petrochemicals are created equal.

Transport further compounds the environmental burden. The majority of F&F ingredients produced in Asia are consumed in Europe and North America. Long-distance shipping adds a significant carbon penalty, particularly for bulky, high-volume aroma chemicals[24].

A structural paradox arises as F&F companies can reduce direct operational emissions (Scopes 1 and 2) by outsourcing production—predominantly to Asia—thereby increasing their upstream carbon footprint. Scope 3 emissions, in particular, also require careful

F-4 **Today, following this cost-driven transition, Asia is a major global hub for chemicals, combining advanced technology, high production capacity, and a skilled workforce**



Source : The Competitiveness of the European Chemical Industry, a joint study by Cefic - Advancy

Courtesy of Alain Frix

evaluation, as reported GHG reductions often rely on third-party claims that are not always readily auditable and, in some cases, on purchased carbon credits rather than actual GHG reductions in the supply chain. This can also occur with some mass-balance products, when they are physically entirely derived from conventional processes but reported as lower-carbon through carbon credit schemes.

Lifecycle Assessment and the Limits of Carbon Footprint metrics

Carbon footprint calculations have become the dominant sustainability indicator in the F&F industry. While useful, they capture only a fraction of total environmental impact. A comprehensive lifecycle assessment must consider resource extraction, processing, formulation, use and end-of-life degradation. (See sidebar: Behind the Green Curtain: Why Carbon Metrics Mask the F&F Industry's True Impact.)

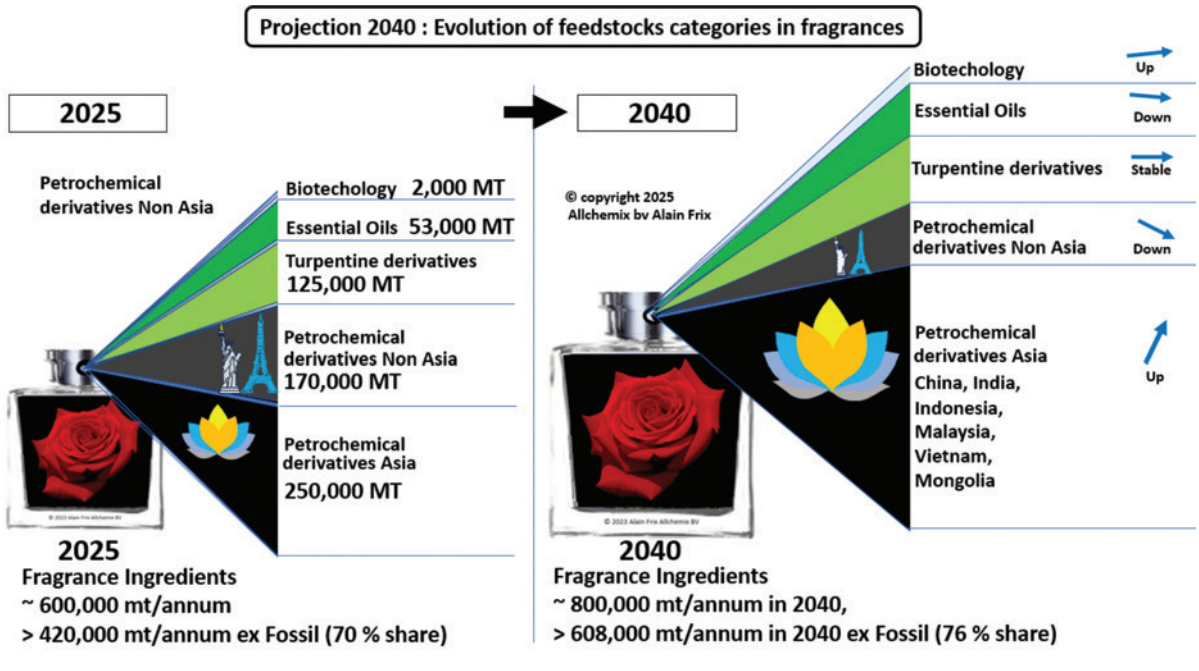
A simplified life cycle can be divided into eight major steps, each associated with distinct sustainability challenges. The most environmentally intensive stages are the first three, corresponding to the primary transformation of Earth's resources. For biomass, this includes

THE RISING SHARE OF PETROCHEMICALS: A 2040 PERSPECTIVE ON FRAGRANCE INGREDIENTS

Market projections indicate that the global demand for fragrance ingredients will continue to grow at an average annual rate of approximately 3% by volume through 2040. This growth, however, will not be evenly distributed across feedstock categories. Petrochemical-based ingredients are expected to grow significantly faster than natural alternatives, increasing their market share from around 70% today to nearly 76% by 2040 (**F-5**).

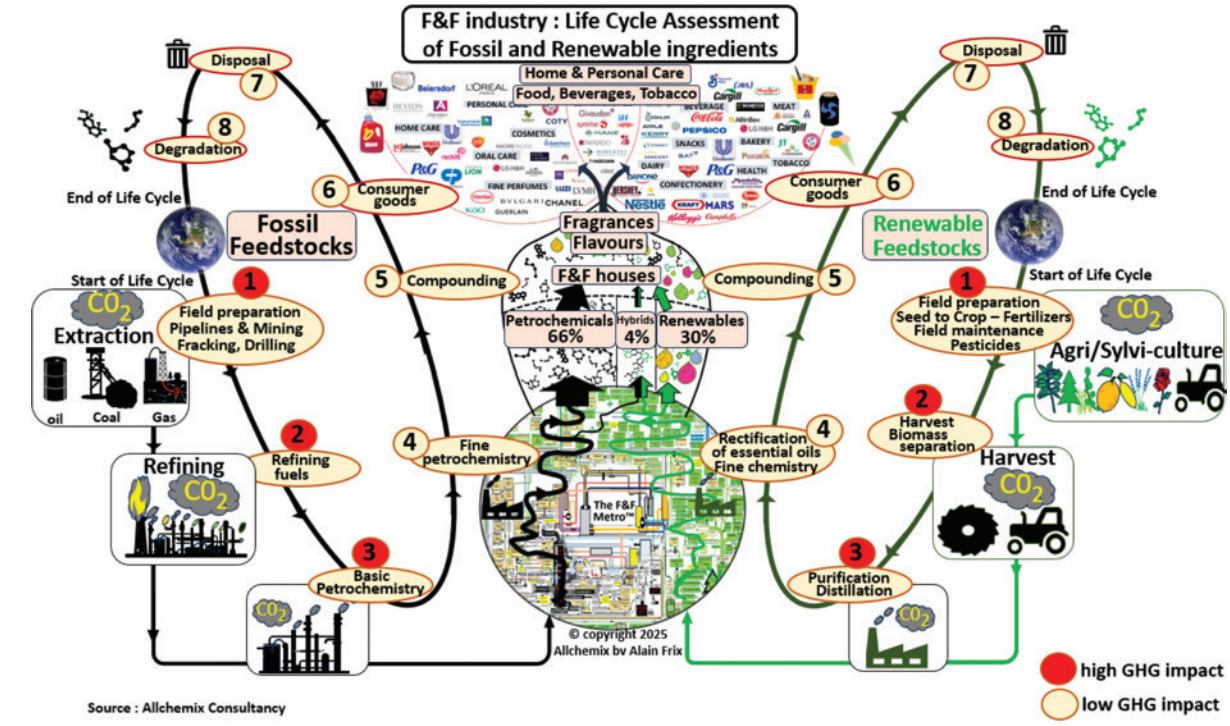
This trajectory reflects several reinforcing dynamics. First, cost sensitivity remains the dominant purchasing criterion in large-volume applications such as household products, personal care, and oral care. Second, standardization favors petrochemical ingredients with consistent quality and predictable supply. Third, regulatory pressure tends to focus on individual molecules, which can often be substituted within the broad portfolio of fossil-based chemicals.

F-5 **Petrochemical-based ingredients are expected to grow significantly faster than natural alternatives, increasing their market share from around 70% today to nearly 76% by 2040**



Courtesy of Alain Frix

F-6 Identification of the eight main stages in LCA of F&F products



land preparation, cultivation, harvesting and initial processing. For fossil resources, it involves land disturbance, drilling, extraction of fossil fuels, refining and heavy chemical transformation (**F-6**).

These stages are responsible for the majority of GHG emissions, water use, and ecological disruption. Methane leakage from coal and gas extraction sites alone accounts for hundreds of millions of tons of CO_2-equivalent emissions annually. Gas flaring increased by more than 5% in 2023, releasing emissions comparable to the United Kingdom's total annual emissions[31]. However, the extent to which these substantial fossil-related emissions are captured within petrochemical derivative audits remains highly unclear. According to UN estimates, farming contributes approximately 11% of global GHG emissions, while fossil fuel extraction and processing contribute around 10%[24].

Later stages of the lifecycle—fine chemistry, formulation and incorporation into finished products—generally have a much lower incremental environmental impact, particularly where green chemistry principles are applied. The author estimates that approximately 80% of the GHG emissions associated with the F&F industry originate from the production of F&F ingredients. By contrast, the core activity of F&F houses—blending these materials—requires relatively little energy. Consequently, the direct emissions of F&F houses (Scopes 1 and 2) are minimal and are rather the tip of the iceberg, when compared with the total lifecycle emissions of the sector, which are dominated by Scope 3 emissions.

End-of-life stages, including degradation and environmental persistence, remain complex and critical, especially for fragrance molecules released into wastewater systems.

Crucially, reliable LCAs require access to primary data from agricultural fields, mines, oil fields, refineries, and chemical plants. Without independent audits and transparent reporting, sustainability claims remain at best incomplete and at worst misleading.

Innovation Gaps and the Slow Emergence of Sustainable Design

While enjoying its creative reputation, the F&F industry has been relatively conservative in redesigning its molecular toolbox. Many high-volume ingredients in use today were developed more than 60 years ago and have changed little since. Regulatory restrictions in Europe are progressively limiting the use of large, persistent molecules, particularly in applications where they end up in wastewater.

One promising response is the development of high-impact "super-molecules" effective at ultra-low dosages. Ingredients such as Ambrostar (from Symrise), Z11 (from

Courtesy of Alain Frix

BEHIND THE GREEN CURTAIN: WHY CARBON METRICS MASK THE F&F INDUSTRY'S TRUE IMPACT

The widespread reliance on carbon footprint metrics has created what might sometimes act as a "green curtain." Products with favorable carbon scores may still generate significant toxic waste, water pollution or social harm. Conversely, some natural ingredients with low apparent carbon footprints may deliver substantial socio-economic benefits.

A clear example is catalyst-related toxic waste. Many F&F ingredients are produced through multi-step chemical processes that rely on catalysts, especially those derived from feedstocks like coal, natural gas, crude oil or turpentine. Despite growing adoption of green chemistry, heavy-metal catalysts are still used, generating toxic waste even when the reported carbon footprint is low. Therefore, when evaluating an ingredient's carbon footprint, its "catalyst footprint", reflecting catalyst use and associated waste, should also be considered, as it can substantially change the factual environmental impact. Especially when compared with essential oils which are produced via simple physical processes like distillation or expression without catalyst-driven reactions. Essential oils can have exceptionally low carbon and low catalyst footprint, such as citrus oils likely ranking among the highest sustainability performers within F&F ingredients, potentially surpassing biotechnological products, which sustainability scores also depend on the environmental footprint of their agronomical feedstocks (e.g sugar cane, rice bran, etc.). The author identified 16 indices directly related to product sustainability, out of 24 metrics defining a commercial product (**F-7**).

Vanillin provides a compelling illustration. Its 24-hour sustainability profile varies dramatically depending on origin: natural vanilla beans, lignin extraction, clove oil, ferulic acid fermentation, sugar-based fermentation, turmeric-derived routes, or petrochemical synthesis in Asia or in Europe. Treating all vanillin as equivalent based on a single metric obscures these differences and undermines informed decision-making. The absence of a standardized protocol for sustainability indicators in the F&F industry reflects a lack of sectoral desire for harmonization, highlighting the effort still required to move from partial transparency to true alignment. Yet, sustainability goes beyond products and the protocols that govern them; it also encompasses business practices. For instance, some F&F houses impose increasingly strict and prolonged credit terms on their suppliers, often as a way to pass on the financial credit requirements they themselves receive from their customers, sometimes with the implicit expectation that maintaining the business relationship depends on accepting these conditions. While these practices are not inherent to the products themselves, companies should also be assessed based on the financial pressures they exert on their broader socio-economic environment, an aspect that is undeniably a significant component of sustainability. Other examples include the gradual upward transfer of supply chain risks to the more upstream vulnerable suppliers within the value chain.

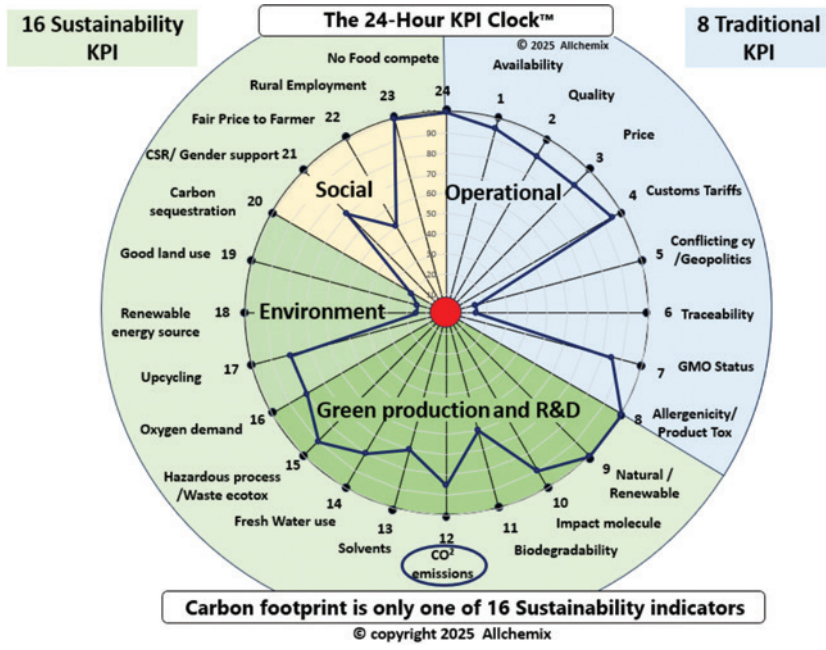
MAPPING DEPENDENCIES: THE F&F METRO

The world of F&F ingredients can be compared to a vast subway system, where each station represents a chemical and individuals are the compounds themselves. Mapping the connections between these "stations" is essential to understanding the dependencies within material flow chains. Only by doing so can we begin to accurately assess the sustainability profile of a specific ingredient.

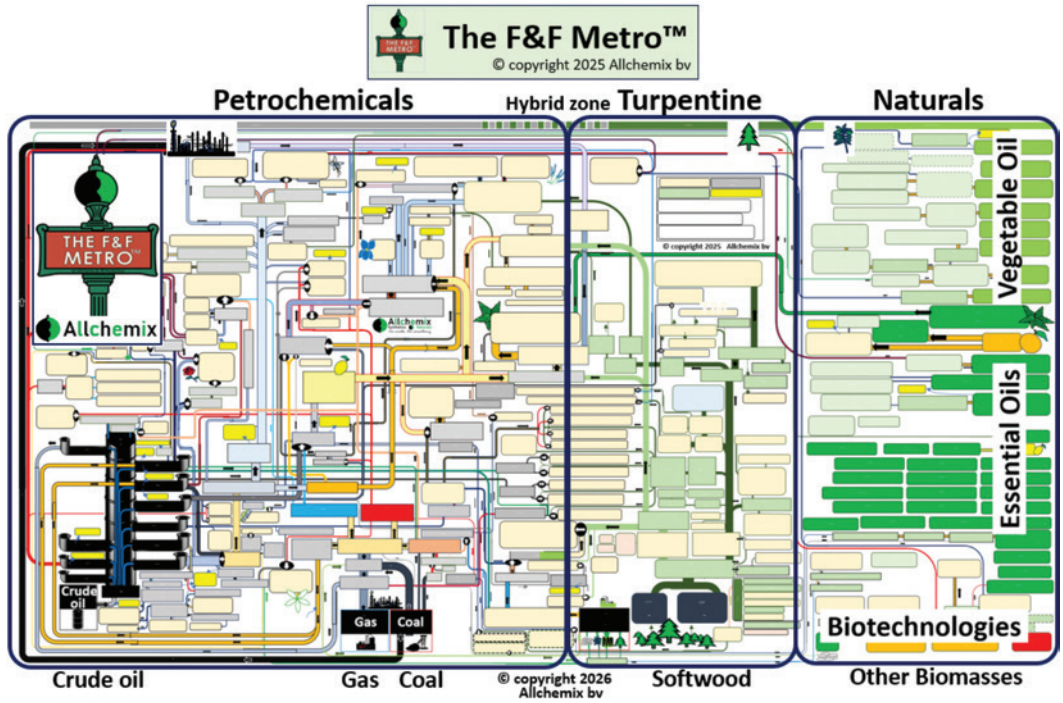
There are often multiple routes to reach the same destination, which adds another layer of complexity to the system. To illustrate this, the chart below shows the practical interactions between different feedstocks and some of the many F&F ingredients. While the visual may appear complex, each pathway—represented by a tube—reflects a series of transformation steps that can increase significantly in complexity, sometimes by a factor of 10.

At this stage, it becomes possible to assess whether the transformation steps involve eco-toxic catalysts, halogenation reactions or other environmentally harsh processes—even when the overall carbon footprint appears low. There's significant variation in the nature of these chemical transformations, particularly in processes linked to petrochemical and turpentine-derived pathways. This contrasts with the generally greener production of essential oils, which rely mainly on distillation rather than extensive chemical modification and molecular assembly (**F-8**).

F-7 **The author identified 16 indices directly related to product sustainability, out of 24 metrics defining a commercial product**



F-8 **Interconnecting feedstocks and F&F ingredients**



Source : Allchemix Consultancy

Courtesy of Alain Frix

dsm-firmenich) or Pomarose (from Givaudan) exemplify this approach. By reducing required volumes, these materials lower the energy needed to manufacture them, cut transportation emissions and minimize waste generation—delivering benefits across multiple dimensions.

However, despite their advantages, these molecules are often more expensive than their larger petrochemical counterparts[25], and they also frequently require a high level of perfumer expertise to use them effectively. Even today, young perfumers are taught to create fragrances using large, conventional petrochemical commodities. This may stem from the fact that, for many decades, major F&F companies operated as primary producers of a wide range of sizeable petrochemical ingredients before eventually shifting their manufacturing operations to external suppliers in Asia.

Some of the large chemicals used in F&F date back more than 100 years and have changed little in that time. Unlike electronics, which have miniaturized products, the F&F industry still relies on massive, energy-intensive chemicals. This is not due to lack of talent, but rather a status quo approach where sustainability competes with other drivers. For agile companies, regulatory constraints—often initially perceived as an obstacle—can become a strategic lever, boosting creativity, strengthening differentiation, and fostering the emergence of responsible models. Rather than hindering progress, regulatory constraints often penalize a lack of anticipation[26], and promote close collaboration between regulators, decision-makers, researchers and industrialists.

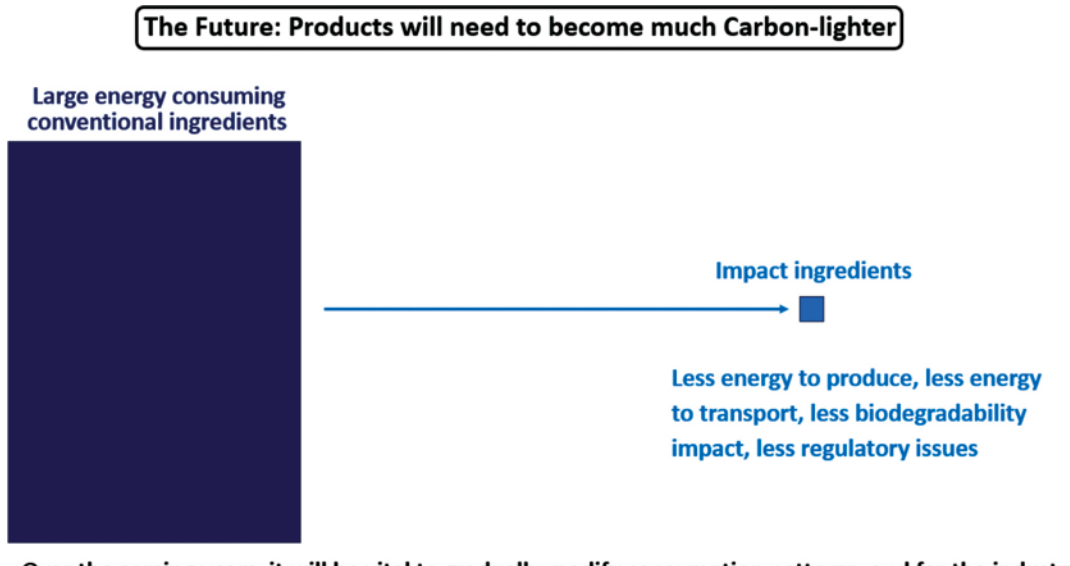
The Biodegradability Paradox

Biodegradability has become a key selection criterion for fragrance ingredients, yet it is frequently misunderstood. Standard biodegradability tests are conducted under ideal laboratory conditions that rarely reflect real-world environments. Passing such tests does not guarantee rapid or complete degradation in natural ecosystems.

Some molecules fragment into smaller compounds without full mineralization, potentially generating persistent micro-pollutants[27,28]. Paradoxically, the use of very small quantities of low-biodegradability materials may, in certain cases, be environmentally preferable to the large-scale use of partially biodegradable ones.

The key question is how to shift from producing 500,000 tons of conventional carbon-based aroma chemicals to just 10,000 tons of highly impactful molecules (**F-9**). Developing ultra-low-dose, high-impact fragrance

F-9 **The key question is how to shift from producing 500,000 tons of conventional carbon-based aroma chemicals to just 10,000 tons of highly impactful molecules**



Courtesy of Alain Frix

COMMON SENSE AT A CROSSROADS: RECLAIMING ETHICS AND INDUSTRIAL LOGIC IN F&F

The F&F industry is increasingly constrained by regulatory uncertainty—at times amplified by decisions developed in isolation at government or regulatory hubs—and by a fragmented industrial landscape. Many consumer goods companies and compounders face rising financial pressures and may overlook supplier continuity, weakening the resilience of the entire ecosystem.

There is broad consensus on the need for sound regulatory and industrial frameworks that promote safer consumption and reduce environmental impact. Progress requires aligning industry and regulators around practical, sustainable solutions guided by common sense—the ability to balance long-term objectives with pragmatic action.

The importance of this principle was remarkably highlighted by Jean Mane in his inspiring address at IFEAT Göteborg on September 16, 2025, emphasizing the resilience needed to preserve common sense amid regulatory and industrial turbulence[29]. Similarly, in his presentation "Will All the Flowers Be Gone?" at IFEAT Dubai on September 27, 2016, Kim Bleimann stressed the need to protect the natural reservoirs of essential oils that have sustained human well-being for millennia—an example of scientifically informed common sense rooted in both tradition and evidence-based reasoning[30].

The F&F industry faces significant strategic challenges driven by leadership imbalances, short-term financial pressures and risk-averse cultures that prioritize stock-market performance over industrial resilience.

While some mergers and acquisitions genuinely create value, many are largely cosmetic, enhancing perceived performance rather than building lasting strength. Frequent mergers—and increasingly, demergers —combined with cost-cutting initiatives and workforce reductions, often result in the loss of critical active expertise, the very foundation of mid- and long-term value.

M&A can, at times, resemble a high-stakes environment, where misjudged timing or pricing can have long-lasting consequences and erode decades of legacy. Leadership in this environment is rather ephemeral, replaced by sophisticated but often inexperienced teams, while functional hierarchies give way to rigid, bureaucratic structures. Encouragingly, not all companies follow this path; the most resilient adopt alternative approaches grounded in common sense and long-term industrial logic.

In the drive to cut costs, some companies compromise on quality, particularly with so-called natural flavor ingredients in the food chain. Genuine natural components are sometimes substituted with ultra-low-cost, certification-only materials from regions with unreliable audits, potentially misleading consumers on the naturality of what they eat. Short-term managerial pressures can stretch ethical boundaries, making rigorous due diligence and robust governance essential, particularly for natural flavor ingredients. Ethical procurement practices face intense pressure from financial management, as a result ethics is prone to gradual erosion. Despite extensive corporate reporting, a new short-term industrial reality has emerged, shaped by shareholder expectations.

This raises the important question of whether the industry can really continue to self-regulate its ethical standards as effectively as it did a decade ago.

Restoring common sense in management, grounded in ethics, empirical knowledge, professional experience, and long-term value creation, could be the most impactful and urgently needed investment for the F&F industry. By taking this approach, both industry leaders and regulators can reconcile ambition with prudence and performance with sustainable purpose, pursuing growth responsibly while delivering lasting value.

ingredients open new sustainable pathways, as their high unit value makes production from renewable biomass economically attractive and competitive.

This represents the only viable path to establish a long-term program for gradually replacing petrochemicals. While they currently drive both quality and cost efficiency, their finite nature of fossil derivatives will compel the F&F industry to accelerate the transition toward lower-carbon, preferably renewable, impactful solutions.

The Biomass Barrier: Why Biobased Molecules Struggle to Outrun the Fossil Legacy

Fossil fuels are hydrocarbons formed from ancient biomass over millions of years under intense underground heat and pressure, at virtually no cost. In contrast, producing comparable hydrocarbons from fresh biomass using current technologies remains both inefficient and expensive.

Forest biomass—the most abundant on Earth—consisting primarily of cellulose, hemicellulose and lignin, is difficult to break down into usable molecules. While emerging technologies such as supercritical hydrothermal liquefaction (HTL), microbial depolymerization and synthetic biology offer promising prospects, it may be several decades before biobased polymers can really compete in mass markets.

Despite major biotech investments in the F&F industry, in aerobic fermentation in particular, only a few biobased molecules have achieved commercial success, representing less than 0.4% of the market by volume. Efforts to replace petrochemicals involve drastically cutting production costs—a challenge that has so far failed for biotechnologies.

While advances in anaerobic fermentation and microbial strain control are promising, scaling them up requires significant investment. If successful, these technologies could benefit agriculture by improving soil health, as well as directly capturing certain GHG and converting them into fuels, chemicals or proteins with lower net emissions than fossil-based methods[30-34].

Although environmental regulatory uncertainty and geopolitical tensions may tempt some companies to delay investments in decarbonization technologies, an increased focus on R&D of biomass-driven solutions remains fundamental, as the increasing scarcity of fossil fuels by the end of this century will pose a major challenge.

Given that biomass will become the last remaining carbon supplier once fossil fuels become scarce, agricultural sectors and rural communities are set to play a key role in addressing current and future challenges.

In Conclusion: A Call to Action

While F&F sector companies have limited influence over raw material extraction practices, they bear full responsibility for their sourcing choices and must accurately assess the actual sustainability of their raw materials and derivatives. To enhance sustainability and reduce our dependency from finite resources, the industry must:

- Implement rigorous lifecycle assessments (LCAs) based on primary and secondary data, for petrochemical and biomass supply chains, to identify products with a lower environmental impact.
- Increase investments in raw material diversification, supporting the development of biomass conversion technologies, synthetic biology and other biobased technologies.
- Promote their R&D investments in biomass-derived ingredients both by distinguishing them from those dedicated to fossil ingredients and by reporting them separately.
- Prioritize high-impact, low-volume solutions that reduce the consumption of raw materials, energy and environmental waste throughout the value chain.
- Partner consumer goods companies in encouraging responsible consumption and the design of lighter, more sustainable products that offer equal or superior quality, as already seen in the electronics sector.
- Foster collaboration between all stakeholders—researchers, regulators and manufacturers—to create innovation ecosystems with a clear, predictable trajectory towards more sustainable products.

A DUTY TO SHAPE A BETTER LEGACY: REDESIGNING THE WEIGHT OF THE F&F INDUSTRY

Adapting processes and strategies towards increased sustainability has the merit to rethink the most adequate way to manufacture a viable product considering changing future supply chains and consumers[31-36].

A foundational principle of sustainability is that reduced consumption often brings the highest environmental benefit. And, ultimately, the most sustainable product is the one we choose not to consume.

Over the coming years, it will be vital for the industry to design smaller-volume, high-quality consumer goods with a significantly lighter carbon footprint, while consumer goods companies work to gradually shift consumer attitudes and educate future generations to embrace lower, more socially responsible consumption patterns. Without bold innovation and profound systemic transformation, the F&F sector risks exacerbating its environmental footprint and undermining its long-term sustainability.

Implementing low-carbon F&F solutions will significantly enhance the sustainability profile, reducing the impact of energy used in both production and transportation.

The industry carries the privilege, and the duty, to leave a better legacy that inspires and uplifts the next generations.

F&F Sustainability Dashboard: A Stepwise Approach

Many corporate sustainability reports rely on extensive datasets, complex metrics and success stories to communicate progress. While initiatives that reduce Scope 1 and 2 emissions—such as installing solar panels at compounding sites—are positive, they address only a limited share of the total environmental footprint. The dominant impact resides upstream, within Scope 3 supply chain activities, particularly ingredient production.

Energy consumption, water use, toxic waste generation, and soil depletion associated with fossil and renewable ingredient manufacturing are generally much higher than the impacts of compounding operations.

To commonly track performance and enable improvement, a focused and comparable sustainability dashboard is required, built on simple yet robust and auditable metrics.

Coverage of Ingredients

All F&F ingredients should be assessed, with exclusions limited to cases where meaningful comparison is not possible. Exclusions should include:

- Solvents present in the finished perfumes and flavors should be excluded from primary calculations and reported separately, as their disproportionate volume relative to F&F aroma materials can skew results and enable manipulation. While they are important adjuvants without intrinsic odor, their levels can be adjusted to artificially improve a compound's sustainability profile, masking the true performance of the fragrance composition itself.
- Ingredients containing more than 50% water (e.g., juices), for the same distortion risk; should be excluded and reported separately.
- Products linked to carbon credit schemes—such as many mass-balance offerings—where operations remain unchanged and reported sustainability gains come mainly from offsets, should be excluded from core performance metrics and reported separately. For example, a compounder might increase the use of carbon-intensive, coal-derived feedstocks and rely on carbon credits to improve reported sustainability. While this may enhance metrics on paper, it does not represent a true reduction in the product's environmental footprint and can mask unsustainable practices. Sustainability reporting should focus on real progress—past and future—and be fully transparent about the role of carbon credits, ensuring that reported improvements reflect genuine environmental impact.
- Hybrid products: For ingredients synthesized from both petrochemical and renewable feedstocks, reported volumes should be allocated in proportion to the fossil versus renewable share of the reaction mass.

Core Metrics

Core metrics (CM) should be developed separately for fragrance compositions and flavor formulations, as their product portfolios differ substantially. In many respects—including feedstock profiles—flavors and fragrances operate as distinct industries. For example, the flavor sector relies less on fossil-based inputs than the fragrance sector, as it incorporates a higher proportion of agricultural ingredients such as fruit juices and vegetable purées. Since CM are intended to enable meaningful performance benchmarking, comparisons must be made within homogeneous categories—comparing like with like, at least as an initial approach.

CM 1: General Indicator: Share of fossil-derived versus renewable finished ingredients by volume used for internal compounding.

This should be followed by eight indicators calculated on the basis of the average performance of the highest-volume ingredients used in the company's compounds, covering 75% of the total volume within each ingredient category (fossil and renewable).

CM2: Average carbon footprint of largest fossil-derived ingredients.

CM3: Average water footprint of largest fossil-derived ingredients.

CM4: Average hazardous waste of largest fossil-derived ingredients.

CM5: ESG quantification: share of fossil-derived ingredients supporting rural employment and certified by ESG-oriented programs.

CM6: Average carbon footprint of largest renewable ingredients.

CM7: Average water footprint of largest renewable ingredients.

CM8: Average hazardous waste of largest renewable ingredients.

CM9: ESG quantification: share of renewable ingredients supporting rural employment and certified by ESG-oriented programs.

Measurement protocols to be applied:

Carbon footprint: ISO 14067, expressed as kg CO_2-equivalent per kg of finished ingredient.

Water footprint: ISO 14046, expressed as m^3 of water per kg of finished ingredient.

Hazardous waste: Defined under applicable regulatory classifications (e.g., U.S., EU) and reported per kg of finished ingredient produced. This includes solid, liquid, or semi-liquid materials deemed hazardous, such as process residues, solvents, sludges, and spent catalysts.

ESG quantification: For fossil-derived ingredients, report each volume share verified by independent auditors such as SGS, Bureau Veritas, DNV, Intertek, TÜV, LRQA, along with the share of ingredients covered by internal ESG audits and on-site inspections of petrochemical and fossil fuel facilities by own specialized teams. For example, 10% of petrochemical ingredients are SGS-verified, and 20% are audited on-site by our specialized teams, with full reporting publicly available indicating the socioeconomic impact. For renewable ingredients, report each volume share verified by independent auditing organizations such as Fair Trade, Rainforest Alliance, UEBT, PEFC, FSC, as well as the share of ingredients subject to internal on-site ESG assessments conducted by own specialized agronomical teams, as has been standard practice. Robust internal audits, grounded in decades of industry experience, should take precedence over external certifications, which may at times rely on less experienced auditors. However, many F&F companies reduce internal oversight for cost reasons and delegate this responsibility to third parties, allowing certification labels to outweigh on-the-ground realities. For example, 10% of renewable ingredients are UEBT-certified, and 20% are audited on-site by our specialized teams, with full reporting publicly available indicating the socioeconomic impact.

Tracked year by year, these nine indicators provide a clear view of each F&F house and, collectively, highlight the industry's sustainability trajectory, provided that ingredient-level data are based on verified LCA datasets, supplier disclosures, or third-party reviewed estimates.

As discussed earlier in the article, many additional sustainability indicators could be considered. However, the CM1–CM9 dashboard already provides stakeholders—compounders, consumer goods companies, regulators and investors—with a clear and practical starting point to monitor progress, identify priorities and drive improvements across the F&F value chain.

Meaningful progress in the F&F industry requires clear, consistent and comparable measurement. To achieve greater impact, the industry must embrace a more ambitious and transparent trajectory, recognizing both its privilege and its duty to leave a legacy that inspires and uplifts future generations.

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Alain Frix founded Allchemix (*www.allchemix.com*) in 2020, as an independent consultancy focused on natural and synthetic ingredients for fragrances and flavors. Based in Belgium, Frix brings 35-plus years of industry experience, advising leading F&F compounders, luxury brands, consumer goods companies, investors and ingredient producers worldwide.

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