Carbon Fibre Won. Now What?
Rethinking Materials Strategy in Formula 1

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Abstract

Carbon fibre in F1 is a Schelling point: not necessarily the best material for every job, but the one everyone has agreed to use, which makes deviating from it a competitive risk no individual team can afford. Coordinated regulation is the only way out.

Formula 1 has reduced its operational carbon footprint by 26% against a 2018 baseline (Formula 1, 2025), and the 2026 regulatory era introduces ≥98% Advanced Sustainable Fuel and a lap-averaged 50:50 ICE/electrical power split. Yet this progress has focused on power units and logistics. The structural materials of the car — principally carbon fibre/epoxy composites comprising approximately 75% of the vehicle by mass (Mercedes-AMG Petronas, 2025) — remain governed purely by performance and safety criteria, with no sustainability dimension in the current regulatory framework. Carbon fibre is energy-intensive to produce, difficult to recycle, and approximately 30% of production enters landfill (Francis, 2019).

This paper proposes a regulatory pathway for the 2028+ cycle, comprising four component-level mandates and three reinforcing financial-regulatory mechanisms (prescriptive component mandates; a sustainability carve-out in the Financial Regulations; a multi-year-tapering Virgin Composite Allocation). The proposals are not an attempt to slow Formula 1 down or dampen its competitive edge; they identify the specific component categories where sustainability gains can be made without eroding the speed, drama, or technical theatre that draws 826 million fans to the sport. Voluntary team initiatives — McLaren's rCF programme, Mercedes' W16 sustainable composites, the VCARB/Holy Technologies recyclable wing-mirror housing — confirm technical feasibility but cannot scale without regulation. A Formula 1 that visibly leads on sustainable materials would not just generate transferable engineering knowledge; it would shift the aspirational benchmark for the next generation of engineers, designers and scientists worldwide, with downstream effects on automotive, aerospace and consumer industries that dwarf the direct environmental impact within the paddock itself.

Keywords

Green Innovation, Technology-based Governance, Formula 1, Materials, Sustainability, Regulations, FIA, Composites, Circular Economy, Recycled Carbon Fibre, Natural Fibre Composites, Additive Manufacturing, Net Zero, FIA Circularity Handbook.

1. Formula 1 and Environmental Sustainability

Formula 1 has long served as a testbed for automotive innovation, and in recent years it has embraced environmental sustainability with the same competitive rigour it applies to lap times. By July 2025, Formula 1 confirmed a 26% reduction in total carbon emissions against its 2018 baseline, reaching 168,720 tCO_2e by the end of the 2024 season, achieved during a period of significant commercial growth, with the race calendar expanding from 21 to 24 events and global attendance rising from 4 million to 6.5 million (Formula 1, 2025). The sport was on course to overshoot a 10% carbon increase had no changes been made; that it instead achieved a 26% reduction represents a genuine structural shift. Stefano Domenicali, President and CEO of Formula 1, affirmed: 'We are strongly committed to achieving Net Zero by 2030. It is a concrete goal, already visible in the significant reduction of our sport's carbon footprint' (Formula 1, 2025).

This progress has been driven by cross-sport collaboration with teams, promoters, partners, and the FIA. Emissions from factories and facilities fell 59%; travel emissions dropped 25%; logistics emissions decreased 9% — all against a backdrop of a larger calendar and a 62% increase in race attendance (Formula 1, 2025). Cars racing on track represent approximately 1% of total F1 emissions (Formula 1, 2023b); the dominant contributors are logistics, travel, and facilities. This context is important: a transition to more sustainable car materials would not alone solve the sport's carbon challenge, but it would address a qualitatively significant area of environmental impact, one that has global visibility among the 826 million fans who follow the sport.

The 2026 regulatory era represents the FIA's most ambitious sustainability mandate to date in the technical arena. All Formula 1 cars now run on at least 98% Advanced Sustainable Fuel and a lap averaged 50:50 ICE/electrical power split is effectively required (Formula 1, 2026a, 2026b). F2 and F3 series completed the transition to sustainable fuel ahead of F1, demonstrating the FIA's established practice of validating sustainability concepts in feeder series before introducing them at the pinnacle of the sport. This precedent is directly relevant to the proposals in Section 5 of this paper. The FIA's demonstrated willingness and ability to use technical regulations as a lever for environmental change provides the institutional foundation upon which further materials-focused regulations can be built.

It should be acknowledged from the outset that the FIA's regulatory achievements extend well beyond sustainability. The organisation's track record on safety — from the progressive reinforcement of the survival cell to the HANS device, and the introduction of the Halo in 2018 — represents one of the most successful safety engineering programmes in any sport (Roberts, 2025). The cost cap has transformed the commercial landscape of the sport. This paper is offered in the same constructive spirit: as a contribution to an ongoing evidence-based process, not as a critique of progress already made.

2. The Role of Carbon Fibre Composites in Motorsport

Carbon fibre composites are integral to modern motorsport, valued for their exceptional stiffness-to-weight ratio and versatility in manufacturing complex aerodynamic geometries. Carbon fibre composites form approximately 75% of the F1 race car by materials (Mercedes-AMG Petronas, 2025) — consistent with earlier estimates of ~85% by volume (Shortland, 2024), the difference reflecting measurement basis. These materials have transformed car performance, enabling light and stiff structures that would be unachievable with conventional metals alone. However, their environmental footprint is a growing concern: carbon fibre composites are energy-intensive to manufacture, difficult to recycle, and around 30% of produced carbon fibre enters landfill as scrap (Francis, 2019). As Savage (2009) described the F1 chassis: 'a shell structure which is more like a jet fighter aircraft cockpit, both in terms of shape and construction, than anything one would expect to find on the road.' This disconnect between F1 composite technology and commercial automotive needs actually strengthens the case for more accessible sustainable alternatives — as discussed in Section 6.

2.1 Recent Industry Developments

Since 2023, the F1 paddock has seen a remarkable acceleration in sustainable composites activity. These developments demonstrate that the proposals in this paper are no longer speculative: they are being implemented, voluntarily, by leading teams today.

McLaren Racing pioneered the use of recycled carbon fibre (rCF) on an F1 car at the 2023 United States Grand Prix. In 2024, McLaren expanded the programme to performance parts during practice sessions at the British Grand Prix (McLaren Racing, 2025), demonstrating that rCF is advancing from proof-of-concept into race-relevant applications. Using the methodology of the F1 Constructors' Circularity Handbook, McLaren measured 37% material circularity in its F1 constructor activities in 2024 (McLaren Racing, 2025).

In May 2024, Visa Cash App RB (VCARB) introduced front wing flap components using molds consisting of 85% recycled carbon fibre at the Emilia Romagna Grand Prix, reducing production emissions by 83% compared to conventional molds. This collaboration with Herambiente — whose parent Hera Group is constructing a new CF recycling plant near the Imola circuit — represents a systemic supply chain intervention (Wilde, D., 2024).

In March 2025, Mercedes-AMG Petronas announced that the W16 would become the first Formula 1 car to use sustainable carbon fibre composites in raced parts. Working closely with the FIA and in partnership with INEOS Nitriles, Toray, Syensqo, and Sigmatex, the team qualified and applied sustainable carbon fibre composites during the 2025 season 'without sacrificing any on-track performance' (Mercedes-AMG Petronas, 2025). Toto Wolff stated: 'When you combine performance and innovation, you create progress.'

In April 2026, VCARB and Holy Technologies (Hamburg) completed an 18-month joint R&D project producing the world's first fully recyclable F1 composite component: a wing mirror housing achieving 20% weight reduction. Holy Technologies' Infinite Fibre Placement (IFP) technology uses a robotically placed single carbon fibre strand in a recyclable epoxy resin, enabling the epoxy to be separated from the fibre for reuse in the same high-performance application. The component was tested during a Grand Prix weekend, demonstrating durability under race conditions (CompositesWorld, 2026). Paolo Marabini, Chief Designer at VCARB, commented: 'It opens up the opportunity to reuse the same carbon fiber and therefore has the potential to significantly reduce the overall amount of material we use for our car components.'

These voluntary team initiatives demonstrate both technical feasibility and genuine commitment. However, the competitive logic of Formula 1 means that no team will accept a unilateral performance penalty, however small. Regulation remains the only lever to create a level playing field for sustainable materials.

3. The Role of the FIA Technical Regulations

3.1 Historical Evolution

McLaren was the first team to race a carbon composite chassis with the MP4/1 in 1981. Since then, the adoption of carbon fibre composites expanded steadily until today's near-total dominance. In the late twentieth century, regulations were more permissive: choosing a carbon fibre chassis while others raced aluminium monocoques provided a genuine competitive edge. Radical design diversity was possible — six-wheeled cars, turbocharged engines, fan cars. Over the decades, regulations have become progressively more prescriptive, for reasons ranging from safety to cost management to the facilitation of overtaking. Today the FIA publishes regulations detailing prescribed materials and laminates for specified structural areas, geometric envelopes, fuel and oil compositions, and a wide range of other parameters. This increased regulatory specificity is the mechanism through which the FIA has delivered consistent safety improvements, cost controls, and, most recently, the sustainability mandates in the 2026 power unit regulations. The same mechanism could be applied to chassis materials.

3.2 The Current 2026 Regulatory Landscape

The 2026 FIA Formula 1 Technical Regulations (Section C, Issue 19, June 2026) represent a landmark achievement in regulatory ambition. Within the power unit perimeter are the requirements for 98% Advanced Sustainable Fuel and a lap averaged 50:50 ICE/electrical power split (FIA, 2026b; Formula 1, 2026a). These are some of the most consequential sustainability mandates ever introduced in motorsport.

Outside the power unit perimeter, carbon fibre composite remains as the primary structural material for the survival cell, crash structures, suspension links, wings, floor and aerodynamic bodywork, with prescribed laminate lay-up specifications for safety-critical regions. No sustainable or recycled alternative may substitute for these materials without FIA approval and homologation test compliance (a notable exception being the Front Wing Endplate prescribed laminate, which allows the use of natural fibre composites). This is entirely appropriate: the survival cell is the last line of defence for the driver, and changes to its materials must be evidence-led and rigorously validated.

A notable piece of non-technical regulation, from 2026, requires a minimum of 55% of the car's external surface area to be covered with painted or stickered livery rather than bare carbon fibre (Autoweek, 2025). While primarily motivated by visual equity, this is the first instance of the external presentation of composite surfaces being regulated for non-performance reasons — a precedent that materially supports the proposals advanced below.

The regulations (FIA, 2026b) also allow the use of natural fibre composites and bio-derived resins. Such as in C15.2.3_b_vii, C15.5.2_b_i for the fibres and C15.2.3.a.vii ("Thermoset resins not derived from petrochemicals").

3.3 The Circularity Handbook: Building the Evidence Base for Future Regulation.

The most significant development for this paper's central argument occurred in April 2025, when the FIA commissioned the F1 Constructors' Circularity Handbook in partnership with McLaren Racing and Deloitte UK (FIA, 2025b). The Handbook provides a standardised methodology for all F1 teams to calculate a single circularity metric for their chassis manufacture, covering the inflow and outflow of materials, waste streams, and their definitions under circularity criteria.

Crucially, the Handbook was explicitly designed to 'create opportunities for future regulatory change to improve the overall sustainability of the sport' (FIA, 2025b). Nikolas Tombazis, FIA Single Seat Director, stated: 'In the longer term, our ambition is for the Handbook to be used more widely, and to influence future regulations and innovation in this space' (FIA, 2025b). Kim Wilson, Director of Sustainability at McLaren Racing, added: 'If we can encourage all teams to measure their circularity, we can collectively influence the technical regulations to improve sustainability without compromising performance' (FIA, 2025b).

To the authors' knowledge, the Handbook is not publicly available — it is distributed by the FIA directly to F1 constructors and power unit manufacturers. Using its methodology, McLaren measured 37% material circularity in its F1 constructor activities in 2024 (McLaren Racing, 2025). This is a decisive shift: the FIA has moved from general material sustainability awareness to active, evidence-based data collection. In the authors' view, this is the kind of groundwork any future materials requirement would need, and it reflects a measured, responsible approach to regulation.

4. A Concise Reference on Material Recyclability and Sustainability

This section provides a high-level overview of the recyclability and sustainability of key materials discussed in this paper. It is context for the regulatory proposals in Section 5, not an exhaustive materials science review.

4.1 Aluminium

Aluminium is 100% recyclable indefinitely, and using recycled aluminium requires only ~5% of the energy needed to produce primary aluminium. Around 75% of all aluminium ever produced remains in active use today, and recycling rates in automotive manufacturing exceed 90% (The Aluminium Association, 2021). These properties make aluminium one of the most compelling materials from a circular economy perspective.

4.2 Steel

Steel is the most recycled material in the world and is likewise 100% recyclable indefinitely. Recycled steel can save 85% of energy, 86% of GHG emissions, and 76% of water pollution compared to virgin production (University College London, 2021; American Institute of Steel Construction, 2024). High-strength steel alloys and additive-manufactured steel components are already used in F1 for specific high-load applications.

4.3 Carbon Fibre Composites

Approximately 30% of produced carbon fibre manufactured currently enters landfill (Francis, 2019). Recycled carbon fibre (rCF) offers ~90% energy and ~84% GHG emission savings compared to virgin fibre (Jacob, 2019). However, while rCF cannot yet replace virgin carbon fibre at industrial scale for primary structural load-bearing applications (Wu et al., 2022), this is an area where progress is being made (Abdi et al., 2025).

The frontier is advancing. In March 2025, Fraunhofer Institute EMI demonstrated a laser-based method to reclaim continuous carbon fibres from composite materials without diminishing material quality (Fraunhofer EMI, 2025), although this is currently only applied to filament wound components. A USC research team reported successful recovery of both carbon fibre and polymer matrix from CFRP with preserved material integrity (Univ. Southern California, 2024). A comprehensive review in Frontiers in Materials (2024) confirms that pyrolysis and chemical recycling pathways are advancing, but significant barriers remain, including energy consumption, potential fibre damage, environmental/process-efficiency issues, and the need for stronger economic viability and scale-up evidence. (Frontiers in Materials, 2024). The conclusion is not that rCF is unsuitable, but that it is improving, and that the regulatory environment should be designed to accelerate — not await — its maturation.

4.4 Natural Fibre Reinforced Composites (NFRCs)

NFRCs incorporating plant-based fibres (flax, hemp, jute, bamboo) offer a compelling eco-friendly alternative for many applications. They are biodegradable, have low energy production footprints, and can be processed using bio-based or biodegradable resin systems (Elfaleh et al., 2023; Zhang et al., 2017). A 2025 peer-reviewed review (Skosana et al., 2025) confirms NFRPCs are viable alternatives for automotive lightweighting (Mason, 2023).

In motorsport, McLaren deployed a Bcomp natural fibre composite racing seat in Formula 1 from 2021, achieving an 85% reduction in carbon footprint vs. the conventional CF seat (Butcher, 2021; McLaren Racing, 2020). In 2025, Bcomp and Porsche Motorsport deployed flax-fibre components at the Nürburgring 24 Hours, achieving equivalent stiffness and weight to carbon fibre parts, 85% lower production CO_2, and 250% better vibration damping (Bcomp, 2025). BMW, in partnership with Bcomp, has achieved series-production-ready flax composites meeting automotive crash-test requirements (Signature Products, 2025). Del Bianco (2025) evaluated hybrid carbon-flax crash boxes for automotive energy absorption (Università di Camerino, 2026). Major automotive manufacturers — Ford, Toyota, Mercedes, Audi — already deploy NFRCs in non-structural components (Elfaleh et al., 2023). Wider adoption of NFRCs in F1 components could provide useful marketing materials and therefore could further incentivise adoption within automotive industry, where the environmental benefits are significant.

4.5 Thermoplastic Matrix Systems

Thermoplastic matrices (PEEK, PA, PP) don't crosslink like epoxy: they can be remelted, reclaimed and reformed, or the whole composite can be mechanically reprocessed without a separation step. Aerospace is already moving on this basis, with CF-PEEK prepreg under active qualification. The penalties are higher processing temperatures, different tooling and expertise. The simplest reprocessing route yields short, discontinuous fibre, carrying the same structural limitation as rCF. But the principle matters for regulation: a thermoset car is one whose recyclability is fixed at the moment of cure, while matrix selection is a design decision a mandate can actually reach.

5. Proposals for More Sustainable Racing

This section proposes changes to the FIA Technical and Financial Regulations to prescribe or incentivise the use of more sustainable materials in the manufacture of Formula 1 cars. Six criteria are assessed for each proposal: Technological Viability, Economic Viability, Manufacturing and Supply Chain Viability, Impact on Sustainability, Impact on Spectacle, and Impact on Safety.

An important structural point underpins all proposals. Even those that are technically and economically straightforward will not be adopted voluntarily by competing teams, because any performance or cost penalty — however small — is competitively unacceptable when borne unilaterally. Regulatory mandates applied uniformly across all competitors are the only realistic mechanism for systematic materials change in Formula 1. The following proposals are designed with this constraint in mind.

This is not abstract reasoning. One of the present authors, while working as a composites engineer in a Formula 1 team, proposed the adoption of natural fibre composites for non-structural components before similar developments were publicly announced by McLaren Racing in partnership with Bcomp. The proposal did not progress internally, despite the materials being technically viable then as they are now. This is precisely the dynamic that uniform regulation removes: when all teams are required to adopt the same approach, no individual team carries the cost or risk of moving first.

5.1 Proposal 1 — Mandate Bio-composites for Non-Structural Components

This proposal calls for the FIA Technical Regulations to prescribe the use of natural fibre composites, bio-resins, thermoplastics or recycled materials for non-structural components including bodywork panels, radiator ducts, intake ducts, small aerodynamic fairings, and the driver seat. These components carry no primary structural loads and are not safety-critical in their material specification.

Criterion	Verdict	Assessment Notes
Technological Viability	Technically Demonstrated	Use of natural fiber composites (such as flax, hemp, linen, cotton, bamboo) is already allowed by regulations, but it is not imposed, (see C15.2.3_b_vii, C15.5.2_b_i, C15.2.3.a.vii of the Technical Regulations (FIA, 2026b)). There are number of bio-based resins that could be used as the matrix further improving the sustainability of these materials, such as biphenolic resins, bio-based epoxy resins, bio-based polyurethane (Zhang, Yuan, & Xu, 2017). Feasible with current F1 manufacturing technologies and staff. These materials present challenges due to variability in their characteristics due to the nature of the fibers and limited research currently available. McLaren raced a Bcomp flax-fibre seat in F1 from 2021 with 85% CO_2 reduction vs. conventional CF (Butcher, 2021). Bcomp/Porsche achieved equivalent stiffness and weight to CF at the 2025 Nürburgring

Criterion	Verdict	Assessment Notes
		24 Hours. BMW/Bcomp have achieved automotive crash-test qualification (Signature Products, 2025).
Economic Viability	Viable	No significant capital investment required. Existing factory infrastructure and staff can process prepreg natural fibre composites. No major material cost increase expected for non-structural components.
Manufacturing & Supply Chain	Advancing	Bcomp is active across multiple motorsport series (F1, Formula E, GT, rally). Prepreg natural fibre formats are compatible with current F1 autoclave infrastructure. Supply chain more developed than in 2023.
Impact on Sustainability	Very Positive	Up to 85% carbon footprint reduction per component vs. conventional CF (Butcher, 2021). McLaren racing claims around a 75% carbon footprint reduction when bio-composites are used in place of conventional carbon composites (McLaren Racing, 2020). Mandatory adoption accelerates industry knowledge and commercial demand for NFRCs. Uniform rule eliminates competitive penalty asymmetry. Because NFRCs have lower specific stiffness and strength than CFRPs, they would result in a mildly heavier car using more energy to accelerate than a lighter one. However, the benefit of the transferable research on these sustainable materials, the benefit of their mass advertisement to the automotive fans together with the lower costs and lower environmental footprint when compared to CFRPs would bring a positive overall impact.
Impact on Spectacle	Neutral	Weight increase per component is small relative to total car mass. Natural fibre textures may generate positive media interest. Lap time effect is imperceptible if applied uniformly, with several articles claiming around 0.03 to 0.05s average lap time increase per extra kg of car weight (F1 technical, 2018)
Impact on Safety	Neutral	Non-structural components are not safety-critical in their material specification. Natural fibres are more thermally vulnerable than carbon, but composite fire behaviour is initially matrix-dominated and FIA cockpit flammability standards apply uniformly. The Bcomp seat raced by McLaren presumably met those standards.

5.2 Proposal 2 — Prescribe Recyclable Metals for the Gearbox Structure

Formula 1 gearboxes are structural elements transferring loads between rear suspension, transmission, engine and chassis. Under the 2026 regulations, the gearbox casing is already predominantly metallic; the carbon fibre element is principally the complex structural casing (FIA 2026b).

Criterion	Verdict	Assessment Notes
Technological Viability	Viable	Metallic gearbox structures were standard until the 2000s. Also, with advancements in metallic AM, this technology could bring innovative metallic recyclable designs. AM titanium/aluminium is permitted in suspension uprights under 2026 regulations; extension to gearbox housing is a logical step. Likely slightly lower specific torsional stiffness vs. CF hybrid is the main trade-off.
Economic Viability	Viable	Existing factory metallics capability is applicable. R&D investment required for structural re-qualification, but outputs are commercially transferable to motorcycle, automotive, aerospace gearboxes and structures.
Manufacturing & Supply Chain	Viable	Casting, machining, fabrication, and ALM are all currently used for F1 metallic parts. The 2026 gearbox cassette and gears are already mainly metallic.
Impact on Sustainability	Positive	Removal of CF composites from the gearbox housing in favour of fully recyclable metals reduces end-of-life waste. R&D outputs transferable to high-performance automotive.
Impact on Spectacle	Neutral	Although the proposed components made of metallics would probably be heavier or larger than the same made of an hybrid of advanced composites and metallics, all the vehicles would experience roughly the same weight penalty. The gearbox would probably be larger than current composite ones to maintain similar stiffness characteristics, resulting in less aerodynamic freedom in the area around the diffuser and under the rear wing, probably making cars slower. The score for "spectacle" is kept neutral as this type of metallic gearbox housing were standard around 2000, and were rare, but still used by 2010 (e.g. Lotus T127 gearbox visible at https://commons.wikimedia.org/wiki/File:F1_Gearbox.jpg. The assumption is that fans are drawn to overtakes and wheel-to-wheel battles, and that a ~1s lap-time difference applied equally to every car is imperceptible in the racing and leaves the competitive order unchanged. The

Criterion	Verdict	Assessment Notes
		FIA has itself publicly prioritised close racing over absolute lap time for the 2026 cars (Woodhouse, 2023).
Impact on Safety	Neutral	The dedicated rear crash structure dissipates rear-impact energy independently of gearbox material. ALM may enable innovative load-path designs potentially with integrated crash performance.

5.3 Proposal 3 — Extend Metallic Materials including AM to Suspension Wishbones and Arms

The performance penalty of metallic suspension is small. The cultural penalty is enormous. The latter is the harder problem. This proposal will, the authors anticipate, attract a degree of measured pushback.

Before proposing change, it is worth being clear: the use of unidirectional CFRP for F1 suspension members is a textbook correct engineering application. Suspension struts are heavily loaded and have a significant impact on both vehicle dynamics and aerodynamics. For these reasons, suspensions need to be stiff and slender, allowing precise control of suspension kinematics with minimal disturbance to the surrounding aero flow structures.

The reason carbon fibre composite dominates is straightforward: specific modulus along the fibre direction. Suspension members are predominantly axially loaded and predominantly laminated from unidirectional CFRP aligned with the load line, achieving a specific modulus far greater than steel, aluminium or titanium — all three of which converge on essentially the same value (~26 GPa·cm^3/g). For a stiffness-critical, buckling-critical, slender axial member, UD CFRP wins. This is, on engineering grounds, a textbook correct application of the material.

A metallic suspension arm sized to equivalent stiffness and buckling resistance will therefore be both larger in cross-section and heavier than its CF counterpart. The penalties are twofold: increased aerodynamic blockage from the larger section, and increased unsprung mass — the latter being the more performance-significant of the two, with consequences for ride frequency, contact patch behaviour, and ultimately lap time.

A regulatory accommodation worth considering is to permit additive-manufactured aerodynamic appendices on the structural suspension member — currently constrained by the constant-cross-section rule in C10.3.6 — to recover some of the aerodynamic loss caused by the larger metallic section and naturally exploit the potentials of AM in metallic suspensions.

This would target one of the two performance penalties directly (aero blockage), drawing on the same AM titanium/aluminium provisions already permitted for suspension uprights under C15.3.3.

The unsprung mass penalty, by contrast, is intrinsic to the material substitution and would have to be accepted as a uniform competitive cost.

This proposal seeks to extend the use of metallic and metallic AM materials to suspension wishbones and load-bearing arms, which currently remain carbon fibre composite. Since the paper was first drafted in 2023, the proposal has been partially validated: the 2026 FIA Technical Regulations explicitly permit additive manufacturing of suspension uprights in titanium and aluminium alloys for the first time (C15.3.3; see also Sher 2026; AlCircle 2024).

Criterion	Verdict	Assessment Notes
Technological Viability	Actively Developing	Moving to more sustainable recyclable metals construction is certainly viable, as it is done in lower-level series and was done in Formula 1 before the current composite solution. Further, with current advancement in additive manufacturing, novel metal ALM designs could be explored as they could demonstrate an effective compromise of efficient use of materials, strength, and geometric freedom for aerodynamics and integration with the wheels systems. AM titanium/aluminium suspension uprights are permitted from 2026. Extension to wishbones is a logical next step, building on the same FIA-approved material and process specifications.
Economic Viability	Positive	Current Formula1 suspension rods and wishbones are manufactured with very expensive processes, including multiple carbon composites curing cycles, part-curing, several machining stages, multiple lamination and trimming stages, inserts and exotic resin systems. Moving to metallic structures would likely reduce manufacturing and design costs while potentially creating transferable technology for high performance commercial cars.
Manufacturing & Supply Chain	Viable	Standard metallic machining and fabrications are readily available in F1. AM titanium/aluminium supply chain has been established in F1 for years. Extending to wishbones uses the same approved processes.
Impact on Sustainability	Positive	Fully recyclable metallic components replace non-recyclable CF wishbones. Aerodynamic fairings for the wishbones can use NFRCs or recyclable polymers.
Impact on Spectacle	Neutral	Metallic wishbones, particularly additive-manufactured, can carry strong visual appeal and would generate fan and media interest. AM designs enable

Criterion	Verdict	Assessment Notes
		novel geometries that reinforce the sport's innovation narrative, and the regulatory accommodation proposed — permitting AM aerodynamic appendices such as winglets or brake duct elements integrated with the structural member — would create a visible, distinctive design space currently absent from the cars. CFRP wishbones, by contrast, are impressive but visually familiar after three decades of use. The aerodynamic penalty from the larger metallic section, applied uniformly across all teams, would have a small absolute effect on lap time and no effect on competitive order.
Impact on Safety	Mildly Positive	Notable CF suspension failures have occurred in F1, including Magnussen (2023) and Kvyat (2016), reflecting the brittle failure mode characteristic of carbon fibre composites under overload. Metals, by contrast, yield and undergo progressive plastic deformation before fracture, absorbing energy and providing visible warning of impending failure. Metallic structures are also better understood from a fatigue and damage-tolerance standpoint, with mature analytical and inspection methods developed over decades of industry practice. The existing anti-intrusion layers in the survival cell remain fully effective regardless of suspension material choice. Fatigue and damage characterisation of additively manufactured metallic structures is an actively advancing research area, and the learning generated through F1 application would transfer directly to automotive, aerospace and other high-performance sectors where AM metallics are entering structural service.

5.4 Proposal 4 — Ban Non-Sustainable Composites for Fluid Piping

A number of F1 teams use carbon fibre composite tubing for certain oil and water pipes, seeking weight savings. Standard industry practice — and the practice in all road cars — is to use aluminium, steel, or polymer piping for fluid-carrying lines.

Criterion	Verdict	Assessment Notes
Technological Viability	Viable	Aluminium fabrication for fluid lines is entirely standard. Polymer alternatives are well established. Immediately available. If sustainable composites are used, such as bio-derived composites, more research needs to be carried out and may result in heavier/thicker laminates.
Economic Viability	Positive	Standard metal pipes are cheaper than CF composite equivalents. Established supplier ecosystem.

Criterion	Verdict	Assessment Notes
Manufacturing & Supply Chain	Viable	Standard fabrication methods. No supply chain development needed. If NFRC are used, same set up as CFRP.
Impact on Sustainability	Mildly Positive	Eliminates CF composite use in a component category where little performance justification exists. Minor but costless sustainability gain.
Impact on Spectacle	Neutral	Components are hidden behind bodywork. No visible change.
Impact on Safety	Neutral	Metal and polymer pipes are the global standard for fluid-carrying lines.

5.5 A note on tyres

Tyres are deliberately excluded from the scope of this paper. They are notoriously difficult to recycle, and a regulatory shift toward longer-life or reusable tyre constructions would in principle deliver a substantial sustainability gain — tyres are one of the largest single waste streams associated with the sport.

Two considerations argue against making tyres a target of this paper.

First, tyre changes are deeply embedded in the car performance, and in the sport's strategic and visual identity. The pit stop is iconic; tyre degradation drives much of the strategic variation that makes races interesting. Removing or substantially reducing tyre changes would alter the texture of the sport in a way that materials reform of the chassis does not.

Second, the relationship between teams, the sole tyre supplier, and the sport's commercial structure makes tyre regulation a different kind of problem from chassis materials regulation — closer to a commercial negotiation than a technical drafting exercise.

Tyre sustainability is therefore worth pursuing — but as a separate workstream, on a different timeline, with different stakeholders, and through different regulatory instruments than the chassis materials proposals advanced here.

5.6 Final notes on these proposals

The spirit of these proposals should extend beyond the specific cases above to the wider population of components currently produced in carbon fibre composite for marginal gains rather than genuine performance need. Small wiring brackets, electronics enclosures, mounting plates, interface fittings and similar non-structural details often use composite construction for geometric flexibility rather than mechanical optimisation — sized to a sensible minimum thickness for sturdiness or to interface with connector envelopes, not to extract every gram of mass at every load path via FEA optimisation. These are precisely the components where a regulatory mandate to use recyclable metals or sustainable composites (rCF, NFRC etc.) carries no meaningful performance cost and a clear sustainability benefit.

It is important to be explicit about what these proposals are not. They are not an attempt to slow Formula 1 down, dampen its competitive edge, or compromise the spectacle that makes the sport what it is. The opposite: they identify the specific component categories where sustainability gains can be made without eroding the speed, drama, or technical theatre that 826 million fans tune in for. Formula 1 is the pinnacle of motorsport precisely because marginal gains routinely separate winning from losing — and that competitive logic is exactly why uniform regulation is the only viable mechanism. No team will voluntarily accept even a marginal penalty in pursuit of sustainability; all teams can accept it if the penalty is shared equally.

Beyond the regulatory mechanics, F1's deeper strength is its capacity to inspire. The sport has, for decades, drawn generations of engineers, designers and scientists into careers in aerospace, automotive, materials and software — not because the sport directly trains them, but because it shows them what is possible at the limits of human and technical performance. A Formula 1 that visibly leads on sustainable materials would not just generate transferable engineering knowledge; it would shift the aspirational benchmark for an entire generation of engineering students, hobbyist designers and industry practitioners who follow the sport closely. The downstream effect on automotive, aerospace and consumer industries — through both supply chain development and the cultural pull F1 exerts on technical communities — would dwarf the direct environmental impact within the paddock itself.

This is the prize. Not a slower, duller Formula 1, but a faster, sharper, more relevant Formula 1 whose innovation narrative includes the materials of the car alongside its power unit and aerodynamics.

6. Technology Transfer to the Automotive Sector

Formula 1 has a distinguished track record of transferring performance innovations to the commercial automotive sector. Turbocharged engines, semi-automatic gearboxes, regenerative braking systems, active suspension concepts, advanced aerodynamic profiling and of course Composites in general all have roots in Formula 1 development. The technology transfer argument for sustainable materials deserves the same serious consideration.

As Savage (2009) observed, the F1 monocoque is ‘more like a jet fighter aircraft cockpit, both in terms of shape and construction, than anything one would expect to find on the road.’ This observation carries a subtle but important implication: because current F1 composite technology is NOT transferable to commercial automotive volume production — owing to highly specialised, manual, low-volume manufacturing methods — mandating more accessible sustainable alternatives would produce technology that IS scalable to automotive. Bio-composites and recyclable CF composites tend toward processes that can be industrialised: press-forming, automated lay-up, and standardised prepreg systems that commercial manufacturers can adopt.

Mercedes-AMG Petronas explicitly stated that its W16 sustainable composites programme provides ‘a significant opportunity to scale this innovation beyond motorsport, to industries such as aviation and aerospace’ (INEOS / Mercedes-AMG Petronas, 2025). The supply chain development required to produce sustainable CF composites to F1’s demanding specifications creates capabilities and supplier ecosystems that serve the broader advanced manufacturing sector.

The market context supports this argument. The global recycled carbon fibre market was valued at approximately USD 500 million in 2024 and is projected to grow at ~15% CAGR to USD 1.8 billion by 2033 (DataInsights Market, 2025). EU regulatory pressure is creating demand-side pull. F1 mandates for rCF or sustainable CF composites would provide a high-profile supply-side stimulus. Bcomp’s natural fibre composite supply chain has expanded from motorsport origins into BMW, Volvo, Porsche, and Škoda Motorsport partnerships, demonstrating the commercial multiplier effect of motorsport-originated sustainable materials innovation (Bcomp, 2025; Signature Products, 2025).

The FIA’s own mission includes ‘driving innovation’ and ‘championing safety, sustainability and equality across motor sport and mobility (FIA, 2025b). In the authors' view, regulation of this kind would serve both objectives: it drives genuine materials innovation in the world’s most technically demanding racing environment, and it creates sustainability benefits that extend well beyond the paddock. As has already been acknowledged above, the environmental impact of these changes in only the F1 arena is small. However, leveraging the benefit of F1 R&D and adoption into such technologies could usefully accelerate use in volume automotive production, which would provide very significant environmental benefits globally.

7. Notes for the Regulator and a Research Agenda

7.1 Acknowledgement and Collaborative Framing

This paper is offered as a constructive contribution to a conversation that the FIA, Formula 1 management, and teams have already begun. It is important to acknowledge the extraordinary breadth and quality of work delivered by the FIA and the Formula 1 ecosystem in recent years.

On safety, the FIA has overseen one of the most successful safety engineering programmes in any sport. The progressive reinforcement of the survival cell from a carbon composite monocoque to a multi-layered structure with Zylon reinforcement, the mandatory Halo structure introduced in 2018 — widely credited with saving multiple lives — and continuous improvements to circuit safety and medical infrastructure have transformed Formula 1 from one of the world's most dangerous sports into one of the safest forms of high-speed competition (Noble, 2022).

On sustainability, the record is equally impressive. The 2026 regulatory framework's mandates — >98% Advanced Sustainable Fuel, lap averaged 50:50 power split — represent genuine structural change. The commissioning of the F1 Constructors' Circularity Handbook, providing a standardised methodology for all teams to measure their materials circularity: Gather the data first, then consider where regulation can add value. Stefano Domenicali's commitment to net-zero by 2030 is backed by verified, independently tracked emissions data (Formula 1, 2025).

On competitive spectacle, the 2026 regulations — with active aerodynamics, radically revised power unit, smaller and lighter cars, and revised overtaking philosophy — represent the FIA's boldest attempt in decades to make Formula 1 closer, more dynamic, and more engaging. These changes were developed through extensive consultation with teams, drivers, and commercial rights holders.

Against this backdrop, the absence of a chassis/bodywork materials sustainability mandate is not a failure — it is the next frontier. The Circularity Handbook is building the evidence base. The team initiatives described in Section 2 are demonstrating technical feasibility. The proposals in this paper are offered to inform the next step in a process the sport has already begun.

7.2 Implementation Framework Options

Three complementary regulatory mechanisms are suggested here; each addressing a different aspect of the adoption challenge. Used together, they form a mutually reinforcing framework.

Prescriptive Component Mandates

The most direct mechanism: prohibit virgin petrochemical composites for specified component categories. Administratively straightforward — the 2026 regulations already *permit* natural fibre composites and bio-derived resins in several clauses; a mandate requires only that "permitted" becomes "required" for defined applications. Best suited to non-structural components where sustainable alternatives are already technically mature, as in Proposals 1 and 4. The FIA's established practice of validating sustainability mandates in the feeder series before F1 — as with sustainable fuel — suggests a natural sequencing model.

Sustainability Carve-Out in the Financial Regulations

Under the current cost cap, sustainability R&D competes directly with performance development — a competition it will lose every season. A ring-fenced allowance, separate from the main cap and linked to verified milestones, removes this barrier without distorting competition. It funds the development that the other two mechanisms demand.

Virgin Composite Allocation (VCA)

Each constructor receives a seasonal budget of virgin petrochemical-derived composite. Sustainable alternatives — rCF, natural fibre composites, certified bio-resin systems or metallics — do not count against it. The allocation reduces on a published multi-year roadmap, giving teams planning horizon to develop supply chains and qualify materials.

The VCA harnesses Formula 1's competitive logic directly: It makes virgin composite a scarce commodity which must be used to best advantage over the season. Teams can invest privately in advancing recycled fibre quality and application because doing so confers a direct performance advantage. "Use less virgin petrochemical composite" is a simple, auditable metric that is difficult to misconstrue or greenwash.

As discussed above, the capability of sustainable composites doesn't currently support application to safety critical components currently, and so regulation must ensure that safety is not compromised by the VCA. Careful stakeholder consideration will also be required for example considering how the VCA is policed, and how materials are qualified as 'sustainable'.

The Circularity Handbook provides the foundational measurement infrastructure. McLaren's 37% circularity score for 2024 demonstrates that the data collection is already underway.

A Question Worth Adding

Should the FIA publish team circularity scores publicly? The risk of not doing so is obvious: Closed culture, lack of scrutiny and inevitably working to the letter of the guidance, rather than the spirit of making sustainable progress for the wider good. Publishing risks gaming an over-simplified metric: narrow optimisation. Both of these scenarios risk the appearance of virtue without substance and subsequent loss of public trust, accusation of greenwashing, and reduced transferable value.

The Circularity Handbook creates a standardised measurement methodology. McLaren has voluntarily published its score (37% for 2024). If that data were published across all constructors — not as a points-scoring system, but as transparent public information — it would create a form of soft-power pressure that complements formal regulation rather than replacing it.

The precedent exists in other domains: fuel efficiency labelling, ESG disclosure, product carbon footprint ratings. All of them influence behaviour. In a sport whose commercial value depends significantly on public perception, the prospect of a team appearing at the bottom of a published circularity league table may be a more immediate and regulation effective incentive than a regulatory penalty scheduled for 2028. It needs care is structuring, but it could provide holistic feedback to 'do the right thing' that regulation find difficult or impossible to control or encourage.

How the Three Mechanisms Reinforce Each Other

Prescriptive mandates force immediate adoption in tractable areas, generating supply chain depth and manufacturing experience. The financial carve-out funds R&D into more demanding applications without penalising teams for investing in materials that are not yet performance-equivalent. The VCA then gives teams a direct competitive return on that R&D investment: improvements in sustainable material performance translate immediately into allocation efficiency and therefore on-track advantage. Together, they convert sustainability from an 'inconvenient' cost centre into a competitive lever — which is the strongest basis on which lasting change occurs in Formula 1. The balance of the three mechanisms can be altered over time to ensure the trajectory is agreeable. A road map for these changes will likely be required so that the teams have sufficient notice to plan their technology programmes.

8. Summary and Conclusions

This paper has argued that the logical next step in Formula 1's sustainability journey is to address the structural materials challenge. Carbon fibre composites dominate F1 car construction. While the 2026 FIA Technical Regulations prescribe specific laminates for safety-critical structures — the survival cell, secondary roll structure fairings, and the floor and bib anti-splinter layers — the broader use of CFRP across suspension and bodywork is a consequence of permissive material rules combined with the sport's competitive logic, rather than direct mandate. Despite the ambitious sustainability provisions of the 2026 power unit regulations, no equivalent sustainability dimension applies to these components.

The evidence base for sustainable composites being a viable technology for F1 has strengthened considerably in only a few years. Mercedes-AMG Petronas has demonstrated

30% bioresin composites can perform to F1's demanding structural requirements (W16, 202). VCARB and Holy Technologies have produced the world's first fully recyclable, and recycled, F1 composite component (Composites World, 2026). Bcomp's natural fibre composites have been deployed in Formula 1 and have reached series-production automotive qualification. Recycled carbon fibre is being used for production parts and molds by McLaren and VCARB. The Fraunhofer EMI's laser recycling method (2025) is advancing the technical frontier for rCF quality. The global recycled CF market is growing at ~15% CAGR.

All of this activity reinforces, rather than undermines, the paper's central thesis: the technology is available; regulation is required to encourage its adoption and further development by teams.

The most important single development since this article was first drafted in 2023 is the FIA Constructors' Circularity Handbook (April 2025). The sport is not standing still — it is building the foundation for the next step.

The proposals outlined in this paper remain relevant. Proposal 1 (natural fibre composites for non-structural components) is the most actionable in the near term, with the strongest supply chain maturity and the lowest performance risk. Proposal 3 (extending metallics to suspension wishbones) is conventional in motorsports and for AM it is partially validated by the 2026 upright regulations and represents the most natural evolutionary next step. Proposals at chapter 7.2 address the structural barrier identified by teams themselves and would unlock investment that the current cost cap prevents.

The competitive logic of Formula 1 is immutable: no team will voluntarily accept a unilateral performance penalty, however small, in the pursuit of sustainability objectives. This is not a failure of values — it is the nature of a sport whose defining objective is to be faster than the competitor. Regulation, applied uniformly, is the only lever that creates a level playing field for sustainable materials. The FIA has demonstrated that it has the institutional capability and willingness to use regulation as a lever for sustainability.

The authors propose the 2028+ regulation cycle as the natural window for introducing the first chassis/bodywork materials-sustainability mandates, building on the Circularity Handbook baseline data and the technical demonstrations already completed by leading teams.

This paper is offered as a contribution to that process: not as a critique of where the sport is, but as an evidence-based argument for where it can go next.

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