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Thermodynamic evaluation of 2026 Power Unit technical regulation changes in Formula 1

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Abstract. Federation Internationale de l'Automobile (FIA) has announced a Power Unit (PU) Regulation change for its Formula 1 (F1) Championship that will become valid from the 2026 season in pursuit of carbon neutralization and a higher commercial value. The change includes a full switch to sustainable fuel and an increase in the power of the electric power output to the car's axles but removed energy retrieving and recovery from the turbocharger. The choice to use fully sustainable fuel will lead to a richer burn. On the other hand, the increase in the hybrid system capacity will outweigh the removal of energy retrieving and recovering from the turbocharger and cause an overall increase in thermal efficiency. Also, the changes are bringing a cost reduction for PU suppliers, which is an attraction for them. The increase in electric power will also integrate the car with new driving characteristics. This paper focuses on respective reviews of the 2023 and 2026 F1 PU Technical Regulations and gives an evaluation of the process for the improvements.

Keywords: formula 1, motorsport, hybrid vehicles, internal combustion engine, thermos-dynamics

1. Introduction

Formula 1 (F1) has been at the pinnacle of world motorsport ever since its establishment in 1950, with the support of some of the world's most advanced engines. Between 1905 and 2005, the phenomenon was displayed at its best as the championship used 3.0 L engines with up to 12 cylinders. However, as carbon neutralization is becoming critical for the destiny of the entire mankind, the sport must make compromises in terms of Federation Internationale de l'Automobile (FIA) to F1 in 2009 in the form of a Kinetic Energy Recovery System (KERS) to provide the cars with time-limited boosts and was enhanced in the 2014 regulation changes to become a component functioning during all track time [1]. 2026 electric power will account for 50% of an F1 car's total output [2]. The previous acts significantly improved the environmental friendliness of the sport [1]. Yet, due to its sheer scale, doubts over the upcoming 2026 regulation changes still stand, questioning if it will make F1 Power Units (PUs) more efficient. This paper mainly focuses on the thermodynamic influence of the 2026 changes based on the recently published *Formula 1 Power Unit Technical Regulations 2026* to predict their effects on the sport.

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2. Overview of F1's 2023 PU technical regulations

Cars competing in FIA F1 World Championship 2023 are required to be powered by PUs consisting of the Internal Combustion Engine (ICE) together with the turbocharger (TC) and the Energy Recovery System (ERS) [3]. The latter is the assembly of the Energy Store (ES), the Kinetic Motor Generator Unit (MGU-K) and the Heat Motor Generator Unit (MGU-H) [3]. The MGU-K is an electric motor mechanically connected to the car's drivetrain, whereas the MGU-H is an electric motor mechanically connected to the TC [3]. On the other hand, the ES is a high-performance battery assembly installed in the car [3]. The energy flow between these components is regulated, as shown in Figure 1.

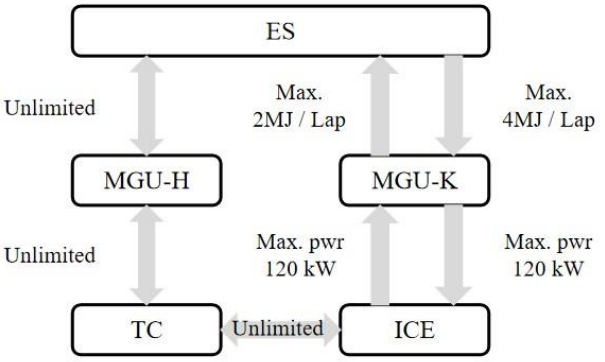

Figure 1. 2023 F1 PU energy flow limitations [3].

2.1. ICE and fuel

ICEs used to power 2023 F1 cars are 4-stroke 1600cc petrol engines, with 6 cylinders arranged in a 90 degrees "V" configuration [3]. Each cylinder must have a circular cross-section and a diameter of 80mm [3]. Each cylinder requires two inlets and two exhaust valves [3]. The fuel they run is required to meet Table 1 and Table 2 standards. In addition, the fuel must contain at least 10% sustainable bio-ethanol [3].

The fuel flow injected into the engine is restricted as well. The fuel mass flow is obligated to stay below 100 kg per hour at all times. The limitation is revving-speed dependent as well, as the fuel mass flow must not exceed 0.09 * N (RPM) +5.5 b) [3].

2.2. ERS

The ERS on 2023 F1 cars has to feature a working voltage of no more than 1000 volts, with which the MGU-H can produce up to 120 kW of power according to the regulations. Also, the ES must not store more than 4 MJ of energy whenever the car is on track, defined by the difference between the ES's maximum State of Charge (SoC) and the minimum value [3]. For safety reasons, the system shuts down under the command of a FIA-homologated ECU [3].

Table 1. 2023 Requirements for fuel properties.

Property	Units	Minimal value	Maximal value
Anti-Knock Index		87	
Oxygen (O)	mass percentage	3.45	
Nitrogen (N)	mg kg^{-1}		500
Benzene	mass percentage		1
DVPE	kPa	45	68

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Table 1. (continued).

Oxidation Stability	minutes	360	
Electrical conductivity	pS m^{-1}	200	
Final Boiling Point	°C		210
Distillation Residue	volume percentage		2

Table 2. 2023 Requirements for fuel composition (in GCMS test method).

Components	Maximal mass percentage
Aromatics	40
Olefins	17
Total di-olefins	0.1
Total styrene and alkyl derivatives	0.1

3. Overview of F1's 2026 PU technical regulations

In 2026, F1 PUs, not considering controlling components, will still be a combination of turbocharged ICE and ERS, and the ERS will consist of MGU-H and ES only [2]. The energy flow will be shown in Figure 2.

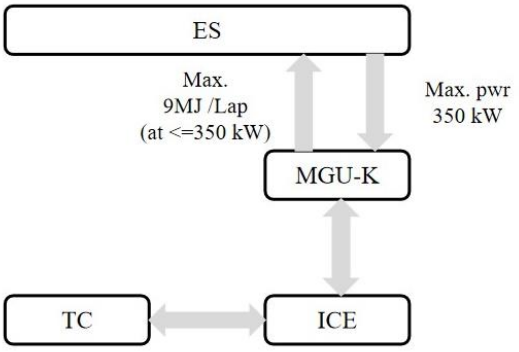

Figure 2. 2026 F1 PU energy flow limitations [2].

3.1. ICE

The requirements for the ICE remain largely the same as the 2023 ones in 2026, with the restriction for cylinder bore diameter deleted [2]. The new requirements for fuel, which is getting fully retrieved from biological, sustainable sources that encourage the practice of carbon neutralization, will be listed in Table 3 [2]. To be noted, the requirements for fuel components remain the same in Table 2 [2].

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Table 3. 2026 Requirements for fuel properties

Property	Units	Minimal Value	Maximal Value
Research Octane No.		95.0	102.0
Sensitivity (RON-MON)			15.0
LHV	MJ kg^{-1}	38.0	41.0
Density at 15 °C	kg m^{-3}	720.0	785.0
Methanol	volume percentage		3.0
Oxygen	weight percentage	6.70	7.10
Nitrogen	mg kg^{-1}		500
Benzene	weight percentage		1
DVPE	kPa	45	68
Oxidation Stability	minutes	360	
Sulfur	mg kg^{-1}		10
Electrical conductivity	pS m^{-1}	200	

The fuel injection limitations of the 2026 PUs will face a significant change. Different from the 2023 regulations governing the fuel mass flow into the engine, 2026 engines only need to satisfy the limitation of a fuel energy flow of no more than 3000 MJ per hour [2]. On the other hand, the revving-speed dependent limit is 0.27 * RPM + 165 MJ h^{-1} [2].

3.2. ERS

The 2026 F1 race cars are seeing a huge increase in ERS capacity despite the prohibition of MGU-H [2]. The system will now account for half of the PU's total energy output at a nearly tripled power of 350 kW (compared to 2023 ERSs), and the maximum energy to be charged into the ES has been increased from 2 MJ to 9 MJ, whereas the delta SoC limit for the ES remains at 4 MJ.

4. Possible thermodynamic effects of the changes

4.1. Modification of fuel injection limitations

As described in Part 2.2 and Part 2.3 of this paper, the fuel flow in 2026 F1 PUs will be limited by the energy it contains rather than their mass of it. Combined with the new fuel composition, the change might cause the combustion characteristic of 2026 PUs to differ from 2023 ones. The heat value of biofuel for 2026 cars, estimated with ethanol (around 27 MJ kg-1), is generally lower than that of traditional petrol (44 to 46 MJ kg^{-1}). As a result, for similar energy provided by the fuel, approx. One hundred ten kilograms of fuel need to be injected into the cylinders of 2026 F1 ICEs that still have a displacement of 1600 cc. Leading to a richer burn and, thus, a lower learning temperature due to a decrease in the contact area between fuel and air. This consequently leads to a decrease in the generation of NOx, a major pollutant for all internal combustion engines, and almost directly a fall in power [4].

Also, as the heat value of the fuel is no longer important, the change implies the possibility of using oxygen solutions to further increase the quantity of oxidizer taken into ICE cylinders, thus increasing the maximum power.

4.2. Removal of MGU-H and the development of MGU-K

According to previous statistics at the F1 2014 Italy Grand Prix, 2014 MGU-Hs output powers of around 12 kW and 67 kW, respectively, at the revving speed of 50 krpm and 110 krpm [5]. The data of 2023 F1 power units is not currently available for retrieving. Yet, due to a rather small difference in PU technical regulations and the fact that all F1 PU suppliers have been updating their engines over the period between 2014 and 2023, it can be inferred that MGU-Hs in 2023 F1 cars are likely to have a similar or slightly higher power than their 2014 predecessors. The removal of the unit will significantly lose the

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competence to restore and recover the energy of 2026 F1 cars.

To compensate for this negative thermodynamic effect, FIA has increased the capacity of 2026 MGU-Ks to 350 kW and the maximum energy regeneration per lap to 9 MJ [2]. An F1 Monaco Grand Prix 2018 dataset, where cars participated with PUs similar to those under 2023 regulations, showed that the total braking energy was 9.77 MJ throughout a 1:15.000 lap [6]. The event occurred at Monaco Street Circuit, a 3.377 km circuit with 43% full-throttle length throughout the track [6,7]. The maximum speed during the event is 293 kph [6]. These statistics imply that the track has rather low-energy characteristics. Hence, under most circumstances, the 9 MJ limit of the MGU-K regeneration power be fully used. Combined with its much higher power compared to 2023 MGU-Hs, the Increase of MGU-K capacity will be a valid compensation for the removal of MGU-H by outweighing the impact of it.

5. Other key effects

5.1. Cost

Developing TCs and MGU-Ks from the ground is troubling for F1 PU suppliers. This fact is apparent in the performance of the 2015 Honda Power Units, which were highly unreliable due to the overheating TCs and MGU-Ks. This caused several “Did Not Finish” situations (DNFs) for Honda’s major customer back then, McLaren [8]. The high cost of refining these devices eventually caused Honda’s retirement from F1 after season 2021 [9]. Therefore, the removal of this problematic PU component is an attraction for new competitors in F1, such as Audi and Porsche [10].

5.2. Commercial value

The sales of hybrid vehicles in the United States have seen a drastic 29% increase in 2021 [11]. The electrification trend in the transport industry has been unstoppable in recent years. Most hybrid vehicles today have their electric motors mechanically connected to their drive axles, similar to how MGU-Ks do on F1 cars [2]. This implies that the focus change to MGU-Ks on F1 PUs could potentially promote the application of F1 technologies on-road vehicles.

5.3. Maneuvering characteristics of the cars

In 2026, the MGU-K will account for more of the total power output of an F1 car, significantly increasing its influence on the car. Electric motors have the nature of putting out maximum torque at zero revving speed. In other words, 2026 F1 PUs will significantly increase low-speed torque output. This increase might lead to a higher chance of spinning since high torque at low speed puts much pressure on the car's rear tires, causing them to lose grip easily. Under this circumstance, the drivers lose most control over the car. In actual racing, the fact makes exiting the corners much trickier for the drivers.

6. Conclusion

The 2026 Power Unit regulation changes in F1 have a good chance to positively influence the sport in various aspects. The direct impact of fuel change is emission characteristics that involve less carbon dioxide emissions. Besides, due to a higher fuel-air ratio, the combustion in 2026 F1 engines occurs under lower temperatures, indicating less generation of nitrogen oxides and a certain extent of power reduction. The development of MGU-K will outweigh the removal of MGU-H, leading to an overall increase in thermal efficiency. The removal of MGU-H, per contra, could reduce the research and development costs of PU Suppliers and accelerate the implementation of technologies from F1 vehicles on road-going consumer vehicles. The change could even test the drivers’ skills further by increasing the low-speed torque output of the PUs. In summary, the 2026 PU regulation changes in F1 will boost the accomplishment of the sport’s “NET ZERO 2030” goal and its fuse into an era of electrification. It can be further deduced that with the trend of electrification being unstoppable and the status quo that F1 is becoming increasingly commercialized, F1 will continue to develop with PU regulations that inherit the nature of the ones being valid since the 2026 season, that introduce more electric power to the PUs. F1 will have a more electric and sustainable future.

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