



Formula One 2011: Power-Train Regulation Framework

*A Briefing Note for the Formula One Manufacturer s'
Advisory Committee*

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BMW Group
Ferrari
Ford Motor Company
Honda Motor Company
Mercedes
Renault
Toyota
VW-Audi Group

**NOTE: PRELIMINARY DOCUMENT – CHANGE MAY OCCUR DUE TO
ONGOING DISCUSSIONS WITH THE MANUFACTURERS AND SIMULATION
WORK BY RICARDO**

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F1 Engine Representatives, Barcelona, 13th May

A note on procedure

During the first six months of 2007 the FIA have visited manufacturers active today in Formula One to garner views on regulation change for 2011 when the present power-train regulations expire.

An exploratory note [*Initial Thoughts on Formula One Regulation for 2011 and Beyond, v 1.5, March 8th 2007*] has been circulated and feedback assimilated.

The FIA are working with the automotive consultancy Ricardo to run simulations and to review strategy in the light of their experience working in mainstream automotive R&D. This work is ongoing and this document will be updated in the light of results from this work.

This document summarizes a framework for the 2011 power-train regulations. To convert this framework into a set of hard proposals to be set before the FIA World Council, a number of open issues need to be clarified. These are highlighted herein and the object of the meetings currently under way is to discuss these with the manufacturers in order to close as many issues as is possible. This document can then be upgraded into a formal proposal for further review. A Power-train Working Group will be formed to assist the FIA in detailing the technical regulations that stem from these proposals. The objective is to complete the 2011 technical regulations before the end of 2007.

When this is complete and a way forward clarified, a similar briefing note will be prepared outlining the principles of the remaining (bodywork/chassis/sporting) regulations.

2011 FIA Formula One Regulation

Top Level Principles and Framework

Executive Summary

There are two principal reasons for change: (1) The need to create a healthier commercial outlook for participants by lowering their costs; and (2) the need to react to public concern about the environment.

The FIA will use future regulations to reduce the effective cost of participation in Formula One:

Research and development relevant only to Formula One will be discouraged, whereas that which has relevance to road car development will be encouraged.

New technologies in Formula One will come from the mainstream R&D of major manufacturers. The result will be a justifiable and mutually beneficial way to fund the main development challenge of Formula One participation.

Combining the need to change with the policy adopted leads to objectives which appear to have broad support among the participant manufacturers:

- Energy efficient power-train development will be overtly encouraged
- Development outside the power-train will be severely constrained
- Waste will be reduced by an increased requirement for longevity of components

This strategy now needs to evolve. How far should the FIA go on each point? The main constraint will be to avoid damage to the emotional attraction of Formula One for its fan base. In particular the technical awe of Formula One and its sheer speed must be retained. Step one is to develop a framework for the regulations aimed at fixing the power-train. Such a framework is put forward, but at each stage guidance is sought from the manufacturers. A detailed proposal can be drawn up quickly once these points are decided upon.

This paper focuses on the 2011 power-train regulations only, but lists implications for the chassis, bodywork and sporting rules. Today the power-train is the determining step and must be decided before the remaining regulations can be detailed.

Overview of Power-Train Regulation Framework and Key Decisions Required

In summary, the framework and its discussion points are as follows:

1. The energy (KJ) available from the fuel for each race is to be 30%¹ less than 2010 levels. This will be achieved through ~20% reduction from today's nominal ~560KW (770PS) to ~450KW for the primary power plant and ~10% improvement in overall power train efficiency.
2. Consensus directs restriction to just 'gas station available' fuel with a sizeable 'bio' constituent. This will be a prescribed gasoline² / 10% bio sourced mix, similar to that proposed by the EU and agreed for widespread use throughout Europe in 2020.
3. The primary power plant is to be a V6, 2.2 litre, 4-poppet valves per cylinder, circular reciprocating piston engine restricted to a maximum energy flow rate. The injection system is free other than a restriction of 500 bar injection pressure. On agreement of the general principles regarding the power-train, the manufacturers will be consulted via a Power-train Working Group on a second level of restrictions aimed at avoiding unnecessary spending. In particular, suggestions will be invited for material and weight restrictions, together with ideas for parts or sub-systems that might come from one FIA-tendered supplier.

Discussion Point: Are further restrictions necessary? Is the suggested process the right one? In particular, the FIA wish to ban any developments that might make the power plant F1 specific, such as metal matrix blocks or peripheral gas turbine generators.

4. A set maximum energy flow rate of fuel will determine the power supplied by the primary power plant. This will be incremented by additional 'assist' power fuelled by recovered energy (kinetic and thermal) to a level unlikely to exceed today's nominal 560KW (~770PS). It is expected, but not compulsory, that manufacturers will obtain at least the first 50KW of this through turbo-compounding. The remaining 60KW (approximate maximum average achievable per lap) of 'assist' power will come by means of energy recovery from kinetic and thermal sources.
5. Energy recovery: Consensus is that this should not be technology-limited, but limited by maximum energy flow rates (power) in and out of an energy store. The FIA propose a maximum 2.5MJ energy store with maximum rates of 200 KW input; and 200 KW output total (this maybe configured as 100KW to and from each of the front and the rear wheels). The assist power may only be coupled to the wheels via front and / or rear differentials. The manufacturers' opinion will be sought as to whether this should be limited to electrically-based technologies and a clarification in this respect will be made once this exercise is complete.

Discussion Point: If the output of assist power (outside the turbo-compounding) is limited to about 60KW, this will eventually be able to increase the primary power for most, if not all of the lap, as the energy recovery systems improve. If the output is raised to the maximum allowable 200KW, assist power can only be used in short bursts, so this will become a strategic element for overtaking.

¹ 30% is at present the nominal target, but is subject to confirmation pending simulation work by Ricardo and others. The aim is to make this a real challenge, but not an unachievable goal.

² Here we mean gasoline as defined by the present FIA F1 regulations, i.e. 'pump' fuel wholly derived from fossil fuels.

6. Regulation period: Consensus is for a four year period of stability, but within this, gradual change may be made.

Discussion Point: The FIA propose an annual reduction in energy quota per race of 2.5%³ starting in 2012, resulting in a 37.5% saving in fuel compared to 2010 for the 2014 season. If energy flow is not reduced in this manner, vehicles will just get continuously faster as efficiency improves. This is in line with improvement targets of proposed EU legislation.

7. Patents: The degree of invention that will be brought to bear, driven by these regulations will be considerable. To avoid distortion of the competition, patented technology may only be used if the owner is prepared to license it for use in F1 without charge.

Once the power-train regulation is decided upon, the rest of the regulations fall into place (although with a number of consequential decisions still required), guided by the outlined strategy. These will be the subject of future meetings.

The manufacturers should consider the following implications of this initiative for a new energy-restricted formula in 2011:

The consequences of an energy-restricted regulation are:

- The rpm of the engines will be dramatically reduced and the sound of the cars will be different, but not necessarily unappealing to fans.
- The whole power-train will need to be considered as one system, thus relatively unconstrained electronic controls are necessary. Electronic control hardware will be based on production, or production intent controllers and operating systems, but the software algorithms will be unrestricted, except for driver aids.

The consequences of road-relevant regulations are:

- The challenge for the power-train design engineers will have a high degree of overlap with the challenge to design road car engines.
- Space must be mandated so that aerodynamic considerations are not a major restriction for the designers.
- Minimum weight must be raised a little so that energy recovery devices are not unduly constrained by weight considerations, but not so much that present sub-systems such as brakes, suspension, and tyres would need to be designed in any substantially different way from today.⁴ Weight is also a safety issue as circuit safety features are energy-limited.
- Development of electronic controls will be a fundamental ingredient, but driver controls will be banned as far as is practicable. Mechanical brakes may not be electronically (or otherwise) modulated.

Discussion Point: power-train optimization will demand sophisticated control systems. The energy recovery and assist systems will need to modulate both input and output, so it may not be practical to ban brake balance and perhaps traction controls. What is the manufacturers' position on the limits that should be applied to the electronic controls?

³ As with the initial 30%, this is subject to adjustment pending simulation work by Ricardo.

⁴ Weight is never desirable on a road or race car so this increase will be kept to an absolute minimum.

The consequences of halting Formula One-specific power-train development within the Teams, in order to lower their costs are:

- A Sporting Regulation will be required to enable independent teams to purchase complete power-train packages at the marginal cost of reproduction. Manufacturers must supply one team if asked to do so, but need not supply more, unless a stage is reached where there are less than six manufacturers participating.
- A degree of restriction over time will be introduced as the technical solutions begin to mature.

Discussion Point: A sequence of development followed by homologation is proposed for the entire power-train. The advanced notice of the new regulations allows the whole power-train to be subject to annual homologation, this to include the first year of competition. Given the requirement for continuing efficiency development, the FIA working with the PWG will set allowable areas of development for the power-train for each new homologation period with at least 24 months notice.

The consequences of regulations that reduce waste are:

- Longer life (five race weekend) power-trains. This likely to drive a move to lower piston speeds, closer to performance road car extremes.
Discussion Point: The FIA suggest that the energy store used for the 'assist' power be exempt from this to allow intense and unrestricted energy store (battery / super-capacitor⁵) development.⁶

The consequences of retaining the technical racing 'awe' of the cars are:

- The overall speed of the cars must be retained. When the power-train regulations are fixed, the FIA will develop accompanying regulations for the chassis and bodywork to ensure that lap times are similar to the preceding year.
- There must be real technical competition in the road-relevant aspects of development, thus relatively unrestricted regulations for the power train. The solutions that emerge will be in keeping with the fans desire for leading-edge technical development in Formula One.

Clarification of the manufacturers' desires on the points above will enable a set of regulations to be put together relatively quickly. The rest of this paper expands on each point in respect to power-train considerations and provides background information.

⁵ Battery/super-capacitor arrays are envisioned, but other types of energy store are allowable, unless good reasons emerge to constrain the energy store solely to electrical power.

⁶ It is envisioned that manufacturers will enjoy active support from battery manufacturers. This regulation will be revisited two years before the adoption of these regulations with the intent of including the energy store should it be clear that freedom here will be an onerous expense for the teams.

MEETING AGENDA

1. Welcome and overview of the principles behind the new regulation proposals. *Prof. Burkhard Goeschel, Chairman, Formula One Manufacturers' Advisory Committee and Max Mosley, President, FIA*
2. Type of fuel to be permitted. If a percentage is bio-sourced should this percentage increase over the period 2011 to 2014?
3. Fuel saving from 2010 to 2011; Feedback on the 30% figure proposed by the FIA and the further 2.5% per year suggested over the 2011 to 2014 period.
4. Approval of the composition and mandate of the Power-train Working Group (PTG).
5. Discussion on primary power regulations: Are any further restrictions on the primary power plant necessary given the energy restrictions, is the process for determining these supported?
6. Discussion on the mix of primary power and 'assist' power levels.
7. Discussion on energy recovery and 'assist' power. Are any further restrictions on the 'assist' power and energy store necessary?
8. Discussion on the limits that should be applied to the electronic controls. Are brake balance and traction control acceptable mechanisms due to the practical difficulties of policing?
9. Discussion on Power-Train supply to independent teams.
10. Discussion on Homologation proposal
11. Discussion on longevity proposals
12. Outline of next meeting subject matter and date

2011 FIA Formula One Regulation

Detail discussion

There are compelling reasons for change: The teams need lower costs to be commercially viable while environmental concerns can not be ignored.

Formula One faces two major threats over the coming years:

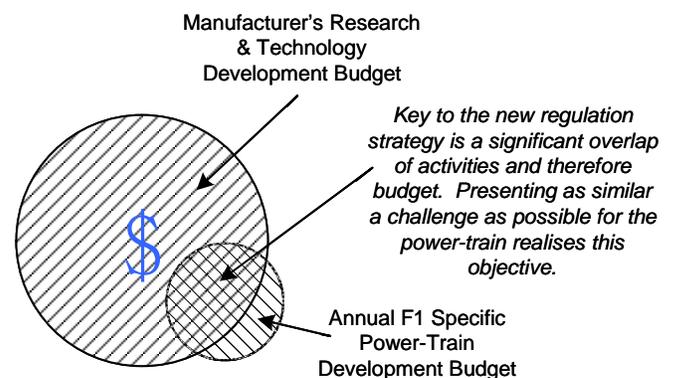
- (1) The costs of fielding a competitive team have escalated to such an extent that annual expense exceeds income by a ratio of 2:1 or more, the shortfall being made up by the team owners, mostly manufacturers. This spend may be justified in marketing terms, but the objective value is open to question.
- (2) The sport is open to justifiable criticism that it is not just wasteful; it actually glorifies excess, flying in the face of societal problems such as global warming and sustainability. Moreover its global communication strength due to its popularity is wasted as a platform for demonstration and encouragement of attitude change. Thus Formula One should consider action not just to protect itself from the possibility of alienation from an increasingly environmentally concerned public, but also on ethical grounds.

There is also a need to protect the independent teams, and to make the teams act as businesses returning a profit, rather than today's cost centres. To achieve this, the cost of participation must be lower than the generated income. Assuming income is maximised this means lowering, by at least 50%, the costs faced by the teams and the engine manufacturers of; (a) manufacture and deployment of the car ('going racing'); and (b) development.

The FIA will set a policy with regard cost of development: R&D relevant to road car development will be encouraged, that which is F1 specific will be discouraged.

A solution to both difficulties is to justify the manufacturer spend on technical as well as marketing grounds, while enforcing cost constraints where this justification fails. The money formerly spent on just F1 engine development, will henceforth be part of the manufacturers' research and technology development budget.

Today the environmental pressures facing Formula One are identical to those facing automobile development laboratories the world over. Thus *if Formula One development can be constrained to areas that are directly relevant to the development of road car technologies*, then this financial justification is realistic as the money would be spent anyway. The focus of competition also offers a realistic opportunity for a faster rate of development and evaluation of results.



Governmental regulations tend to drive environmental improvements for production cars. The FIA therefore, in its role governing Formula One, will set regulations to reflect the trends for automobiles in this regard.

Combining the need to change with this policy leads to a set of top-level decisions that appear to have a broad consensus among the leadership of participant manufacturers:

- 1) Energy efficient power-train development will be overtly encouraged
- 2) Development outside the power-train will be severely constrained
- 3) Waste will be reduced by an increased requirement for longevity of components

All this is to be achieved while retaining the public's awe of F1 and making sure the 2011 cars look new, futuristic, and 'cool', with racing that is closer and more exciting to fans.

(1) Energy-efficient power-train development will be overtly encouraged

The key elements in the 2011 regulations will be those defining the power-train. If these regulations present a challenge to engineers *as identical as possible* to the challenge they face in developing future technologies for road cars, then road relevance is assured and the spend will be to a large extent a spend that would occur anyway:

For Formula One, consensus among the FIA and the manufacturers is that the following will constrain developments, reflecting 'governmental regulation' for road cars:

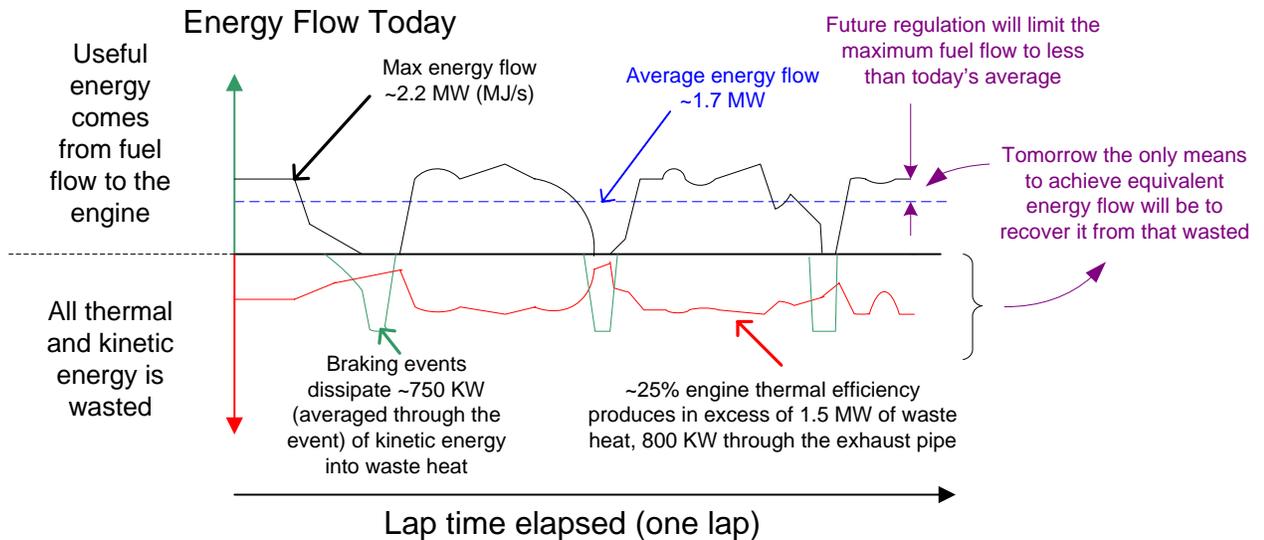
- The total amount of energy allowed per vehicle, per race is to be constrained. *[The purpose here is to limit the overall energy consumption of the vehicle to mandate the efficiency targets desired. Within this constraint the objective is clearly to produce as much power as possible.]*
- A fuel flow restriction will restrict the maximum energy per second that can be delivered at any moment to the reciprocating engine. *[Purpose is to limit the engine maximum power so that the driver can drive 'flat out'. It also encourages, but does not necessarily directly mandate 'mild' hybrid architectures. There is also a need to prevent the development of engines that can produce considerable, but non-efficient, extra power in short bursts, again to avoid the races becoming tactical economy runs with confusing sudden increases in speed.]*

In developing these regulations Formula One must be able to give a clear and unequivocal message to the public that it is at the very 'leading edge' in terms of efficiency.

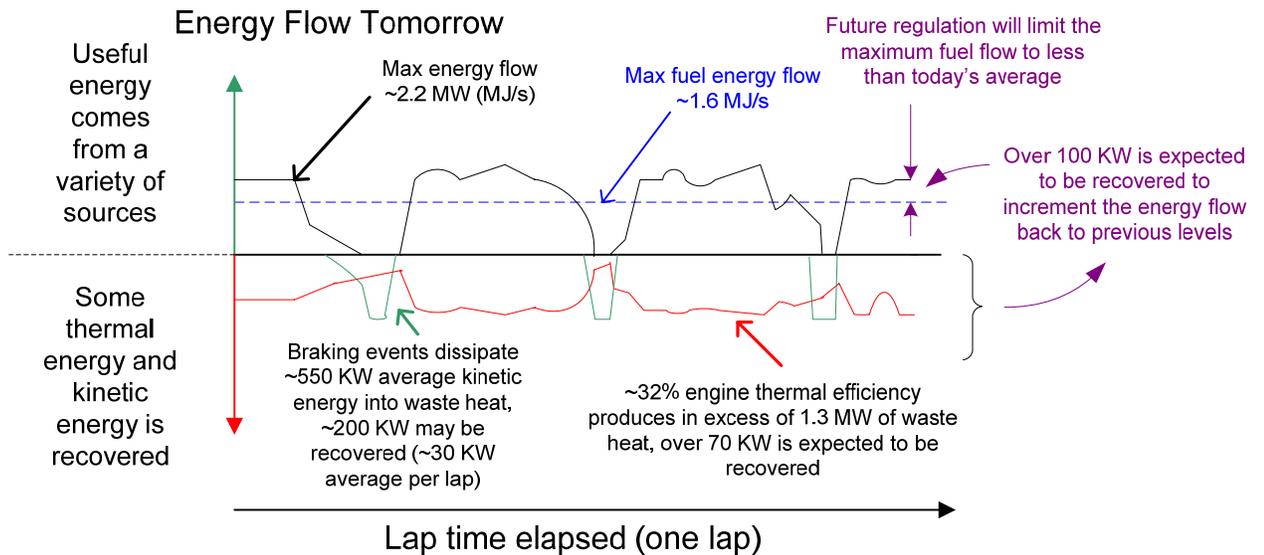
To develop these efficiency regulations the present fuel economy of F1 cars will be analysed and appropriate targets set

The approach to developing this regulation will be to calculate the average energy flow per race today (assuming we wish to retain approximately the same power requirements). This is simply equal to the calorific value of the total amount of fuel used, call this N kilo-joules, divided by the time the car is running. Then we pick a figure for the amount of energy it is reasonable to recover from the kinetic and / or thermal energy and put into storage over the same period. This is deducted from N to give us a value for the amount of fuel that is to be made available for the race. The amount will be further reduced to allow for the sizeable increase in efficiency one can expect from the new engines compared to today. This is because the 2011 engine will place fuel efficiency as a primary design consideration, as opposed to today's engine's where fuel efficiency is an important performance goal, albeit a secondary objective.

2011 starts with a regulation defining the amount of fuel available for each race by virtue of this sort of calculation. It also limits the maximum flow rate allowed to the reciprocating engine to a value equivalent to an amount based on the average energy flow per lap assuming no energy recovery.



Thus in 2011 the only way to get the power equivalent of the previous year will be to: (a) improve the efficiency of the engine; (b) increment the power of the engine by power scavenged from thermal sources (turbo-compounding being the most apparent means to achieve this) and; (c) assist the reciprocating engine with power from kinetic or heat energy recovery, a good proportion of which will need to be stored in some manner until required.



The quantities will be calculated by assuming that the engine does not assist directly in charging the energy store. If the manufacturer wishes, they may do this, but they will use more energy to do so and the various energy conversion losses may make it unattractive. Ricardo has been

commissioned to produce figures for the quantity of fuel and the maximum flow rates appropriate using this construct.

Using this approach the FIA propose a 30%⁷ fuel efficiency gain in 2011

In order to reduce carbon dioxide emission levels the Automobile Industry is expected to play its part. The targets being suggested by various agencies are that by ~2050 new cars must display about a 50% improvement in efficiency to make an impact on global CO₂ levels.⁸ The production car industry is faced with a task of producing significant gains in fuel efficiency over the coming decade.⁹ The FIA wish Formula One to spearhead such changes. Formula One starts at rather a backward state in this respect, given that efficiency has never played much of a role in F1 engine development, thus the figure chosen must be significant to avoid accusations of 'green-wash'.

On advice from Ricardo (to be confirmed as on going simulation work is scheduled) and considering that the 2011 F1 engines will be designed for fuel efficiency, something new in F1 engine design, the FIA recommend a starting point of 30% less fuel used. The objective here is to provide a challenge similar in magnitude to those facing production cars over the coming decades, but not to set a goal that is unachievable. The targets will be confirmed after the results of simulation work are complete.

This will reduce the power from the primary plant considerably, although not pro-rata as the engine will now be designed for efficiency. Ricardo estimates that a 30% gain in economy, represents a loss in power (assuming the engine will be driven flat out) of some 19%. Thus today's 'sticker' power of ~560KW (770PS), would drop to about ~450KW (620PS) to derive the required economy. However the FIA propose to augment this with power released from energy recovery to return to today's power level.

Given a 30% gain in overall economy, the maximum flow rate will be ~1.6 MJ/s

The ~450KW (620PS) engine will be restricted as to maximum flow-rate in order that the driver may always drives as fast as he can'. Working with Ricardo, the FIA suggest this should be reduced from today's values of ~ 2.2 MJ/s (~25% thermal efficiency, 560PS) to ~1.6 MJ/s (~32% thermal efficiency)¹⁰. (The precise figure will be proposed by Ricardo on completion of simulation work.) This figure should not significantly restrict an advanced high efficiency 450KW engine, but does prevent extra power generation through wasteful strategies when circumstances might tempt such usage.

⁷ Subject to ongoing simulation work, see footnote #1 on page 4.

⁸ See for example 'Stabilization Wedges solving the Climate Problem for the next fifty years with Current Technologies', S.Pacala and R.Socolow, Science Magazine, 13 August 2004

⁹ The EU proposal for fleet averages of 130g/km of CO₂ by 2012 defines this target. This is considered to be very demanding. Fuel economy reductions are likely to come from improvements in powertrain efficiency rather than drastic reductions in vehicle weight, size and power.

¹⁰ The 32% figure is for the base engine + the contribution made from turbo-compounding; predicted to be an increment of 50 KW. Although further energy savaging from thermal sources would increase this figure still further for the purposes of the flow rate calculation, this has been ignored because such devices are not expected to effect the efficiency of the base engine. Turbo-compounding or turbo-charging does effect the base engine due to the effect of exhaust back pressure increase, so must be included.

To make up the power back to ~560KW, the first step will be to recovery energy from the exhaust resulting in a ~500KW power plant

A race engine spends ~70% of its duty cycle on full throttle, where the engine operates at its most efficient. This is ideal for use of turbo-compounding to increment the output power, either directly via mechanical means, or indirectly by, for example, electrical generation. Scania use turbo-compounding on their top-of-the-line truck engines and gain in excess of an extra 10% of power. On advice from Ricardo it is reasonable to expect some 50KW of power by this means. Thus the engine with a turbo-compounding system can be rated at about 500KW.¹¹

To make up the power back to ~560KW, an average of 60KW of assist power will be allowed per lap from energy recovered and stored

To return to a nominal power of 560KW some ~60KW average 'assist' power will be required. This must come from recovered energy. This is approximately the same power output as manufacturers will be seeking from 'assist' in future premium-power split-hybrid vehicles, as well as for future 'plug-in' vehicles for inner city use. The assist power will rely on an energy store which will use recovered kinetic energy as its main source of replenishment. To make this useful, a significant amount of energy must be channelled into the energy store in the short periods of vehicle retardation. To allow this it is suggested that the maximum input energy recovery rate will be set at 200KW, essentially two enhanced-capability KERS units, one acting on the front and one on the rear axle.¹²

A Formula One car has a typical lap time of 1min 30s, which typically will consist of ~65s on full power, a small period of part throttle and ~15s of braking activity, although this can be as low as 10 seconds. If we set a figure of 60s of assist per lap, this will use 60KW for 60s, or 3.6 MJ (~1KWh) of stored energy, so ideally at least 4MJ of energy store would appear to be required, allowing for losses. To recharge the energy store, kinetic energy recovery units working on both the front and rear axles will be able to recover ~200KW during this short 15s period, resulting in some 3MJ of energy. The amount one can recharge the energy store will be circuit dependent, but in the event that there is a shortfall, it would not be a catastrophic problem by any means, the cars will just have less power when racing at these circuits. The worst example would be Shanghai which offers only 10 seconds braking time for a 95 second lap. Thus only 2MJ would be available from the kinetic energy, and so the assist power would be limited to an average of ~30KW. At the other extreme, Monaco with 25s of braking over a 75 sec lap allows the energy store to be fully replenished each lap, resulting in an average of ~60KW of assist possible because of the limited size of the store.

These calculations show that the average amount of assist power will vary from circuit to circuit by as much as 30KW, because the energy store will not always be replenished by kinetic energy, *but in calculating this there is no allowance for any thermal recovery.* Will it be possible for thermal recovery to provide energy to fill the energy store, when kinetic sources are inadequate? The primary engine is to be ~500KW, so will produce towards 800KW of waste heat. What percentage of this heat could be turned into useful energy to top up the energy store to the required level?

Estimates for what is possible from thermal recovery vary wildly. Turbo-compounding offers a sure route to energy recovery as the energy is 'high grade' and here a substantial amount of

¹¹ While turbo-compounding is the expected route, the FIA do not intend to enforce their use. If another method is thought better, then the manufacturer is free to make use of it, although advised to consult the FIA first to discuss any difficulties that may emerge.

¹² It is not intended to overly restrict this, thus configurations of one central 'assist' motor/generator or, as more commonly envisioned, one front and one rear (all acting via differentials) would be permitted.

power can be generated, although at cost to combustion efficiency because of the increase in exhaust back pressure. A reasonable number for power generated this way would be as much as 50KW for a 500KW engine as already described¹³. Energy recovery from the heat of the cooling systems and the exhaust gas is also possible, but more difficult.

The FIA feel that a target of 25KW for 70% of the lap (i.e. while on full power) is an achievable target, representing just 3% of the ~800KW (68 % waste) available thermal energy. This represents ~1.5MJ per lap, but it would make little sense to put this into the energy store, better to connect it directly to the motors. Thus for most circuits full store replenishment appears possible with just a 2.5MJ store, that is the 4MJ needed for an average of 60KW per lap less the 1.5MJ generated by thermal recovery. (Note - 15s of kinetic recovery gives 3MJ leaving an excess to cover losses in conversion at most circuits, not withstanding any thermal recovery when the engine is not at full power).

Given that the next four years one can expect to see many innovations in these recovery technologies, the FIA consider that the challenge set by the need to refill the energy store each lap by the most efficient route is a stretch, but an achievable target. Certainly the developments involved will be of interest to road vehicles.

While the output power is set to be a maximum of 60KW *average* whenever power is required, it is not suggested that 60KW be necessarily the *maximum* power available from the assist, instead that this be set at 200KW i.e. the same as the maximum input power allowed. This is an interesting option as it allows not just 'push to pass', but 'push to whizz past', although at the significant cost of depleting the energy store.¹⁴ Thus the charging of the energy store and its depletion through using assist power becomes a significant strategic element in racing. This is at first sight in conflict with the principle of avoiding 'burst power' from the primary power plant (restricted by the fuel flow rate), but here the extra power is achieved only from recovered energy. This is 100% in line with the environmental message that these regulations set out to achieve. The resulting maximum figures of 200KW output, and 200KW input power for the 'assist' along with a maximum energy store of 2.5MJ are a step up, but still a sensible evolution from the two years KERS experience that the teams will have by 2011.

Discussion Point: The FIA suggest an appropriate mix of primary and recovered power of ~500KW from the primary + exhaust energy, plus about 60KW average from the assist. Maximum input and output rates of 200 KW along with a 2.5MJ maximum energy store are suggested as all that is required to regulate energy recovery and the 'assist' power systems.

***Note:** These figures are the preliminary results from simulation work. Some tuning to these figures may occur in the light of further experimental results. Today these are a 'stretch target', but one should always bear in mind the tremendous rate of development that F1 engineers have produced in the last two decades, especially with regard to power-train.*

¹³ Note that the turbo-compound unit fitted to the Scania 420 engine provides about 10% more power.

¹⁴ A 2.5MJ store would allow 200KW of assist for some 12 seconds, but with the penalty that for about the next 90s (one lap) the car would be down on average power by about 10%, until the store was largely replenished.

Weight Implications – the average weight must be raised by 35Kg

The new regulations, as stated, require a number of additional sub-systems to complete the car, relative to today. Given that most of the world’s manufacturers are considering battery storage as their ‘prime path’ it is reasonable to make an estimate of the rise in regulated minimum weight allowing their use:

Sub-system	Δ Min Weight (Kg)	Δ Fuelled Weight (Kg)
Batteries and Super-capacitors (Energy Store)	45	No difference
Front generator/motor 100KW	12.5	
Rear generator/motor 100KW	12.5	
Power / control electronics / etc	15	
Thermal recovery systems	15	
<u>Total additional</u>	<u>+100</u>	
Less ballast + lighter chassis	-60	
Less lighter primary engine	-5	
Less 30% fuel – average value	-0Kg	-30Kg
Total weight limit rise	+35Kg	+0Kg

Note: Today 24Kg batteries (343 cells) from supplier A123 would be able to produce 60KW, but need about 20Kg of super-capacitors¹⁵ (assuming 10KW/Kg specific power) to soak up the braking energy in the short periods of vehicle retardation and then release this over the rest of the lap to charge the batteries. Thus 45Kg seems a reasonable estimate for a battery/capacitor energy store of 2.5MJ.

The calculation and a look at the battery specifications reveal that everything is right on the limit to provide the assist required. The progress in battery and capacitor technology however makes this estimate a reasonable limit, which should be bettered by 2011¹⁶. Thus it is suggested that the minimum weight rises to 640Kg from today’s 605Kg given the regulations listed, but this will only raise the car running weight by less than 18Kg or so on average. This allows the tyres, suspension, chassis strength and final drive components to be unchanged in their running regime from previous years. The car will suffer a loss of about +1 sec per lap on average, due to this extra weight.

¹⁵ In a ‘long’ 5 second braking event, 1 MJ of energy can be generated by the 200KW maximum input limit. The requirement to absorb 200KW results in 20Kg of super-capacitors, assuming 10KW/Kg, the requirement to drain this over the next 20s, just 15Kg assuming 20 Wh/kg.

¹⁶ The authors have already seen specifications for development batteries which would reduce the weight required for the batteries still further, by as much as 5Kg.

Pump fuels with 10% bio-mass will be used

Fuel that will be available at the pumps, is to be used, with 10% of the fuel to be derived from 'bio' sources, the rest derived from fossil fuel. The following will also be built into the regulation:

It is not desired to have a fuel development race, this must happen in the mainstream market led by natural market forces. Therefore the FIA will nominate the fuel allowed, along similar lines to the present fuel regulations. The blend will be stable for three years, with any changes announced on a three year rolling basis.

Discussion Point: Should this be fixed for 2011 to 2015 or change, for example, to have an increasing bio-mass content each year, in line with auto-industry targets?

For: Governmental regulation is largely aimed at CO2 reduction, which will encourage increasing bio fuel content due to the increased energy release from hydrogen, as opposed to carbon, molecular components. If Formula One is to spearhead industry change, then the fuel should always be a step ahead in terms of bio content compared to that available (commonly) at the gas station 'pumps'.

Against: The regulation goals are challenging enough. The present agreed target for bio sourced content is 5.75%, and the suggestion is for 10%, entirely in keeping with being one step ahead. Within the regulation period this is unlikely to change substantially. A change should be considered only at the end of this regulation period; i.e. for 2015.

The primary power plant is to be a reciprocating piston engine restricted to a maximum energy usage rate.

Given the energy regulations described above, there will be a primary power plant, producing about 450KW of power¹⁷, incremented to 500KW including exhaust energy derived power. The intention of the FIA is to encourage a technology race for the most efficient engine; however solutions such as fuel cells or turbine engines are too far away from being production viable today. Therefore the rule will encourage development of just 'conventional' (i.e. circular piston in cylinder) reciprocating engines, converting the energy provided by the fuel in the most efficient manner possible. This keeps engine development road-relevant, and given that it will produce the majority of the power available, it has the appropriate balance in development focus: The next decade will see the manufacturers' main concentration on increasing the conversion of gasoline or diesel fuel energy into motive power, with hybrid, fuel cell, and other new technologies being important, but secondary to this main effort.

The top level framework for the power-train is suggested as follows:

- Fuel amount, type and maximum flow rate
- An engine of V6 configuration, with a swept volume of 2.2 litre +/- 0.1%
- The engine must be a reciprocating type (pistons in cylinders), with four poppet valves per cylinder

¹⁷ Actual power depends on the achievement of the engineers. However if one assumes that the fuel efficiency of a Formula One engine can be improved by ~10%, a difficult but not unreasonable target, then a drop of ~20% power (giving about a pro-rata fuel efficiency gain) will achieve the desired 30% improvement.

- The injection system must not be pressurised beyond 500 bar

The FIA wish to ensure direct road relevance, so have decided that 'exotica' such as oval pistons, or metal matrix blocks, be banned. While some of these points are covered by the rules above, the nature of F1 engineers is that they will push for any solutions that add to the performance, whether it is inherently Formula One-specific or not. Given this, it is suggested that the manufacturers all join a process to set further restrictions, if any are appropriate. This will be achieved via consultation with the Power-train Working Group:

- (a) The general format of the engine is set (as described above)
- (b) Each manufacturer is asked to list any further restrictions that they would like to see
- (c) Suggestions are collated into one spread-sheet
- (d) Each manufacturer is asked to comment on each idea in one of three ways, 'accept', 'reject', or 'acceptable in principle, subject to detail'
- (e) The FIA will form a working group, incorporating some expertise from Ricardo, and the detail regulations will emerge from this group guided by the collated list

Examples of the type of detail that will be considered by this process might be:

- Cylinder spacing, 'V' angle, bore and stroke - fixed by Ricardo after simulation work
- List of acceptable materials?
- Minimum weights of specified parts (as with the present V8 engine)?
- Number of injectors per cylinder?
- FIA tendered injectors?
- FIA tendered ignition system?
- Ban on inter-cooling?
- Etc

Discussion Point: *Are further restrictions on engine configuration desired? What is the manufacturers' position on the suggested process is it necessary?*

For: It is not clear which engine configuration will emerge as the most efficient solution for tomorrow's production cars. The FIA wish to overtly encourage the most fuel efficient power-train solutions from 2011 onwards. Therefore no further restriction is necessary, nor pertinent. Moreover simulation and know-how is such that near optimum engine layout for any chosen technology can be derived, without the need to build actual examples to discover the best.

Furthermore this lack of clarity is clear from discussions with each manufacturer indicating favour for a particular engine configuration, but no consensus readily apparent.

New materials may be the key to super efficiency in the future and so should not be banned. Often exotic materials are needed, but in tiny amounts, so do not affect production cost significantly.

Against: Allowing total freedom may lead to a spending race, with manufacturers feeling compelled to build many different types of engine to discover the most suitable. Additionally the engine homologation and 'freeze' has been a major step in lowering costs, so why reverse this stance? The majority of restrictions that will emerge from the suggested process, which has worked effectively before in

respect to the present V8, will only prevent 'F1 specific' work, which is in line with the principles stated.

Notes: *Consideration should be given to allowing a period of relatively unconstrained activity, followed by an increasing set of constraints, mirroring the development of today's V8 engines. This might achieve a good balance between free development and the need to constrain costs. This is referred to later under the subject of homologation.*

The FIA would welcome a ruling allowing small amounts of exotic material and even allowing novel solutions, providing it could be shown that such developments were 'road relevant' rather than 'F1 specific'. To allow this the FIA would demand that any 'exotic' solutions were cleared by the FIA before development was ramped up. Would the manufacturers want this?

Lower engine rpm will result from these regulations

Road engine research centres on low rpm engines for many technical and durability reasons. The fuel efficiency demanded for 2011 has the consequence that the engine rpm will need to be lowered nearer that which is optimal for lean-burn, high-efficiency engines. Ricardo estimate that the 450KW, energy restricted engine, driving a mechanical turbo-compound, will probably need to drop below 10,000 rpm to achieve this fuel performance. Thus rpm will not need to be restricted. However the FIA, while for the present not imposing any limit, feel it prudent to reserve their position. At this stage it is only important that decisions on this issue are guided by a desire to ensure the pertinence of these engines as 'applied research beds' for production technology development.

Transmission will be unrestricted initially, but then subject to homologation

Transmission is envisioned to be part of a whole power-train system, and its seamless integration with the engine will be important to achieve true efficiency. Road cars are tending towards more and more gear speeds with efficient mechanisms such as dual clutch. Some hybrid architectures use CVT gearboxes. Given these developments and the integral part the transmission is likely to play in uniting the assist and primary power, the FIA feel that transmission should be free initially, but subject to the same homologation procedure and durability constraints as the primary engine. (To be described later).

The Power Train must be considered as 'one system'; therefore electronic 'system' control will be largely free compared to today

The immediate future has an increasing emphasis on the engine/clutch/gearbox/recovery system/brakes/assist power all being considered as one system, rather than a collection of independent sub-systems. This is to be reflected in the 2011 regulations. The road relevance is only achievable if the controlling electronics are relatively free as they are a fundamental and significant part of the power-train development. However the FIA are mindful of the prevailing need to prevent unnecessary spending and will therefore favour the incorporation of industry standard 'production' controllers and operating systems such as are being considered by the 'Autosar' consortium or any 'production intent' hybrid / power-train controllers. (In effect the purpose designed exotic and expensive controllers of today will be replaced with low cost production based units)

There is a view that controls which affect the dynamics of the car are at odds with the concept of a sport whereby the driver skill is a key element. Such controls (dynamics stability, traction control, ABS, torque steer etc.) are aimed at assisting poor drivers. There is an argument that allowing such controls will close up the racing as fewer mistakes will be made, it is unlikely that they will render the difference in skill of drivers as unimportant¹⁸.

Should a ban be deemed appropriate, the following is recommended:

- A 'supervisory' data logger will be mandated. This will police the controls.
- To keep enforcement simple and to allow optimisation of the kinetic recovery system, automatic brake balance adjustment will be allowed.
- Power and energy recovery may only be via a differential system front and rear. Note that 'assist' power may be delivered both front and rear, but no torque steer or left-right bias braking is allowed.
- ABS braking will be banned, but the energy recovery mechanism may be modulated, this to allow the combination of the two to be 'fused' into one system and to favour the development of the recovery system. The pressure applied to the pedal must be directly and unchangingly related to the retardation quanta applied to the vehicle.
- Traction control is debatable, but the FIA wonder if policing is too complex with these systems to warrant the regulation.
- The manufacturers will be asked to pledge adherence to this regulation and to instruct all their staff accordingly.

Discussion Point: Do the manufacturers prefer a complete ban on driver aids? Is allowing brake balance and traction control desirable on practical grounds?

For: There is a general consensus that the 2008 controls on F1 cars is appropriate for F1 and that the introduction of any further electronically controlled driver aids blur the distinction between the best drivers and the 'also rans'.

A ban will help with cost containment as the amount of testing of such controls is most considerable, both on the track and in the factory.

Against: Future systems that find their way into road cars will incorporate these 'aids' into the overall control strategies, especially the need to seamlessly combine the brakes and the kinetic energy recovery, and the need to corner and accelerate as efficiently as possible. Thus 'free' systems are road relevant.

Electronic controls will be so intrinsic to the power-train solutions imagined that policing as to whether or not driver aids are incorporated will be difficult. Thus it would be simpler in terms of enforcement to just allow freedom on controls, however the FIA believe that they will be able to police any left/right biasing, and the banning of ABS systems and/or traction control to a first order. However if a team chooses to interpret the rules in a manner contrary to the spirit of the regulation, policing can become difficult.

The regulation period is to be for four years period of stability, but within this gradual change may be made.

The intention of the FIA is to implement these changes with a guarantee of long regulation stability, as this is a request from all manufacturers involved. Given the degree of change

¹⁸ Michael Schumacher thinks this is true of simple controls seen in his era like traction control, but is wary of self-learning systems that might aid turn in, braking and control when the car is 'nervous'.

necessary to attend to the needs of cost reduction and environmental concerns, some latitude must be built into the regulations to allow for adjustment.

The first item that may require such a 'sliding scale' regulation is recognition of the fact that development of the power train is likely to be dramatic. A look at engine development in F1 over the years will verify this. Therefore it is proposed to adjust the fuel efficiency requirement each year by 2.5%, taking the initial 30% improvement over today to 37.5% in 2014 and perhaps a full 40% for 2015.¹⁹

Discussion Point: Should the energy quota (both amount and max flow rate) per race reduce over 2011 to 2015?

For: The technology proposed is immature by F1 standards, yet even with the relatively mature V8 engines a gain of 5% power each year was being achieved. Thus it is possible that the power will increase each year even with the 2.5% increase in efficiency proposed. This is the beauty of F1 and indeed the very reason production car development has the possibility of real gain from F1 involvement.

Against: The proposed concept will present a moving goal post that may tip the balance for whole new engine layout each year (in extremis).

The concept of clearly defined 'sliding regulations' is referred to again in respect to the bio-mass percentage in the fuel and the step by step homologation process.

(2) Development outside the power- train will be severely constrained

The key principle is to heavily restrict F1 relevant technologies such as tyres and aerodynamics, which have a dominant effect on performance yet offer little pertinent knowledge to production car development. Moreover these dominate to such an extent that they tend to mask improvements in power-train development that might otherwise be a decisive factor between the various entries. Therefore their importance must be suppressed. This will be addressed in future meetings, the following however is pertinent to the decisions required on power-train:

Power-train solutions must be made available to at least one independent team at marginal cost.

Clearly it is the intention of the FIA to maintain F1's technical 'awe' in 2011 via perhaps the most sophisticated power-trains that Formula One has ever seen; the expense justified and balanced by its overlap with production vehicle development. This leads to a flow of regulations designed to channel development into this area. In implementing this policy the FIA must protect the existence of the 'independent' team:

The power-train regulations will be backed with a sporting rule to ensure *state of the art* power-train components and whole systems are available at a low, non-profit, marginal cost to independent teams. Each manufacturer will be mandated to supply a power-train to at least one independent team, more should the number of manufacturers involved reduce. In the event that there are more manufacturers than independents, the manufacturer who finished lowest in the Championship may opt not to supply.

¹⁹ This reflects the challenge ahead for the manufacturers in respect to EU directives on CO2 emissions; an average of 2.7% over these years is needed to make proposed government targets.

Discussion Point: *Does marginal cost power-train supply as described meet with the approval of the manufacturers?*

For: *The existence of independent teams is threatened if the manufacturers choose to profit from supply, or refuse it entirely.*

Against: *Engines have always been supplied at a profit to independent teams or at subsidised rates. The FIA should not interfere with a free market*

The centre of gravity will be subject to a tolerance in the 'z' dimension so not to compromise the power-train development unduly

In a similar policy to restricting the aerodynamics so that it does not have a significant impact on power-train development, a feverish desire to keep the centre of gravity low must be guarded against. The obvious manner to overcome this is to mandate a tolerance for the centre of gravity in the vertical dimensions.

Space must be allowed so that power-train components are not aerodynamically constrained

The need for road relevance leads to constraints on the car design as the power-train should not be additionally constrained by aerodynamic 'shrink wrapping'. This will need a rethink from today's aerodynamics rules. The need is to have regulations that mandate space for the power-train components. Two 'virtual' boxes will be defined. These spaces must be fully enclosed by bodywork such that they are impervious to airflow, but with the following allowances:



These will be designed to provide ample space for power-train elements, both front and rear, given that four wheel energy-recovery will be allowable under these regulations. These spaces must be fully enclosed by bodywork such that they are impervious to airflow, but with the following allowances:

- Front box allows, say, 20% of frontal area for fully ducted vents to cool power-train elements which may include ducting for radiators.

- Rear box allows, say, 25% of frontal area for fully ducted vents for radiators, intake cooling, airflow for cooling of power-train elements, and intake air for the reciprocating engine (although the latter may alternatively come from above the box, as today).

In addition space within the side pods between the front and rear wheels might be mandated to provide more space for thermal recovery elements and will have the added attraction of further side impact protection for the driver. The main radiators for the power-train may still be placed in the side pod area.

The 2011 power-train will not diminish the speed of the cars

The 2011 power-train may be down on power compared to 2010 cars (which have KERS on top of their 560KW engines) when introduced and the car will be on average 15Kg heavier. A theoretical loss of lap time of a little more than 1.5 seconds might be experienced due to these two factors (18Kg would account for about 1s of this, a loss of ~20KW about 0.75s). The FIA intend to regain much of this loss by working with the tyre supplier so that the grip of the tyres increases by some 3%, making the cars a little under one second per lap faster.

Four-wheel drive, automatic brake bias, and traction control would improve the lap times of the cars a little; 0.5 seconds a lap is not an unreasonable estimate here.

Thus, in the round, the speed of the cars will not be unduly diminished by power-train influence. [Note: Bridgestone's support of this is clearly fundamental.]

The new power-train will be part of a regulation package designed to encourage closer racing

There has been a clamour for regulations to encourage closer racing with more overtaking seen each race. There are elements within the proposed package of power-train regulations that are designed to encourage this:

- The regulations for 2011, when taken as a whole, will attempt to make the power-train effectiveness as the *main* technical differentiation between cars. (Note on average a 1% gain in power will give ~0.18s advantage, thus the difference in power produced by the different solutions while important, is not overwhelming.)
- The ability to configure the assist to deliver as much as 200KW, albeit only for ~13 seconds a lap, allows overtaking in a completely novel manner. It will take great skill from the driver to adapt his driving to accommodate the changing nature of the car (braking from different top speeds especially). It is highly likely that once overtaken, an equally matched car will be able to make a realistic attempt to overtake on the next straight. This will be suitably researched via simulation to better understand the effect it might have on the entertainment value of races.
- Driver skill and judgement in the use of the assist power will be critical

Severely restrict development after a period of initial freedom via homologation requirements and specified parts

Homologation Proposals

Homologation is a proven and accepted mechanism for controlling costs. The FIA propose the following homologation with respect to the power-train for the 2011 to 2015 period:

- The power-train will be homologated annually from December of the preceding year for the major parts and then frozen from 1st March prior to each season. Each year a number of elements may be changed to enable the new efficiency targets to be reached. These will be decided two years ahead via consultation with the Power-train Working Group.
- System configuration: Systems around the primary power plant must not be changed with regard to overall system design from 2013. Thus if the water pump and oil pump are electrically driven at the beginning of 2013, they must remain electrically driven until 2015.

Note: New regulations are to be introduced for 2015 and will be announced at least three years ahead. It is hoped that the next set of regulations for 2015 will simply be an extension of the 2011 regulation set.

Discussion Point: *Are the homologation periods proposed effective for cost containment?*

For: The purpose of homologation is to constrain costs. A period of development is allowed to push each element to a high level, but then it is 'frozen' so more money is not spent. This has worked well with the V8 engine and is a formula to be repeated to gain the cost reduction required.

Against: Freezing can mean that teams are unable to remedy a system of their car which is uncompetitive, thus leaving them in a possibly hopeless position.

(3) Reduce waste by increased requirements for longevity of components.

There is a need to make these rules embrace other environmental aspects:

- The power-train should last for a considerable time. The FIA suggests an increase to five weekends, (note: the much lowered rpm makes this far more straight-forward than in the past). Thought will be given to a better penalty system than today and this will be included in the 2011 proposals.
- To encourage leading edge development, the energy store will be exempt from the five weekend longevity requirement, but subject to a one weekend requirement initially. The FIA will review this two years ahead of each season and make a ruling depending on the involvement of energy store companies (eg battery manufacturers) and the cost impact of this regulation.

(4) Retain the 'awe' of F1, both technically and in terms of racing.

In considering the power-train regulations outlined the FIA have attempted to retain and build upon Formula One's unique and premier position in the world of motor racing:

- F1 will still be very fast. The total power is kept more or less constant, the peak power increased considerably (albeit for short bursts), the ability to put the power down via four wheel drive, and the ability to overtake all improved.
- There will be real technical competition but only in the road relevant aspect of power-train development. This will be fascinating to observe, unpredictable and indications are that it may well be quite varied compared to the relative homogeneity of today.
- The noise of high rpm is to be replaced, by what we don't know, but it will be quieter. The view is that the risk of this new noise being unappealing is low. Quieter cars are 100% in line with environment demands. The unique and sophisticated power-trains are certain to make a dramatic, if very different noise of their own.²⁰
- The racing excitement will be protected not only by the power-train regulations, but also by chassis regulations which will be debated in the same manner once the power-train is fixed.

Cost reduction summary

The proposed regulations are far reaching in their approach to cost reduction through the mechanisms of true road-relevance, homologation and longer life parts. These should produce a pronounced effective cost reduction after the initial change and an effective reduction for the manufacturers through the merge of technology development activities. Summarising this:

- In the past engine and transmission have been Formula One-specific activities, with very little direct benefit to road cars, mainly because the challenge for the engineers involved has been completely different in the two disciplines. The 2011 rules are designed to make the challenge similar, and thus the money spent on development of power-train benefits both racing and production. Moreover the focus and speed of development in racing may amplify the pace of development of efficient power-trains. *A win-win situation as the money previously spent on F1 solutions will be spent on solutions generally applicable throughout the manufacturers' activities.*
- Annual homologation of the power-train including gearbox and final drive elements (subject to freedom where necessary to refine efficiency).
- Electronic modules that are 'production' items in line with the operating systems and core control hardware being development by the Autosar Consortium.
- Longer life components.

Note: The remaining regulations with respect to the rest of the car will be very much focused on cost reduction, so the above is by no means the only action intended in this respect by the FIA.

²⁰ A trip to the Goodwood revival meeting will clearly demonstrate how 'emotional' even a 8,000 rpm racing engine can sound, add to this the new 'futuristic' high pitched whine of the electrical systems and one can see that it is not clear cut that the 2011 will sound 'unemotional' to the fans.

Appendix : The Power-train Working Group

A consultative working group will be formed to assist the FIA in the translation of the framework agreed by the FOMAC meetings into detailed technical regulations.

The group will consist of:

- a. A member from each manufacturer with the following profile:
 - i. Credible experience in power-train development for road cars
 - ii. Credible experience in race power-train technology along with an understanding of costs associated with development and F1 engine reproduction
- b. A representative from Ricardo to assist the FIA in determining road relevance and technical achievability.
- c. Representatives of the FIA

The mandate of the group will be to make recommendations to the Technical Working Group with respect to regulations pertaining to power-train, and that in doing so the following principles are adhered to:

- a. Uses its best endeavours to implement the framework agreed by the FOMAC committee into detailed regulations.
- b. Uses its best endeavours to maximise the overlap between road relevant technology research and development and reflect this in the regulations.

The group will conduct its activities in line with the objective to produce a complete set of power-train technical regulations by the end of 2007.