

# 2009 Formula ELECTRIC & HYBRID ITALY (EHI) RULES

## Contents

Contents .....	1
1 Formula EHI overview.....	2
1.1 The Objectives.....	2
1.2 Eligibility .....	3
1.2.1 Society Membership .....	3
1.2.2 Registration .....	3
1.3 Admitted Classes.....	3
2 Rules for Class 1.....	4
2.1 Vehicle safety .....	4
2.2 Static Events.....	4
2.2.1 General Presentation .....	4
2.2.2 Engineering Design .....	4
2.2.3 Technical inspection .....	5
2.3 Dynamic Events .....	5
2.3.1 Classification and awarding .....	6
2.3.2 Acceleration Event .....	6
2.3.3 Autocross Event.....	6
2.3.4 Endurance/Energy-Economy evaluation .....	7
2.3.5 Performance evaluation .....	13
2.3.6 Hill Starting ability.....	14
2.3.7 Pursuit Test Demonstration.....	14
2.3.8 Events and scoring summary .....	15
3 Rules for Class 2.....	16
3.1 Vehicle safety .....	16
3.2 Static Events.....	16
3.2.1 General Presentation .....	16
3.2.2 Engineering Design .....	16
3.2.3 Technical inspection .....	17
3.3 Dynamic Events .....	17
3.3.1 Classification and awarding .....	18
3.3.2 Acceleration Event .....	18
3.3.3 Autocross Event.....	18
3.3.4 Endurance/Energy-Economy evaluation .....	19
3.3.5 Performance evaluation .....	25
3.3.6 Hill Starting ability.....	25
3.3.7 Pursuit Test Demonstration.....	26
3.3.8 Events and scoring summary .....	26
4 Rules for Class 3.....	27

# 1 Formula EHI overview

## 1.1 The Objectives

The 2009 Formula EHI addresses the same scope and overall objectives of the previous 2008 Edition.

The Formula EHI addresses the development and competitive demonstration of advanced electric & hybrid vehicles integrating powertrains based on advanced technologies. The development and the demonstration shall be performed by students of Universities and advanced technical Institution.

A main objective is to show outcomes of research in the field of new technologies, which can contribute to reach the target of a sustainable ecological and energy effective mobility.

A part of the goal is to address the industry attention to new solutions in this field, suitable to be transferred to the engineering and industrial development process.

Another scope is to stimulate and activate exchange of information and contacts among Academic Institutions and relevant supportive Industries about these new and socially beneficial technologies.

A final aim is to promote and contribute to the diffusion of the culture of electric and hybrid vehicles and to encourage industries and users to the development and the acceptance of these environment and energy conscious vehicles.

To the above aims, the structure and the various tests of the Formula have been conceived to stimulate the development of vehicles, which should balance different performance as to be both suitable for real use in urban and suburban context, and to be environment friendly. At the same time, show and race aspects have been taken into account, to juice up the tests.

Therefore, the evaluation of the merits of the research products demonstrated by the participants are addressed to the following aspects:

- Energy effectiveness
- Dynamic response
- Environmental impact
- Innovation level
- Industrial development potential.

Two classes of vehicle are welcome:

- Sport prototype cars, more oriented to enhanced dynamic performance
- Vehicles more oriented to balance energy efficiency enhancement and acceptable performance, addressing urban and suburban operation requirements.

The presentation of the vehicles and their evaluation should be performed for both classes on the basis of the above criteria, but with respect to the appropriate oriented features.

Projects and demonstrators related to hybrid and electric technologies are welcome, in a third class, to be presented and evaluated separately, but on the basis of the same criteria.

To create synergies with other competitions addressing the same technical areas, the 2009 Formula Hybrid USA Rules (see PDF file) have been assumed as a reference for basic concepts and test procedures.

## **1.2 Eligibility**

### ***1.2.1 Society Membership***

Students, Technical Institute's participants, Team Leaders and Faculty Advisors must be **members** of their national referent Association or of **ATA**. For example, Italian Teams must be associated to ATA, English to IMechE, etc.

Proof of membership, such as membership card, is requested while registering.

### ***1.2.2 Registration***

Teams may enter a vehicle as many years as they like, provided they can show evidence of substantial development since the last time the vehicle was entered.

## **1.3 Admitted Classes**

Formula EHI welcomes the following research product classes:

**Class 1:** Four wheel car, single seat, open-wheeled and open-cockpit (formula style body, as for 2009 Formula Hybrid USA Rules, see PDF file).

The car can be equipped with the following types of powertrain:

- Hybrid Electric (HE), with Internal Combustion Engine (ICE) fuelled by gasoline, diesel, CNG, LPG, hydrogen, including plug-in (externally chargeable) hybrid system
- Battery Electric (BE), rechargeable from external electrical energy source and/or from on board solar photovoltaic panels
- Fuel Cell (FC), fuelled with hydrogen, pure or hybrid-electric, including plug-in (with electric storage externally chargeable).

Vehicles built with chassis already used in Formula SAE or commercially available and SAE compliant are admitted.

**Class 2:** Other types of vehicle (including Two or Three or Four wheel vehicles), without formula constraints equipped with the following types of powertrain:

- HE with ICE, fuelled by gasoline, diesel, CNG, LPG, hydrogen, including plug-in (externally chargeable) hybrid system
- BE, rechargeable from external network and/or from on board solar photovoltaic panels

- FC, fuelled with hydrogen, pure or hybrid-electric, including plug-in (with electric storage externally chargeable).

**Class 3:** Static vehicle concepts, systems, components and projects, concerning electric and hybrid technologies. Solutions will be presented orally and/or in poster session and include:

- Static demonstrators
- Working components and systems
- Conceptual design (paper, real/virtual models, simulation data).

## 2 Rules for Class 1

### 2.1 Vehicle safety

For the vehicle requirements the car construction provisions relevant to safety as reported in 2009 Formula Hybrid USA Rules are to be met (see PDF file).

*A Structural Equivalency Form should be submitted to Formula EHI according to the Action Deadlines.*

### 2.2 Static Events

**The maximum score for the Static Events is 200 points.**

#### 2.2.1 General Presentation

**The maximum score for General Presentation is 50 points.**

The General Presentation is a room presentation of the vehicle global characteristics. The elements, that are related to the main objectives should be put in evidence:

Evaluation elements	Max. score (points)
• Dynamic performance	30
• Energy consumption, refuelling and battery charging procedures	10
• Prototype realisation program and cost report	10
total	50

#### 2.2.2 Engineering Design

**The maximum score for Engineering Design is 150 points.**

The concept and architecture of the powertrain and its integration in the vehicle structure should be presented in the room or in the box, with particular respect to the following aspects:

Evaluation elements	Max. score (points)
• Elements of innovation with respect to the state of the art of technology	40
• Adequacy of design solution to the design rules	30

• Industrial aspects, including cost estimation for the potential industrial production	50
• User aspects, including: mission analysis, infrastructure requirements and estimated operating cost	30
total	150

A design report should be presented including drawings.

The deadline for Design Specification Sheet submission will be posted in Formula EHI website.

### ***2.2.3 Technical inspection***

The inspection of the vehicle, to be performed by the Technical Committee, aims to verify the consistency with the basic requirements and the general adequacy of the vehicle to perform the dynamic events.

The positive result of the technical inspection is a prerequisite for performing the dynamic tests.

The team might be requested to demonstrate the compliance of the powertrain with the prescribed displacement limits through appropriate documentation and declaration.

As for as the engine is concerned, the prescriptions reported in 2009 Formula Hybrid USA Rules (see PDF file) are to be met, including Engine Limitation and Throttle Actuation and Intake Restrictor.

The diameter of the circular restrictor must be:

- Gasoline fuelled cars – 12.9 mm (0.508 inch)
- E-85 fuelled cars – 12.3 mm (0.483 inch)
- Diesel fuelled cars – no inlet restrictor required
- LPG fuelled cars – 13.4 mm (0.527 inch)
- CNG fuelled cars – 13.8 mm (0.543 inch)
- Hydrogen fuelled cars – 16.7 mm (0.657 inch).

As a part of the verification, the brake system will be dynamically tested and must demonstrate the capability of locking all four (4) wheels and stopping the vehicle in a straight line at the end of an acceleration run, specified by the brake inspector.

To stop the vehicle, the action on brake pedal must prevail in any case over the action on the acceleration pedal.

The vehicle will be weighted as kerb weight and payload.

The load of the vehicle must be the same for all dynamic events, otherwise a penalty of 20 points for each event will be applied.

## **2.3 Dynamic Events**

**The maximum score for Dynamic Events is 800 points.**

The dynamic events are established to demonstrate the practical behaviour of the vehicle and to complement the evaluation resulting from the static events.

Vehicle systems shall have the same hardware configuration and the same load for all events, subject to check.

The development of the dynamic events will in principle take place also in case of wet ground. The organizer reserves the right to alter the conduct and scoring of the competition based on weather conditions.

**2.3.1 Classification and awarding**

Dedicated classification will be given for each dynamic event. An award certificate will be assigned to the winner of each dynamic event.

**2.3.2 Acceleration Event**

**The maximum score for Acceleration Event is 150 points.**

The acceleration event evaluates the car acceleration in a straight track on flat pavement.

**2.3.2.1 Acceleration procedure**

The car will accelerate from a standing start over a distance of 75 m (82 yards).

The foremost part of the car will be staged at 0.30 m (11.8 inches) behind the starting line.

There will be 4 accelerations runs, performed with possible involvement of two pilots, without mode restriction (electric only or hybrid). The recorded acceleration time for each team will be the average of the 4 runs.

**2.3.2.2 Acceleration scoring**

The acceleration score is based upon the corrected elapsed time. Elapsed time will be measured from the time the car crosses the starting line until it crosses the finish line.

A penalty of 2 s will be added for each cone Down Or Out (DOO), including entry and exit gate cones, that occurred on particular run, to give the corrected elapsed time.

Acceleration scoring formula:

$$\text{ACCELERATION SCORE} = 150 * \frac{(T_{\text{max}}/T_{\text{your}}) - 1}{(T_{\text{max}}/T_{\text{min}}) - 1}$$

where:

- $T_{\text{your}}$  is the average corrected elapsed time for the team
- $T_{\text{min}}$  is the minimum corrected elapsed time among the different teams
- $T_{\text{max}}$  is established as 8 s.

Negative score is considered equal 0.

**2.3.3 Autocross Event**

**The maximum score for Autocross Event is 150 points.**

The objective of the autocross event is to evaluate the car behaviour in terms of manoeuvrability and handling quality. The autocross course combines the performance features of acceleration, braking and cornering in one event.

Autocross course specification is the same as for 2009 Formula Hybrid USA Rules (see PDF file) with possible adaptation to the specific characteristics of the proving ground.

The circuit is to be run by one team a time with a total 4 laps. After the first 2 laps, an interval of maximum three minutes is available to continue for the further 2 laps, with the same or another driver.

$$\text{AUTOCROSS SCORE} = 150 * \frac{(T_{\max}/T_{\text{your}}) - 1}{(T_{\max}/T_{\min}) - 1}$$

where:

- $T_{\text{your}}$  is the average of the corrected elapsed time during the 4 laps
- $T_{\min}$  is the minimum corrected elapsed time among the different teams
- $T_{\max}$  is the maximum corrected elapsed time among the different teams.

Penalties: the course boundaries are defined with plastic cones. Cone DOO will be penalized 2 s each. Vehicle rollover will cause the stop of the test with disqualification of the team (score 0).

### ***2.3.4 Endurance/Energy-Economy evaluation***

**The maximum score for the Event is 100 points.**

#### **2.3.4.1 Concept**

This test is designed to evaluate the reliability and the energy efficiency.

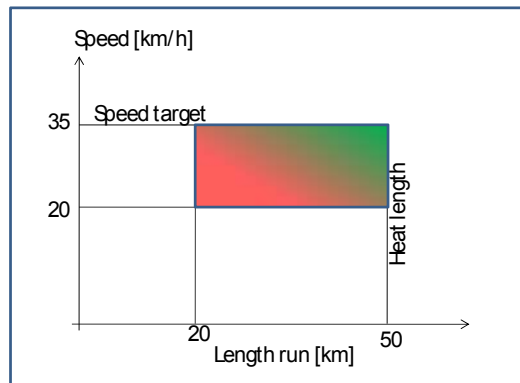
The cars will run for a distance of about 50 km (about 31 miles), to be established in accordance with the circuit configuration, starting in sequence, with appropriate intervals. The circuit will be structured to simulate an urban-suburban driving profile, including barriers and chicanes. Some uneven stretches and slow slopes could be also present in the track.

Penalty is applied in case of incomplete test; 20 km is the absolute minimum.

The cars should run at an established average speed (around 35 km/h or 22 mph) over the lap, which will be fixed in accordance with the characteristics of the circuit. A tolerance of  $\pm 3\%$  will be accepted. Over this tolerance, penalties will be applied.

A driver change can be made during a three minute period at the mid point of the heat.

Overtaking is allowed in appropriately indicated zones, under the supervision of the race controller. The running circuit, for the Energy Economy Evaluation, will include many straight line sections.



Test operation area allowed and penalty concept

### 2.3.4.2 Test procedure

The procedure is based on the following steps:

#### 1. Vehicle preparation:

BEV The battery should be fully charged

HEV For externally chargeable hybrid (plug-in) the battery should be fully charged. The fuel tank should be filled up to the reference level.  
For non externally chargeable hybrid the fuel tank should be filled up to the reference level.

FCV Take note of the initial quantity of the H<sub>2</sub> in the tank.

#### 2. Run on track for a reference distance $L_{ref}$ of about 50 km (to be established in accordance with the circuit configuration) at the target speed ( $V_{target}$ ) of about 35 km/h (which will be fixed in accordance to the characteristics of the circuit) with a tolerance of 3%. A driver change can be made during a three-minute period at the mid point of the heat.

### 2.3.4.3 Energy-Economy evaluation

The Energy Economy evaluation event intends to define:

- the Energy Economy score of the team to determine the classification score, which is related to the other teams performance
- the Specific Energy Consumption (kWh/kg\*km or l/kg\*km) referred to the test distance and the vehicle payload.

a) It aims at the definition of the CO<sub>2</sub> emission amount, produced from the primary energy source to make available electricity and fuel at the external energy supply infrastructure. This is the basis for the comparative evaluation of the various type of vehicles. The operational characterisation of the vehicle will be done in terms of CO<sub>2</sub> emission from primary energy source per distance run and vehicle payload.

b) It is intended the energy consumption referred to the run distance and the total vehicle payload and is considered as an informative parameter for the vehicle characterisation.

#### **2.3.4.4 Energy measurement**

The measurement is performed as follows:

#### **2.3.4.5 BEV**

For battery electric vehicles (BEV) the energy consumption will be measured in kWh, as the amount of electric energy supplied by the grid to bring the battery at the end of the test to the same state of charge (SOC) as at the beginning, typically fully charged.

#### **2.3.4.6 HEV**

The hybrid electric vehicles (HEV) from energy supply standpoint can be of two types: "externally chargeable" or "non external chargeable". The external chargeable cars are supplied by two sources of energy: fuel and electricity; the non externally chargeable cars are supplied only by one source of energy, that is the fuel.

For externally chargeable HEVs, the electric energy consumption will be measured as previously described for BEVs; the fuel consumption will be measured in liter, by refilling the tank up to the same level as at the beginning of the run. For this purpose, the tank should be provided by a visible inlet.

For one source of energy cars the fuel consumption will be measured in liter by refilling the tank at the end of test to the initial level and measuring the difference of the SOC of storage unit from the beginning to the end of the test.

The measurement will be done by means of an Ampere-hours meter, which will be provided by the Technical Committee. In the case of storage made with a supercapacitor, initial voltage will be measured.

The energy will be computed on the basis of the nominal characteristics of the storage system (battery voltage, supercapacitor capacitance).

The energy unbalance will be conventionally converted in fuel consumption, according to the following conversion formula: 0.27 gasoline l/kWh.

#### **2.3.4.7 FCV**

The evaluation will be done by measuring the hydrogen consumption (ref. Standard ISO 23828) at the end of test in gram of hydrogen, verifying that the powertrain storage unit (if any) is at the same SOC at the end as at the beginning of the test.

#### **2.3.4.8 Energy reference to CO<sub>2</sub>**

The energy is evaluated in terms of CO<sub>2</sub> emission at the primary energy source.

The following prospect should be used to calculate the CO<sub>2</sub> produced, starting from the primary energy source to make available electricity at the grid and the CO<sub>2</sub> produced to make available fuel at the refuelling infrastructure.

Energy source	CO <sub>2</sub> generation	
Gasoline	3.55 kg CO <sub>2</sub> /kg of fuel	2.66 kg CO <sub>2</sub> /liter of fuel (at 15° C)
Diesel	3.66 kg CO <sub>2</sub> /kg of fuel	3.00 kg CO <sub>2</sub> /liter of fuel (at 15° C)
CNG	2.84 CO <sub>2</sub> /kg of fuel	
Electricity	0.46 kg CO <sub>2</sub> /kWh	According to European mix of primary energy sources
Hydrogen	9.73 kg CO <sub>2</sub> /kg H <sub>2</sub>	According to production of H <sub>2</sub> from Natural Gas

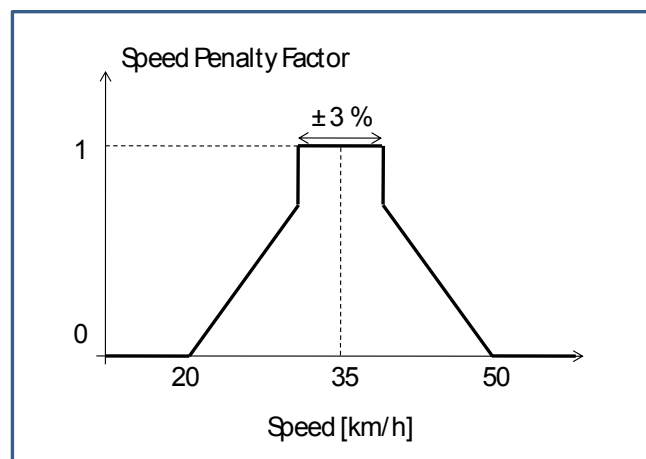
### 2.3.4.9 Scoring

The following formula will be applied:

$$\text{ENERGY ECONOMY SCORE} = 100 * \text{EnduranceFactor} * \text{EnergyFactor}$$

The EnduranceFactor is given by:

$$\text{EnduranceFactor} = \text{SpeedPenaltyFactor} * \text{HeatPenaltyFactor}$$



Speed Penalty Factor (diagram not in scale)

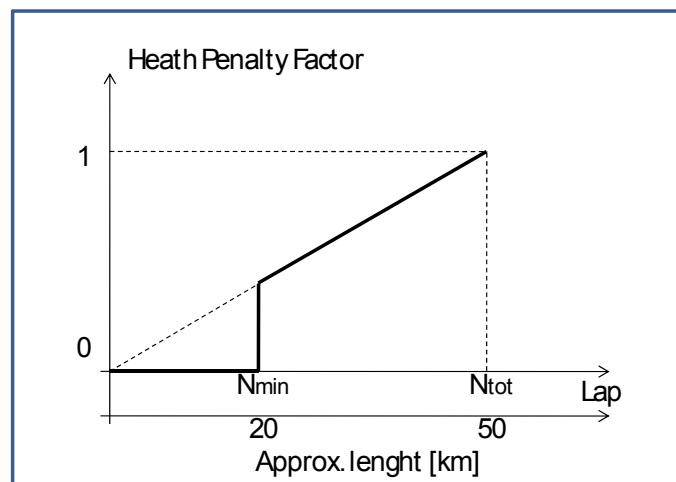
The SpeedPenaltyFactor is related to the deviation from the established running time. This deviation will be checked every given block of laps (t.b.d.) and penalties will be applied by reducing the overall score related to the blocks by the factor shown in the figure, weighted with block weight with respect the overall heat length according to the following formulas. Speed deviations will be computed on the basis of the laps run.

$$\text{SpeedPenaltyFactor}^1 = 1 - k \cdot \sum_i d_i \cdot n_i / N_{\text{tot}}$$

- $N_{\text{tot}}$ : Total number of laps
- $n_i$ : Number of the "lap-block<sub>i</sub>" laps
- $d_i$ :  $d_i = d_{\text{imeas}}$  if  $d_{\text{imeas}} > 0.03$ , otherwise  $d_i = 0$
- $d_{\text{imeas}}$ : Absolute value of the relative speed deviation related to lap-block<sub>i</sub>
- $k$ :  $v_{\text{target}} / \Delta v_{\text{max}}$  ( $v_{\text{target}} = 35$ ;  $\Delta v_{\text{max}} = 15$ )
- HeatPenaltyFactor is a factor that is less of 1 if the heat is not completed. In this case, the score is reduced proportionally to the laps run  $N$ :

$$\text{HeatPenaltyFactor} = N / N_{\text{tot}}$$

The minimum number ( $N_{\text{min}}$ ) of laps correspond to approx. 20 km. Below this length the score will be zero.



Heath Penalty Factor

The EnergyFactor is given by the formula:

$$\text{EnergyFactor} = \frac{(C_{\text{max}} / C_{\text{your}}) - 1}{(C_{\text{max}} / C_{\text{min}}) - 1}$$

<sup>1</sup> For instance, in the following case:

Total number of laps:

$$N_{\text{tot}} = 27$$

Number of laps of the "lap-blocks":

$$n_i = 9, i=1,3$$

Speed deviations related to the lap-blocks:

Measured (for instance):

$$d_{1m} = +2\%; d_{2m} = 5\%, d_{3m} = 10\%$$

Used in the penalty formula:

$$d_1 = 0\%; d_2 = 5\%, d_3 = 10\%$$

SpeedPenaltyFactor

$$= 1 - (35/15) \cdot (0 + 0.05 + 0.1) \cdot 9/27 = 0.88$$

where:

- $C_{max}$  is the maximum of the CO<sub>2</sub> emission, referred to the payload, among the participants for the complete heat
- $C_{min}$  is the lowest CO<sub>2</sub> emission, referred to the payload, among all the teams
- $C_{your}$  is the CO<sub>2</sub> emission, referred to the payload, of the team
- $C_{your} = E_{CO2-C} / (L * P_c)$
- $E_{CO2-C}$  is the CO<sub>2</sub> emission, in kg, to run the test or the estimated value of CO<sub>2</sub> emission to run the complete heat in the case the heat is not completed. In this case the estimate takes into account the additional consumption, due the additional weight (to carry an additional battery or more fuel) and to run more space<sup>2</sup>.
- L : the total distance of the event
- $P_c$  : the available payload, which will be equal to the actual payload  $P_p$ , decreased by an amount of battery/fuel weight, if the team does not complete the endurance test. The following formulas will be used:

$$P_c = P_p - \Delta P_{battery/fuel}$$

$$\Delta P_{battery/fuel} = P_{B/F} * (N_{tot} - N) / (N - N_{tot} * P_{B/F} / P_V)$$

$$E_{CO2-C} = E_{CO2} * (N_{tot} / N) * (1 + \Delta P_{battery/fuel} / P_V)$$

where:

$P_p$  : Payload, in kg, as measured in the preliminary inspection phase. Payload includes the driver and any additional mass added to increase the payload during the test

$\Delta P_{battery/fuel}$ : Additional battery/fuel weight, in kg, in the case the run is not completed

$P_{B/F}$  : Actual battery/fuel weight utilised during the run, in kg

$P_V$  : Total vehicle weight, including payload, as measured in the preliminary inspection phase, in kg

$E_{CO2}$  : CO<sub>2</sub> emission produced during the event, as calculated with the following table, referred at primary source. In the case the test is not completed, the value is corrected to take into account the additional emission to be produced to fulfil the test, giving  $E_{CO2-C}$ .

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<sup>2</sup> The formulas, that give  $\Delta P_{battery/fuel}$  and  $E_{CO2-C}$  are derived with the following hypothesis:

The specific energy consumption is constant and does not depend on battery/fuel weight:

$$E = c * P * l$$

The energy content is proportional to battery weight or fuel content:

$$E = k * P_{battery/fuel}$$

Where:

E: Energy to perform the test, running L km, with a total vehicle weight of P

c: specific energy consumption

k: energy factor for the specific energy source.

If  $P_c \leq 0$ , the score is 0.

### 2.3.4.10 Specific energy consumption

The specific energy consumption  $E_s$  is evaluated for information only.

#### **BEV**

$$E_s = \frac{E_{\text{elect}}}{P_p * L} \quad \frac{(kWh)}{(kg * km)}$$

where:

$E_{\text{elect}}$ : Electric energy (kWh) consumed from the grid plus the energy unbalance of the supercapacitor (if any, kWh)

$P_p$ : Vehicle payload

$L$ : Run length

#### **HEV**

The specific energy consumption  $E_s$  can be determined as the energy consumption in fuel and in electricity referred to the run distance, according to the formulas:

$$E_s = \frac{E_{\text{fuel}} + E_{\text{elect}}}{P_p * L} \quad \frac{(l)}{(kg * km)}$$

where:

$E_{\text{fuel}}$ : Gasoline consumed

$E_{\text{elect}}$ : Electric energy (kWh) consumed from the grid plus the energy unbalance of the supercapacitor (if any, kWh), converted to gasoline liters, assuming the conversion formula: 0,27 l gasoline/kWh

$P_p$ : Vehicle payload

$L$ : Run length.

### 2.3.5 Performance evaluation

**The maximum score for Performance Event is 350 points.**

#### 2.3.5.1 Concept

This test is addressed to the appreciation of performance and handling of the car in a circuit simulating the urban – suburban conditions and is based on the time measurement to accomplish the run, without energy consumption target constraints.

Team can recharge batteries before the run.

Every vehicle will run for a distance of about 22 km (about 13,7 miles) to be established in accordance with the circuit configuration.

Dry runs could be possible before the tests, if compatible with test schedule and track availability.

### 2.3.5.2 Scoring

The performance score is based upon the corrected elapsed time. Penalty of 2 s will be added for each cone DOO.

$$\text{PERFORMANCE SCORE} = 350 * \frac{(T_{\max}/T_{\text{your}}) - 1}{(T_{\max}/T_{\min}) - 1}$$

where:

- $T_{\min}$  is the minimum corrected elapsed time among the different teams
- $T_{\text{your}}$  is the corrected elapsed time for the team
- $T_{\max}$  is the maximum elapsed time among the different teams.

### 2.3.5.3 Interruption of the run

In case of necessity for technical problems, on either energy economy or performance evaluation, the vehicle can enter again in the competition if this can occur before last competitor team has completed the run.

### 2.3.6 Hill Starting ability

**The maximum score for Hill Starting ability is 50 points.**

#### 2.3.6.1 Concept

The test will consist of starting on a given slope and run over an established distance. The slopes and the distance to be run will be defined depending on the track characteristics.

The team should declare the slop which intends to climb and should perform the test with only one run.

In case of success, the team may repeat the run on a higher slope. In case of failure, the test may not be repeated on a slower slope.

#### 2.3.6.2 Scoring

The scoring will be based on the highest climbed slope. The points will be assigned with reference to the climbed slope<sup>3</sup>.

Before the test, the loaded vehicle will be subject to the weight check. Penalty will be given in case of non correct weight.

### 2.3.7 Pursuit Test Demonstration

An informal competition will take place at the end of the event, involving different couples of cars racing on the circuit.

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<sup>3</sup> An exemplum is here given:

Slope %	Score
8	20
12	30
16	40
20	50

Each couple will run 2 laps. The two vehicles will start from two different points of the circuit, which will be at a distance equal to about half length of the circuit; they will start at the same time; the vehicle, which will reach the finish line in the lowest amount of time (elapsed time plus possible penalties), will win the game.

The run will be repeated with reverse starting position of the vehicles.

The winner of 2 games overcomes the preliminary heat. Other preliminary heats will define the vehicles, which will compete towards the final round.

### ***2.3.8 Events and scoring summary***

Events		Maximum score (points)
Static Events	General Presentation	50
	Engineering design	150
	Total	<b>200</b>
Dynamic Events	Acceleration	150
	Autocross	150
	Endurance/Energy-Economy	100
	Performance	350
	Hill Starting Ability	50
	Pursuit Test	0
	Total	<b>800</b>
General total score		<b>1000</b>

## 3 Rules for Class 2

### 3.1 Vehicle safety

For the vehicle requirements the car construction provisions relevant to safety as reported in 2009 Formula Hybrid (USA) Rules are to be met (see PDF file).

As an alternative, the vehicle has to present construction solutions and declare that to assure an equivalent safety level.

The vehicle structure should be described and stated, for the safety related aspect, in a "Structural Equivalency Form", which can be part of the design report and should be submitted by the dead line established for the design report.

The adequacy of the safety measures to the requirement will be checked during the technical inspection.

### 3.2 Static Events

**The maximum score for the Static Events is 350 points.**

#### 3.2.1 General Presentation

**The maximum score for General Presentation is 50 points.**

The General Presentation is a room presentation of the vehicle global characteristics. The elements, that are related to the main objectives, should be put in evidence:

<u>Evaluation elements</u>	<u>Max. Score (points)</u>	
• Dynamic performance	10	
• Energy consumption, refuelling and battery charging procedures	20	
• Environmental aspects	10	
• Prototype realisation program and cost report	10	
	total	50

#### 3.2.2 Engineering Design

**The maximum score for Engineering Design is 300 points.**

The concept and architecture of the powertrain and its integration in the vehicle structure should be presented in the room or in the box, with particular respect to the following aspects:

<u>Evaluation elements</u>	<u>Max. Score (points)</u>	
	<u>Powertrain</u>	<u>Vehicle</u>
• Elements of innovation with respect to the state of the art of technology; a test of rolling resistance will be done	80	50
• Adequacy of design solution to the design rules	20	10
• Industrial aspects, including cost estimation for	30	30

the potential industrial production		
• User aspects, including: mission analysis, infrastructure requirements and estimated operating cost	20	10
• Other innovation aspects		50
	total	150
		150

A design report should be presented including drawings.

The deadline for Design Specification Sheet submission will be posted in Formula Electric and Hybrid Italy website.

### ***3.2.3 Technical inspection***

The inspection of the vehicle, to be performed by the Technical Committee, aims to verify the consistency with the basic requirements and the general adequacy of the vehicle to perform the dynamic events.

The positive result of the technical inspection is a prerequisite for performing the dynamic tests.

The Team might be requested to demonstrate the compliance of the powertrain with the prescribed displacement limits through appropriate documentation and declaration.

As for as the Engine is concerned, the prescriptions reported in 2009 Formula Hybrid USA Rules (see PDF file) are to be met, including Engine Limitation and Throttle Actuation and Intake Restrictor,

The diameter of the circular restrictor must be:

- Gasoline fuelled cars – 12.9 mm (0.508 inch)
- E-85 fuelled cars – 12.3 mm (0.483 inch)
- Diesel fuelled cars – no inlet restrictor required
- LPG fuelled cars – 13.4 mm (0.527 inch)
- CNG fuelled cars – 13.8 mm (0.543 inch)
- Hydrogen fuelled cars – 16.7 mm (0.657 inch)

As a part of the verification, the brake system will be dynamically tested and must demonstrate the capability of locking all four (4) wheels and stopping the vehicle in a straight line at the end of an acceleration run specified by the brake inspector.

To stop the vehicle, the action on brake pedal must prevail in any case over the action on the acceleration pedal.

The vehicle will be weighted as kerb weight and payload.

The load of the vehicle must be the same or all dynamic events, otherwise a penalty of 20 points for each event will be applied.

## **3.3 Dynamic Events**

**The maximum score for Dynamic Events is 650 points.**

The dynamic events are established to demonstrate the practical behaviour of the vehicle and to complement the evaluation resulting from the static events.

Vehicle systems shall have the same hardware configuration and the same load for all events, subject to check.

The development of the dynamic events will in principle take place also in case of wet ground. The organizer reserves the right to alter the conduct and scoring of the competition based on weather conditions.

### ***3.3.1 Classification and awarding***

Dedicated classification will be given for each dynamic event. An award certificate will be assigned to the winner of each dynamic event.

### ***3.3.2 Acceleration Event***

**The maximum score for Acceleration Event is 100 points.**

The acceleration event evaluates the car acceleration in a straight track on flat pavement.

#### **3.3.2.1 Acceleration procedure**

The car will accelerate from a standing start over a distance of 75 m (82 yards).

The foremost part of the car will be staged at 0.30 m (11.8 inches) behind the starting line.

There will be 4 accelerations runs, performed with possible involvement of two pilots, without mode restriction (electric only or hybrid). The recorded acceleration time for each team will be the average of the 4 runs.

#### **3.3.2.2 Acceleration scoring**

The acceleration score is based upon the corrected elapsed time. Elapsed time will be measured from the time the car crosses the starting line until it crosses the finish line.

A penalty of 2 s will be added for each Cone Down Or Out (DOO), including entry and exit gate cones, that occurred on particular run, to give the corrected elapsed time.

Acceleration scoring formula:

$$\text{ACCELERATION SCORE} = 100 * \frac{(T_{\max}/T_{\text{your}}) - 1}{(T_{\max}/T_{\min}) - 1}$$

where:

- $T_{\text{your}}$  is the average corrected elapsed time for the team
- $T_{\min}$  is the minimum corrected elapsed time among the different teams
- $T_{\max}$  is established as 8 s.

Negative score is considered equal 0.

### ***3.3.3 Autocross Event***

**The maximum score for Autocross Event is 100 points.**

The objective of the autocross event is to evaluate the car behaviour in terms of manoeuvrability and handling quality. The autocross course combines the performance features of acceleration, braking and cornering in one event.

Autocross course specification is the same as for 2009 Formula Hybrid USA Rules (see PDF file) with possible adaptation to the specific characteristics of the proving ground. The circuit is to be run by one team a time with a total 4 laps. After the first 2 laps, an interval of maximum three minutes is available to continue for the further 2 laps with the same or another driver.

$$\text{AUTOCROSS SCORE} = 100 * \frac{(T_{\text{max}}/T_{\text{your}}) - 1}{(T_{\text{max}}/T_{\text{min}}) - 1}$$

where:

- $T_{\text{your}}$  is the average of the corrected elapsed time during the 4 laps
- $T_{\text{min}}$  is the minimum corrected elapsed time among the different teams
- $T_{\text{max}}$  is the maximum corrected elapsed time among the different teams

Penalties: the course boundaries are defined with plastic cones. Cone DOO will be penalized 2 s each. Vehicle rollover will cause the stop of the test with disqualification of the team (score 0).

**3.3.4 Endurance/Energy-Economy evaluation**

**The maximum score for the Event is 250 points.**

**3.3.4.1 Concept**

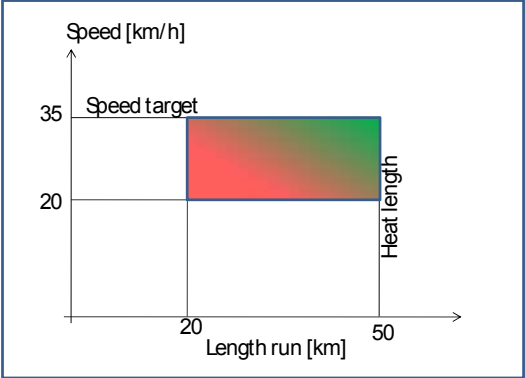
This test is designed to evaluate the reliability and the energy efficiency. Some unevenness and low slopes could be also present in the track. The cars will run for a distance of about 50 km (about 31 miles), to be established in accordance with the circuit configuration, starting in sequence, with appropriate intervals. The circuit will be structured to simulate an urban-suburban driving profile including barriers and chicanes. Some uneven stretches and slow slopes could be also present in the track.

Penalty is applied in case of incomplete test; 20 km is the absolute minimum.

The cars should run at an established average speed (around 35 km/h or 22 mph) over the lap, which will be fixed in accordance with the characteristics of the circuit. A tolerance of ± 3% will be accepted. Over this tolerance, penalties will be applied.

A driver change can be made during a three-minute period at the mid point of the heat.

Overtaking is allowed in appropriately indicated zones, under the supervision of the race controller. The running circuit, for the Energy Economy Evaluation, will include many straight line sections.



### 3.3.4.2 Test procedure

The procedure is based on the following steps:

1. Vehicle preparation:

- |     |   |
|-----|---|
| BEV | The battery should be fully charged   |
| HEV | For externally chargeable hybrid (plug-in) the battery should be fully charged. The fuel tank should be filled up to the reference level<br>For non externally chargeable hybrid the fuel tank should be filled up to the reference level |
| FCV | Take note of the initial quantity of the H <sub>2</sub> in the tank.  |

2. Run on track for a reference distance  $L_{ref}$  of about 50 km (to be established in accordance with the circuit configuration) at the target speed ( $V_{target}$ ) of about 35 km/h (which will be fixed in accordance to the characteristics of the circuit) with a tolerance of 3 %. A driver change can be made during a three-minute period at the mid point of the heat.

### 3.3.4.3 Energy-Economy evaluation

The Energy Economy evaluation event intends to define:

- a) the Energy Economy score of the team to determine the classification score, which is related to the other teams performance
- b) the Specific Energy Consumption (kWh/kg\*km or l/kg\*km) referred to the test distance and the vehicle payload.
  - a) It aims at the definition of the CO<sub>2</sub> emission amount, produced from the primary energy source to make available electricity and fuel at the external energy supply infrastructure. This is the basis for the comparative evaluation of the various type of vehicles. The operational characterisation of the vehicle will be done in terms of CO<sub>2</sub> emission from primary energy source per distance run and vehicle payload.
  - b) It is intended the energy consumption referred to the run distance and the total vehicle payload and is considered as an informative parameter for the vehicle characterisation.

### 3.3.4.4 Energy measurement

The measurement is performed as follows:

#### 3.3.4.5 BEV

For battery electric vehicles (BEV) the energy consumption will be measured in kWh, as the amount of electric energy supplied by the grid to bring the battery at the end of the test to the same state of charge (SOC) as at the beginning, typically fully charged.

#### 3.3.4.6 HEV

The hybrid electric vehicles (HEV) from energy supply standpoint can be of two types: "externally chargeable" or "non externally chargeable". The externally

chargeable cars are supplied by two sources of energy: fuel and electricity; the non externally chargeable cars are supplied only by one source of energy, that is the fuel.

For externally chargeable HEVs, the electric energy consumption will be measured as previously described for BEVs; the fuel consumption will be measured in liter, by refilling the tank up to the same level as at the beginning of the run. For this purpose, the tank should be provided by a visible inlet.

For one source of energy cars the fuel consumption will be measured in liter by refilling the tank at the end of test to the initial level and measuring the difference of the SOC of storage unit from the beginning to the end of the test.

The measurement will be done by means of an Ampere-Hours meter, which will be provided by the Technical Committee. In the case of storage made with a supercapacitor, initial voltage will be measured.

The energy will be computed on the basis of the nominal characteristics of the storage system (battery voltage, supercapacitor capacitance).

The energy unbalance will be conventionally converted in fuel consumption, according to the following conversion formula: 0.27 gasoline l/kWh.

#### **3.3.4.7 FCV**

The evaluation will be done by measuring the hydrogen consumption (ref. Standard ISO 23828) at the end of test in gram of hydrogen, verifying that the powertrain storage unit (if any) is at the same SOC at the end as at the beginning of the test.

#### **3.3.4.8 Energy reference to CO<sub>2</sub>**

The energy is evaluated in terms of CO<sub>2</sub> emission at the primary energy source.

The following prospect should be used to calculate the CO<sub>2</sub> produced, starting from the primary energy source to make available electricity at the grid and the CO<sub>2</sub> produced to make available fuel at the refuelling infrastructure.

Energy source	CO <sub>2</sub> generation	
Gasoline	3.55 kg CO <sub>2</sub> /kg of fuel	2.66 kg CO <sub>2</sub> /liter of fuel (at 15° C)
Diesel	3.66 kg CO <sub>2</sub> /kg of fuel	3.00 kg CO <sub>2</sub> /liter of fuel (at 15° C)
CNG	2.84 CO <sub>2</sub> /kg of fuel	
Electricity	0.46 kg CO <sub>2</sub> /kWh	According to European mix of primary energy sources
Hydrogen	9.73 kg CO <sub>2</sub> /kg H <sub>2</sub>	According to production of H <sub>2</sub> from Natural Gas

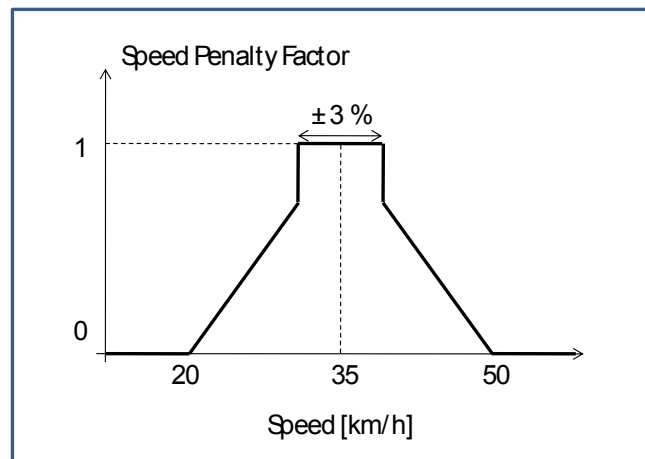
### 3.3.4.9 Scoring

The following formula will be applied:

$$\text{ENERGY ECONOMY SCORE} = 250 * \text{EnduranceFactor} * \text{EnergyFactor}$$

The EnduranceFactor is given by:

$$\text{EnduranceFactor} = \text{SpeedPenaltyFactor} * \text{HeathPenaltyFactor}$$



Speed Penalty Factor (diagram not in scale)

The SpeedPenaltyFactor is related to the deviation from the established running time. This deviation will be checked every given block of laps (t.b.d.) and penalties will be applied by reducing the overall score related to the blocks by the factor shown in the figure, weighted with block weight with respect the overall heat length according to the following formulas. Speed deviations will be computed on the basis of the laps run.

$$\text{SpeedPenaltyFactor}^4 = 1 - k * \sum_i d_i * n_i / N_{\text{tot}}$$

- $N_{\text{tot}}$ : Total number of laps
- $n_i$ : Number of the "lap-block<sub>i</sub>" laps
- $d_i$ :  $d_i = d_{\text{imeas}}$  if  $d_{\text{imeas}} > 0.03$ , otherwise  $d_i = 0$
- $d_{\text{imeas}}$ : Absolute value of the relative speed deviation related to lap-block<sub>i</sub>
- $k$ :  $v_{\text{target}} / \Delta v_{\text{max}}$  ( $v_{\text{target}} = 35$ ;  $\Delta v_{\text{max}} = 15$ )
- HeatPenaltyFactor is a factor that is less of 1 if the heat is not completed. In this case, the score is reduced proportionally to the laps run N:

$$\text{HeatPenaltyFactor} = N / N_{\text{tot}}$$

<sup>4</sup> For instance, in the following case:

Total number of laps:

$$N_{\text{tot}} = 27$$

Number of laps of the "lap-blocks":

$$n_i = 9, i=1,3$$

Speed deviations related to the lap-blocks:

Measured (for instance):

$$d_{1m} = +2\%; d_{2m} = 5\%, d_{3m} = 10\%$$

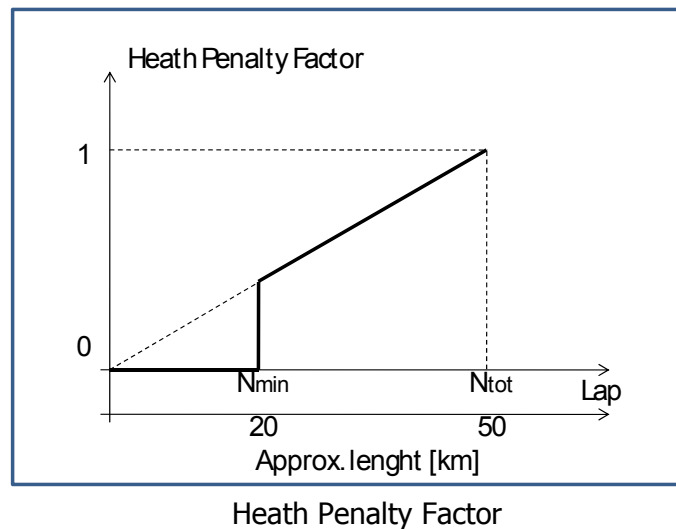
Used in the penalty formula:

$$d_1 = 0\%; d_2 = 5\%, d_3 = 10\%$$

SpeedPenaltyFactor

$$= 1 - (35/15) * (0 + 0.05 + 0.1) * 9/27 = 0.88$$

The minimum number ( $N_{min}$ ) of laps correspond to approx. 20 km. Below this length the score will be zero.



The EnergyFactor is given by the formula:

$$\text{EnergyFactor} = \frac{(C_{max}/C_{your}) - 1}{(C_{max}/C_{min}) - 1}$$

where:

- $C_{max}$  is the maximum of the CO<sub>2</sub> emission, referred to the payload, among the participants for the complete heat
- $C_{min}$  is the lowest CO<sub>2</sub> emission, referred to the payload, among all the teams
- $C_{your}$  is the CO<sub>2</sub> emission, referred to the payload, of the Team
- $C_{your} = E_{CO_2-C} / (L * P_c)$
- $E_{CO_2-C}$  is the CO<sub>2</sub> emission, in kg, to run the test or the estimated value of CO<sub>2</sub> emission to run the complete heat in the case the heat is not completed. In this case the estimate takes into account the additional consumption due the additional weight (to carry an additional battery or more fuel) and to run more space<sup>5</sup>.
- L: the total distance of the event

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<sup>5</sup> The formulas that give  $\Delta P_{battery/fuel}$  and  $E_{CO_2-C}$  are derived with the following hypothesis:

The specific energy consumption is constant and does not depend on battery/fuel weight:

$$E = c * P * L$$

The energy content is proportional to battery weight or fuel content:

$$E = k * P_{battery/fuel}$$

Where:

E: Energy to perform the test, running L km, with a total vehicle weight of P

c: specific energy consumption

k: energy factor for the specific energy source.

- $P_c$ : the available payload, which will be equal to the actual payload  $P_p$ , decreased by an amount of battery/fuel weight, if the Team does not complete the endurance test. The following formulas will be used:

$$P_c = P_p - \Delta P_{\text{battery/fuel}}$$

$$\Delta P_{\text{battery/fuel}} = P_{B/F} * (N_{\text{tot}} - N) / (N - N_{\text{tot}} * P_{B/F} / P_V)$$

$$E_{\text{CO2-C}} = E_{\text{CO2}} * (N_{\text{tot}} / N) * (1 + \Delta P_{\text{battery/fuel}} / P_V)$$

where:

$P_p$  : Payload, in kg, as measured in the preliminary inspection phase. Payload includes the driver and any additional mass added to increase the payload during the test.

$\Delta P_{\text{battery/fuel}}$ : Additional battery/fuel weight, in kg, in the case the run is not completed.

$P_{B/F}$  : Actual Battery/fuel weight utilised during the run, in kg

$P_V$  : Total vehicle weight, including payload, as measured in the preliminary inspection phase, in kg

$E_{\text{CO2}}$  :  $\text{CO}_2$  emission produced during the event, as calculated with the following table, referred at primary source. In the case the test is not completed, the value is corrected to take into account the additional emission to be produced to fulfil the test, giving  $E_{\text{CO2-C}}$ .

If  $P_c \leq 0$ , the score is 0.

### 3.3.4.10 Specific energy consumption

The specific energy consumption  $E_s$  is evaluated for information only.

#### **BEV**

$$E_{S=} = \frac{E_{\text{elect}}}{P_p * L} \quad \frac{(kWh)}{(t * km)}$$

where:

$E_{\text{elect}}$ : Electric energy (kWh) consumed from the grid plus the energy unbalance of the supercapacitor (if any, kWh)

$P_p$ : Vehicle payload

$L$ : Run length.

#### **HEV**

The specific energy consumption  $E_s$  can be determined as the energy consumption in fuel and in electricity referred to the run distance, according to the formulas:

$$E_{S=} = \frac{E_{\text{fuel}} + E_{\text{elect}}}{P_p * L} \quad \frac{(l)}{(kg * km)}$$

where:

$E_{\text{fuel}}$ : Gasoline consumed

- $E_{\text{elect}}$ : Electric energy (kWh) consumed from the grid plus the energy unbalance of the supercapacitor (if any, kWh), converted to gasoline liters, assuming the conversion formula: 0,27 l gasoline/kWh
- $P_p$ : Vehicle payload
- L: Run length.

### **3.3.5 Performance evaluation**

**The maximum score for Performance Event is 150 points.**

#### **3.3.5.1 Concept**

This test is addressed to the appreciation of performance and handling of the vehicle in a circuit simulating the urban – suburban conditions and is based on the time measurement to accomplish the run, without energy consumption target constraints.

Team can recharge batteries before the run.

Every vehicle will run for a distance of about 22 km (about 13,7 miles) to be established in accordance with the circuit configuration.

Dry runs could be possible before the tests, if compatible with test schedule and track availability.

#### **3.3.5.2 Scoring**

The performance score is based upon the corrected elapsed time. Penalty of 2 s will be added for each cone DOO.

$$\text{PERFORMANCE SCORE} = 150 * \frac{(T_{\text{max}}/T_{\text{your}}) - 1}{(T_{\text{max}}/T_{\text{min}}) - 1}$$

where

- $T_{\text{min}}$  is the minimum corrected elapsed time among the different teams
- $T_{\text{your}}$  is the corrected elapsed time for the team
- $T_{\text{max}}$  is the maximum elapsed time among the different teams

#### **3.3.5.3 Interruption of the run**

In case of necessity for technical problems, on either energy economy or performance evaluation, the vehicle can enter again in the competition if this can occur before last competitor team has completed the run.

### **3.3.6 Hill Starting ability**

**The maximum score for Hill Starting ability Event is 50 points.**

#### **3.3.6.1 Concept**

The test will consist of starting on a given slope and run over an established distance. The slopes and the distance to be run will be defined depending on the track characteristics.

The team should declare the slop which intends to climb and should perform the test with only one run.

In case of success, the team may repeat the run on a higher slope. In case of failure, the test may not be repeated on a slower slope.

### 3.3.6.2 Scoring

The scoring will be based on the highest climbed slope. The points will be assigned with reference to the climbed slope<sup>6</sup>.

Before the test, the loaded vehicle will be subject to the weight check. Penalty will be given in case of non correct weight.

### 3.3.7 Pursuit Test Demonstration

An informal competition will take place at the end of the event, involving different couples of vehicles racing on the circuit.

Each couple will run 2 laps. The two vehicles will start from two different points of the circuit, which will be at a distance equal to about half length of the circuit; they will start at the same time; the vehicle, which will reach the finish line in the lowest amount of time (elapsed time plus possible penalties), will win the game.

The run will be repeated with reverse starting position of the vehicles.

The winner of 2 games overcomes the preliminary heat. Other preliminary heats will define the vehicles, which will compete towards the final round.

### 3.3.8 Events and scoring summary

Events		Maximum score (points)
Static Events	General Presentation	50
	Engineering design	300
	Total	<b>350</b>
Dynamic Events	Acceleration	100
	Autocross	100
	Endurance/Energy-Economy	250
	Performance	150
	Hill Starting Ability	50
	Pursuit Test	0
	Total	<b>650</b>
General total score		<b>1000</b>

<sup>6</sup> An exemplum is here given:

Slope %	Score
8	20
12	30
16	40
20	50

## 4 Rules for Class 3

**The maximum score will be 80 points.**

Static vehicles concepts, Systems and Components will be object of static events: room presentation and demonstration in the box.

The demonstration should address the energy efficiency and the performance with procedure based on relevant standards and system features.

The evaluation will take into account the merits related to the following aspects:

Evaluation elements	Max. Score (points)
<hr/>	
General presentation	
<hr/>	
• Dynamic performance	10
• Energy consumption, refuelling and battery charging procedures	10
• Environmental aspects	10
• Prototype realisation program and cost report	10
total	40
<hr/>	
Engineering design	
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• Elements of innovation with respect to the state of the art of technology	10
• Adequacy of design solution to the design rules	10
• Industrial aspects, including cost estimation for the potential industrial production	10
• User aspects, including: mission analysis, infrastructure requirements and estimated operating cost	10
total	40
<hr/>	
total	80
<hr/>	