12/12-10-96 JSD

1997 Hybrid Electric Vehicle Specifications

**Center for Transportation Research
Argonne National Laboratory**

Operated by The University of Chicago,
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United States Department of Energy

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ANL/ESD/TM-136

1997 Hybrid Electric Vehicle Specifications

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by S. Sluder, R. Larsen, and M. Duoba

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October 1996

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Work sponsored by the United States Department of Energy,
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1997 HYBRID ELECTRIC VEHICLE SPECIFICATIONS

by S. Sluder, R. Larsen, and M. Duoba

1 INTRODUCTION

The U.S. Department of Energy (DOE), through Argonne National Laboratory, sponsors Advanced Vehicle Technology Competitions to help educate the public and advance new vehicle technologies. For several years, DOE has provided financial and technical support for the American Tour de Sol. This event, organized by the Northeast Sustainable Energy Association (NESEA), showcases electric and hybrid electric vehicles in a road rally across portions of the northeastern United States.

The specifications contained in this technical memorandum apply to vehicles that will be entered in the 1997 American Tour de Sol. However, the specifications were prepared to be general enough for use by other teams and individuals interested in developing hybrid electric vehicles. The purpose of the specifications is to ensure that the vehicles developed do not present a safety hazard to the teams that build and drive them or to the judges, sponsors, or public who attend the competitions. The specifications are by no means the definitive source of information on constructing hybrid electric vehicles — as electric and hybrid electric vehicle technologies advance, so will the standards and practices for their construction. In some cases, the new standards and practices will make portions of these specifications obsolete.

2 ADMINISTRATION

2.1 LISTSERVER E-MAIL

The listserver electronic mail (e-mail) list is the primary method for asking questions about the *1997 Hybrid Electric Vehicle Specifications* and data acquisition systems (replacing the BBS from previous competitions). To become a subscriber, send an e-mail message to the following address:

`majordomo@anl.gov`

The following words (which are case-sensitive) should appear in the text body (not the subject line):

`SUBSCRIBE ATDS_hybrids`

You will receive a message indicating that you are a subscriber. Thereafter, send messages to the following address:

`atds_hybrids@anl.gov`

Messages sent to this address are automatically forwarded to all subscribers. More than one person per team can subscribe. If a response is needed right away, teams may also contact Argonne National Laboratory by phone at the number provided in Section 1.2. All messages are filed at the following URL address:

`gopher://gopher.ctd.anl.gov:70/11/ANL_Computing_info/ANL_newsgroup_archives/atds`

2.2 TELEPHONE, FAX, AND MAILING ADDRESS FOR ARGONNE NATIONAL LABORATORY

- The telephone number is: (630) 252-6489
- The official telephone fax number is: (630) 252-3443

The mailing address is:

American Tour de Sol
c/o Scott Sluder
Argonne National Laboratory
9700 South Cass Avenue, ESD/362-C264
Argonne, IL 60439-4815

2.3 APPLICATION OF SPECIFICATIONS

The specifications, as set forth in this document (to be known as *1997 Hybrid Electric Vehicle Specifications* or the Specifications), shall apply to the 1997 American Tour de Sol.

2.3.1 Effective Date of Specifications

The Specifications become effective immediately and replace any previously released drafts.

2.3.2 Right to Revise

The Organizers reserve the right to revise the Specifications at any time. Participants in the American Tour de Sol will be notified of changes via the listserver e-mail system, as well as in writing in the form of newsletters. A final version of the regulations and any changes will be sent out prior to the competition.

2.3.3 Acceptance of Specifications

All persons and groups selected to participate in the American Tour de Sol should be familiar with the Specifications. Participation in the American Tour de Sol shall constitute acceptance of the Specifications.

3 VEHICLE REQUIREMENTS AND SAFETY SPECIFICATIONS

All competition vehicles will be inspected for compliance with the following Specifications. Restrictions must be set to ensure that the competition is safe and enjoyable for all participants and to maintain a relative equality among teams and vehicles. All efforts have been taken to minimize the impact of these Specifications on creativity.

3.1 BODY AND CHASSIS

3.1.1 Body and Chassis Section Definitions

To prevent confusion, certain terms used throughout this section are defined below. For consistency, please use these terms when communicating with the Organizers and with other teams.

3.1.1.1 Vehicle Structure

Vehicle structure is defined as the structural part of the vehicle that bears loading from the suspension mounting points or provides structural stiffness for the vehicle and crash protection by energy absorption.

3.1.1.2 Passenger Compartment

This space encompasses the seating area plus any compartment or volume that is in contact with the passenger airspace. The trunk is part of the passenger compartment *unless* an airtight bulkhead is added behind the rear seats to protect the passenger compartment.

3.1.1.3 Ramp Angle

This term refers to the plane formed between the contact patch of the tires and the farthest point of the vehicle structure (usually the bumper).

3.1.2 Wheelbase, Track Width

For conversion vehicles, no modifications to the wheelbase or track width are allowed except small changes associated with replacement tires or rims. Purpose-built ("ground-up")

vehicles must have a wheelbase of at least 216 cm (85 in.) and a track width of at least 127 cm (50 in.).

3.1.3 Ground Clearance and Ramp Angle

The running ground clearance may be reduced to a minimum of 127 mm (5 in.). Also, if the vehicle has four flat tires, it must still clear the ground. The ramp angles (both front and rear) of the vehicle must not be reduced by the placement of added components without the explicit approval of the Organizers. Purpose-built vehicles must have a minimum ramp angle of 12°. The lowest point of the vehicle must be a structural or sturdy component that, upon impact with ground features, will not cause a hazardous situation (e.g., a discharge of parts and/or fluid) or electrical shorts or ground faults.

3.1.4 Modifications to Chassis

3.1.4.1 Structure

The critical structure of the vehicle must remain intact; however, modifications to chassis sheet metal for component packaging are allowed. Rare exceptions for modifications to the critical structure may be allowed if the plan demonstrates that the alteration will not compromise vehicle safety. Modifications to critical areas must be approved by the Organizers *in advance of the competition*.

3.1.4.2 Body Sheet

The outer body skin sheet metal may be modified for the purposes of venting, controlling aerodynamic airflow, and reducing weight. Teams have the freedom to make small changes to the general body shape within the following constraints:

- The changes must not affect the crashworthiness of the vehicle.
- The size, angle, and configuration of the windshield and side windows must remain identical to those of the stock vehicle. (The rear window may be modified for improved aerodynamics.)
- The head lamp location must remain identical to that of the stock vehicle.
- Belly pans may be used to smooth airflow under the vehicle, but they must not impair vehicle operation (e.g., suspension movement and steering) in any manner or allow fluids to collect under the engine and transmission.

- Purpose-built vehicles must not be longer than 508 cm (200 in.), not wider than 190 cm (75 in.), and not higher (excluding antenna) than 152 cm (60 in.). Front and rear overhangs must not exceed 102 cm (40 in.).
- Vehicles must have a full floor closeout panel to separate the occupants from the road. The floor panel must be substantial enough to protect the occupants from road debris.

3.1.4.3 Vehicle Windows and Wipers

The windshield may not be removed or replaced with a lighter component. Any windows, aside from the windshield, may be replaced with laminated safety glass or 0.125-in.-minimum-thickness, shatter-resistant plastic. The windshield wipers cannot be modified. For purpose-built vehicles, shatter-resistant plastic may be used for windshields provided that the plastic is at least 6.5 mm (0.25 in.) thick. Purpose-built vehicles must be equipped with a mechanical means of clearing the windshield (windshield wipers.)

3.1.4.4 Occupant Visibility

Tinting, shading, or any process that alters the transmission of light through the glass to a greater extent than that applied or installed as standard equipment by an original equipment manufacturer (OEM) is prohibited. Decals, graphics, or lettering may not be placed on any window, except on the top 10 cm (3.93 in.) of the windshield, provided that visibility is not impaired. For purpose-built vehicles, the eyes of a driver sitting in the normal driving position (hands on steering wheel, seat back reclined as desired, eyes looking straight ahead) at a height of 87.8 cm (35.5 in.) must be at least 100 cm (39 in.) above a horizontal plane defined by the contact patch of the tires. The driver must be able to see a point on the ground 9.2 m (30 ft) ahead of the front bumper of the vehicle and the top of a target that is 7.3 m (24 ft) high and 27.5 m (90 ft) ahead of the front bumper.

3.1.4.5 Mirrors

All vehicles must have adjustable, central rear-view and right- and left-hand side-view mirrors that can be adjusted for use by all drivers. If the OEM mirrors are replaced, the replacement mirrors must meet the following criteria:

- The driver can see headlamps that are 0.61 m (2 ft) above the ground and 15.25 m (50 ft) behind the rear bumper of the vehicle.

- With the driver's mirrors in a fixed position, a small vehicle passing on either side of the driver should never completely disappear from the driver's direct or peripheral view when the passing vehicle is on a parallel path 3.7 m (12 ft) away (measured between the vehicle centerlines). The driver's head rotation is limited to that necessary to look directly at the side-view mirrors.
- A pedestrian must not be hidden from view by either A-pillar when the pedestrian is walking along a path that is 7.3 m (24 ft) either to the left or the right from the centerline of the vehicle, starts even with the front bumper, and extends 7.3 m (24 ft) ahead. The driver is allowed lateral head movement of 5 cm (2 in.) left or right.
- If a convex mirror is used, the average radius of curvature may not be less than 90 cm (35 in.) and not more than 165 cm (65 in.). In addition, the mirror must be permanently marked at the lower edge of its reflective surface, in letters measuring not less than 0.48 cm (3/16 in.) and not more than 0.64 cm (1/4 in.) high, with the words "Objects in Mirror are Closer Than They Appear."

3.1.4.6 External Lighting

The lighting equipment specified in Table 1 must be mounted rigidly and securely on the vehicle according to the requirements listed in Table 2. Visibility or function of the lamps must not be obstructed or impaired by other parts of the vehicle. All lamps must have Society of Automotive Engineers/U.S. Department of Transportation (SAE/DOT) markings indicating compliance with Federal Motor Vehicle Safety Standards (FMVSS)/SAE standards, or have documented equivalent illumination. This equipment may include OEM lamps from any passenger car sold in the United States or Canada and/or aftermarket lamps including sealed beam headlamps and signal lamps sold for trailers.

3.1.4.7 Weatherproofing

It is each team's responsibility to ensure that the vehicle body provides protection from inclement weather for all sensitive components. All events will be held rain or shine.

TABLE 1 Required Lighting Equipment

Item	Number and Color	Applicable SAE Standard
Headlamps	2 white	J579, Dec. 1984 J580, Dec. 1986 J383, April 1985
Tail lamps	2 red	J585e, Sept. 1977
Stop lamps	2 red	J586c, Aug. 1970
High-mounted stop lamp	1 red	J186a, Sept. 1977
Backup lamp (reverse)	1 (or more) white	J593c, Feb. 1968
Turn signal lamps	2 amber (front) 2 red or amber (rear)	J588e, Sept. 1970
Turn signal operating unit	1	J589, April 1964
Turn signal flasher	1	J590b, Oct. 1965
Vehicle hazard warning signal operating unit	1	J910, Jan. 1966
Vehicle hazard warning signal operating unit	1	J945, Feb. 1966

3.1.5 Interior

3.1.5.1 Occupant Safety Equipment

Safety helmets with a rating of Snell M85 or better must be worn during some of the competition events. Fire-resistant suits are recommended but not required. Fire-resistant suits should be constructed of one of the following materials: Nomex, Kevlar, PBI, Kynol, FPT, IWS (wool), fiberglass, Durette, or Fypro.

3.1.5.2 Fire Protection

Vehicles must be equipped with an on-board, remote-operated (active or passive) fire-extinguishing system consisting of at least 5 lb of 1211 or 1301 halon (or equivalent environmentally friendly, approved substitute). The system must be sized and configured to adequately cover the engine compartment and battery box(es).

TABLE 2 Locations of Required Lighting Equipment

Item	Location	Height ^a
Headlamps	On the front, each headlamp providing the upper beam, at the same height, one on each side of vertical centerline; each headlamp providing the low beam, at the same height, one on each side of the centerline and as far apart as practical	Not less than 55.9 cm (22 in.), not more than 137.2 cm (54 in.)
Tail lamps	On the rear, one on each side of the vertical centerline, at the same height, and as far apart as practical	Not less than 38.1 cm (15 in.), not more than 182.9 cm (72 in.)
Stop lamps	On the rear, one on each side of the vertical centerline, at the same height, and as far apart as practical	Not less than 38.1 cm (15 in.), not more than 182.9 cm (72 in.)
High-mounted stop lamp	On the rear on vertical centerline	Not lower than 7.6 cm (3 in.) below rear window
Backup lamp (reverse)	On the rear	No requirement
Turn signal lamps	At or near the rear, one red or amber on each side of the vertical centerline, at the same height, and as far apart as practical	Not less than 38.1 cm (15 in.), not more than 210.8 cm (83 in.)
	At or near the front, one amber on each side of the vertical centerline, at the same height, and as far apart as practical	Not less than 38.1 cm (15 in.), not more than 210.8 cm (83 in.)

^aAbove road surface, measured from center of item on vehicle, at competition weight.

3.1.5.3 Roll Cage

All purpose-built vehicles must be equipped with a roll cage constructed of mild or alloy steel with an outer diameter measuring at least 3.5 cm and with a nominal wall thickness of 0.30 cm. Teams wishing to use other materials must present detailed drawings and documentation of strength equivalent to the requirement in advance of the competition for approval by ANL. All vehicles equipped with a roll cage must have foam padding to a depth of 2.54 cm (1 in.) covering all areas of the roll cage that might contact the driver or passengers during normal operation. No roll cage members should be closer than 5.08 cm (2 in.) to the helmeted head of the driver or any passenger.

3.1.5.4 Vehicle Egress

Modifications to the seats, door handles, latches, seat belts, etc., should not in any way or in any situation impede occupant egress. Occupants must be able to make an unassisted exit from the vehicle in less than seven seconds.

3.1.5.5 Seating Capacity

Vehicles must be able to seat at least two passengers including the driver. Seat belts must be retained unless five-point safety harnesses have been properly installed. (Some states do not allow five-point harnesses. Entries from these states should document this fact and install three-point standard seat belts.) Occupants must not be subjected to any vehicle modifications that compromise their safety or comfort.

3.1.5.6 Instrument Panel

The instrument panel, gauges, and control dials and switches may be altered to suit the needs or tastes of the teams.

3.1.5.7 Dashboard

The stock dashboard may not be altered in any way that may render occupant crash protection less effective. Small cosmetic changes or emblems may be added. Because they provide critical crash protection, the dash and instrument panel should not be considered for vehicle weight reduction.

3.1.5.8 Seats

The seats may be replaced by prototype or other "high-tech" seats, if the seating position and location are identical to those of the stock vehicle and the seats are as strong or stronger than the original seats. The padding on the back of the front seats must prevent injuries to rear occupants like the original seats do. If the stock seats are retained, the original seat belts must be used and should remain in the same position and employ the original mounts. If the seats are replaced, five-point safety harnesses must be used in place of the original seat belts. (Except in states where five-point harnesses are illegal. See Section 3.1.5.5.) Each of the harness straps must be firmly secured to the structure of the vehicle.

3.1.5.9 Doors

Teams must not alter the side-impact structure or energy-absorbing padding without explicit approval from the Organizers.

3.1.5.10 Other Interior Modifications

With the exception of the above-mentioned items, the interior of the vehicles may be modified. The resulting interior will be scrutinized for appearance and consumer acceptability. Sufficient padding in and on the back of seats should not be overlooked. Sharp edges or loose panels are not acceptable.

3.1.6 Vehicle Graphics and Decals

3.1.6.1 Graphics and Lettering Size

Other than vehicle numbers, school name, fuel-type lettering, and competition logo, no lettering may be more than 8 cm (3.1 in.) high. In addition, no lettering or graphics may be greater than 1,045 cm² (162 in.²) in area.

3.1.6.2 Competition Logo

Competition logo decals will be provided by the Organizers and should be placed on the top portion of the front doors on each side of the vehicle. The logo decal will measure 21.6 cm (8.5 in.) high and 35.6 cm (14 in.) wide and must have at least 5 cm (2 in.) of unobstructed color on all sides. The Organizers reserve the right to use the top 10 cm (4 in.) of the windshield.

3.1.6.3 Local Sponsor Decals

Local sponsor decals may be placed on the vehicle, but they must not be larger or more prominent than the competition sponsor decals.

3.1.6.4 Vehicle Numbers

A number must be displayed on both sides of each vehicle. The numbers must be at least 25 cm (9.8 in.) high and 12 cm (4.7 in.) wide and have a brush stroke of at least 4 cm (1.6 in.). The numbers must be displayed on an unobstructed background of a contrasting color with a

border of at least 5 cm (2 in.) on all sides. The colors can be black on white, white on black, or other high-contrast colors approved by the Organizers.

3.1.6.5 School Names

School names or approved abbreviations are mandatory and must be located on both sides, the front, and the back of the vehicle. The lettering on the sides must be at least 8 cm (3.1 in.) high with a brush stroke of 2 cm (0.8 in.). The lettering on the front and back must be at least 5 cm (2 in.) high with a brush stroke of 1.5 cm (0.6 in.).

3.1.6.6 Vehicle Names

Vehicle names are optional.

3.1.6.7 Sponsor/Supplier Decals

The Organizers may require that certain decals from major competition sponsors be placed on the vehicle, and the location(s) may be specified. On each side of the vehicle, 1,742 cm² (270 in.²) of useful space, or a total of 3,484 cm² (540 in.²), must be reserved for Organizer-provided sponsor decals. Otherwise, teams are free to place sponsor decals on their vehicles, provided that all specifications regarding vehicle markings are strictly followed. Decals from an individual sponsor are limited to one per side and a total of three per vehicle. No single graphic may be larger than 1,045 cm² (162 in.²).

3.1.6.8 Fuel-Type Identification

All vehicles must display lettering on the front, rear, and both sides of the vehicle identifying the type of fuel being used. The only labels approved for use are M85, E85, LPG, DME, Diesel, and CNG. The lettering must be displayed on an unobstructed background of a highly contrasting color with a border of at least 3 cm (1.2 in.) on all sides and must be clearly readable with the naked eye from a distance of 15 m (49 ft) by a person standing on the same plane as the vehicle. The lettering may be no less than 8 cm (3.1 in.) high with a brush stroke of 2 cm (0.8 in.).

3.1.6.9 Additional Decals

Several other decals will be affixed to the vehicles at the time of the Technical and Safety Inspection to identify battery type and voltage, fuel type, and the location of activation controls for the fire-extinguishing system and battery disconnect switch.

3.1.6.10 Natural Gas Shut-Off Decal

See Section 3.4.3.2, Compressed Natural Gas.

3.1.7 Vehicle Weight and Distribution

3.1.7.1 Gross Vehicle Weight

Vehicles will be weighed fully loaded, including cargo, driver, and passenger. The weight of an Escort conversion must not exceed 1,808 kg (gross vehicle weight [GVW] + 15%). Saturn conversions must not exceed 1,763 kg (GVW + 15%). Neon conversions are restricted to 1,686 kg (GVW + 10%). All other conversion vehicles will be limited to GVW. The gross vehicle weight rating (GVWR) of a vehicle can be found on the label located on the doorjamb.

3.1.7.2 Weight Distribution

The front axle must bear no more than 67% and no less than 50% of the total vehicle weight without explicit approval from the Organizers. Side-to-side weight distribution bias must not cause unsafe handling.

3.2 MECHANICAL SYSTEMS

3.2.1 Mechanical Section Definitions

To prevent confusion and ambiguity, certain terms used throughout this section are defined below. For consistency, please use these terms when communicating with the Organizers and other teams.

3.2.1.1 Hybrid Electric Vehicle

A hybrid electric vehicle (HEV) is defined as a vehicle that can draw propulsion power from both of the following sources of energy: (1) consumable fuel, and (2) an energy storage system (e.g., batteries) that is capable of being charged by an on-board generator or an off-board source. The systems may be combined in any configuration (e.g., series or parallel).

3.2.1.2 Engine

For clarity, all internal combustion engines will be designated as “engines.” The terms APU and motor will *not* be used to describe the engine.

3.2.1.3 Motor

For clarity, all electrically driven motors will be designated as “motors.” The term motor will *not* be used to describe the internal combustion engine.

3.2.1.4 Critical Vehicle Components

Defined as any part or component that, if it became unfastened, could cause the driver to lose control of the vehicle, *or* any part that could fall from the vehicle and pose a hazard to another vehicle.

3.2.1.5 Charge Sustaining

“During vehicle operation over a given driving schedule, the vehicle no longer relies on electrical energy originally supplied from an off-board source. While the state-of-charge (SOC) of the energy storage system (ESS) may be rising or falling instantaneously during this type of operation, enough on-board charging occurs during driving for the SOC to remain level or increase when averaged over a sufficiently long series of repeated driving cycles. As a result, a hybrid vehicle that is charge-sustaining in a given driving schedule can be treated as if it were operating (on average) solely on its on-board consumable fuel.” (From Draft SAE J1711.)

3.2.1.6 Charge Depleting

“During vehicle operation over a given driving schedule, electrical energy originally supplied from an off-board source is depleted during the same time that the on-board consumable fuel is consumed. While the SOC of the ESS may be rising or falling instantaneously during this type of operation, not enough on-board charging occurs during driving to prevent the SOC from progressively depleting when measured over a sufficiently long series of repeated driving cycles. As a result, a hybrid vehicle that is charge-depleting on a given driving schedule can be treated as operating on both ‘fuels’ (off-board-charged electricity and a consumable fuel) simultaneously.” (From Draft SAE J1711.)

3.2.1.7 Conventional Vehicle Controls

Conventional controls for driving are those found in a typical vehicle today: steering wheel, brake pedal, parking brake, accelerator pedal, gear-selector or gear shifter, clutch pedal, key start/on.

3.2.1.8 Driving Modes

Because drivetrains in the vehicles are expected to be highly complex, we expect some manual controls or selectable modes to control vehicle operation. *Teams are free to have any number or type of modes they desire.* The common modes are defined here; *only the passively operating "Normal Mode" is required for the competition.* However, we recommend that some or all of these modes be available for use in the dynamometer testing, if needed.

- **Normal Mode:** The normal mode enables the vehicle to operate on almost any driving cycle. For the purposes of the competition, this mode will be used for all range and fuel economy events; the acceleration event will require that this mode be used for at least one run. This mode must be used to operate the vehicle without occupant intervention (i.e., must be passive). The vehicle should have the ability to operate properly without additional control (besides conventional vehicle controls) after the mode is selected.
- **ZEV Mode:** In the zero emissions vehicle (ZEV) mode, the vehicle is forced to operate using electricity only. The engine is prevented from engaging.
- **Engine-Only Mode:** For parallel HEVs and non-HEVs, the engine-only mode will prevent the electric drive from engaging — the engine will provide all motive power. This mode is not particularly applicable to series HEVs.
- **Engine-On Mode:** In the engine-on mode, the engine is forced to start and stay on all the time. For parallel HEVs, the electric drive may only be used to augment the engine power if required to maintain the driver power command. For series HEVs, this mode must override any conditions where the engine would be commanded to shut down. Otherwise, the operation should be the same as in the normal mode. (Note: Because it may be used during parts of the emissions test, the "engine-on" mode cannot trigger a separate engine-control strategy. Such strategies include, but are not limited to, spark timing, air/fuel ratio, valve operation, and exhaust gas recirculation operation. In addition, for series-configuration vehicles, the throttle position, engine speed, etc., must be controlled by the battery state, as they would be under normal HEV operation. Any attempt to use a separate engine-control strategy will be considered a defeat device and is strictly prohibited.)

3.2.2 General Vehicle Operation

The vehicles must represent automobiles ready for consumer use on the road today. Vehicle controls and response should resemble those of the stock vehicle. Gains in efficiency should not be at the expense of vehicle driveability or utility. The following items are required for the American Tour de Sol.

3.2.2.1 Horn

All vehicles must be equipped with a production electric automotive horn capable of steady, uninterrupted sound at a level of 82-102 dB at a distance of 15 m (49 ft).

3.2.2.2 Vehicle Controls

All vehicles must have conventional automotive controls. Additional controls for vehicle operation are not allowed to be used during the competition; only driver controls for suspension and transmission are allowed.

3.2.2.3 Steering Mechanism

Steering mechanisms must have positive stops at the end of travel so that the wheels responsible for steering do not contact the vehicle body, chassis, or suspension components throughout their range of motion. If the original steering rack is replaced, a suitable automotive replacement must be used — “steer-by-wire” systems are not allowed. If power-assisted steering mechanisms are used, they must not rely on the engine for power unless the vehicle operation strategy requires the engine to be running full time. The steering function must be unaffected by selection of any possible operational mode. Purpose-built vehicles must be able to execute a U-turn in a lane 12 m (39.4 ft) wide, curb to curb.

3.2.2.4 Passive Control Strategy

All vehicles must have at least one passive control system and strategy. This operation must be selected by a switch or dial clearly labeled as “Normal Mode.” The normal mode will be selected for use in the road rally, dynamometer testing (if performed), and acceleration event. Once the normal mode is selected before the start of the event, no other adjustments or controls are allowed by the occupants during the event. Manual adjustments to devices that directly control current, voltage, frequency, etc., to the traction motor or the engine system or drivetrain are not allowed, except conventional vehicle controls (e.g., accelerator pedal, brake pedal, and clutch pedal). Additional manual vehicle controls are only allowed if they are related to the transmission or suspension settings. If programmable control devices (e.g., PROMS, EPROMS,

PCs, and software) are used, teams must develop a single strategy and calibration flexible enough to operate the vehicle in all events. Calibration changes of any type will not be allowed once the vehicle has passed the Technical and Safety Inspection. If no monitoring and control system is used, the vehicle must be set to a particular type of operation before the start of an event and safely operate during the entire event without driver intervention. The Organizers may apply seals to appropriate control components to ensure that no adjustments are made after the inspection.

3.2.2.5 Noise Limits

No vehicle may gain advantage in efficiency or power by purposeful modification or elimination of the exhaust muffler. A consensus of the Inspection Committee will determine whether a vehicle is too loud — in which case, the team must correct the problem in order to pass the Technical and Safety Inspection.

3.2.2.6 Allowable Suspension Modifications

Teams should modify the suspension only if they have experience in suspension part(s) fabrication and can demonstrate (through finite-element modeling and other applicable analyses) that the part(s) can adequately substitute for the stock part(s). The original front suspension geometry must be retained with original mounting points. The rear suspension geometry can be altered only in order to provide more space for such large, bulky components as a battery box or fuel tanks. Dynamic modeling of roll, center, understeer/oversteer, critical speed, etc., must ensure that the new suspension can perform safely under all normal driving conditions. All vehicles must have suspensions with a usable wheel travel of at least 100 mm (3.93 in.).

3.2.3 Wheels

3.2.3.1 Tire Size/Rating

Tires must be DOT-approved and have a wheel diameter measuring 13 in. or greater. The total load rating of the tires must be greater than the weight of the fully loaded vehicle, including occupants, fuel, and batteries. If nonproduction wheels are used, the team must ensure that the wheels are capable of withstanding the expected loads as well as a reasonable amount of road abuse. Wheels and tires must pass the qualifying events without failure or evidence of excessive tire deflection.

3.2.3.2 Tire Pressure

Tire pressures must be within the range recommended by the manufacturer.

3.2.3.3 Tire Modifications

The tire tread depth cannot be less than 4 mm (5/32 in.) at the start of any event. Markings on the tire sidewalls may not be altered or removed. Tires may not be regrooved or altered in any way.

3.2.3.4 Tire Replacement

Wheels and tires may not be changed after final inspection. If a change is necessary due to failure or excessive wear, replacement(s) must be identical to the wheel or tire being replaced, and any replacement tire must be inspected.

3.2.3.5 Tire Softeners and Warmers

Teams may not use tires that have been subjected to liquids or chemical compounds that soften the tire or change its composition. Tire warmers may not be used.

3.2.4 Brake System

3.2.4.1 Primary Brake System

All vehicles must incorporate the stock brake system or a substitute system intended for automotive use (split hydraulic system) that is at least as effective as the original system. All brake systems must be operated by a common pedal and act directly on the wheels. Power-assisted brake systems must not rely on the engine for vacuum or power, if the vehicle can ever be operated in an electric-only mode (ZEV mode). Regenerative brake systems will be allowed but cannot be employed as the primary brake system.

3.2.4.2 Parking/Emergency Brake

All vehicles must have a manual parking brake capable of holding the vehicle's weight at rest on a 20% grade *and* that can be used while driving in the event the primary brake system fails.

3.2.4.3 Braking Performance

All vehicles must pass the braking test component of the qualifying events. (The qualification process is outlined in the Northeast Sustainable Energy Association [NESEA] *American Tour de Sol Rules, Regulations, and Resources* book.)

3.2.5 Avoidance of Hazardous Mechanical Failure

The vehicles competing in the American Tour de Sol will essentially be on display throughout the competition. The vehicles are objects of interest to spectators, other teams, officials, and judges. Because people will be looking under hoods and in other areas, the vehicles must be safeguarded for mechanical failure. Each vehicle should be safe while it is idling or running with the hood or trunk open. The vehicles will be dynamometer-tested with the hood open and the wheels spinning. Shields and covers should prevent flying objects from injuring spectators; critical fasteners must be extra secure to prevent component failure that may cause loss of vehicle control or parts falling from the vehicle that can endanger other vehicles and participants.

3.2.5.1 Covers

Rotating parts added by the teams must be properly shielded to prevent injury in the case of failure. The amount of shielding needed is broken down into two categories, described below:

- **High-Speed Components (above 1,000 rpm).** Heavy components of this type include flywheels, gears, chain drives, clutches, torque converters, and other devices having substantial unshielded rotating mass (this does not apply to electric motors and similar devices). Light accessory drive belts, such as v-belts or small cog belt drives, similar to those used in OEM applications do not require shielding. Components in this category (not enclosed in stock bellhousing) must be shielded by a scattershield constructed of at least 12-gauge mild steel or documented equivalent (such as an National Hotrod Association [NHRA]-approved flywheel scattershield). Any exposed drivetrain, suspension, and steering components must be shielded from the occupants. Flywheel energy storage devices must be fully enclosed in a scattershield constructed of 9.5-mm (3/8-in.)-thick mild steel.
- **Low-Speed Components (1,000 rpm or less).** Low-speed components must be covered with a shield of 18-gauge mild steel or equivalent. Light accessory drive belts, such as v-belts or small cog-belt drives, similar to those used in OEM applications, do not require shielding. Finger guards made of expanded metal or heavy screen may be used to shield low-speed components if cooling air flow is required.

3.2.5.2 Critical Fasteners

All fasteners on critical vehicle components are considered critical fasteners. The critical components include, but are not limited to, suspension, steering, brakes, battery containment, seat belts, ballast carrier, and drivetrain; they must be secured with lock nuts, double nuts, nuts secured by safety wires, or cotter pins. If the location precludes the use of one of these devices, products such as Loctite may be used.

3.2.6 Drivetrain Components

3.2.6.1 Throttle Return

The throttle on all vehicles must be free-moving and, when released, must return to the zero-current position on the electric motor. There must be at least two independent spring mechanisms to close the throttle in case one spring system fails. If the engine is connected mechanically to the drivetrain, the throttle must return to the closed or idle position when released. If the engine is connected mechanically to the drivetrain *and* an actuator (motor) is used for throttle control, loss of signal or power to the motor must result in the throttle closing. If cruise control is used, it must be deactivated when the brake pedal is depressed.

3.2.6.2 Engine and Transmissions Leaks

The vehicle must not have any active fluid leaks while sitting at rest or while operating. A fluid leak is defined as active if, after it is wiped away, it has dripped or wets to an impending drip after at least one hour.

3.2.6.3 Engine Modifications

It would be against the spirit of the competition to use the stock engine with gasoline. Modifications to the stock engine are expected, either by using alternative fuels or by enhancing the engine efficiency.

3.2.6.4 Collection of Flammable Fluids

Body panels, trays, or any flat surface below the engine must be equipped with provisions to prevent the collection of engine oil (even if the engine is assumed to be, at present, oil-tight). Panels must have leakage holes; flat surfaces must be inclined and channel away fluid. Care must be taken that the oil does not leak on any exhaust system component.

3.2.6.5 Exhaust System

The exhaust system of your team's vehicle most likely has leaks. Exhaust system work from muffler shops is notoriously poor. In previous competitions, we have found that virtually all vehicles have exhaust leaks. Unless your team has tested for leaks and fixed the problems, 99 times out of 100, leaks will be found. Teams should test for leaks by attaching an air hose, regulated to a few psi, to the exhaust exit with a flange and gasket — or at the very least, with the engine running, cover the exhaust exit and check for adequate pressure and gas escaping in the exhaust piping. If the exhaust system is found to have leaks, the vehicle cannot be tested on the dynamometer. Exhaust systems judged to have potentially dangerous leaks must be repaired before the vehicle can pass the Technical and Safety Inspection.

Exhaust piping for the engine must be heat-shielded where necessary and routed directly to the rear of the vehicle so that the exhaust exits behind the rear wheels. Piping may not pass through the passenger compartment or battery compartment. The outlet of the exhaust tubing must be circular, between 44.5 mm (1.75 in.) and 50.8 mm (2.00 in.) in diameter, with a straight, perpendicular cut (i.e., no fancy exhaust tips), and extend past the bodywork at least 2.5 cm (1 in.) to facilitate connection of emission sampling equipment.

3.2.7 Component Packaging

3.2.7.1 Bulkheads

If the engine, motor, and batteries intrude into the passenger compartment, they must be separated and isolated from the passenger compartment by (1) a bulkhead of the same thickness and material as the stock bulkhead, or (2) securely fastened and sealed covers to protect the occupants from mechanical failure, fluids, and fumes. (See the Electrical and Fuel Systems sections [3.3 and 3.4] for regulations on battery enclosures and fuel-line routing.)

3.2.7.2 Crashworthiness

Many factors contribute to the structural crashworthiness of a vehicle. The body panels that are "hung" to the main structure do not provide significant energy absorption (see Section 3.1.1.1). Teams must give careful attention when packaging and fabricating the rest of the vehicle. Sharp edges or protruding parts (or bolts) should not be pointed at fuel tanks, battery boxes, fuel lines, or high-voltage lines in the vehicle. Components that create any type of hazard if crushed or broken must be in protected areas of the vehicle. Do not put these components in areas that may be crushed in a crash.

3.2.7.3 Airbags

If the vehicle was originally equipped with airbag(s), they must be retained and fully operational in the vehicle. When work is being performed on the vehicle, the airbags must be disconnected to prevent an accidental deployment.

3.3 ELECTRICAL SYSTEMS

3.3.1 Background

Much of this section was drawn from the National Electrical Code (NEC) and from the American National Standards Institute (ANSI) and the Institute of Electrical and Electronics Engineers (IEEE) publications. Teams should be familiar with the practices suggested in these references. Please note that, although these references are standards in the electric industry, they were not designed specifically for electric vehicle applications.

3.3.2 Electrical Section Definitions

Certain terms used throughout this section are defined below. For consistency, please use these terms when communicating with the Organizers and with other teams.

3.3.2.1 Electric Drive, Electric Drivetrain, Electric Propulsion

These terms refer to the electric motor system (i.e., the electric motor and controller).

3.3.2.2 Energy Storage System

The energy storage system (ESS) comprises electrochemical batteries, flywheels, or capacitors that provide a single energy source for the vehicle's electric drive system.

3.3.2.3 Alternator

The alternator is the component connected to the engine that converts mechanical power into electrical power.

3.3.2.4 Generator

This term refers to the system of components that produces electrical power from consumable fuel (i.e., the engine and alternator).

3.3.2.5 Conductors

Conductors are current-carrying parts (e.g., large traction drive cables, high- or low-voltage wiring, and bus bars).

3.3.2.6 Conductor Sizes

Conductor sizes are expressed in American Wire Gage (AWG), or for conductors over 4/0 AWG, in circular mil area (cmil). The circular mil area of a conductor is the diameter of the conductor (in mils) squared.

3.3.2.7 Bus Bars

A conductor of solid material, such as copper, is referred to as a bus bar.

3.3.2.8 High Voltage

For American Tour de Sol regulations, any potential over 36 V between any two conductors in a circuit is considered high voltage.

3.3.2.9 Rated Voltage

Rated voltage is defined as the typical operating voltage of a device, such as a motor.

3.3.2.10 Breakdown Voltage

This term refers to the voltage at which the dielectric strength of a wire's insulation is exceeded and the insulation ceases to be a high-impedance path to the flow of current.

3.3.2.11 High-Voltage Surface

Any part of a terminal, wire, bolt, nut, fuse, bus bar, resistor, etc., to which insulation is not directly applied. The “surface” need not be flat; the term refers to the exposed metal surface of the part that is energized with either positive or negative high voltage (greater than 36 V) with reference to the opposite polarity of the circuit.

3.3.2.12 Continuous Current Rating

Continuous current rating is the maximum current a device, such as a motor, can carry for three or more hours.

3.3.2.13 Peak or Full-Load Current Rating

The maximum current a device, such as a motor, can carry at any time while operating normally is its peak or full-load current rating. The peak or full-load current is usually defined by the current and the amount of time the device can carry the current.

3.3.2.14 Ampacity

Ampacity is a value (in amperes) that expresses the maximum safe current-handling value for a particular wire and insulation combination. This value is dependent on the conductor type and cross-sectional area, the insulator type and thickness, the desired maximum operating temperature, and the ambient temperature.

3.3.3 General Electrical System

3.3.3.1 General Electrical Practice

The entire electrical system must be constructed in accordance with accepted electrical practices such as those of the NEC, IEEE, and Underwriters’ Laboratory (UL). The goal is to prevent electrical shock, over-current, chemical spills, fire, and other hazards. The teams are encouraged to research works on human exposure to electrical currents, such as the studies conducted by Charles Dalziel (IEEE Publication, *Reevaluation of Lethal Electrical Currents*, 1970). Teams are also encouraged to review National Fire Protection Agency (NFPA) 70E, Part II, Chapter 2, “Personal and Other Protective Equipment,” and Chapter 3, “Specific Safety-Related Work Practices.”

3.3.3.2 Component Documentation

Documentation of all electrical components in the vehicle must be kept with the vehicle at all times. Such components include, but are not limited to, motors, generators, converters/inverters, and batteries.

3.3.3.3 Electrical System Circuit Diagram

A clear circuit diagram of the entire high-voltage electrical system of the vehicle must be kept with the vehicle at all times.

3.3.4 General Electrical Safety

This section pertains to all electrical systems within all vehicles, including those without an electrical propulsion system. The purpose of these regulations is to prevent electric shocks, sparks, fires, and short-circuits caused by improper design and unsafe conditions.

3.3.4.1 Voltage Rating

All components of an electrical system must be rated at the appropriate voltage for the system's application. The components must also be rated for the appropriate type of voltage (DC or AC). These components include, but are not limited to, motors, controllers, converters/inverters, generators/alternators, fuses, switches, conductors, connectors, terminal strips, insulators, and electrical tape.

3.3.4.2 Current Rating

All components of an electrical system must be rated at the appropriate current for the system's application. The components must also be rated for the appropriate type of current (DC or AC). These components include, but are not limited to, motors, controllers, converters/inverters, generators/alternators, fuses, switches, conductors, connectors, terminal strips, insulators, and electrical tape.

3.3.4.3 Temperature Rating

All components of an electrical system must be rated at the appropriate temperature for the system's environment. These components include, but are not limited to, motors, controllers, converters/inverters, generators/alternators, fuses, switches, conductors, connectors, terminal

strips, insulators, and electrical tape. (Note: The engine will produce extremely high temperatures that must be considered.)

3.3.4.4 Over-Current Protection (Fuses)

Our objective is to protect electrical devices and related components from over-current or short circuit that could cause hazardous sparking or fires. Vehicles that have an electric propulsion system have additional over-current protection requirements, discussed in Sections 3.3.7.2 and 3.3.8.1. All electrical components (high- and low-voltage) must have over-current protection in the form of nonrenewable, current-limiting fuses. Renewable fuses, circuit breakers, or relays may be used in special cases by petitioning the Organizers.

The voltage ratings of the fuses must equal or exceed actual system voltage; ratings on systems exposed to variable voltages must equal or exceed the maximum voltage possible. The current rating of a fuse should meet the specifications of the component that the fuse is protecting. If no specification is given, the current rating of the fuse should not exceed 150% of the full-load current that the system can draw. Fuses may not be used in parallel. The components must also be rated for the appropriate type of current (DC or AC).

Dual-element or time-delay fuses may be used in series provided the fuses still meet the requirements listed above.

3.3.4.5 Covers, Boxes, and Shielding

All high-voltage systems (greater than 36 V) must be placed in insulated boxes or be shielded to prevent accidental contact with high-voltage surfaces. We also strongly recommend that all electrically energized systems be protected from contact. Covers, boxes, and shielding should not carry current, except during an electrical malfunction.

Metal Boxes. If covers or boxes are made from metal, the cover or lid must be designed so that it can never come in contact with the enclosed components or energized surfaces when opened or closed or if bumped or pushed. One way this can be accomplished is with a hinged lid that cannot be pushed inside. Some method, such as a hinge or clasp, must be used to positively secure the cover closed. Components such as motors and controllers that are purchased with metal containers are allowed. Metal heat-sink bases are allowed, provided that they cannot come in contact with any high-voltage surface.

Shielding. For electrical components, shielding must be constructed of nonconductive plastic.

Nonconductive Plastic for Covers and Boxes. Boxes and covers made from nonconductive plastic are allowed and are not bound by the requirement given for metal boxes (Section 3.3.4.5). Wood, carbon fiber composites, Plexiglas, or any other materials that are combustible or conductive are not allowed.

Grounding Enclosures. The Ground Fault-Detection System (Section 3.3.6.6) must be able to detect when any conductive enclosures (covers, boxes, and shielding) become energized with high voltage. Therefore, conductive enclosures exposed to or containing high-voltage surfaces must either be grounded to the chassis of the vehicle or have their own ground-fault detection systems. Enclosures must be connected to the frame by a positive means, such as bolted or screwed connections.

3.3.4.6 Spacing and Insulation Barriers

Table 3 specifies the minimum spacing to prevent accidental contact, or arcing, between any uninsulated energized (positive or negative) parts and conductive material or between any two parts of opposite polarity.

An insulating barrier or liner such as rubber may be used in place of required spacings but not as the sole support. The barrier must be at least 0.71 mm (0.03 in.) thick.

TABLE 3 Minimum Spacing Required to Prevent Contact/Arcing

Potential, Volts rms (peak)	Minimum Spacing (mm)		
	Between any Two Uninsulated Live Parts of Opposite Polarity		Between any Uninsulated Live Part and any Conductive Material
	Through Air	Over Surface	Shortest Distance
0 to 50 (0 to 70.7)	1.6	1.6	1.6
< 50 to 150 (70.7 to 212.1)	3.2	6.4	6.4
<150 to 300 (212.1 to 424.2)	6.4	9.5	12.7
<300 to 400	9.5	12.7	12.7

3.3.4.7 Protection from Liquids and Corrosives

All portions of an electrical system located inside the same compartment as components using liquids or corrosives must be shielded from spills, leaks, or corrosive vapors. The shielding must be able to withstand the temperature and corrosive conditions that the nearby liquids can cause. Electrical components should not be placed directly below components that contain fluids or below liquid-fill areas without barriers that must, under any conditions, prevent fluids from reaching the electrical components.

3.3.4.8 Drop-Proofing

All electrical components must be covered or shielded to prevent any tool or small metal part from falling onto exposed energized surfaces and causing a short circuit. For 12-V system components, all positive energized surfaces (e.g., terminal, battery post, bolt) must be covered to satisfy the “drop-proof” criteria. See Section 3.3.6 for additional requirements for components with voltage ratings higher than 36 V.

3.3.4.9 Arc Protection

Any system that may generate arcs must be enclosed in a sealed, flame-resistant cover or enclosure to prevent fused material from contacting flammable substances.

3.3.5 Conductors and Terminals

This section describes the requirements for conductors, such as wires, connectors, and terminals.

3.3.5.1 Conductor Insulation

All conductor insulation must meet the appropriate voltage, temperature, and environmental ratings for its application. Insulation must also be in good physical condition, with no breaks. Electrical tape is not a satisfactory permanent insulation but may be used for small, temporary applications.

3.3.5.2 Conductor Material

All conductors must be made of aluminum, copper-clad aluminum, or copper.

3.3.5.3 Labeling

All wiring must be labeled at both ends of the connection and every 5 ft. Numerical-, letter-, or color-coded insulation may be used, provided the key is attached to a nearby surface or kept with the vehicle at all times.

3.3.5.4 Protection Against Damage

All conductors must be securely fastened and strain-relieved throughout the vehicle to minimize movement. Conductors that may be damaged by moving parts, bending, chaffing on corners or surfaces, pinching, crushing, high temperatures, or corrosive liquids must be protected by nonmetallic protective conduit or similar protection. When a conductor must pass through a frame, panel, or bulkhead, it must be protected by feedthroughs or grommets securely fastened to the opening. Conductors should not be routed near moving parts or within crush zones of the vehicle.

3.3.5.5 Ampacity Rating/Conductor Size

Teams should use the size and type of wiring recommended by the manufacturer for all electrical components and electric propulsion systems. If such information is not available, the ampacity of the conductor should be determined according to NEC code specifications (Section 310-15, Tables 310-17 and 310-19). The conductor must be sized so that its ampacity rating is at least 150% of the expected full load current from the components to which it is connected. This rating should reflect the time over which the maximum current is expected (i.e., transient spikes in current flow do not necessarily merit a larger cable size). The ampacity rating of the conductor must also be above the rating of the over-current protection device (fuse) to which it is connected. The ampacity temperature correction factor must be considered when selecting the proper conductor. Teams may petition the Organizers to use smaller-size conductors if they can technically demonstrate that no overheating of the wires or other unsafe conditions will occur.

We highly recommend that stranded wire, not household wiring (solid conductor wiring), be used in vehicle applications. For high current applications, welding cable should be used.

3.3.5.6 Conductors in Parallel

Conductors in parallel may be used, provided both conductors meet the ampacity requirements (Section 2.3.5.5) and are independently fused (see Section 3.3.4.4, Over-Current Protection).

3.3.5.7 Terminals

Our objective is to prevent exposed wiring that may cause mechanical failure, improper connections, fire, or hazardous electrical accidents. All connections must be made through proper connectors rated for the dimensional size, voltage, temperature, and environmental conditions. Proper connection techniques must be used. Furthermore, wherever practical, all high-voltage leads must be made in such a manner that, when separated, the energized side of the connection is finger-proof. (Twisting two wires together and wrapping them with electrical tape is not acceptable.)

3.3.5.8 High-Voltage Conductors

High-voltage conductors (greater than 36 V) must not be routed with low-voltage conductors. All high-voltage conductors within the engine or motor compartments or routed under the vehicle must be protected by conduit.

3.3.5.9 High-Voltage Conductor Labeling

All conductors carrying high voltage (greater than 36 V) must be labeled with distinctive marking, such as red or orange tape. The labeling must be the same for all high-voltage conductors and significantly different from that for all low-voltage conductors.

3.3.5.10 Bus Bars

Bus bars may be used as conductors, provided they have a direct insulation barrier to prevent accidental contact. (Note: Each bus bar must have its own insulation; shielding that covers multiple bus bars is not adequate.) Bus bars must use a positive connection, such as a rivet or bolt. In addition, connections must be made using a spring washer or a split-ring lock washer and a flat washer. Table 4 lists the current ratings for single copper bus bars.

3.3.6 High-Voltage Systems

This section applies specifically to vehicles that have electrical systems that exceed 36 V, nominal.

TABLE 4 Bus Bar Ratings

Current Rating (A)	Cross Section (mm ²)
225	70.3
400	242.0
600	322.6
800	483.9

3.3.6.1 Maximum Voltage

The nominal open-circuit voltage of any part of an electric system may not exceed 400 V. The peak voltage limit is 450 V during charging, but the voltage must return to below 400 V within 24 hours after the charging period.

3.3.6.2 Warning Signs

All visible equipment or conductors operating at high voltage (greater than 36 V) must be properly insulated and labeled with signs reading "Warning – High Voltage."

3.3.6.3 Incidental Contact

Our objective is to prevent accidental contact with any portion of a high-voltage electrical system at any time, except when the vehicle is being serviced and the system is de-energized. All high-voltage conductors and connectors must be insulated. All electrical components must be shielded or contained in an appropriate box. All high-voltage electrical systems must satisfy the following conditions:

Finger-proof. All portions of an electrical system must be protected against accidental contact with the human body.

Drop-proof. All portions of an electrical system must be protected against loose or dropped items, such as a wrench or bolt.

For example, an exposed terminal strip should be contained in a plastic box or covered with plastic. An electric motor can be covered by wire mesh to allow air circulation and prevent any contact by fingers or loose items. The plastic box and the mesh can be removed to service the component only when the manual isolation switch is in the "Off" position.

3.3.6.4 Permanently Energized Systems

Any high-voltage electrical component that is always energized (even when the manual isolation switch is off) must be shielded or isolated from all other electrical components. These components include, but are not limited to, fuses, switches, contactors, relays, and solenoids. This separate enclosure must have labeling that states, "High Voltage — Always Energized."

3.3.6.5 Leakage Currents (Ground Faults)

All high-voltage systems (greater than 36 V) must be isolated from the chassis of a vehicle or any other exposed component. Components requiring isolation include power and low-current leads such as those for voltage monitoring, the battery box, and the chassis of the motor. To prevent electrical shock, we strongly recommend that the teams frequently check for ground faults as they install the electrical system.

The leakage current will be tested (with a charged ESS) by measuring the voltage across a 10-k Ω resistor that is connected between the chassis and the most positive and negative parts of the electrical system, with all switches in the "On" position and all components connected (see Figure 1). The maximum allowable leakage current between the battery pack and the vehicle chassis is 1 mA (10 volts across a 10 k Ω resistor). Note that the data acquisition system (DAS) has a leakage current detector, but it measures for higher leakage currents; teams must check manually to find smaller leakage currents.

3.3.6.6 Ground-Fault Detection System

All vehicles must be equipped with a ground-fault detection system that alerts the operator to any ground faults on the vehicle. The system must measure the leakage current between the chassis and the most negative and positive parts of the electrical system. Fuses must be used on sensor wires connected to the ESS and ESS shunt.

FIGURE 1 Measurement of Current Leakage to Chassis

3.3.7 Electric Propulsion Systems

The following sections apply to vehicles that use an electrical propulsion system.

3.3.7.1 Overall System

The electric propulsion system must include main fuses, emergency disconnect, manual isolation, charging isolation, and (if not included in existing hardware) a motor switch. The system must be wired as shown in Figure 2. All electrical components, including the DAS, must be connected after the main fuse, emergency disconnect switch, and manual battery isolation switch. In addition, some method must fully isolate the electrical system from the battery pack when charging (in Figure 2, this method is shown as the charge/run selector).

3.3.7.2 Main Fuses

The purpose of the main fuse is to protect the entire high-voltage electrical system from a short circuit. These fuses do not replace the over-current protection that each electrical component must have. The energy storage system(s) must have over-current protection in the form of nonrenewable current-limiting fuses connected to the most positive and negative terminals of the ESS. Renewable fuses, time-delay fuses, circuit breakers, or relays may not be used. The fuses must be placed as close to the battery pack as physically possible. In addition, the main fuses must be the first electrical component connected to the battery pack.

The DC voltage ratings of the main fuses must equal or exceed actual system voltage; ratings on systems with variable voltages must equal or exceed the maximum voltage possible.

FIGURE 2 General Wiring Diagram

The current ratings of the main fuses should not exceed 150% of the full-load DC current the system can draw.

The main fuses must satisfy the incidental-contact requirements governing covers, boxes, shielding, and permanently energized components.

3.3.7.3 Emergency Disconnect Switch

The purpose of the emergency disconnect switch (EDS) is to disconnect the entire electrical system from the ESS under full-load current and in case of an emergency. The leads from the ESS must be equipped with an EDS that can disconnect the system under a full-load current. The switch must fully disconnect the most positive and negative terminals of the ESS. The EDS may be double-throw, a manually thrown switch, or a normally open contactor/relay activated by a fail-safe switch. If a contactor or relay is used, it must be normally open and must not require external power to put it into the closed position. An EDS that interrupts the fused positive power supply to a relay is allowable.

The EDS must be located as close to the battery pack as physically possible. It must be activated by a fail-safe mechanism or switch that is within reach of a belted-in driver and a person standing outside the vehicle. (Disconnecting the system by physically pulling and separating conductors through a connector is not acceptable.) The EDS must be labeled "Emergency Disconnect" and must have clearly indicated "On" and "Off" positions. Letters must be at least 2.54 cm (1 in.) high and be in a high-contrast color.

The EDS must be located after the main fuses but before the manual isolation switch. No components may be connected before the EDS. The DC voltage ratings of the EDS must equal or exceed actual system voltage; ratings on systems with variable voltages must equal or exceed the maximum voltage possible. The current rating of the switch should exceed the current rating of the main fuse. The EDS must have arc suppression when operated under full-load conditions.

The EDS must satisfy the requirements regarding incidental contact that apply to covers, boxes, shielding, and permanently energized components.

3.3.7.4 Manual Isolation Switch

The purpose of the manual isolation switch (MIS) is to de-energize the entire high-voltage electrical system while the vehicle is serviced. The MIS must be able to be physically locked in the open position and re-energized only with a key. The MIS must be located after the main fuses and EDS. No components may be connected in the circuit before the MIS. The switch may be located in any convenient location in the vehicle, so that it will be used every time the vehicle is being serviced. It should be in a location where it will not be confused with the EDS by a person unfamiliar with the vehicle.

The MIS is not required to interrupt the current at full load. The DC voltage ratings of the MIS must equal or exceed actual system voltage; ratings on systems with variable voltages must equal or exceed the maximum voltage possible. The current rating of the switch should exceed the current rating of the main fuse.

The MIS must satisfy the same requirements on incidental contact as covers, boxes, shielding, and permanently energized components. The MIS may be disconnected by physically pulling and separating contacts or terminals, provided it can be locked out and is inherently finger- and drop-proof.

3.3.7.5 Combined Emergency Disconnect and Manual Isolation Switch

The emergency disconnect switch and manual isolation switch may be combined in a single switch, provided it meets the requirements of both systems.

3.3.7.6 Charging Isolation Selector

The entire electrical propulsion system must be completely isolated from the battery pack while charging off-board (with the exception of the battery box ventilation system). A switch may be used if the voltage ratings equal or exceed the actual system voltage; ratings on the switch with variable voltages must equal or exceed the maximum voltage possible. The current rating of the switch should exceed the current rating of the main fuse. The MIS may be used if it isolates the battery pack and charger from the rest of the system and the charger is de-energized when the MIS is in the open position. Physically disconnecting/connecting the electric propulsion system before/after the charging period is also allowed, again, provided the MIS isolates the batteries and charger.

3.3.7.7 Electric Motors

Each propulsion system electric motor(s) must have its own short circuit over-current protection device. We recommend that the motor also have a device that de-energizes it to prevent overheating. AC motor controllers that supply power to the motor using three single-phase conductors must have over-current protection on all three conductors. The teams do not have to add fuses to the electric motor system if fuses are included in the system as purchased.

Our intent is to prevent the vehicle from lunging forward by accident when the electric drive system is connected to the batteries. The electric motor must also have a device (built into the system or added) that prevents it from operating while the remaining electrical system is energized. A separate control must be engaged to activate the electric drive system and an indicator (light) must unmistakably show that it is on. If a switch is used, it must be labeled "Motor Switch" and be clearly labeled "On" and "Off." Letters must be at least 2.54 cm (1 in.)

high and be in a high-contrast color. If the automotive ignition key is used as the control, it must be labeled, but smaller letters may be used. A switch that disables the 12-V power supply to the motor controller is also acceptable, provided there is no method of operating the motor in the "Off" position.

3.3.7.8 Regenerative Braking Disable Switch

All vehicles with regenerative braking must have a way to disable the regenerative braking system. The regenerative braking will be disabled for the Braking Qualifying. The disable method must be employed so that it does not prevent the vehicle from performing this task. Contact the Organizers if there are any problems meeting this requirement.

3.3.7.9 Erroneous Signal Failure

Our objective is to prevent high-power components, such as the electric motor, from carrying out an erroneous order that may cause a hazardous situation. If a power component receives an erroneous signal from a control device that has failed, such as an accelerator potentiometer with a short circuit, the control hardware for the propulsion system (electric and fuel) or generator system (for series hybrids) must have a fail-safe system that prevents operation. For example, if the accelerator pedal has a potentiometer that normally provides a signal from 0.5 to 4.5 V, the motor control system must prevent the motor from operating when a 0-V (open-circuit) or 5.0-V (full-scale) signal is received.

3.3.8 Energy Storage Systems

3.3.8.1 ESS Over-Current Protection Device (Fuses)

The purpose of the ESS over-current protection device is to protect against a short circuit within the ESS. These fuses do not replace the main fuses or the over-current protection that are required for each electrical component.

The ESSs must have over-current protection in the form of nonrenewable, current-limiting fuses halfway through the ESS series string. Renewable fuses, time-delay fuses, circuit breakers, or relays may not be used. The fuses must be placed as close to the ESS as physically possible. If the vehicle uses multiple parallel strings of ESSs, each string must have its own ESS fuse. If any two ESS enclosures are separated by more than 2 ft of conductor, an ESS fuse must be used in each enclosure (halfway through the string).

The DC voltage ratings of the ESS fuses must equal or exceed actual system voltage; ratings on systems with variable voltages must equal or exceed the maximum voltage possible.

The current rating of the ESS fuses should not exceed 150% of the full-load DC current that the system can draw. The ESS fuses must satisfy the requirements regarding incidental contact that apply to covers, boxes, shielding, and permanently energized components.

3.3.8.2 ESS Terminals

All ESS terminals and electrically exposed conductors within the ESS enclosure must be individually covered and must satisfy the requirements for incidental contact that apply to covers, boxes, shielding, and permanently energized components. The terminals should be insulated when the ESS enclosure is open or the vehicle is being serviced. For example, each battery post should be covered with an individual plastic cover to prevent incidental contact.

3.3.8.3 ESS Enclosure

The ESS enclosure must perform two functions: enclose the ESS (including liquids and fumes) and secure individual batteries to the chassis. Each ESS must be fully contained in a separate enclosure. The enclosure must be made of a reasonably strong fire-resistant material. In addition, the enclosure must electrically insulate the ESS. If a metal enclosure is used, the box must be lined with an insulating material that is at least 1/8 in. thick, with a breakdown voltage rated at 150% of the maximum ESS voltage. Insulating sprays are not acceptable.

ESS Ventilation Fan. The ESS enclosure must be equipped with forced-air ventilation to the outside of the vehicle to remove gases and vapors. The ventilation system must not draw vapors from the passenger compartment. The battery box must remain fully sealed from the passenger compartment. The exhaust of the venting system must be mounted so that air is drawn from the bottom to the top of the ESS enclosure. The fan must draw gases out of the enclosure, not blow gases out.

The fan must be rated for at least 10 cfm. The fan motor must be a brushless type or have an explosion-proof rating so that it does not produce sparks. The fan must draw its power from the main battery pack (e.g., via the DC/DC converter). It must operate any time the battery system is energized and during recharging of the batteries.

ESS Support. The ESS and its enclosure must be securely fastened to a structural frame member of the vehicle to prevent movement in all directions. The ESS support must be sufficient to withstand two times the force of gravity in all directions (including up). Insulated metal bars or thick noncorrosive straps may be used.

3.3.8.4 Spare ESS

Any spare ESS will be inspected and tagged during the Technical and Safety Inspection. The Organizers must approve all ESS changes. The ESS may be changed only in the event of a failure or malfunction, such as physical damage or an internal short circuit. Batteries discharged during normal usage do not constitute failure. An ESS discharged in the course of vehicle operation, but otherwise undamaged, may not be exchanged for a charged ESS.

3.3.8.5 Multiple Battery Packs

The packs may be contained in any number of battery enclosures, as long as each conforms to the guidelines provided in Section 3.3.8.3, ESS Enclosure.

3.3.8.6 Batteries

No restriction is placed on battery capacity (measured in kWh) for any class. No restrictions are placed on the size or number of cells. Teams should note battery chemistry requirements, as outlined in NESEA's *American Tour de Sol Rules, Regulations, and Resources*.

3.3.8.7 Auxiliary 12-Volt Power Supply

Batteries that provide power to auxiliary components (e.g., lights, fuel pump, data acquisition systems) are allowed, provided they meet the following requirements:

- Rated below 36 V;
- Isolated from the traction battery pack; and
- Isolated from propulsion system high voltage.

Auxiliary batteries may be recharged from the traction batteries, as long as they are still isolated (e.g., through a DC/DC converter). The auxiliary battery may be grounded to the chassis, provided it does not ground the traction batteries to the chassis. If a DC/DC converter is used, it should have an isolation voltage rating at least twice the maximum ESS voltage.

3.3.8.8 Capacitors

Capacitors used in the propulsion system including, but not limited to, main fuses, ESS fuses, emergency disconnect switch, and manual isolation switch, must meet all of the above requirements. In addition, all capacitors (including nonpropulsion capacitors) must meet the following regulations.

- **Pressure.** The capacitor may not develop pressures capable of causing injury in the event of a malfunction.
- **Hazardous Materials.** Under normal and abnormal conditions, including internal shorting, a capacitor containing flammable materials must not result in the risk of fire or electric shock. The capacitor must also be constructed to reduce the risk of expelling hazardous materials.
- **Discharging.** All large capacitor(s) (greater than 36 V) must be equipped with an automatic means of discharging stored energy when disconnected from a power source. For high-voltage capacitor systems, the residual voltage must be reduced to below 36 V, nominal, within one minute after being disconnected from a power source.

3.3.9 Chargers

3.3.9.1 Charger Specifications

The charger must be properly grounded and bonded and also be finger-proof and drop-proof. The charger must be of sufficient rating to supply the load served and must be fused on supply circuits to the charger and the vehicle. The supply equipment must be marked "For Use with Electric Vehicles." It is each team's responsibility to ensure that its charger is weatherproof or to provide sufficient cover to prevent adverse weather conditions from interfering with the charger. The power supply to the charger will be provided by NESEA. Each team should make certain that it has the appropriate connector on the power input to its charger and that appropriate arrangements have been made with NESEA to meet power requirements.

3.3.9.2 Noisy Chargers

Chargers that exhibit a disruptive amount of total harmonic distortion (THD) will be unplugged at the event. Teams should have their chargers checked for THD (seek help from local utility power quality group if needed); we recommend that the THD be below 10%.

3.3.10 Other Electrical Systems

3.3.10.1 Data Acquisition System

All vehicles must be equipped with a DAS to measure the total energy usage to and from the ESS. All vehicles must use identical systems, including shunts, which will be provided by the Organizers prior to the competition. The meters must be installed according to the provided schematic, which will show the locations of all required connections and shunts.

Any conductors used to measure the voltage or current from the ESS must be fused and marked with "High Voltage" signs.

The teams are responsible for ensuring that the DASs function properly with their vehicles, including providing an adequate power supply. The meters must remain powered at all times; they may not be turned off by a key or switch during the competition. Teams should ensure that they have made adequate provisions for powering the meter for extended periods. We recommend using a small gel-cell battery (or DC/DC converter; contact ANL for details) to power the meter. The battery can be kept charged by using solar cells, so long as the solar cells are electrically isolated from the chassis. Batteries powering the DAS may be changed, but only during certain times (daily) when the DAS is scheduled to be reset. The DAS is used for scoring in several events, including the Road Rally, Emissions, and Energy Economy. If the DAS fails to operate during an event, the Organizers reserve the right to score the event with the best data available. The DAS may also measure other data for the Organizers, although these additional data will not be used in the scoring.

3.3.10.2 Solar Cells

Photovoltaic (PV) cells are limited to a potential of 36 V with respect to all nodes of the PV circuitry (series strings 36-V modules should not be used). The cells can only be used to charge the main battery pack if the current flows through the DAS shunt with the on-board charging system. No high voltage produced from the low-voltage cells may be located in the passenger compartment, and participants must adhere to all regulations concerning high-voltage wiring. The cells should be protected from damage (e.g., rain, physical contact) and must be completely covered to prevent electrical contact.

3.3.10.3 Electronics

Any type of electronics or control devices may be used for motor and engine management systems. Remote-control systems may not be used, but telemetry systems may be used for data acquisition and monitoring.

3.4 FUELS AND FUEL SYSTEMS

Fuels will be limited to methanol (M85), ethanol (E85), diesel, compressed natural gas (CNG), liquefied petroleum gas (LPG), or propane. We strongly recommend that all the fuel tanks on the vehicles be empty on the first day of the competition (for liquid fuels, empty fuel tanks should be kept open to the air to prevent condensation inside). Teams using liquid fuels will be required to provide their own fuels. Submittal of samples or fuel analysis reports may be required prior to the competition in order to determine fuel properties.

3.4.1 Definition of Fuel-Compatible Material

Compatibility, for this competition, means not only free from deterioration in the equipment, but also free from deterioration in fuel quality. All components that come in contact with the fuel should be verified by soak or be certified as compatible by the manufacturer or supplier.

3.4.2 Liquid Fuels

This section applies to diesel, M85, and E85. The fuels composition for the competition must meet American Society for Testing Materials (ASTM) standards for alcohol fuels.

3.4.2.1 General

The fuel tank on the vehicle must be fully contained within the vehicle frame and be protected from collision damage. The tank must be firmly attached to the frame of the vehicle and designed so that no fuel spillage occurs when the vehicle is at a 35° lateral tilt. Fuel lines and hoses must be secured to prevent damage or failure and must not pass through the passenger compartment. High-pressure systems must have appropriate lines and fittings, such as metal braided hoses. The fuel tank must be completely isolated from the passenger compartment, and the materials used in the tank and fuel system must be compatible with the intended fuel.

3.4.2.2 Tank Sizes

Tank capacities will be limited to 56.7 L (15 gal) for diesel, 98.3 L (26 gal) for M85, and 80 L (21 gal) for E85. Propane cylinders will be limited to 20 gal at the 80% fill level. CNG cylinders will be limited to 15 equivalent gallons of gasoline. (Calculations should use the heating values from Section 4.2.3.2 and assume a maximum pressure of 3,000 psig.)

3.4.2.3 Tank Draining

Provisions must be made to completely empty the vehicle fuel tanks. The tanks will be drained a minimum of two times at the competition. The following method should be used to empty the tanks of all vehicles fueled by RFG, diesel, M85, and E85. A drain hose should be connected to a "T" valve somewhere on the fuel line upstream of the fuel rail in the engine compartment. All fuel from the tank should be drained using the fuel pump. With the fuel pump switched on, the high pressure of the fuel will force all fuel out of the tank via the valve and through the connected drain hose. To allow fuel pump operation when the vehicle is in the "Power Down" mode, teams should include a manual override switch supplying power to the fuel pump mounted in the driver's compartment (be sure to fuse the lead).

3.4.2.4 Evaporative Emissions System

The existing evaporative emissions system must remain intact and operational unless an equally adequate system is substituted. Teams using diesel fuel may remove the system.

3.4.3 Gaseous Fuels

This section applies to those fuels that are in a gaseous form under standard pressure and temperature (25 °C and 1 atm), such as CNG and LPG.

3.4.3.1 General Considerations

Lowest Point of Vehicle. No component of the fuel system should be located so as to make it the lowest point of the vehicle at any location under the chassis. Surrounding components or the vehicle's structure should protect the fuel system from damaging contact with the road or road features.

Installation of Cylinders. No modifications to the cylinder shell (i.e., welding) will be allowed. Other brazing or welding is permitted only on saddle plates, lugs, or brackets attached by the manufacturer of the vessel. The mounting mechanism must ensure that no container weight is supported by the outlet valves, manifolds or other fuel connections. Cylinders shall be placed at least 203 mm (8 in.) from any exhaust component, unless a steel shield with a minimum thickness of 3.2 mm (1/8 in.) is employed, which will allow the cylinder to be placed no closer than 5.1 mm (2 in.) from exhaust components. Cylinders shall not be placed closer than 5.1 mm (2 in.) from any moving suspension component (through entire range of travel) and must be shielded from road debris by a firmly supported shield.

Location of Cylinders and Ground Clearance. Cylinders shall not be mounted ahead of the front axle or beyond the rear bumper. Cylinders mounted under the vehicle must not be mounted so that they decrease the ground clearance of the vehicle when loaded to GVW. The tanks cannot be the lowest point on the vehicle. Cylinders located behind the rear axle must not reduce the ramp angle of the vehicle, which is defined as the plane formed between the contact patch of the rear tires and the farthest rear structural point of the vehicle (usually the lower edge of the bumper). Cylinders located behind the rear axle must be oriented so that valves and fittings are on the end of the container most protected from a source of impact.

Lines. Lines shall be routed outside of the passenger compartment and shall maintain a minimum distance of 5.1 mm (2 in.) from the driveshaft tunnel, exhaust components, and moving suspension components (through full range of travel). Lines must be supported every 610 mm (24 in.) by metal, corrosion-resistant hangers covered by rubber surfaces where they contact the metal fuel line tubing. Lines must be routed so that they make no contact with the vehicle except at mounting points and are protected from road debris (use shielding where necessary).

Fuel Gauges. If fuel gauges are used (i.e., for the vehicle instrument panel), they must not allow gas flow into the passenger compartment. All gauges must be mounted securely to the vehicle body.

Evaporative Emissions System. The existing evaporative emissions system may be removed.

3.4.3.2 Compressed Natural Gas

These regulations are a compendium of the NFPA 52 *Standard for Compressed Natural Gas (CNG) Vehicular Fuel Systems*. The major points have been expressed here, but each team is responsible for ensuring that its vehicle complies with all sections of NFPA-52 or CAN/CGA-B149.4-M91 regulations. The use of components specific to the vehicle conversion system (i.e., fuel metering devices/injectors) not meeting the previous standard(s) will be allowed.

The maximum refueling pressure delivery during the competition will be 3000 psig.

Cylinders. Each cylinder must be manufactured, inspected, marked, tested, retested, equipped, used, and maintained in accordance with the DOT or Canada Transport TC regulations, exemptions or special permits, or ANSI/AGA NGV2 or CSA B51 standards. All cylinders must be rated for an operating pressure of at least 20.7 MPa at 21°C (3000 psig at

70°F). Any container and CNG fittings within enclosed compartments (such as, among other areas, the trunk and passenger compartment) shall be fitted with a gas-tight enclosure made of linear, low-density polyethylene (minimum thickness of 200 μm [8 mils]), or a suitable alternative, to provide gas-tight venting to the outside of the vehicle.

Pressure Relief. Each cylinder must be fitted with a pressure-relief valve that is in direct contact with the fuel and will vent directly to the atmosphere. The venting mechanism must ensure that all fuel is vented outside the vehicle and must be able to withstand the maximum pressure that will result from operation of the pressure-relief valve.

Fuel Shutoff Valve. Each cylinder must be fitted with an individual shutoff valve that will completely isolate the cylinder from the rest of the vehicle fueling system yet not interfere with or prevent operation of the pressure-relief device.

Piping and Fittings. No use of aluminum, copper alloy (with copper content exceeding 70%), plastic, cast iron, or galvanized pipe, tubing, and fittings will be allowed. Exceptions: refueling connector may be made of a non-sparking wrought aluminum alloy suitable for the pressure employed and downstream of the first-stage regulator. Aluminum pipe, tubing, and fittings may be used in the engine fueling system. Stainless steel tubing and compression fittings (1/4 in. $\times$ 0.035 in. wall or 3/8 in. $\times$ 0.049 in. wall), which meet all criteria, are suggested. No flexible high-pressure hose will be allowed.

Vehicle Fueling Connection. Each vehicle must be equipped with a fueling connector complying with the ANSI/AGA NGV1 standard (rated to a minimum of 20.7 MPa [3000 psig]). This connector must be located under the stock fuel-filler door and must be securely mounted to the vehicle body.

Automatic Fuel Lockoff Valve. Each vehicle must be equipped with an automatic fuel shutoff valve placed on the high-pressure side of the first-stage regulator, as close to the fuel cylinder as possible. This valve must automatically prevent fuel flow when the engine is not running, even with the ignition on. Exception: a brief on/off cycle may be employed when the vehicle's ignition is turned on to allow for priming of the system.

Master Manual Shutoff Valve. Each vehicle must have a 1/4-turn manual valve mounted directly below the vehicle refueling receptacle. This valve must be located so that it is open when pointing toward the front of the vehicle. The location and operation of the valve must be clearly marked on the side of the vehicle, directly above the valve. The label shall be a

minimum of 7.6 mm × 7.6 mm (3 in. × 3 in.), contrast with the vehicle color, and contain the words "Manual Shutoff Valve."

3.4.3.3 Liquefied Petroleum Gas

These regulations are a compendium of the NFPA-58 *Standard for the Storage and Handling of Liquefied Petroleum Gases*. Each team is responsible for ensuring that its vehicle complies with all sections of NFPA-58 (U.S. vehicles) or CAN/CGA-B149.Z-M91 (Canadian vehicles) regulations for propane.

Fuel Containers. Containers should be designed, fabricated, tested, and marked in accordance with the regulations of DOT or the *Rules for Construction of Unfired Pressure Vessels*, ASME Boiler and Pressure Vessel Code.

- DOT containers shall be designed and constructed for at least 160 MPa (240 psi) service pressure.
- ASME containers shall be constructed for a minimum of 1.7 MPa (250 psi) design pressure.
- A stainless steel metal nameplate must be attached to the containers. The nameplate shall be located so as to remain visible after the container is installed. The nameplate shall be attached in such a way as to minimize corrosion to the nameplate or its means of fastening and shall not contribute to corrosion of the container. An individual container shall not exceed 0.8-m³ (200-gal) water capacity.
- Container appurtenances shall be suitable for a working pressure of at least 1.7 MPa (250 psi).
- Calibration equipment shall be suitable for a working pressure of at least 1.7 MPa (250 psi).

Piping, Hose, and Fittings. Piping, hoses, and fittings should meet the following criteria:

- Pipe shall be wrought iron (ASTM B36.10M), black steel (ASTM A53), galvanized steel (ASTM A106), brass (ASTM B43), or copper (ASTM B42). The pipe should be Schedule 80 or heavier.

- Tubing shall be steel (ASTM A539) with a minimum wall thickness of 0.049 in., brass (ASTM B135), or copper type K or L (ASTM B88 and ASTM B280).
- Fittings shall not be cast iron. Fitting materials should be steel, brass, copper, malleable iron, or ductile iron. Fittings should be suitable for a working pressure of at least 1.7 MPa (250 psi).
- Hose, hose connectors, and flexible connectors used for conveying LPG liquid or vapor shall be fabricated of materials resistant to the action of LPG both as liquid or vapor. Hose shall be designed for a working pressure of 240 MPa (350 psi). Hose shall be continuously marked "LP-Gas," "Propane," "350 psi Working Pressure," and the manufacturer's name.

Fuel Drain. Provisions will be made between the team and the Organizers to drain the fuel tank at the competition if necessary.

4 COMPETITION

4.1 SAFETY AND CONDUCT

4.1.1 Recommended Equipment for the American Tour de Sol

- Safety goggles for every team member.
- Chemical-resistant gloves; several pairs may be necessary (a pair for acids and a pair for organics/flammable liquids).
- Absorbent material (prepackaged absorbent pillows are generally the easiest to use and most are compatible with a wide range of chemicals).
- Disposal bags for cleaned-up material (the bags must be properly labeled to identify the material as hazardous waste).
- In addition to the chemical spill cleanup kit, we highly recommend that each team bring its own portable eyewash station to keep in the garage area. (Simple plastic, gravity-driven units with their own water storage tanks are not expensive and are readily available.)
- Fire extinguisher: greater than 10 lb BC type.

4.1.2 Recommended Team Safety Training for the American Tour de Sol

Each team should provide safety-related training to team and crew members. At a minimum, the training should include the following:

- Fire extinguisher/emergency response;
- Electrical safety (e.g. grounding, shielding, use of insulated hand tools, hazards of wet locations, voltage/current rating of conductors, over-current protection);
- Control of hazardous energy sources (lockout/tagout);
- Chemical spill control/cleanup procedures; and

- Hazard communication (e.g., precautionary measures to minimize exposure to hazardous materials, labeling, storage, transportation, dispensing, disposal, material safety data sheet [MSDS] interpretation).

4.2 DYNAMOMETER TESTING

Optional dynamometer testing may be conducted as part of the American Tour de Sol. If dynamometer testing is conducted, a special award will be given for the team that has the lowest emissions and the best energy economy, but the testing will not be scored as part of the competition. Dynamometer testing incorporates standard industry test practices to collect data from the vehicle. The details of conventional vehicle dynamometer testing can be found in the Code of Federal Regulations: 40 CFR part 86 (emissions) and 40 CFR part 600 (fuel economy). With hybrid-vehicle drivetrains, multiple tests at distinct initial battery conditions will allow evaluation of the results. Teams should contact ANL for additional information concerning dynamometer testing.

4.2.1 Dynamometer Testing Definitions

Certain terms used throughout this section are defined below. For consistency, please use these terms when communicating with the Organizers and with other teams.

4.2.1.1 State of Charge

State of charge is a dimensionless value that describes the amount of usable energy that remains in the ESS compared to the total energy capacity. SOC can be expressed as a percent of total and is measured by integrating the current in and out (ampere-hours) of the ESS and comparing the ampere-hours (Ah) taken out with the rated ampere-hour capacity of the ESS. Because Δ SOC and Δ Ah are proportional, their ratios are used interchangeably.

4.2.1.2 100% SOC

Batteries are at ~100% SOC after a full charge is given.

4.2.1.3 SOC High

This term refers to the highest SOC during normal hybrid operation. This point is not defined for HEVs that are always charge-depleting.

4.2.1.4 SOC Low

SOC low is the lowest SOC during normal hybrid operation. For charge-depleting HEVs, this point is at the lowest SOC where performance is still acceptable for at least 25 miles and the engine is engaged and working at its hardest.

4.2.1.5 Battery Conditioning

Depending on the type of HEV and the SOC desired, either the batteries are charged off-board or with engine idle charging, or the vehicle is driven with the electric motor to deplete the batteries.

4.2.1.6 Urban Dynamometer Driving Schedule

The Urban Dynamometer Driving Schedule (UDDS) is the first 1,370 seconds of the Federal Test Procedure (FTP) consisting of the cold transient (bag 1) and the stabilized (bag 2) phases. The schedule, also referred to as the "city cycle," is a cycle of non-repeating idle, acceleration, cruise, and deceleration modes of various time sequences and rates, 22 minutes 52 seconds in duration and 12 km (7.45 miles) in length. It corresponds to the Cold and Stabilized portions of the FTP.

4.2.1.7 FTP

The FTP is a dynamometer test that consists of a UDDS cycle (bag 1 and bag 2), a 10-minute soak, followed by the first 505 seconds of the UDDS (bag 3). Data from this test are referred to as coming from the "city cycle" (see Figure 3).

4.2.1.8 Highway Fuel Economy Dynamometer Schedule

HFEDS is a highway-speed cycle that is 16.4 km (10.2 mi) long and 12 minutes 44 seconds in duration. It is also referred to as the "highway cycle" or the Highway Fuel Economy Test (HWFET). The average speed is 77.8 km/h (48.3 mph) and the maximum speed is 96.4 km/h (59.9 mph) (see Figure 4).

FIGURE 3 FTP Speed Trace

FIGURE 4 HFEDS Speed Trace

4.2.2 Dynamometer Testing Procedures

Special test procedures will be followed to test HEVs for emissions and fuel economy. Non-HEVs will be given standard FTP and highway fuel economy tests. The key elements in the special hybrid test procedures are the addition of ZEV-mode data (for charge-from-the-wall vehicles) and SOC correction of HEV data to achieve vehicle efficiency results for the city and highway cycles and a single emissions result for the city cycle.

Because vehicles that normally charge from the grid will be compared to vehicles that use only consumable fuel in the emissions and fuel economy results, every effort has been made to offset the effects of mixing in the electrical portion of the vehicle's operation. Power plant emissions and efficiency rates are used in a way that eliminates any possible incentives to choose one hybrid type over another for the sole purpose of doing well with the HEV test procedure. It

is our belief that there are equal trade-offs for vehicles with small and those with large battery packs. We encourage teams to pursue their original concepts in vehicle design to make an ultra-high efficiency, low-emitting vehicle without regard to the test procedure.

4.2.3 Vehicle Energy Economy

4.2.3.1 Objective

The objective of the Vehicle Energy Economy testing is to determine the energy economy of each vehicle in the competition. The energy economy is based on the electric and hydrocarbon fuel energy consumed, as well as the distance traveled during a standard driving cycle, which provides a distance/energy ratio that can be used to compare these competition vehicles to conventional vehicles.

4.2.3.2 Evaluation

Energy economy will be evaluated on equivalent energy consumed per unit distance. Table 5 lists the approximate Btu/gallon and actual Btu/kWh conversions to be used in determining distance/energy (the actual Btu/gallon conversions will be based on the fuel properties of the specific fuel batch, if available).

TABLE 5 Conversions Used to Determine Distance/Energy

Fuel	Conversion
Reformulated Gasoline	115,400 Btu/gal
No. 2 Diesel	128,400 Btu/gal
E100	75,670 Btu/gal
M85	65,836 Btu/gal
Propane	84,500 Btu/gal
DME	12,480 Btu/lb
CNG	1000 Btu/scf
Electric	0.3727 x 33.4 kWh AC energy/gal

4.2.4 Emissions

4.2.4.1 Objective

Emissions reduction from on-road consumer vehicles is very important to future air quality. Manufacturers must design the new generation of vehicles with increasing constraints on emissions levels. This effort must be reflected in the development of competition vehicles.

4.2.4.2 Emissions Test

If the vehicle is charge-sustaining, two tests will be given for SOC corrections. Charge-depleting vehicles will be tested at the highest engine loading that would be expected under normal use, and the electrical energy used will be equated to power plant emissions (see following section).

4.2.4.3 Emissions from Off-Board Electricity Use

If an HEV is always charge-depleting, the equivalent power plant emissions will be added to the engine emissions to determine the vehicle's overall emissions rate. The emissions rates listed below will be used. These rates, from *Utility Emissions Associated with Electric and Hybrid Vehicle (EHV) Charging*, DOE/CE-0395, April 1993, are based on power plant data for the year 2000.

- NO_x: 1.25 g/AC kWh
- CO: 0.117 g/AC kWh
- NMHC: 0.016 g/AC kWh

APPENDIX A:
VEHICLE SPECIFICATIONS LIST

APPENDIX A: VEHICLE SPECIFICATIONS LIST

Date: _____ School: _____
 Advisor: _____ Phone: _____
 Team Leader: _____ Fax: _____

Please show all units!!!

General Specifications:

Make: _____ Model: _____

Year: _____

Original Vehicle Weight (if measured): _____(kg) Curb Weight: _____(kg)

Front Axle Weight: _____(kg) Rear Axle Weight: _____(kg)

If Available, Coast-Down time, from: 50 to 40 mph _____(sec)

40 to 30 mph _____(sec)

30 to 20 mph _____(sec)

20 to 10 mph _____(sec)

ZEV Current Draw at 50 mph _____(amps)

Powertrain (Circle one): HEV Non-HEV

Circle Powertrain Configuration: Series Parallel Other (e.g., combination)

If other, please explain: _____

Engine:

Manufacturer: _____ Model Number: _____

Size (L): _____

Peak Power Rating: _____(kW) _____(hp)

Type (# of cylinders, 2/4 stroke): _____

Describe modifications to the engine:

Fuel Type (Circle one): Reformulated Gasoline M85 E85 CNG

Propane DME Low Sulfur Diesel

Fuel Tank Capacity (gasoline equivalent gallons): _____ (Gallons)

If CNG, LPG, or DME, Total Fuel Tank Volume: _____ (L or m³)

Electric Motor Specifications:

Manufacturer: _____ Model Number: _____

Motor Type (e.g., DC series, AC induction): _____

Rated Continuous Power: _____ (kW) _____ (hp) @ _____ (RPM)

Peak Power: _____(kW) _____(hp) @ _____(RPM)

Maximum Torque: _____(N-M) _____(ft-lb) @ _____(RPM)

Maximum RPM: _____(RPM)

Rated Efficiency: _____(%) @ _____(RPM)

Weight: _____(kg)

Controller Specifications:

Manufacturer: _____ Model Number: _____

Controller Type: _____

Input Voltage Range: _____ Low (V)   _____ High (V)

Current Limit: _____ (amp)

Efficiency: _____ (%) (If given)

Dimensions: _____ (cm x cm x cm)

Weight: _____ (kg)

Battery Specifications:

Manufacturer: _____ Model Number(s): _____

Battery Type: _____ Total Pack Weight: _____(kg)

Number of Batteries per String: _____ Number of Parallel Strings: _____

Number of Batteries: _____ Individual Nominal Battery Voltage: _____ (V)

Total Nominal Battery Pack Voltage: _____(V)

Battery Pack Capacity: _____(amp-hr) _____(kWh) for c/20 rate of discharge.

_____ (amp-hr)   _____ (kWh) for c/2 rate of discharge.

Cycle Life at a Depth of Discharge of 80%: _____

Sealed Batteries?	Yes	No
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
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41		
42		
43		
44		
45		
46		
47		
48		
49		
50		

Battery Charger:

Manufacturer: _____ Model Number: _____

Transformerless?   Yes   No

Efficiency: _____ (state if claimed or measured) _____

Charger shutoff mechanism: _____ (i.e., timed, voltage cutoff, etc.)

Charger Input: AC voltage   _____(V)   AC current   _____(amp)

Charger Output: DC voltage   _____(V)   DC current   _____(amp)

Required Charge Time: Initial State of Charge   _____(%)

Final State of Charge   _____(%)

_____ (hrs)

Series Generator Information:

Manufacturer: _____ Model Number: _____

Generator Power Rating at Speed: _____(kW) Efficiency _____(%) @ speed _____(RPM)

Charging/Power Usage Strategy:

Drivetrain Information:

Please provide a brief explanation of the following items.

Transmission:

Manufacturer: _____ Model Number: _____

Year: _____ Number of Gears: _____

Axle Ratio: _____

Does it have a clutch?   Yes   No

How is the clutch operated (check one)?   _____Manual   _____Automatic

If transmission is CVT, state the transmission ratio range: _____

If transmission is automatic or manual, state the gear ratio for each gear. If the transmission is a single speed, then state the gear ratio in the 1st space.

Transmission gear ratios: _____1st,   _____2nd,   _____3rd,   _____4th,   _____5th,
_____Final Drive Ratio

State the approximate transmission shifting speed:

1st to 2nd   _____(mph)

2nd to 3rd   _____(mph)

3rd to 4th   _____(mph)

4th to 5th   _____(mph)

Braking System (modified vacuum assist?):

Provide a simple schematic of your drivetrain, including the following components: engine, motor, generator (if used), clutch, and transmission. Show where chains or belts are used.

Hybrid Control Strategy:***Describe Hybrid Control Hardware (computers etc.):******Emissions Control Strategies:***

Tire Specifications:

Manufacturer: _____ Model Number: _____

Size (as stated on side wall): _____

Maximum Tire Pressure: _____(psi)

Actual Tire Pressure (psi): _____(Front) _____(Rear)

Additional Instrumentation:

Manufacturer: _____ Model: _____

Information monitored:

Additional Features or Information:

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