THE PENNSYLVANIA STATE UNIVERSITY
LARSON INSTITUTE
HYBRID AND HYDROGEN VEHICLE RESEARCH LABORATORY

RULES AND SCORING FOR THE

21ST CENTURY AUTOMOTIVE CHALLENGE

APRIL 10-13, 2013

DRAFT VERSION 1.4

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Abstract

As our petroleum resources dwindle, many are looking to transition towards vehicles which are more fuel efficient and or powered by alternative fuels. Consumers remain largely uninformed, however, of the differences between alternative fuel vehicles on the market today including electric, hybrid electric, pluggable hybrids, bio-diesel, ethanol, and natural gas. The 21st Century Automotive Challenge (21st CAC) addresses this need for consumer education by carefully measuring and communicating the effects of innovative vehicle technologies as competitors, ranging from independents to automotive producers, compete over a series of local and highway routes and performance events. Public display of the alternative fuel vehicles is also a part of 21st CAC which allows consumers to see the vehicles first hand and speak directly to vehicle owners about their experience with the technologies. The scoring rubric for this competition tests vehicles not only their fuel efficiency but also on the lifestyle decisions of the vehicle users as they live out a day of errands based from a solar and wind powered home. The competition culminates in a thorough evaluation of the event data and publication of compiled results. These results can help consumers make more informed vehicle purchase decisions and also promote adoption of alternative fuel technologies into the automotive fleet.
Table of Contents

Contents
Chapter 1: Introduction ............................................................................................................. 6
  1.1 What’s New and Notable for 21st CAC 2014 ................................................................. 6
  1.2 What to Bring .................................................................................................................. 8
  1.3 How to Get There .......................................................................................................... 9
  1.4 Competition Format and Background ......................................................................... 10
Chapter 2 Agenda .................................................................................................................. 18
  2.1 Thursday and Friday – Technical Inspection and Range Events .............................. 20
      Registration and Technical Inspection ........................................................................ 20
      Range and Meter Calibration ....................................................................................... 21
      Dynamic Handling ...................................................................................................... 21
      Friday Lunch and Opening Discussion at CPI .............................................................. 21
      Dinner .......................................................................................................................... 22
      Range Events .............................................................................................................. 22
      Pit Work at Test Track ................................................................................................. 22
      Charging and Fueling ................................................................................................. 22
  2.2 Saturday – Lifestyle Efficiency Events ....................................................................... 23
      Charging, Liquid Fueling, Extra Laps for State of Charge Adjustment ....................... 23
      Breakfast and Drivers Meeting .................................................................................... 23
      Morning Errands Event ................................................................................................. 23
      Display Only Event ...................................................................................................... 24
      Lunch and Tailgating Event .......................................................................................... 24
      Afternoon Errands Event ............................................................................................. 25
      Tour de Thor Event ........................................................................................................ 25
      Dinner Out in State College .......................................................................................... 26
      Fireside Technical Seminar ......................................................................................... 26
      Pit Work at Test Track ................................................................................................. 26
      Charging and Fueling ................................................................................................. 26
  2.3 Sunday Autocross Event and Preliminary Awards ...................................................... 26
      Charging and Liquid Fueling ....................................................................................... 26
      Breakfast ...................................................................................................................... 26
      Autocross and Drivers Meeting ................................................................................... 26
      Lunch, Display, and Awards at Test Track .................................................................. 27
      Final Awards at EEVC Meeting .................................................................................... 27
Chapter 3 Vehicle Category, Size, and Technology Groups .............................................. 28
  3.1 Vehicle Divisions .......................................................................................................... 29
      Production ................................................................................................................... 29
      Independent ................................................................................................................. 29
  3.2 Weight Classes .............................................................................................................. 29
      Light-Duty .................................................................................................................... 29
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Chapter 1: Introduction

1.1 What’s New and Notable for 21st CAC 2014

Several notable changes have been made to competition this year:

- The 21st CAC will be held this year during Blue White football weekend which averages crowds of between 50-70 thousand spectators. This will significantly increase exposure of the event to the public and press. It will also require extra caution due to increased vehicle and pedestrian traffic along with unexpected delays on routes. Please be patient and respectful pedestrians, law enforcement, and university officials and follow their directions even during unplanned circumstances. TEAMS WILL NOT BE PENALIZED FOR DELAYS OR DETOURS AS A RESULT OF FOOTBALL TRAFFIC OR COOPERATING WITH EVENT OFFICIALS. Please be safe, respectful, and help present the best image for 21st CAC, the University, and public.

- For the second year, registration, technical inspection, dynamic testing, and range events will occur from the Central Pennsylvania Institute of Technology (CPI) on Thursday April 10 and Friday April 11.

- The highway range event will begin at 12:30 pm on Friday April 11 starting from CPI. This year the highway range event will be conducted on an approximate 100 mile loop on Interstate 99 between CPI and Altoona. Highway competitors should be fully charged and fueled by noon.
Highway range event scoring this year will be modified to include components of both measured and estimated vehicle range on a single fueling. See section 4.11 for details.

The local range event will begin at 4:00 pm from CPI with a leg to the Penn State Bus Test Track including the first few track laps before dinner break. Local competitors should be fully charged and fueled by 3:30 pm.

Teams should be prepared to vacate CPI and move all vehicles, equipment, and people to the bus test track beginning at 4:00 pm on Friday April 11. Highway vehicles still on course can make arrangements for Penn State vehicle to move their equipment if needed. Dinner will be made available at CPI for team still on the highway course.

Duplicate Route Slips will part of data collection and must be completed and turned in within 30 minutes of finishing all routes. This data will be considered final unless a petition is filed and accepted. Failure to turn in Route Slips within 30 minutes will result in a 50 point penalty.

All vehicles will complete the first local route on Saturday immediately upon leaving the test track on route to the MorningStar Home to stage for public display as early as possible and minimize impact on football game traffic and parking. All support vehicles must remain at the test track. A shuttle van and cargo van will be made available to move non-drivers and team equipment to the MorningStar.

On Saturday the MorningStar Solar Home will be the site of:

- Strategy session during breakfast
o Charging and public display from 10:00 am to 4:00 pm during the Blue White game

o Cargo and tailgating events

o Scoring meeting and technical seminar on Saturday night

o Lunch and Preliminary Awards Event on Sunday

➢ For the second year, scoring within local and highway divisions will include a hypothetical CAFÉ standard vehicle. Winners will be determined by class and overall winner within each division by comparison to the CAFÉ standard vehicle on the 1000 point scale.

➢ Overall 21st CAC champions will be also determined by comparing their division scores to the 1000 point scale. For the first year, raw data and calculated scores will be circulated among all competitors for peer review and error checking one week prior to the final awards ceremony.

1.2 What to Bring

The following is a condensed list of helpful things to bring for competition. However, the list is an aid and not an exhaustive checklist so competitors are encouraged to read the rules completely.

➢ Advanced chemistry batteries (Lithium ion or NiMh) must have functional original equipment or aftermarket battery monitoring or management system and must demonstrate that functionality during technical testing to be eligible for charging or competing.
50 foot waterproof extension cord and kWhr meter base as described in Appendix IV.

- **All pluggable teams should bring their own socket in a waterproof outlet box for installation onto the charge trailer which is compatible with the voltage and current rating of their charger.**

- Vehicle mounted Class D chemical fire extinguisher.

- Rubber gloves rated for high voltage for vehicles with batteries above 24 V.

- Baking soda, safety glasses for teams with lead acid batteries

- Pop up tent canopy per team to reduce sun exposure

- Sun screen, sun hat, rain gear, lawn chair per person

- Tailgating supplies if you intend to compete for best tailgate at the MorningStar home on Saturday April 12. Charcoal grills are prohibited during game day however.

- Display poster and easel for presentation to the public.

### 1.3 How to Get There

Competition registration will begin on Thursday April 10 at 8:00 am at the:

Central Pennsylvania Institute of Technology  
540 North Harrison Road  
Pleasant Gap, PA 16823  
[http://www.cpi.edu/contact.php](http://www.cpi.edu/contact.php)

Contact information in Appendix III if you need last minute directions.

CPI is a vocational high school. Please sign in all participants and guests at the CPI main office in the front of the building **before** proceeding counter clockwise around the facility.
to the Auto Technology facility in the rear. Please report to 21st CAC registration for further instructions on where to unload and setup charging. Vehicles must arrive and be registered by noon Friday to avoid penalty points. Conversion vehicles are especially encouraged to arrive on Thursday to ease the work load on tech inspection.

### 1.4 Competition Format and Background

![21st Century Automotive Challenge at Penn State](image)

Figure 1.1: 21st CAC 2014 announcement

Imagine you live in a net zero energy house with a high power photovoltaic array and wind generator. Imagine you can choose any vehicle technology you want to match your driving style – electric, solar electric, hybrid, pluggable hybrid, fuel cell, bio-diesel, alcohol, hydrogen, or natural gas. Imagine you also have the technology and account to buy and sell energy to and from the electric utility grid. What vehicle would you choose and what travel choices would you make to live the most energy efficiency lifestyle on a
busy day of errands and a day of leisure travel? This is the context for participation in the 21st Century Automotive Challenge to be hosted again this year at Penn State on April 10-13, 2014 as announced in Figure 1.1 above. This competition mimics the energy lifestyle of homeowners with renewable power generation and pluggable or alternative fuel vehicles as depicted in Figure 1.2.

Figure 1.2: MorningStar home with pluggable vehicle and bi-directional grid interface

The first vehicles to use non-petroleum energy were designed in the late 19th century. Many users and inventors of the electric vehicle (EV), including Thomas Edison, were very enthused about the potential of this type of technology; however, the discovery of plentiful petroleum would lead to the dominance of gasoline and diesel internal combustion engines to power vehicles (Struben, 2007). The next transition to take over the vehicle market is difficult to predict because there isn’t yet a clear-cut technology to challenge the dominance of petroleum fueled internal combustion engines. One of the main issues is fueling infrastructure. Consumers won’t invest in alternative fueled
vehicles until there is a widespread fueling infrastructure built out to support them. Likewise, governments are reluctant to invest in new fueling infrastructure until alternative fuel vehicles are penetrating the market in large numbers. It is a classic “chicken or egg” dilemma.

Key to this problem may be market dynamics. There are social processes that affect innovation such as word of mouth, social exposure, and the willingness of consumers to consider an alternative platform (Struben, 2007). Increased public exposure of viable alternative fueled vehicles will enable future consumers and government policy makers to move away from internal combustion vehicles. A proven method to provide public exposure to alternative fuel vehicle technology is through alternative transportation competitions. Competitions offer a way to showcase multiple types of vehicles and technologies in a low-cost and low-risk setting. These competitions host vehicles ranging from home conversions to new ground breaking production vehicles. Aside from showcasing the performance of these technologies, these competitions allow a direct and fair comparison between each of the alternative fuel technologies. Student and private participants are able to use these competitions for educational and research purposes as well. Lastly, a great deal of public awareness is generated through these highly visible competitions as the data is published through press releases and web site content.

In 1988, the Northeast Sustainable Energy Association (NESEA) initiated one of the first and most successful US alternative transportation competitions called the American Tour de Sol (ATdS) which was patterned after the Tour de Sol which began in Switzerland in 1985. The competition format was a multiple-day road rally event where vehicles
traveled between major cities (Quong, 1994). The initial competition was only for electric vehicles (EV’s) equipped with photovoltaic cells. Vehicles were scored on their efficiency and range (i.e. their average kWh/mile data and total mileage traveled on a single charge). This event gained popularity and grew to several dozen competitors. Over time it evolved to include electric and hybrid electric vehicles as well. However, the last ATdS event was hosted by NESEA in 2006.

In 2007 the Eastern Electric Vehicle Club (EEVC), a chapter of the U.S. Electric Auto Association, hosted a follow on alternative transportation competition by establishing the 21st Century Automotive Challenge. The first annual 21st CAC was held June 9th and 10th, 2007. They repeated the competition a year later. The 21st CAC organized by the EEVC differed from the ATdS in that the 21st CAC incorporated more fuel types into the competition including gasoline, diesel, bio-diesel, hybrid, or electric power. While this was a significant departure from the ATdS, the 21st CAC competition continued to score the competitors on the vehicle’s fuel economy as well as how well the competitors were able to perform in the rally format. If a vehicle arrived at a certain checkpoint too early or too late they would lose points (Eastern Electric Vehicle Club, 2007).

Dr. Joel Anstrom, director of The Hybrid and Hydrogen Vehicle Research Lab (HHVRL) at Penn State and research associate of The Thomas D. Larson Pennsylvania Transportation Institute (LTI), had participated in the ATdS as a graduate student on the Penn State HEV Team and shared the vision of continuing alternative transportation competitions with his former EEVC competitors. In 2009, the HHVRL began hosting the
21st CAC at Penn State University Park Campus and incorporated several new competition elements including a new focus of distributed renewable power generation and consumer lifestyle efficiency choices. The new 21st CAC format incorporated the realities of integrated renewable energy production in homes, power sharing opportunities with the utility grid, and new vehicle categories based on seating capacity to better reflect market choices as depicted in Figure 1.3. (Hybrid & Hydrogen Vehicle Research Laboratory, 2008) This revised competition format is designed to help consumers better understand how their purchasing and daily driving decisions impact the environment through their use of renewable energy versus fossil fuels.

To better understand this new competition format, it’s important to understand a relatively new principle for vehicles sharing energy with the utility grid commonly called

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“vehicle to grid” or V2G. Most cars are parked 95% of the day. V2G technology enables electric power to flow bi-directionally between a parked hybrid or electric vehicle and the utility grid following a power company signal and within vehicle owner predefined parameters. V2G allows grid or home generated power to be stored by your vehicle’s battery while providing voltage down regulation service to the grid. Likewise, your parked vehicle can send energy up to the grid providing voltage up regulation service. All this occurs automatically based on an internet based grid regulation signal. Utility companies pay vehicle owners for V2G services which can be worth around $4,000 per year (Kempton, 2005). An example of the V2G concept can be seen in Figure 1.4. Independent System Operators (ISO) measure grid voltage and send out a correcting regulation signal to vehicles with V2G plugged in at homes and businesses. In response the vehicles either begin charging their batteries or uploading power to the grid in proportion to the regulation signal. Regulation signals typically average out to zero energy over time. V2G can also store energy during periods of low demand; such as during the night when wind power is high for later upload to the grid during periods of peak demand.
Figure 1.4: Vehicle to Grid Concept (Kempton, 2005)

To integrate V2G technology into the 21st CAC competition, Dr. Anstrom has partnered with the Penn State Center for Sustainability directed by Dr. David Riley. The Center for Sustainability operates the MorningStar solar home as the HyRES laboratory, a net zero energy home. [http://sustainability.psu.edu/learn/students/programs/hybrid-and-renewable-energy-systems-hyres-lab](http://sustainability.psu.edu/learn/students/programs/hybrid-and-renewable-energy-systems-hyres-lab) The MorningStar solar and wind powered home collects data on all power generated and used. A sample of this data representing a typical day of renewable power generation is used in the formula to calculate greenhouse gas emissions for each competitor as they charge with both grid and renewable power. In this way their driving and charging decisions affect their environmental impact through their greenhouse gas score. Any excess energy in the vehicle at the end of the day can be uploaded to the grid.
through V2G, offsetting even more greenhouse gases if it was derived from renewable power and further lowering the competitors greenhouse gas score.

The original ATdS scoring divisions were grouped by power train technologies such as electric or hybrid electric. Sub-divisions based on power train technology do not allow for direct comparison of technologies within similar consumer market segments. For example, you might be interested in a vehicle with five seats for family use on long trips. What many people are currently unsure of is whether an alternative fuel power train technology would be acceptable for their intended use. The 21st CAC competition sub-divisions group cars by their seating capacity and intended use, either highway or local. This allows direct performance comparisons within sub-divisions between each of the conventional and alternative fuel technologies. Another significant change in the 21st CAC competition format is the expansion of scoring categories. Past competitions have focused scoring mainly on vehicle performance and fuel economy. Beginning with the 2009 21st CAC, new scoring categories were added to focus on attributes which make cars more marketable including seat-miles/gallon, cargo-miles/gallon, and CO₂ g/mile scoring categories.
Chapter 2 Agenda

The 21st Century Automotive Challenge is a four day event starting with technical testing on a Thursday morning and ending with an autocross event and preliminary awards on Sunday. Friday is range event day. Saturday the competitors live out a typical day of travel and charging assuming they live in a solar home. The agenda for 21st CAC 2014 is as follows:
THURSDAY, APRIL 10: – 21ST CAC TECH/DYNAMIC EVENTS
8:00-Sunset Arrivals at CPI Auto Technology Facility, Tech Inspection, Dynamic Testing, Cargo Events
12:00-1:00 Lunch at CPI
4:00-6:00 Dinner on your own
8:30-12:00 Pit work and charging setup at CPI

FRIDAY, APRIL 11: – 21ST CAC TECH/DYNAMIC EVENTS and RANGE EVENTS
8:00-11:30 Arrivals at CPI Auto Technology Facility, Tech Inspection, Dynamic Testing, Cargo Events continue
8:00-11:30 Liquid and gaseous refueling, charging for highway range event
11:30-12:15 Lunch – 21st CAC Orientations at CPI
12:30 Start Highway Range Event with Interstate 99 route
2:00-3:30 21st CAC Tech Inspection and Dynamic Events completed
4:00 Start Local Range Event with rally to LTI Test Track
4:30-5:30 BBQ dinner at LTI Test Track, takeout at CPI (for Highway Class)
5:30-10:30 Closed track Local Range Event and Highway Class conclusion
8:30-12:00 Pit work and charging setup at LTI Test Track

SATURDAY, APRIL 12: – 21ST CAC LIFESTYLE EFFICIENCY EVENTS
6:00-7:00 Charger readings, liquid and gaseous refueling, drivers meeting
7:00 Start Morning Local Route from Test Track to MorningStar house
7:00-9:00 Breakfast, Display setup, MorningStar Orientation
9:00-12:00 Cargo event and Charging at MorningStar Solar Home
10:00-4:00 Vehicles on Public Display at MorningStar home for Blue White fans!
10:00-2:00 Tailgating Competition and lunch at MorningStar home
12:00 Penn State Blue White Game kickoff
2:00-7:00 Afternoon Local Route, Highway Route, Tour de Thor Range Event
7:00-8:00 Dinner on your own or group walk to the Penn State Creamery
8:00-9:00 Fireside Seminar - Green House Gas Emissions by Fuel and Vehicle Technology at MorningStar home (smores)
9:00-12:00 Return to LTI Test Track, pit work and charging

SUNDAY, APRIL 13: – 21ST CAC RANGE EVENTS
6:00-7:00 Charger readings, liquid and gaseous refueling
7:00-9:00 Breakfast at Test Track
7:00-10:00 Liquid and gaseous refueling, charging for autocross event
8:00-10:00 Autocross Tech Inspection
10:00-12:30 Drivers meeting and Autocross Event at Test Track
1:00-3:00 Lunch and Preliminary Awards Event at Test Track

WEDNESDAY, May 14TH, 7 PM: – (TENTATIVE) FINAL AWARDS AT EEVC MEETING, WHITEMARSH HS
2.1 Thursday and Friday – Technical Inspection and Range Events

Registration and Technical Inspection

Competition registration will begin on Thursday April 10 at 8:00 am at the:

Central Pennsylvania Institute of Technology
540 North Harrison Road
Pleasant Gap, PA 16823
http://www.cpi.edu/contact.php

Vehicles arriving after noon Friday will be penalized 50 points. Inspection will begin on a first come first serve basis. No points will be awarded for order of inspection. Each car must pass a thorough technical inspection before competing in any dynamic event.

**Vehicles are required to be currently and legally registered and inspected if required in their state of origin to compete. All registration and inspection paperwork must be available to the inspection team before technical inspection begins including current state registration and proof of insurance.** Charger plug information will also be required at this station. Each team is required to bring a 50 foot extension cord with kWhr meter base as specified in Appendix IV. Each team must provide a list of designated competition drivers along with copies of valid their driver licenses. Vehicles will be inspected by a team for general safety along with specialized inspections related to their alternative energy systems. Teams must complete inspection by 4 pm Friday to receive any Technical Inspection points. **Vehicles with advanced chemistry batteries (NiMh or Lithium) must be prepared to demonstrate their battery management system is operational at technical inspection to the satisfaction of technical inspectors in order to be eligible to charge or compete in non-display events at the discretion of technical inspectors.** This includes the ability to monitor

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20
pack voltages and temperatures and warn the driver of an unsafe condition at a minimum. Preferably, the BMS will be capable of automatic pack disconnect if safety thresholds are exceeded. Additional conditions and procedures may be imposed by the technical inspectors or officials to insure safety. Alternatively, a reasonable safety strategy may be approved at the discretion of technical inspectors.

**Range and Meter Calibration**
Following Technical Inspection, a Range and Meter Calibration Event may be completed for pluggable vehicles. The purpose of this event is to estimate vehicle range and insure state of charge measurement for scoring. Vehicles with installed state of charge meters and/or odometers will be calibrated by running short laps on the test track. This event is not scored but vehicles which do not complete the event may not be scored for the Vehicle to Grid (V2G) credit in the Carbon Footprint Event.

**Dynamic Handling**
The dynamic handling portion of the competition will evaluate the overall handling, braking, and accelerating performance of the vehicle. This event is designed to confirm that each vehicle is capable of safe road travel. Dynamic tests will consist of acceleration, braking, and slalom. Teams must complete all three tests successfully before start of their range event on Friday. Dynamic testing may be waived at the discretion of technical inspectors.

**Friday Lunch and Opening Discussion at CPI**

Lunch and a competition opening discussion on winning strategies will be held on Friday at CPI.
Dinner
Dinner will be held buffet style from 4:30-5:30 at the Test Track featuring Clems Barbeque. Upon request, portions will be delivered to CPI for highway vehicles wishing to stay on route past 4 pm.

Range Events
On Friday, 21st CAC vehicles will demonstrate their range on a single charge and fueling. Highway vehicles will begin their range event at 12:30 pm from CPI with long laps on the I99 at posted speeds. Local vehicles will begin their range event at 4 pm with a leg from CPI to the Test Track followed by a few Short Laps around the LTI test track at a constant 35 mph. After dinner, short laps will continue with 5 minute breaks each hour until the allotted time expires at 10:30 pm. Highway vehicles must complete one leg from CPI to the Test Track and may optionally complete Short Laps until the allotted time expires at 10:30 pm. Once at the test track, highway vehicles may not return to the highway route or CPI leg.

Pit Work at Test Track
Pit work will be allowed until midnight following the range event.

Charging and Fueling
Charging will be allowed after the Range Event until 6:30 am Saturday. Liquid fueling will stop at midnight Friday and resumes between 6:00-7:00 am Saturday.
2.2 Saturday – Lifestyle Efficiency Events

**Charging, Liquid Fueling, Extra Laps for State of Charge Adjustment**

Charging ends at 6:30 am at the Test Track. Extra Short Laps can optionally be run by vehicles without functional kWhr meter who wish to start the day at a middle State of Charge to allow capacity for Vehicle to Grid (V2G) events. Vehicle efficiency will be calculated later in the day and used to estimate initial SOC.

**Breakfast and Drivers Meeting**

A continental breakfast will be served at 6:00 am. Teams will gather for a brief drivers meeting at 6:45 am. Vehicles will then lineup by 7:00 am in random order. Drivers will leave the Test Track and proceed to complete their Morning Errand route ending at the MorningStar where vehicles will immediately go on display and the continental breakfast will continue. Support vehicles should remain at the test track because of the football parking. Shuttle and cargo vans will be provided to move team members and equipment to the MorningStar. If possible, parking spaces will be reserved for support vehicles but teams must cover the parking fee. At a minimum, teams should take their charging equipment and display. See What to Bring section for additional equipment suggestions.

**Morning Errands Event**

Both Local and Highway vehicles categories will participate in the Morning Errands Event around the Penn State Campus Lap which will start from the Test Track. See Appendix for route information. During the Campus Lap, teams will also perform special errands including visiting the Penn State Creamery and the Nittany Lion. Local vehicles may complete the two errands in any order during the morning or afternoon.

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errands event. Highway vehicles must complete both errands in the morning Campus
Lap. Distance traveled will count towards mileage.

Upon completion of the Morning Errands route, charging will be available at the
MorningStar. This venue simulates power from the MorningStar PV array and wind
turbine on an hour by hour basis and is scored with the carbon footprint from Table 4.4.
Competition vehicles must be on public display at all times while at the MorningStar.

Corresponding Route Slips must be completed, submitted, and signed by team member
and scoring officials within 30 minutes of returning from the route at which point the data
becomes official. Failure to submit Route Slips within 30 minutes will result in a 50
point penalty.

**Display Only Event**
Vehicles register to participate as Display Only on Saturday from 10 am to 4 pm but
must register in advance or on-site.

**Lunch and Tailgating Event**
Teams are invited to participate in a non-scored Tailgate Competition during lunch on
Saturday. At their option, teams may setup and conduct a tailgate in the grassy area next
to their vehicle display slot. Multiple teams may combine into a single tailgate.
Transportation for tailgate supplies and equipment will be provided on a trailer between
the Test Track and the MorningStar on Saturday morning and evening. If teams use
power from their vehicles they should include a means to measure the kWhr used for
later subtraction from mpgge scoring. A team of judges will visit each tailgate between
noon and 2:00 during the event to judge each teams tailgate setup and food for the following potential awards:

- Best Tailgate Recipe
- Best Tailgate Games
- Best Tailgate Style
- Greenest Tailgate
- Best use of Energy to Power a Tailgate

**Afternoon Errands Event**

The Afternoon Errands Event starts at 2 pm. Local vehicles will complete a second Campus Lap and remaining errands. Highway vehicles will leave after 2 pm for a Long Lap. See routes in Appendix VI. Teams will start from the MorningStar. Afternoon Errands must be completed by 7:00 pm by arriving back at the MorningStar. Late vehicles will be assessed a penalty. Distance traveled will count towards mileage.

Corresponding Route Slips must be completed, submitted, and signed by team member and scoring officials within 30 minutes of returning from the route at which point the data becomes official. Failure to submit Route Slips within 30 minutes will result in a 50 point penalty.

**Tour de Thor Event**

The Tour de Thor event allows vehicles to register and complete the afternoon on of two Highway Routes for a fuel economy measurement between 2:00-7:00 pm Saturday.
Dinner Out in State College
Competitors will have free time from 7:00-8:00 for dinner out in State College or may choose to participate in a group walk to the Penn State Creamery.

Fireside Technical Seminar
A brief scoring meeting will be held at the MorningStar starting at 8:00 pm followed by a Fireside Technical Seminar until 9:00 pm. Competitors will be dismissed after the meeting to return to the test track for charging and fueling. A trailer will be provided for transporting tailgating supplies back to the Test Track.

Pit Work at Test Track
Pit work and fueling will be allowed until midnight.

Charging and Fueling
Charging and fueling will be allowed at the Test Track until 6:30 am Saturday.

2.3 Sunday Autocross Event and Preliminary Awards

Charging and Liquid Fueling
Charging and liquid fueling ends at 7:00 am at the Test Track.

Breakfast
A continental breakfast will be held 9:00-10:00 at the test track. During this time, drivers are encouraged to walk the autocross course.

Autocross and Drivers Meeting
The autocross event is held to measure vehicle handling and performance in terms of speed, acceleration, braking, and turning. The Autocross Drivers Meeting is mandatory and scored for participation points. One at a time, vehicles will negotiate a course of
carefully placed cones and receive a run time. Each vehicle will make several runs and be scored using their fastest time. Time penalties will be assessed for knocking cones over. Going off course will nullify the run. The specifics will be discussed during the drivers meeting.

**Lunch, Display, and Awards at Test Track**
A preliminary awards ceremony and picnic lunch will be held at the Test Track following the autocross event. Teams are free to leave after the ceremony.Drafts of the raw data and scoring will be distributed for review one week prior to the final award ceremony. 

**Final Awards at EEVC Meeting**
A final awards ceremony will be held at the next regular EEVC meeting.
Chapter 3 Vehicle Category, Size, and Technology Groups

The 21st CAC categorizes vehicles by market segment and utility rather than technology to better reflect the purchasing decisions of consumers. Two divisions separate OEM production vehicles (Production) and independent teams with modified or conversion vehicles (Independent). There are three sub-divisions to further define each group. One separates vehicles into Light Duty from the Heavy Duty categories. A second separates the cars intended for urban driving (Local) and highway driving (Highway). Lastly, cars are grouped by adult passenger seating accommodation. Each division and sub-division will be further explained in the following sections. Table 3.1 breaks down the divisions.
Table 3.1: Vehicle Category, Size, and Technology Groups

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<td>Passenger Accommodation</td>
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<td>6+</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Local + Highway</td>
<td>Local + Highway</td>
<td>Local</td>
</tr>
</tbody>
</table>

3.1 Vehicle Divisions

Production
This division is for teams, individuals, and manufacturers to demonstrate the capabilities of unmodified OEM vehicles. Aftermarket tires are not considered a modification.

Independent
This division is defined for teams, individuals, and manufacturers to demonstrate capabilities of non-production, modified, conversion, or prototype vehicles.

3.2 Weight Classes

Light-Duty
All vehicles less than 10,000 lb GVW (gross vehicle weight)

Heavy-Duty
All vehicles more than 10,000 lb GVW (gross vehicle weight)
3.3 Distance Capability

Local
Vehicles intended for local urban or neighborhood travel rather than long distance.

Generally these vehicles will not be required to travel at highways speeds for any significant distance but must be legal and capable of traveling on urban surface streets.

Highway
This category includes vehicles capable of long distance highway driving including interstate travel.

3.4 Passenger Accommodation

Vehicles will be further categorized by adult passenger seating accommodation. The technical inspectors will have the final say on practically how many seats a vehicle has depending on seating arrangement.

1-2 Passengers
All vehicles that accommodate up to two adults

3-5 Passengers
All vehicles that accommodate between 3 and 5 adults

6+
All vehicles that accommodate 6 or more adults
Chapter 4: Scoring

Point distribution can be seen in the Table 4.1. Each scoring category will be further described in the following sections.

Table 4.1: Scoring Point Distribution

<table>
<thead>
<tr>
<th>Weight Class</th>
<th>Light Duty</th>
<th>Heavy Duty</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Distance Capability</strong></td>
<td>Local</td>
<td>Local + Highway</td>
</tr>
<tr>
<td>Passenger Accommodation</td>
<td>1-2</td>
<td>3-5</td>
</tr>
<tr>
<td><strong>Technical Events</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1) Participation</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>2) Display</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>3) Inspection and Technical Testing</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td><strong>Performance Events</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4) Dynamic Handling</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>5) Autocross</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td><strong>Energy Efficiency Events</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6) Fuel Efficiency</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>7) Fuel Efficiency per Passenger Mile</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>8) Fuel Efficiency per Cargo Mile</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td><strong>Environmental Impact Events</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9) Petroleum Displacement</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>10) Carbon Footprint</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td><strong>Utility and Consumer Acceptability Events</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11) Range</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1000</strong></td>
<td></td>
</tr>
</tbody>
</table>
For the second year, scoring within local and highway divisions will include a hypothetical CAFÉ standard vehicle. Winners will be determined by class and overall winner within each division by comparison to the CAFÉ standard vehicle on the 1000 point scale. Overall 21st CAC champions will be also determined by comparing their division scores to the 1000 point scale. For the first year, raw data and calculated scores will be circulated among all competitors for peer review and error checking one week prior to the final awards ceremony.

**Conversion Data**

Many of the scoring calculations above require reference data from various sources. One important source of data used was the US DOE GREET model, which is a multi-dimensional spreadsheet designed to allow researchers and analysts to evaluate different fuel and vehicle cycles. To learn more about the GREET model, visit their website. We also used the Corporate Average Fuel Economy standards to help estimate the average petroleum displaced per year. Tables 4.2-4 summarize data compiled from these and other sources to be used in subsequent calculations.

Table 4.2: Fuel Data and Conversion Values (The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model, 2009)

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>BTU Energy / X</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>116,920 BTU / Gal</td>
</tr>
<tr>
<td>Bio-Diesel(B100)</td>
<td>119,550 BTU / Gal</td>
</tr>
<tr>
<td>Grid Power</td>
<td>3,412 BTU / kWh</td>
</tr>
<tr>
<td>Solar Power</td>
<td>3,412 BTU / kWh</td>
</tr>
</tbody>
</table>

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Table 4.3: Corporate Average Fuel Economy

(Corporate Average Fuel Economy (C A F E ))

<table>
<thead>
<tr>
<th>Year</th>
<th>MPG</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>30.2</td>
</tr>
</tbody>
</table>

Table 4.4: Greenhouse Gas Emissions (The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model, 2009)

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Grams of Greenhouse Gas per Gallon of Gasoline Equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>11,356</td>
</tr>
<tr>
<td>Bio-Diesel(B100)</td>
<td>TBD</td>
</tr>
<tr>
<td>Grid Power</td>
<td>18,673</td>
</tr>
<tr>
<td>Solar/wind Power</td>
<td>0</td>
</tr>
</tbody>
</table>

Figure 4.1 is electrical power versus time data from the MorningStar with a sine wave curve fit. Using 6:30 am as the X-axis origin of the graph and the Y-axis as Watts produced, we can compute the solar power generated at any given time using the equation:

\[ y = 6500 \times \sin \left( \frac{x \times \pi}{43200} \right) \]
Figure 4.1: MorningStar kWh of Solar Power Generated vs. Time

In order to simplify this information, we generalized the data output into hourly blocks as shown in Figure 4.2. We assumed the house on average would need 2 kWh per hour. The available solar power for charging is then 2 kWh less than the table shows. This information is provided for competitors on the Saturday Event and Log Sheets.
4.1 Participation

Description
Participation points will be awarded to teams with at least one representative and vehicle present during roll call at formal meetings and events. Participation scored meetings will be marked on the daily Event & Log sheets with the symbol. Teams that arrive late to a participation scored meeting or event will not receive participation points and may be subject to penalties as well.

Scoring
Each team will have an opportunity to earn a total of 40 participation points for attending all of the participation scored meetings and events. Total participation points earned will be:

\[
\text{Participation Points} = 40 \times \frac{\text{# Scored Meetings Attended}}{\text{Total # Scored Meetings}}
\]
4.2 Display

Description
An important component of the 2014 21st Century Automotive Challenge will be public outreach through display, especially during pre-game hours. Each team will be expected to have a poster, visual aid, or display which describes their vehicle. This display will need to travel with the competition vehicle or a support vehicle to Display Scored Events. Display scored events will be marked on the daily Event & Log sheets with the \( \text{Pu} \) symbol. The vehicle and display should be manned at all times during a display scored event except during meetings, errands, and meals. A Best Display award will be presented to the team with the best display content, creativity, discipline, and presentation skills.

Scoring
Each team will have an opportunity to earn a total of 30 display points on Saturday and Sunday. Judges will make four random checks of all vehicles on display during display scored events. Display points will be awarded to each team actively on display during that event. Display points will be awarded according to the equation:

\[
\text{Display Points} = 30 \times \frac{\# \text{ Display Scored Events}}{\text{Total } \# \text{ Display Scored Events}}
\]

4.3 Inspection and Technical Testing

Description
Each team is required to pass inspection and technical testing to participate in any dynamic or on road events. The Technical Inspection Station will open at 8 am April 10. Inspection will be first come first serve in line. No points will be awarded by inspection.
order. Vehicles arriving after noon Friday April 11 will be penalized 50 points. Charger plug information will also be required at this station. Each team is required to bring a 50 foot extension cord with kWhr meter base as specified in Appendix IV. There will be three stations: paperwork station, weigh station, and vehicle lift inspection. Vehicles are required to be currently and legally registered and inspected in their state of origin to compete. Vehicles without complete registration, insurance, and inspection may be allowed to complete closed track simulations of local range events in lieu of on road competition while receiving a one-time penalty of 50 points. All paperwork must be presented to the inspection team before technical inspection begins including state registration and insurance. A list of drivers must be presented along with copies of valid driver licenses. Vehicles will be weighed to determine wheel loads. Gross Vehicle Weight Rating (GVWR) and curb weight will be used to determine available seat rating assuming passenger weight of #150 lbs. Vehicles will be restricted to this GVWR value of seating during competition. Vehicles without GVWR rating will be assessed seating using their tire load ratings. Vehicles will be inspected by a team for general safety along with specialized inspections related to their alternative energy systems. All high voltage wiring must be identified with orange coloring. All high voltage terminals must be covered with individual terminal covers or a shield which should prevent shorting by falling items in a “key drop test.” Competitors are encouraged to securely install a chemical fire extinguish in the vehicle within reach of a belted driver. BMS systems must be operational for advanced chemistry batteries. Alternatively, a reasonable safety strategy may be approved at the discretion of technical inspectors.
Scoring
Highway teams must complete inspection by 12:00 pm Friday to receive any points.
Local teams must complete inspection by 4:00 pm Friday to receive any points. Each team will have an opportunity to earn a total of 30 inspection and technical testing points. For n attempts to complete the inspection and technical testing, the team will earn points according to the equation:

\[ \text{Inspection Points} = 30 - (n-1) \times 10 \] points.

4.4 Range and Meter Calibration

Description
The Range and Meter Calibration is an un-scored event but vehicles must successfully complete the event to be eligible for V2G scoring credit in the Carbon Footprint Event. After inspection is successfully completed, the vehicle will undergo a short charge and discharge test on the AV900 machine to estimate battery capacity and calibrate State of Charge meter. Vehicles must be equipped with an Anderson 150 amp connector or adapter to directly connect their battery to the AV900. After this test the vehicle will complete several Short Laps on the track to calibrate their odometer.

Scoring
None

4.4 Dynamic Handing

Description
The dynamic handling portion of the competition will evaluate the overall handling, braking, and accelerating performance of the car. This event is designed to demonstrate
that each vehicle is capable of safe road travel. Dynamic events will consist of acceleration over a distance, braking within a specified distance, and a slalom course.

Dynamic Handling is demonstrated in three stations. Station 1 consists of a starting line, 100 foot acceleration zone, 100 foot speed stabilization zone, and a braking zone. Cars must demonstrate the ability to accelerate to 20 mph within 100, maintain 20 mph for 100 feet, and brake to a stop within 26.2 feet. Station 2 consists of a starting line, 100 foot acceleration zone, and a slalom with cones places at 60 foot intervals. Vehicles must demonstrate the ability to accelerate to 20 mph within 100 feet and then negotiate the slalom at 20 mph in a stable fashion. Station 3 consists of any safe parking area where drivers and passengers can demonstrate exiting the vehicle in under 5 seconds.

Teams will earn 30 points for meeting the minimum standards of each event on the first attempt. All three events must be successfully completed before 12:00 pm (highway vehicles) or 4:00 pm (local vehicles) Friday to receive any points. Two points will be deducted from available points for each subsequent attempt. All vehicles must successfully complete dynamic to be eligible for participation in the Autocross and other on road events. In addition, the drivers and passengers must demonstrate the ability to exit the vehicle in under 5 seconds from a seat belted position. This is pass fail for now score but counts towards successful completion of the dynamic event.
Table 4.5: Dynamic Event Minimum Standards

<table>
<thead>
<tr>
<th>Dynamic Event</th>
<th>Minimum Standard</th>
<th>Point Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceleration to 20 mph</td>
<td>100 feet</td>
<td>10</td>
</tr>
<tr>
<td>Braking distance from 20 mph</td>
<td>26.2 Feet</td>
<td>10</td>
</tr>
<tr>
<td>Slalom course at 20 mph</td>
<td>Demonstrate stability</td>
<td>10</td>
</tr>
<tr>
<td>Driver and passenger</td>
<td>5 Seconds</td>
<td>Pass Fail</td>
</tr>
<tr>
<td>emergency exit time</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Scoring**

Each team will have an opportunity to earn a total of 30 dynamic handling points if each event is completed on the first attempt. For n attempts to complete each dynamic handling test, the team will earn points according to the equation:

\[
\text{Dynamic Event Points} = 10 - [(n-1) \times 5]
\]

**4.5 Autocross**

**Description**

Autocross officials will perform a separate technical inspection to determine vehicle safety for the event between 9-10 am. An autocross drivers meeting will begin at 10 am Sunday where race officials will discuss rules and penalties. At their discretion, vehicle may be deemed safe or not safe for participation in the autocross. Vehicles deemed unsafe receive participation points and the minimum autocross score. Autocross officials will have the final say on timing and penalties. Typically, a 2 second penalty will be
applied for knocking over a cone and a run will be disqualified for going off course. Vehicles will line up single file and negotiate a handling course one at a time. Each team will have several runs to complete the course. Scoring will be based on best time.

**Scoring**
The lowest qualified run time for each vehicle will be used in the final scoring within each vehicle category. The max score a team will receive is 70 and the minimum will be 30 using a linear scale to calculate the relative scores within each vehicle category according to the equation:

\[
\text{Score} = \frac{\text{Max Score} - (\text{Vehicle Raw Data} - \text{Best Raw Data}) \times (\text{Max Score} - \text{Min Score})}{(\text{Worst Raw Data} - \text{Best Raw Data})}
\]

For example, if the best score is 60 seconds and the worst score is 95 seconds, the score for a car completing the course in 72 seconds would be:

\[
\text{Score} = 70 - (72 - 60) \times \frac{(70 - 30)}{(95 - 60)} = 56.29
\]

**4.6 Fuel Efficiency**

**Description**
The fuel efficiency events will be based on chemical and electrical energy consumed on a tank to wheel basis during all Saturday Events for both local and highway vehicle categories. Fuel tanks will be topped off and sealed on Saturday morning and battery state of charge will be estimated. The Local and Highway category vehicles will travel the same ~25 mile Campus Lap during morning errands. Local vehicles will travel a second Campus Lap during afternoon errands. Highway vehicles will travel a ~100 mile Highway Lap on routes 26, 22, and 322 and return to the MorningStar. The mileage for each car will be tracked during the day on Saturday using the Events and Log sheets and
Route Slips. Saturday evening recharging and refueling will provide data on total electrical energy consumed by pluggable vehicles. A Hotel Route Slip will be provided for those using competition vehicles to and from hotel accomidations. **Hotel Route Slips for Saturday night must be submitted by 10:00 am Sunday morning to avoid a 50 point penalty.** Chemical refueling will occur on Sunday morning before the autocross event. Saturday mileage, kWhr, and chemical fuel data will be used to calculate tank to wheels miles per gallon gasoline equivalent (mpgge) values for scoring the fuel efficiency events.

**Scoring**

Using the data in Figure 3.3.2 and the measured mileage and fuel energy consumed, we will calculate the tank to wheels mpgge with the following equation:

\[
\text{MPG gasoline equivalent} = \frac{\text{Miles Traveled}}{\left(\frac{\text{Total BTU}}{\text{BTU per gal of Gasoline}}\right)}
\]

For example, if a hybrid vehicle travels 200 miles using 3 gallons of bio-diesel fuel and 5 kWh of electrical energy, MPG gasoline equivalent will be:

\[
\text{MPG gasoline equivalent} = \frac{200}{(3 \times 119,550 + 5 \times 3,412) / 116,920}
\]

= 62.24 MPG gasoline equivalent

The max score a team will receive is 200 and the minimum will be 50. We will use a linear scale to calculate the rest of the scores. Please note the following example:

\[
\text{Score} = \text{Min Score} + \frac{(\text{Vehicle Raw Data} - \text{Worst Raw Data}) \times (\text{Max Score} - \text{Min Score})}{(\text{Best Raw Data} - \text{Worst Raw Data})}
\]

For example, if the best MPG gasoline equivalent is 96 and the worst is 42, the score for a vehicle with a 57 MPG gasoline equivalent would be:

\[
\text{Score} = 50 + \frac{(57 - 42) \times (200 - 50)}{(96 - 42)}
\]

= 91.67
4.7 Fuel Efficiency per Passenger Mile

**Description**
Fuel Efficiency per Passenger Mile event normalizes fuel efficiency by passenger seating as a way of rewarding designs which deliver both high fuel efficiency and ample seating since adding seats generally increases frontal area and vehicle mass at a loss to fuel efficiency. A passenger seat is defined as an adult seat which is accessible by walking through a door and/or temporary folding of other seats. Total seating capacity is the number of adults that can be seated at once during transport. Seatbelts and airbags must comply with US model year requirements. Events should be completed with a minimum of the driver, however, a full complement of passengers is not required.

**Scoring**
With the passenger accommodations data, we will compute the fuel efficiency per passenger mile with the following equation:

\[
\text{Fuel Efficiency per Passenger Mile} = \frac{(\text{Miles Traveled} \times \text{Total Adult Accommodation})}{[\text{Total BTU} / \text{BTU per gal of Gasoline}]}
\]

For example, if the vehicle in the example in Section 3.3.6 is capable of transporting a total of 4 adults, the fuel efficiency per passenger mile will be:

\[
\text{Fuel Efficiency per Passenger Mile} = \frac{(200 \times 4)}{[(3\times119,550 + 5\times3,412) / 116,920]}
\]
\[
= 248.96 \text{ passenger miles per gallon}
\]

The max score a team will receive is 50 and the minimum will be 10. We will use the same example equation that was used in Section 3.3.6 to compute the scores for this section.
4.8 Fuel Efficiency per Cargo Mile

Description
The Fuel Efficiency per Cargo Mile event normalizes fuel efficiency by cubic feet of cargo space as a way of rewarding designs which deliver both high fuel efficiency and ample cargo volume since adding cargo volume generally increases vehicle frontal area and mass at a loss to fuel efficiency. The cargo event will be held as convenient during technical testing on Thursday and Friday and during the Display Event on Saturday to measure cubic feet of cargo volume and corresponding seating. Teams will have ten minutes to load their vehicle cargo area(s) using a selection of boxes with predetermined volume. Vehicles may not be on charge during this event. Legitimate cargo areas include trunks, compartments, and other non-seating areas. Cargo placed on seats, in foot wells, on dashboard ledges, and other driver or passenger use or visibility areas will count towards cargo volume so long as it does not impair the driver or create a safety hazard. Cargo may be placed under seats if it does not interfere with seat adjustment in any way. If the vehicle has folding seats to allow more cargo area, the team may make one attempt for each seating/cargo configuration. However, the seating value used for scoring will be proportional to the number of seats available for given cargo value divided by the total seat number. Open truck beds may be filled to one foot above the permanent bed rails so long as a tarp could be secured over of the cargo on four sides.

Scoring
Using the cargo capacity data, we will compute fuel efficiency per cargo mile points using the following equation:

\[
\text{Fuel Efficiency per Cargo Mile}
\]

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If the example vehicle in Section 3.3.6 has 21 cubic feet of cargo area, the fuel efficiency per cargo mile will be:

\[
\text{Fuel Efficiency per Cargo Mile} = \frac{200 \times 21}{\left[(3 \times 119,550 + 5 \times 3,412) / 116,920\right]} = 1307.04 \text{ cubic feet miles per gallon}
\]

The max score a team will receive is 50 and the minimum will be 10. We will use the same example equation that was used in Section 3.3.6 to compute the scores for this section.

4.9 Petroleum Displacement

**Description**

The Petroleum Displacement Event will score each vehicle based on an average amount of petroleum it would displace if driven 10,000 miles per year compared to Corporate Average Fuel Efficiency (CAFÉ) Standards. Scoring calculations will also be normalized by comparing seating capacity to CAFÉ standard vehicles. Light trucks have traditionally been excluded from CAFÉ standards but are treated here as cars. Heavy Duty vehicles scoring will be compared to an appropriate standard for their category.

**Scoring**

The Corporate Average Fuel Economy standards found in Figure 3.3.2 will be used to estimate the petroleum displaced. We will assume an average yearly mileage of 10,000 miles and an average seat count of 4.5 in a 2011 CAFÉ standard vehicle. The estimated petroleum consumed per year for the competitor will be based on achieved mpgge and the proportion of petroleum used in total fuel energy. Finally, the petroleum displaced
will be normalized by the amount of seats in the car compared to 4.5 for a CAFÉ standard vehicle. The petroleum displacement will be scored using the following equation:

\[
\text{Total Petroleum Displaced} = \left[ (\text{CAFÉ gasoline per 10Kmiles}) - (\text{Vehicle gge per 10kmiles}) \times (\text{proportion of petroleum in total chemical fuel energy}) \times (\frac{\text{Number of Seats}}{\text{CAFÉ 4.5 seats}}) \right]
\]

For example, if a two seat hybrid vehicle travels 200 miles at 62.24 mpgge using 3 gallons of B90 bio-Diesel at 119550 BTU/gal that is 10% petroleum by energy content plus 5 kWh of electrical energy, the petroleum displaced per 10,000 miles in one year would be:

\[
\text{Petroleum Displaced per year} = [(\frac{10,000 \text{ mi/yr}}{30.2 \text{ gge}}) - (\frac{10,000 \text{ mi/yr}}{62.24 \text{ mpgge}}) \times \left( \frac{3 \times 119550 \times 0.10}{3 \times 119,550 + 5 \times 3,412} \right) \times (\frac{2}{4.5})
\]

\[= 158.5 \text{ gallons of petroleum displaced per year}\]

The max score a team will receive is 150 and the minimum will be 50. We will use the same example equation that was used in Section 3.3.5 to compute the scores for this section.

### 4.10 Carbon Footprint

**Description**

Each car will be scored on the grams of CO₂ added to the atmosphere by their vehicle per mile or “carbon footprint” during the Saturday events. The total CO₂ emitted by each vehicle will be the sum for all fuels used including petroleum, bio-fuel, grid electricity, and renewable electricity. In everyday use, an electric vehicle operated from a solar home would converge on an average kWhr usage per day. It should also start and finish the day at the same battery state of charge somewhere in the middle range where battery turn around efficiency and power are high. This operating strategy would have several benefits. It would reduce the effective charge cycles on the battery and improve battery...
life by avoiding operation at low and high states of charge where corrosion and material degradation occur at greater rates. It would also provide higher energy turnaround efficiency by operating at middle state of charge where battery internal resistance is typically lower. Vehicles should use their state of charge meter to start Saturday at a middle state of charge. Vehicles without a SOC meter can run extra laps Saturday morning to adjust initial SOC value to the desired morning value. This SOC will be estimated based on vehicle efficiency in miles/kWhr achieved on Saturday. Throughout the day, pluggable vehicles will have ample opportunity to charge from the simulated photo voltaic array and wind turbine of the MorningStar Home which is scored as having virtually no carbon emissions. Charging may also be available at the test track during Saturday events but it will be accessed carbon footprint for the grid. At the end of the day, pluggable vehicles will be at a new state of charge most likely higher than their starting value. If a pluggable vehicle ends the day on Saturday at a higher state of charge than it started with, then the excess electric energy will be virtually “sold back” to the grid through a simulated Vehicle to Grid (V2G) calculation using that evenings charge data. This will offset the carbon impact of an equivalent amount of grid produced energy. Charging from a PV array during off peak hours and selling energy pack during peak hours could result in a net zero or net negative carbon footprint for that day.

**Scoring**

The carbon footprint will be based on the data in Figure 3.3.3 and will be calculated using the following equation:
Total Carbon Footprint in grams / mile
\[ \text{Carbon Footprint} = \frac{(\text{Amount of Gasoline Equivalent of Fuel(s) Consumed}) \times (\text{Carbon Footprint per Gallon of Gasoline Equivalent of Fuel(s) Consumed})}{\text{Miles Traveled}} \]

For example, the carbon footprint for the example vehicle used in Section 3.3.6 would be:

\[ \text{Carbon Footprint} = \frac{(3 \times 119550 / 116920) \times 3223 + (5 \times 3412 / 116920) \times 0}{200} = 49.43 \text{ grams of fossil fuels emitted / mile} \]

The max score a team will receive is 150 and the minimum will be 50. We will use the same example equation that was used in Section 3.3.5 to compute the scores for this section.

4.11 Range Event

Description
The scored range event consists of 21st CAC vehicles demonstrating their range on a single charge and/or fueling. There are separate range events for local and highway vehicles. In fact, it is range that separates vehicles into either local and highway categories with local vehicles intended for in town use and highway vehicles capable of longer trips of 100 miles or more on a single charge and/or fueling. The scored range event occurs on Friday. Highway and Local vehicle categories will be scored separately. Highway vehicles start their range event at 12:30 pm with ~ 100 mile laps on I99 to the Bus Test garage in Holidaysburg and return after which they must follow the route from CPI to the test track arriving no later than 10:30 pm or be penalized at one point per minute late. At the test track they may complete Short Laps on the closed track with local vehicles by joining the end of the line. Once on the local track, highway vehicle may not return to the highway route. The maximum possible demonstrated highway
range will be about 500 miles. Local vehicles will start their range event at 4:00 pm completing the route from CPI to the test track and the first lap on the one mile closed course. After a dinner break, local and highway vehicles continue closed course laps at 35 mph with a 5 minute break on the hour until 10:30 pm. Vehicles will travel in single file behind the pace car with no passing until they are unable to keep pace at which time they should pull off the track. If the pace car catches up to the last vehicle then judges will determine which vehicle is not keeping pace and wave them off the track ending their range event. The maximum possible demonstrated local range will be about 175 miles.

Starting in 2014, the above highway and local routes will constitute 150 out of 200 points for demonstrated range. A second 50 point component of the range score will devoted to an estimated range. Vehicles which have remaining range (energy) at 10:30 pm will be refueled and/or recharged and the percent of fuel used along with the OEM/nameplate rated electrical and chemical energy storage will be used to estimate useful maximum range. For instance, if a bio-diesel vehicle with a 15 gallon OEM rated tank capacity uses 10 gallons while demonstrating 500 miles of range, then its estimated range will be:

$$R_{est} = E_{capacity} \times \frac{R_{demonstrated}}{E_{demonstrated}} = 15 \times \frac{500}{10} = 750 \text{ miles}$$

The Range Event will not count towards fuel economy scoring.

**Scoring**

The maximum demonstrated range score a team will receive is 150 and the minimum will be 50. Likewise, the maximum estimated range score a team will receive is 50 and the
minimum will be 25. A linear scale will be used to calculate the relative scores within separate local and highway range categories according to the equation:

\[
\text{Score} = \frac{\text{Max Dem Score} - (\text{Best Dem Data} - \text{Vehicle Dem Data}) \times (\text{Max Dem Score} - \text{Min Dem Score})}{\text{Best Dem Data} - \text{Worst Dem Data}} + \frac{\text{Max Est Score} - (\text{Best Est Data} - \text{Vehicle Est Data}) \times (\text{Max Est Score} - \text{Min Est Score})}{\text{Best Est Data} - \text{Worst Est Data}}
\]

For example, if the best demonstrated highway range is 500 miles and the worst demonstrate range is 100 miles while the best estimated range is 700 miles while the worst estimated range is 110 miles, then the total range score for a car demonstrating 250 miles with and estimated range of 320 miles would be:

\[
\text{Score} = 150 - (500 - 250) \times (150 - 50) + 50 - (700 - 320) \times (50 - 25)
\]
\[
= 150 - 62.5 + 50 - 16.1 = 121.4
\]

4.12 Tour de Thor
Competitors can vehicles to compete in the Tour de Thor only and will be scored on their tank to wheels fuel economy only based on a single Tour de Thor Long Lap of either 67 or 100 miles. Scoring will be calculated similar to the fuel efficiency event in section 3.3.6. Tour de Thor vehicles will be compared to the Highway Vehicle Category

4.13 Penalties

Description
Point penalties will be accessed to teams which fail to comply with the rules and regulations of the competitions or by their actions cause a safety concern or bad image
for the event. In severe cases a competitor may be ask to forfeit and event or be removed from the competition base on the ruling of a disciplinary panel.

**Scoring**
Safety infractions may be penalized up to 50 points per incident.
References


Appendix I – Abbreviations

21st CAC – 21st Century Automotive Challenge

ATdS – American Tour de Sol

CAFE – Corporate Average Fuel Economy

EEVC – Eastern Electric Vehicle Club

EV – Electric Vehicle

GHG – Greenhouse Gas

GREET - Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation

HHVRL – Hybrid and Hydrogen Vehicle Research Laboratory

LTI – The Thomas D. Larson Pennsylvania Transportation Institute

NESEA – The Northeast Sustainable Energy Association

V2G – Vehicle to Grid
Appendix II – Tools

The following tools were used to gather results for this thesis:

MorningStar (Penn State Center for Sustainability) located across the street from Beaver Stadium. Provides real-time solar power generation data.

Aerovironment AV 900 (LTI) located at LTI test track. Offers very specific and precise power charging and discharging options.

Aerovironment AV C150 (LTI) located in Research Building B. Offers very specific and precise power charging and discharging options.

Microsoft Excel
Appendix III – Officials and Contact Info

Dr. Joel Anstrom – Director of 21st Century Automotive Challenge

Cell 814 880-2970 email jra2@psu.edu

Theresa Maher – Administrative and Technical Coordinator

Cell xxx xxx-xxxx email yyy@xxx.zzz

James D’Iorio – Scoring Calculations Coordinator

Cell xxx xxx-xxxx email yyy@xxx.zzz
Appendix IV – Extension Cords and Plugs

All pluggable vehicles are required to bring a waterproof 50 foot extension cord and kWhr meter base to reach from the central charging trailer or panel to their charger and record energy consumed. Figure 1 shows the NESEA Tour de Sol design for this extension. Teams which have an extension and meter from previous events should bring it for this event. Teams which do not have an extension should bring the cord and base and the 21st CAC will loan digital kWhr meters to those teams. The extension wire gauge should be rated for the maximum charger current and to minimize voltage drop with compatible waterproof plugs and receptacles at each end. The meter should be nearest the charger socket to eliminate power lost due to voltage drop in the extension cord.
Figure IV-1: example 50 foot charging extension cord with kWhr meter stand
Appendix V Event and Log Sheets

The following log sheets are to be used for data collection during the event. Data should be updated every hour. Scoring officials will maintain a parallel copy and visit teams frequently for updates to the scoring. Copies will be collected at the end of each day.
Appendix V: 2013 21st CAC Friday Event & Log Sheet V1

Team Name_______________________
Category _________________________

☐ 8 am __________________________
☐ 9 _____________________________
☐ 10 _____________________________
☐ 11 Liq Fueling Topoff___________
☐ 12 Box Lunch Orientation ______
☐ 1 Highway Range Event Lineup
Route 1 Long Laps miles __________
Route 2 Long Laps miles __________
Short Laps after 5 pm ______________
☐ 2 _____________________________
☐ 3 _____________________________
☒ 4 Local Range Event Driver Meeting
☒ 4:30 Lineup for CPI to Test Track
☐ 6 Clems Dinner________________
☐ 8 _____________________________
☐ 9 _____________________________
☐ 10 Laps ____ Charging and Pit Work
☐ 11 _____________________________
☐ 12 Pits close___________________

Scoring

☐ Paperwork ______________________
☐ Weights RF ______ LF ______
RR ______ LR ______ lbs
☐ Tech Inspection attempts ______
☐ Tech Inspection notes __________

☐ Seating ________________________
☐ Range and Meter Calibration ______

☐ Acceleration ____________________
☐ Braking Distance________________

Electric Energy Log

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<th>Time</th>
<th>Meter Readings</th>
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<td>at…….Meter/Vehicle………………</td>
</tr>
<tr>
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<td>______________</td>
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Liquid Fueling

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<tr>
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<td>units</td>
<td>Time</td>
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Comments: ______________________

Penalties____________________________________

☑ Participation Event☐ Display Event

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Appendix VI: 2013 21st CAC Saturday Event Log Sheet V1

Team Name_______________________

☐ 6:30 am Liquid Fueling Topoff
☐ SOC Calibration Short Laps ________
Event Comments Odom

☐ 7 Lineup ________________________
☐ 7:15 MorningStar Breakfast ________
☐ 8 Drivers Mtg ____________________
☐ 9 Lineup _________________________

☐ 10-2 MorningStar Display__________

☐ AM Campus Lap (all) ______________
☐ Errand stops ______________________

☐ 12-2 Unscored Tailgating Competition
☐ 2-7 Campus Lap (Local) _____________
☐ Errand stops ______________________

☐ 2-7 Long Lap (Hwy) _________________

☐ V2G _____________________________

☐ 7-8 Dinner OYO or Creamery Walk

☐ 8-9 Scoring and Seminar

MorningStar

☐ 9-12 Pit Work and Charging ________

☐ 12-6:30 Charging __________________

☐ Cargo ___________cu ft ___#seats

1 Nittany Lion _________________________
2 Creamery _________________
3 Beaver Stadium ________________

Comments:
__________________________________
__________________________________
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Electric Energy Log

Sat 6:30 am Start_____________kWhr
at.......Meter/Vehicle......................

Time PV Available
7am________________ PV1.16kW
8am________________ PV2.25kW
9am________________ PV3.18kW
10am________________ PV3.90kW
11am________________ PV4.35kW
12am________________ PV4.50kW
1pm________________ PV 4.35kW
2pm________________ PV3.90kW
3pm________________ PV3.18kW
4pm________________ PV2.25kW
5pm________________ PV1.16kW
6pm________________
7pm________________
8pm________________
9pm________________
10am________________
11am________________
12am________________
1am________________
2am________________
3am________________
4am________________
5am________________
6am________________

Fuel_____ units_______Time_____
Fuel_____ units_______Time_____
Fuel_____ units_______Time_____

Comments:________________________
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ABC__________________________
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Penalties________________________
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Team Copy

Morning Local Errand Route Slip
Team____________________________
Start odo_________________________
Start kWhr car_______ Meter________
Start time ________End Time_______
Errand _________________________
Deviations ______________________
Initials Team________ 21CAC ______

Afternoon Local Errand Route Slip
Team____________________________
Start odo_________________________
Start kWhr car_______ Meter________
Start time ________End Time_______
Errand _________________________
Deviations ______________________
Initials Team________ 21CAC ______

Afternoon Highway Route Slip
Team____________________________
Start odo_________________________
Start kWhr car_______ Meter________
Start time ________End Time_______
Errand _________________________
Deviations ______________________
Initials Team________ 21CAC ______

Hotel Route Slip
Team____________________________
Start odo_________________________
Start kWhr car_______ Meter________
Start time ________End Time_______
Errand _________________________
Deviations ______________________
Initials Team________ 21CAC ______

21st CAC Copy

Morning Local Errand Route Slip
Team____________________________
Start odo_________________________
Start kWhr car_______ Meter________
Start time ________End Time_______
Errand _________________________
Deviations ______________________
Initials Team________ 21CAC ______

Afternoon Local Errand Route Slip
Team____________________________
Start odo_________________________
Start kWhr car_______ Meter________
Start time ________End Time_______
Errand _________________________
Deviations ______________________
Initials Team________ 21CAC ______

Afternoon Highway Route Slip
Team____________________________
Start odo_________________________
Start kWhr car_______ Meter________
Start time ________End Time_______
Errand _________________________
Deviations ______________________
Initials Team________ 21CAC ______

Hotel Route Slip
Team____________________________
Start odo_________________________
Start kWhr car_______ Meter________
Start time ________End Time_______
Errand _________________________
Deviations ______________________
Initials Team________ 21CAC ______
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Appendix VII: 2013 21st CAC Sunday Event Log Sheet

Team Name ______________________
6:30 Charging Fueling Ends _________
Fuel_____ units_________Time_____  
Fuel_____ units_________Time_____  
Fuel_____ units_________Time_____  
 7-8 Breakfast and Drivers Mtg
 8-10 Autocross Tech Inspect/Walkthru

_________________________________
_________________________________
_________________________________

 10-12 Driver Meeting and Autocross
Best time __________________________

 12-1 Packup at track
 1-3 MorningStar Lunch Awards
Comments:________________________

_________________________________
_________________________________
_________________________________
_________________________________

Penalties_________________________
Comments:_______________________

- Participation Event - Display Event
Appendix VI: Google Map Links to Routes

Friday Highway Range Event: CPI to LTI Holidaysburg and return - 104 miles, 1 h 39 m

https://www.google.com/maps?saddr=540+N+Harrison+Rd,+Bellefonte,+PA+16823&daddr=2237+Old+Route+220+N,+Duncansville,+PA+16635+to:540+N+Harrison+Rd,+Bellefonte,+PA&hl=en&sl=40.666877,-78.074583&sspn=0.644777,0.883026&geocode=FQHQbwIdwMZd-ymjAu8QsbzOiTHLREd6sGyFtg%3BFW0zaQldWpJT-yn55ZiyZbLTGATouchbm8mw%3BFQHQbwIdwMZd-ymjAu8QsbzOiTHLREd6sGyFtg&oq=540+N+Harrison+Rd,+Bellefonte,+PA+16823&mra=ls&t=m&z=10

Friday Local Range Event: CPI to Bus Test Track Leg - 19.0 miles, 17 m

https://www.google.com/maps/dir/540+North+Harrison+Road,+Pleasant+Gap,+PA+16823/164+Test+Track+Road,+Bellefonte,+PA/@40.886265,-77.780457,12z/data=!4m23!4m22!1m15!1m1!1s0x89cebcb17ba244a1:0x4e25352f54947f89!2m2!1d-77.737463!2d40.879218!3m4!1m2!1d-77.765534!2d40.906625!3s0x89cea2320f8841129:0x8e383fa3eg9634ca13m4!1m2!1d-77.775812!2d40.911099!3m4!1m2!1d-77.839249!2d40.864007?hl=en

Saturday Morning Local and Highway Leg: Test Track to MorningStar 18.8 miles 36 minutes

No Errands

https://www.google.com/maps/dir/Test+Track+Rd,+Bellefonte,+PA+16823/40.8106003,-77.8441951/@40.8155481,-77.8352973c8bfcc17!2m2!1d-77.8767065!2d40.8285583!3s0x89cea41d7738a8a5:0x1352973cf8bfcc17!2m1!d-77.8909053!2d40.8195383!3s0x89cea7c1401b93177!0xbfaaeae144cbf1847e!3m4!1m2!1d-77.922573!2d40.8120581!3s0x89cea7fbeb01eea7d:0x124ef9248bc816c!3m4!1m2!1d-77.9059135!2d40.7885395!3s0x89cea814af7feb2c9:0x8260da75f7cb04a!3m4!1m2!1d-77.8780089!2d40.7599795!3s0x89cea901c1c94a81:0x6146d5273c68274!3m4!1m2!1d-77.819032!2d40.8088927!3s0x89cea5ec21bf2ca5:0x4c80f9948d9c8d0!1m0!3e0

Saturday Afternoon Belleville Highway and Tour de Thor Route 1 from MorningStar – 61.7 miles, 1 h 32 m

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Saturday Afternoon Huntingdon Highway and Tour de Thor Route 2 from MorningStar – 97.9 miles, 2 h 3 m

https://www.google.com/maps/dir/40.809509,-77.850575/40.7346,-77.88436/40.64121,-77.8312/40.60424,-77.7306/40.66796,-77.60464/40.79394,-77.62463/40.81473,-77.85623/40.80968,-77.8509/@40.7572756,40.7572756,-77.8312,40.7346,77.88436,77.60464,77.62463,40.81473,77.85623,40.80968,77.8509?hl=en

Saturday Afternoon Local Leg 1: MorningStar to Pa Military Museum - 5.0 miles, 11 minutes
Errand – Take group vehicle picture under Naval Cannons from USS Pennsylvania

https://www.google.com/maps/dir/Porter+Rd,+State+College,+PA+16801/Pennsylvania+Military+Museum,+51+Boal+Ave,+Boalsburg,+PA+16827/@40.8042778,-77.850275/Test+Track+Rd,+Bellefonte,+PA+16823/@40.8222349,40.8222349,-77.850275,40.8042778,-77.850275,40.8222349,40.8222349

Saturday Afternoon Local Leg 2: Pa Military Museum to Nittany Lion – 5.4 miles 11 minutes
Errand – Take group vehicle picture at Nittany Lion (Drive by picture if crowded)

https://www.google.com/maps/dir/Pennsylvania+Military+Museum,+51+Boal+Ave,+Boalsburg,+PA+16827/Nittany+Lion+Shrine,+State+College,+PA+16801/@40.7904931,-77.8410345,40.8222349,-77.850275,40.8042778,-77.850275,40.8222349,40.8222349,-77.850275,40.8042778,-77.850275,40.8222349,40.8222349

Saturday Afternoon Local Leg 3: Nittany Lion to Test Track via Rock Road – 9.6 miles 24 minutes
Errand – Detour to the top of the creamery parking garage for picture

https://www.google.com/maps/dir/Nittany+Lion+Shrine,+State+College,+PA+16801/40.8042778,-77.857025/Test+Track+Rd,+Bellefonte,+PA+16823/Test+Track+Rd,+Bellefonte,+PA+16823/@40.8222349,40.8222349,-77.857025,40.8042778,-77.857025,40.8222349,40.8222349,-77.857025,40.8042778,-77.857025,40.8222349,40.8222349,-77.857025,40.8042778,-77.857025,40.8222349,40.8222349
Saturday Afternoon Local Leg 4: Test Track to MorningStar 18.8 miles 36 minutes (same as morning)
No Errands

https://www.google.com/maps/dir/Test+Track+Rd,+Bellefonte,+PA+16823/40.8106003,-77.8489294/@40.8155481,-77.8441951,12z/data=!4m27!4m26!1m5!1m1!1s0x89cea89ce9018c09:0xca6a64673a6f84e9!2m1!d-77.8690244!2d40.798618!1m0!1m5!3m4!1m2!1d-77.8619064!2d40.7941955!3s0x89cea898d713ac51:0x9bec770ddca7805b!1m5!1m4!1s0x89cea41d7738a8a5:0x1352973cf8bfcc17!2m2!1d-77.8189158!2d40.8181797!1m5!1m1!1s0x89cea41d7738a8a5:0x1352973cf8bfcc17!2m2!1d-77.8359249!2d40.864007!3e0

Saturday Evening All vehicles: MorningStar to Test Track

http://maps.google.com/maps? Katz=Porter+Road,+State+College,+PA&daddr=164+Test+Track+Road,+Bellefonte,+PA&hl=en&ll=40.836801,-77.833157&spn=0.066885,0.169086&sspn=35.821085,86.572266&geocode=FW2ybglJdxte-vnV6wgdEKbOITHVJHGi_CjQ%3BFU-IbwIdQ1Jc-ymlqDh3HaTOiTExzL_4PJdSEw&oq=164+Test+Tra&mra=ls&t=m&z=13
Appendix VII Conduct and Safety

Safety is the highest priority for the 21st CAC competition. If in doubt, chose the safe alternative in all situations regardless of impact on scoring. 21st CAC officials will make every exception to insure your teams’ competitiveness in cases where you put safety first.

The first rule of safety will be to obey all traffic regulations including posted maximum and minimum speeds. Follow the directions of all traffic and parking authorities and if in doubt, always yield to pedestrians especially near the stadium.

Because of Penn State AD39 policy, absolutely no minors may ride in competition vehicles except their own and only with their team members. Do not offer or accept rides from other competitors if this will put minors into vehicles with adults not from their team.

Consider all voltages above 24 VDC or VAC as hazardous and use high voltage personal protective equipment and best safety practices. If high voltage repairs must be performed on your vehicle, contact 21st CAC organizers to set up a marked off restricted area free from foot traffic. Use high voltage rated personal protective equipment including gloves and flash protective clothing and face shields. Use only properly insulated tools with non-conductive or insulated handles. If in need of personal protective equipment please ask to borrow some form 21st CAC coordinators.

Vehicles in the pit area must proceed at a walking pace.
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