Safety
For Project Teams

A Presentation for CENG
Interdisciplinary Senior Project Lecture

Art MacCarley, Ph.D., PE. (EE, ME, CPE)

Photo: Times Picayune (online), New Orleans, May 2, 2010.
Safety in Team Project Development: *How to do what you have to do without injuring you or someone else, damaging equipment, or potentially causing harm to the user.*

**Safety Areas by project activity:**

- **Fabrication safety** - machine shop use, electrical fabrication or chemical synthesis

  **Fatal workplace injuries:** U.S., 2010 - 4,690 fatalities, or 3.6 fatal injuries per 100,000 full-time equivalent workers.  **Serious workplace injuries:** 1170 cases per 100,000 full-time workers in 2011.  *That’s more than 1% of all workers injured on the job last year (includes office workers).*  

- **Transportation safety** – moving stuff between facilities during development or testing, or travel.  35,419,000 highway crashes alone in the US in 2012.  Complete data for all transportation modes at  

- **Experiment/testing safety** – during development or testing phases.  Reference for electrical projects alone:  

- **Product safety** – is the result of your work safe in the hands of the user?  Classic example, Ford Pinto:  
  [http://www.youtube.com/watch?v=rcNeorjXMrE](http://www.youtube.com/watch?v=rcNeorjXMrE)

- **Safety related to information:** misinformation, incorrect or inadequate labeling/warning/security.  Reference: US Consumer Product Safety Commission:  
  [http://www.cpsc.gov/about/cpsia/sect105.html](http://www.cpsc.gov/about/cpsia/sect105.html)

- **Product end-of-life environmental safety issues:** Classic example - Love Canal, 1977, dioxon, lead, arsenic, benzene used in electrical equipment manufacturing:  
  [http://www.youtube.com/watch?v=MXSE9kcBQCI](http://www.youtube.com/watch?v=MXSE9kcBQCI)
Safety Issues by type of hazard:

- Physical contact safety – physical injury using hand tools, power tools, automated equipment, or dangerous chemicals

- Eye protection – Hazards due to eye exposure to harmful chemicals, impact or electrical discharge

- Hearing hazards – high audio levels, especially during fabrication, testing or use of product/project

- Inhalation hazards – whenever toxic chemical fumes or gases are present, or adequate air is NOT present
• Electrical hazards – due to contact with high voltage a sufficient current to cause physical injury

With respect to worker protection ONLY, the US Occupational Health and Safety Administration (OSHA) defines a multitude of safety standards.  [http://www.osha.gov/](http://www.osha.gov/)  ALL OSHA REGULATIONS APPLY TO STUDENT PROJECTS.

**The only way that safety hazards can be completely avoided is to do nothing – not an option in any project work or product development.**  So project safety requires that we **manage, limit and protect ourselves and others from the potential for harm that will be encountered in the hazardous situations we inevitably must deal with.**
Safety is a very broad topic - several entire courses...

In this 50-minute presentation we cover only a relevant subset

- Information and training resources specific to Cal Poly facilities

Campus-wide Safety and Risk management

http://www.afd.calpoly.edu/ehs/

Environmental Health and Safety

Environmental Health and Safety assists the campus in providing a safe and healthful workplace through the development and implementation of programs which minimize the risk of occupationally related injury or illness. Also, EH&S develops and implements programs to ensure the safe use, handling and storage of hazardous materials and appropriate and compliant disposal of hazardous wastes. These are accomplished through employee training programs, procedures and policies, and compliance surveys.

Online MSDS System

Environmental Health & Safety subscribes to MSDSOnline, an online database to provide Material Safety Data Sheets (MSDS) for hazardous materials used on campus http://hq.msdsonline.com/csuedusl/Search/Default.aspx. No login or special access codes are required, if accessed from a campus computer. Cal OSHA allows this online system to replace our paper MSDS files as long as hazardous materials users have access to a computer with the link to the MSDSOnline in the immediate vicinity of the hazmat use.
Mechanical Engr Dept Machines Shops (Bldg 4 and Mustang 60/Bonderson)

Open to all students after certification by ME Department

Contacts: Jim Gerhardt, (805) 756-1278, jgerhard@calpoly.edu

and George Leone, Technician, (805) 756-6350, gleone@calpoly.edu

and Erik Pulse (find in in office of Mustang 60 shop) – CNC machines requiring specialized courses.

Requires safety testing and service commitment to use. Red and Yellow Tag certification to allow use of specific equipment. Students required to enroll in a 1-unit online ME course to use facilities (may have been recently rescinded).

Online training resources:

- Cal Poly machine shop website: http://me.calpoly.edu/machineshop/
- Red Tag Tool Manual: http://me.calpoly.edu/machineshop/redtag/
- Shop Rules & Regulations: http://me.calpoly.edu/machineshop/rules/

College of Architecture Fabrication Shop (210-137) http://www.arch.calpoly.edu/

Open to all students with proper – non-arch students may have to demonstrate skills prior to use of machine tools.

Contacts: Doug Allen, Support Shop Manager, dallen@calpoly.edu, 756-2720

and Royce Chow, Assistant Support Shop Technician, rchow@calpoly.edu


Open to all students. No certification required. Just common sense. Lab supervisor and lot’s of EE students present to help non-EE’s with EE aspects of a project.

Contacts: Jaime Carmo, Electronic Technician, jcarmo@calpoly.edu, 756-2647

**College of Agriculture fabrication shops (engines, welding, machine shop)**

Especially suited for fabrication of really large projects like competition Tractor Pull vehicles.

General shop safety rules online


Ag Safety Institute

[http://www.agsafety.calpoly.edu/](http://www.agsafety.calpoly.edu/)

**Other facilities** - Some intended for staff use only but will often help students who are over their head on required skills or tools. Ask around!

- e.g., Bonderson specialized labs, ATL specialized labs, Computer Engineering Capstone Lab, QL+ Labs, General Engineering “Sandbox” (Bldg 192).
Common guiding principles for any fabrication task involving potentially dangerous equipment: **Awareness, Common Sense, Consideration others, and Vigilance**

Safety Rules for each resource documents have been uploaded to the ENGR 470 PolyLearn web site, and more information is available online or at each facility.

• **A learn-by-example: How things are done at one New York commercial art studio.**

  *Even artists recognize the importance of safety, order, consideration of others, clear communications, and attention to details over free-form creativity.*

  [http://www.tenbullets.com/](http://www.tenbullets.com/) by Tom Sachs (20 minutes total)
Just one of the many potentially applicable safety areas for MD Senior Project Students:

• Safety Issues for Electric Vehicle Development or Similar Projects

Traction battery-related safety issues

Vehicle traction batteries contain an enormous amount of electrical energy that can potentially vaporize a limb that short-circuits the output. You need to know how to work around high voltages and currents if you are going to work on any type of electric or hybrid vehicle project.

The most common battery used for converted electric vehicles is the flooded deep cycle battery. This is because the cost is the lowest of any type of battery ($50/kWh), even though energy density is poor. All commercially-produced battery-electric vehicles use lithium-based batteries (Li-ion, LiFePO4, LiMgO4) which have approximately three times the energy density (three times the range for the same mass), but at a much higher cost ($600/kWh FOB China). Potential hazards: chemical, electrical, inhalation, physical, thermal. Note: At present, there are NO Lithium-based battery cells manufactured in the USA; some cells are assembled into packs (e.g, AB123 or Tesla) in the US but all cells are imported from China. This is because of the safety risks and environmental consequences associated with the manufacture of Lithium-based batteries.
**Voltage and Current Considerations**

**Electrocution hazard:**

What voltage is dangerous? If current is not limited to a very small value...

The U.S. National Electric Code (NEC) NFPA 70E, for example, Par. 1 10.7(F) sets threshold of safety at 50 volts.

IEEE Specification TS-60479-1 suggest that these longstanding limits are too high.

OSHA: safe "touch voltage" voltage limit set as low as 35 Volts in the USA, and 24-25 Volts in European countries. The Canadian Electrical Code defines "extra low voltage" as "up to and including 30 volts" and national health and safety regulations consider that voltage as the worker safety threshold.

International Electrotechnical Commission Specification IEC 60479-5 the IEC (European Standard) states: body contact between 36 and 49 volts could cause ventricular fibrillation; recommends safe limit between 25 and 30V.

**A current student project example: Electrical hazards for Electric Vehicle Engineering Club’s (EVEC) RBX Project:**

Original batteries in two 1991 G-Vans (upgraded by author): Two parallel strings of 18 12-volt Group 27 deep-cycle batteries in series: 216 volts nominal (227 volts fully charged, disconnected from charger)

Typical HCA (Hot Cranking Amps) rating of one Grp 27 Deep-cycle 12 battery: 1200 amps, pulse discharge as high as 1700 amps.

227 x 1700 amps x 2 strings in parallel = 772 kW pulse power (or 386kW for one RBX battery pack)

(This is enough power to vaporize an arm or leg, far more than used for execution by the electric chair)
What about battery chargers?

G-Van battery charger (large green): output 270 VDC @ 50 Amps = **13.5kW**

Maintenance chargers: output 90 VDC @ 20 Amps = **1.8kW**

For comparison, residential 115 VAC (RMS) outlet with 15A circuit breaker: **1.7kW**, which can be lethal.

**Electrical burns:**

Electrical hazards are not limited to potential electrocution – a wrench across the terminals of an EV battery pack can vaporize like a fuse. If held in your hand, it will take your hand with it. Even a single 12 Volt automotive battery can cause serious burns if your skin is in contact with a conductor that short-circuits the battery.  
[http://www.youtube.com/watch?NR=1&v=j25dh7w48Xs](http://www.youtube.com/watch?NR=1&v=j25dh7w48Xs)

**Battery explosion:**

**Batteries of all chemistries are dangerous is overcharged!** The lowest risk is actually the lead-acid battery, which will produce hydrogen gas and oxygen gas by electrolysis of the acid/water electrolyte. This naturally occurs in the final stages of a full charge cycle. If the rate of overcharge is small, the small amount of gas will be dissipated harmlessly. However, if overcharged or if ventilation is inadequate, especially as the gas space in the battery increases as electrolyte is lost, a flammable concentration of hydrogen will remain in the cell. An internal spark, e.g., due to a high-discharge-current burst upon vehicle acceleration, can cause a hydrogen/oxygen explosion, which will usually rupture the case and disperse acid into the surroundings. Anyone close to the battery may be injured. If charging in an enclosed area, or batteries are located in the interior of a closed vehicle, ventilation is required to keep hydrogen concentration below 1%.

*Battery explosions in EV’s are far more common than most people assume.* It typically occurs when one or a few battery(ies) in a long series string of many batteries (like the G-Van) is bad, while the remaining batteries in the string
are good. Charging the series string exhausts the remaining electrolyte in the bad battery(ies). The first time the vehicle is operated, high current flows through the string, causing a melting or vaporization of the internal conductors inter-cell dendrites accompanied by an arc flash, fuse-like vaporization of an inter-cell dendrite bridge. This ignites the mostly gas-filled battery, causing the rupture of the case.

An Exploded 12V SLI Battery (from http://www.rayvaughan.com/battery_safety.htm)
How to reduce the risk of EV battery explosion? Check each battery in a series string individually with a hygrometer and/or voltmeter. Remove bad or weak batteries from the string. Make sure that all batteries in the series string are in approximately the same condition. *Don’t mix new with old batteries!*

**Acid burns:**

Acid splash or spill can result from battery explosion as previously mentioned, or during battery watering or initial electrolyte filling. Will also occur if a battery is dropped and the case is ruptured.

Battery electrolyte is concentrated sulfuric acid. Can cause chemical burns on skin or blindness if in contact with eyes. Inhalation of acid vapor or mist can cause respiratory damage, but fortunately, sulfuric acid is not a highly volatile liquid (compared with solvents or gasoline); it evaporates more slowly than water – clean it up immediately!

Always wear acid-proof gloves nitrile (not leather or fabric) gloves, and wear full-eye-coverage goggles when servicing batteries. Work in a well-ventilated area.
Safe charging considerations:

Voltage and current depend on the battery pack configuration. For a single 12V Lead-acid battery of any size:

<table>
<thead>
<tr>
<th>Open circuit voltage</th>
<th>Approximate charge</th>
<th>Relative acid density</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 V 6 V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12.65 V 6.32 V</td>
<td>100%</td>
<td>1.265 g/cm³</td>
</tr>
<tr>
<td>12.45 V 6.22 V</td>
<td>75%</td>
<td>1.225 g/cm³</td>
</tr>
<tr>
<td>12.24 V 6.12 V</td>
<td>50%</td>
<td>1.190 g/cm³</td>
</tr>
<tr>
<td>12.06 V 6.03 V</td>
<td>25%</td>
<td>1.155 g/cm³</td>
</tr>
<tr>
<td>11.89 V 6.00 V</td>
<td>0%</td>
<td>1.120 g/cm³</td>
</tr>
</tbody>
</table>

- Quiescent (open-circuit) voltage of a fully-charged battery after a few hours: 12.6 V
- Open-circuit voltage of a fully-discharged battery: 11.8 V
- Charging voltage range: 13.2–14.4 V. Gassing voltage: 14.4 V. Continuous-preservation charge voltage (max) 13.2 V
- Smart chargers schedule the charging voltage to store the maximum amount of energy in the battery without degrading its life (much).
- Charging to 100% capacity requires a final gassing phase, in which some electrolyte is lost to electrolysis. This necessitates more frequent battery watering. Hydrogen gas is released, which is explosive. Hydrogen has the widest limits of flammability in air of any combustible mixture – doesn’t take much to ignite it.

This table was copied from [http://en.wikipedia.org/wiki/Automotive_battery](http://en.wikipedia.org/wiki/Automotive_battery) but the data may be found in almost any reference on lead-acid batteries.
• Battery Voltages are temperature-dependent. Each cell (nominally 2.1 volts at 68 deg F.) has a positive temperature coefficient of approximately 3.3 mV/deg F., or 20 mV/deg F. for a 6-cell 12 V battery.
• Most automotive voltage regulators are set to charge the 12V battery at slightly above 14 Volts.
• After a full charge the terminal voltage will drop quickly to 13.2 V and then slowly to 12.6 V. This is due to the surface charge (also called space charge) which adds to the battery voltage, but contributes almost no usable energy capacity. It will dissipate naturally, so wait at least an hour, and ideally 12 hours, to get a reliable open-circuit voltage measurement. If you need to assess the battery immediately, the next best method is to slightly discharge the battery, say, by driving the electric vehicle about 30 seconds.
• A resistive battery load tester will provide a good indication of the battery health, even if done shortly after charging. This draws heavy current from the battery for a few seconds and measures the voltage under load. Note that commercially-available load testers work only on individual 12V batteries – they do NOT work on a series string of batteries as found in an EV; the load tester will fail catastrophically if used on anything other than a 12V battery.

Charging current depends on the size of the battery and the phase of the charging cycle. Current should be monitored to confirm charging, but it is the charging voltage that is usually the primary control variable. Charging voltages at or above 2.4 V/cell or 14.4 volts for a 12V battery will cause excessive “gassing” and loss of electrolyte. As electrolyte is electrolyzed and vented, the current density in the remaining acid and on the remaining plate surfaces increases, accelerating the loss process and unevenly re-plating the lead electrodes. Charging voltages above 15V will eventually destroy a lead-acid battery due to this process.
Inattentiveness or carelessness is the greatest cause of project accidents or injuries

Case history: “Cal Poly and MIT students both destroy EV motor controllers, 32 years apart”

MIT:

1968: During the 1968 Great Transcontinental Electric Car Race between Caltech and MIT, the Caltech-converted 1958 VW microbus won (by only 30 minutes) over the MIT-converted 1968 Corvair, which on the last day of the race was in the lead and not far from the finish line in Pasadena. This occurred because a member of the MIT team incorrectly connected their charger which burned up the motor controller. Their car was towed across the finish line. The Caltech entry ran on Lead-Cobalt batteries costing about $2,000. The MIT entry ran on NiCad batteries costing about $20,000. Both vehicles carried less than 2 kW of energy onboard.
Cal Poly:

2000: EVEC students working unsupervised on the RX7 race car incorrectly connected a new $1200 Zilla controller. They did not understand the controller manual, and were too in a hurry to consult with their adviser. When activated, the car accelerated at maximum power in reverse into the side of the EE Building. Fortunately, no one was injured, although the car was damaged and the controller destroyed.

*When working on any high-power electrical circuit, understand the circuit, keep your focus, and do not allow any distractions. Wear insulating gloves and protective goggles. Remember the One-Hand Rule. Never work alone. Have a safety-buddy with you who is ready at any moment to help you, and knows how to help you.*
For reference: If a line current or EV battery-related accident occurs:

- If the person is still connected to a high-voltage electrical source, get them away from it *without touching them*.
- Check for pulse and breathing. Administer CPR and/or rescue breathing if necessary.
- Call 911. Yell for help.
- If acid splash, wash with lots of water ASAP. Be sure water does not get near the batteries or electrical source. Use eye-wash station if nearby. Baking soda has little value on a person after acid contact with skin or clothes. Get immediate medical attention if severe.
- If electrical burns, also treat with cold water ASAP, again, keeping water away from the voltage source. Get immediate medical attention.
- Most acid contact is not severe – just wash it off your skin immediately (don’t wait, you won’t feel it at first).
- Acid on clothing – remove clothing as soon as feasible, and wash with water. Battery acid will easily eat a hole in cotton or most natural fabrics, often well after the initial contact, if it has not been washed out right away. Note the holes in the jeans of people that work on batteries frequently.
Other Electric Vehicle Design Safety Precautions

- Neither side of an EV traction battery is ever connected to the vehicle chassis. Both the positive and negative power circuits are isolated.
- The battery/motor/controller system must have at least one expendable fuse in each leg from the battery (note the dual fuse box in the G-Van).
- A manually-actuated contactor must be provided which breaks both connections to the battery.
- Battery enclosure must be well-ventilated, usually outside the vehicle cabin. Note that the RX7 does not have closable windows.
- The battery enclosure must be separated from the driver and passengers in such a way as to contain the explosion of multiple batteries.
- The added vehicle mass due to batteries and motor, less the weight reduction from the IC engine removal, must remain at least 800 lbs less than the GVWR for a 4-passenger vehicle. If the GVWR is exceeded with driver, passengers and cargo onboard, the safety of the vehicle depends on the original safety margin used in the design of the brakes, suspension, and steering systems. (This is frequently violated in home-built conversions).
- Any electric vehicle offered for sale to the public in significant quantities must meet the same crash safety regulations as an IC engine vehicle. [http://www.nhtsa.dot.gov/cars/rules/import/fmvss/index.html](http://www.nhtsa.dot.gov/cars/rules/import/fmvss/index.html). Most limited-production EVs based upon originally-certified IC vehicle chasses are allowed under an FMVSS low-production/experimental exemption.
- Silent electric propulsion leads to an increased risk of collision with pedestrians at slow speeds. Under the Federal “Pedestrian Safety Act of 2010” [http://www.govtrack.us/congress/bill.xpd?bill=s111-841](http://www.govtrack.us/congress/bill.xpd?bill=s111-841), a battery-electric vehicle must include some audible device to warn pedestrians when operating at very slow speeds, turning or backing up.
- Careful routing of power wiring to avoid abrasion, deflection of cables under high current.
• Use double barriers to contact with power-carrying conductors – insulation on cables and connectors, inside secure enclosures.
• Sweat the details. Sloppy or poorly-thought-through work leads to dangerous situations for which the engineer is liable.

Many online resources, training references and case histories, e.g.,

A good general online reference for lead acid battery data: http://www.hupsolarone.com/about-batteries.htm

Online reference on battery types and purpose-classifications is: http://www.windsun.com/Batteries/Battery_FAQ.htm#Major%20Battery%20Types


GM’s free (really slick) accident response training for Volt: http://nfpaevresources.gypi.net/

Results of DOE Study on Lead-acid Battery Safety from LLNL: www.lanl.gov/safety/electrical/docs/battery_safety.ppt

Example of a badly-built commercially-sold EV: http://www.blyon.com/tag/hybrid-technologies/

Off-beat but apropos shop regulations and project team management: http://www.youtube.com/watch?v=49p1JVLHUos&feature=relmfu

Un-cited sources: Most material presented above is from the author’s personal experience or general knowledge, but all photos, some data and recommendations were taken from standard reference sources or non-copyrighted web sites (citations in text).