Recommendations for Rescue Teams

Deliverable 8.2

SmartBatt

with support of the Research Project E-Vehicle Safe Rescue

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Cell/Battery related topics: Peter Miller (Ricardo)

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Content

- Introduction
- Constraints for the presentation
- EV related topics
- Battery/Cell related topics
- Safety related topics

Abbreviations

- EV: Electric Vehicle
- BEV: Battery Electric Vehicle
- HEV: Hybrid Electric Vehicle
- PHEV: Plug-in Hybrid Electric Vehicle

INTRODUCTION, SMARTBATT

SmartBatt

- Objective:
  - Development of an electric vehicle battery focusing on
    - Minimization of weight (weight ratio cells/housing)
    - Optimization of safety (all kind of possible hazards to be considered)
    - Mass production
      - Minimization of costs
      - Optimization of manufacturing process

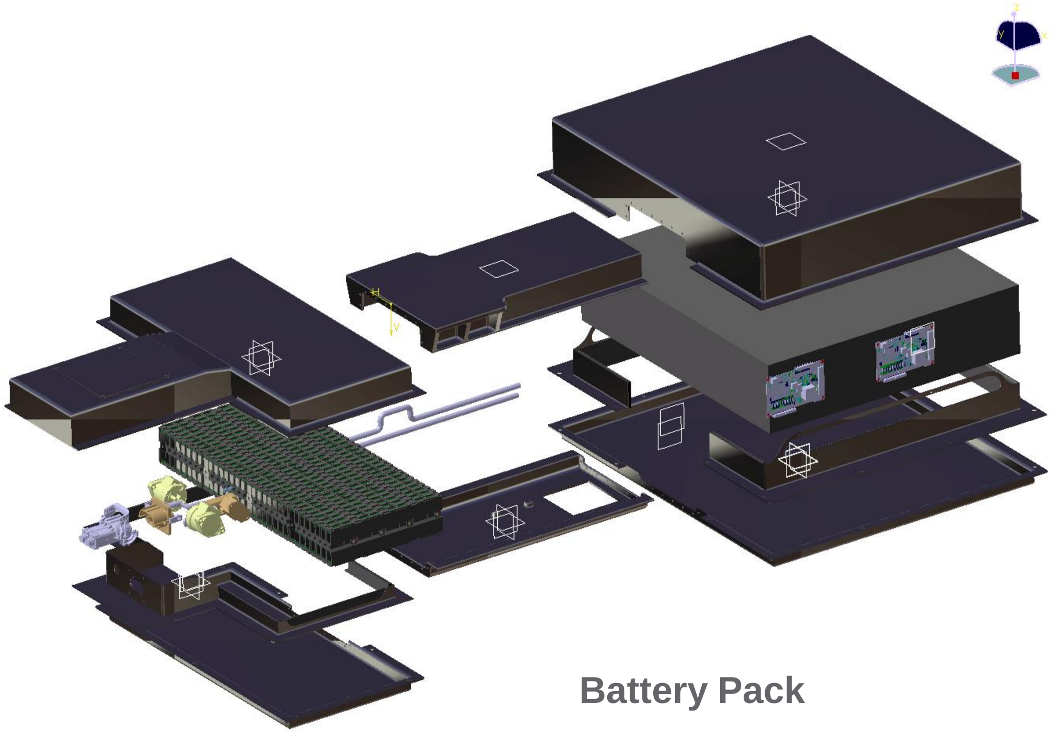
SmartBatt

- 9 Partners from 5 European countries:
  - Austrian Institute of Technology
  - LKR Ranshofen (AIT LKR)
  - Axeon Technologies Limited
  - Fraunhofer-Gesellschaft
  - Impact Design Europe
  - Ricardo UK Limited
  - SP Sweden
  - Graz University of Technology
  - Volkswagen AG

SmartBatt Battery System

- **Technical information of the SmartBatt system**

- Cells (Li-Ion): 1408
- Voltage: 325,6 V
- Weight: 160 kg
- Range: ~100 km



Battery Pack

CONSTRAINTS FOR THE PRESENTATION

Road map for e-mobility & statistics

- EV´s (Passenger Vehicles) on the road

Country	Petrol	Diesel	Liquid gas (including bivalent)	Natural gas (including bivalent)	Electric	Hybrid	All
Germany	30.452.019	11.891.375	456.252	74.853	4.541	47.642	42.927.647
Change [%] (01.01.2012-01.01.2011)	-0,1	+5,5	+9,0	+4,7	**+96,8**	**+27,9**	+1,5

Country	Petrol	Diesel	Liquid gas (including bivalent)	Natural gas (including bivalent)	Electric	Hybrid	All
Austria	2.007.095	2.542.512	152	2868	1211	6970	4.560.808
Change [%] (30.06.2012-31.12.2011)	+0,5	+1,4	**+21,6**	+7,4	**+22,4**	**+15,0**	+1,05

Source: www.kba.de , www.statistik.at

- IEA statement from Technology Roadmap:
  - Global sales by 2020: 5.000.000 EV/PHEV per year

What can happen (EV-Crash, Test, Normal use):

- Accident: Car 1 against Car 2 (travelling same direction)
  - Accident reconstruction shows that both cars drove with high speed (Car 2: 180kph, Car 1: 80kph)
  - Intrusive damage reached 1050mm
  - 2nd Collision with narrow object
  - Type and severity of the accident is extremely rare

- Vehicle battery catches fire after crash test (3 weeks later):
  - After a crash test the battery system fails due to damaged cooling circuit (short circuit)

Sources:
BYD COMPANY LIMITED, Voluntary Announcment relating to the results of Quality Examination on the Electric Taxi involved in the 5.26 Major Traffic Accident
http://www.nytimes.com/2011/11/12/business/energy-environment/regulators-examine-electric-car-batteries-after-fire.html
http://www.nytimes.com/2012/05/30/business/global/byd-releases-details-about-electric-taxi-fire.html?_r=3
http://www.nhtsa.gov/About+NHTSA/Press+Releases/2012/NHTSA+Statement+on+Conclusion+of+Chevy+Volt+Investigation
http://www.autoguide.com/auto-news/2012/05/byd-burning-car-concerns-addressed-by-automaker.html

Other accidents

- HV-Battery explodes at labs
  - undergoing „extreme testing" on a prototype battery"

Source: http://www.bloomberg.com/news/2012-04-11/gm-lithium-battery-lab-explosion-injures-2-fire-department-says.html

- Hybrid vehicle burns

Source: http://www.nbcchicago.com/investigations/series/target-5/target-5-hybrid-cars-122193889.html (08.2012)

- Electirc vehicle burns in the garage – unknown source for fire
  - This indicates probably different scenarios for „vehicles on fire"
    - For example at home (garage) – charging, any other failure
    - Electric vehicles in closed rooms → car workshop

Source: http://www.nationalreview.com/planet-gore/299555/fisker-electirc-car-burns-down-house-texas-greg-pollowitz

Constraints for presentation

- <u>What EV types are discussed/adressed</u>

- Included:
  - Standard Passenger vehicles which are tested and certificated for street use
  - OEM first responder guides can be found online (for example: www.evsafetytraining.org, Project of the National Fire Protection Association)

- Hybrid Electric Vehicles / Battery Electric Vehicles

Source: www.toyota.at, http://www.volvocars.com, http://www.daimler.com

Constraints for presentation

- What EV types are not discussed/adressed
- Excluded but dangerous:
  - Own Modifications, …
  - Self-Made electric vehicles, small series production cars don’t have to pass crash tests, ...
  - Heavy duty vehicles, …

Source: http://cbelectriccar.com

- **Problems Tuning**
  - Additional Components
  - Replacement of original components (replica)
  - Replacement of original components with used parts
  - Software tuning

Source: safe-e-mobility 2011, TÜV SÜD, Mast

EV RELATED TOPICS

Content

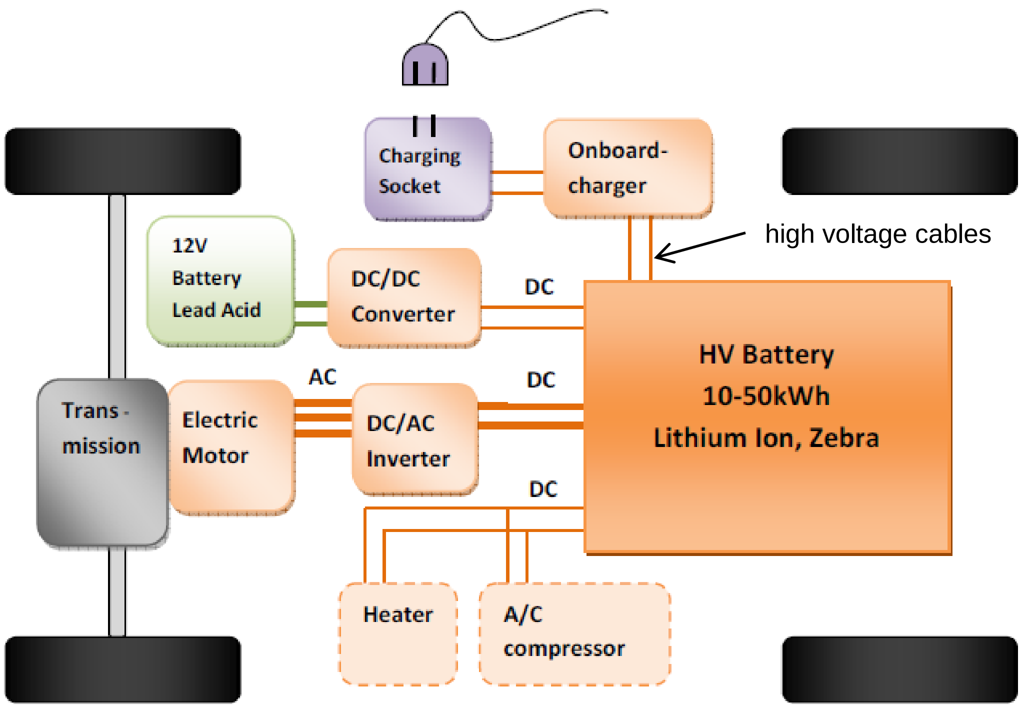
- Electric vehicle architectures
- Batteries for EV´s
- Potential of hazards in crashes
  - Relevant tests for batteries
  - Safety Equipment in the laboratory
  - Norms / Legislations

HV electric components in EV, HEV and PHEV architectures

Mandatory:

- Battery package
- Inverter
- Electric motors
- DC/DC converter
- Cabling
- On-board charger
  - (no must but very likely)

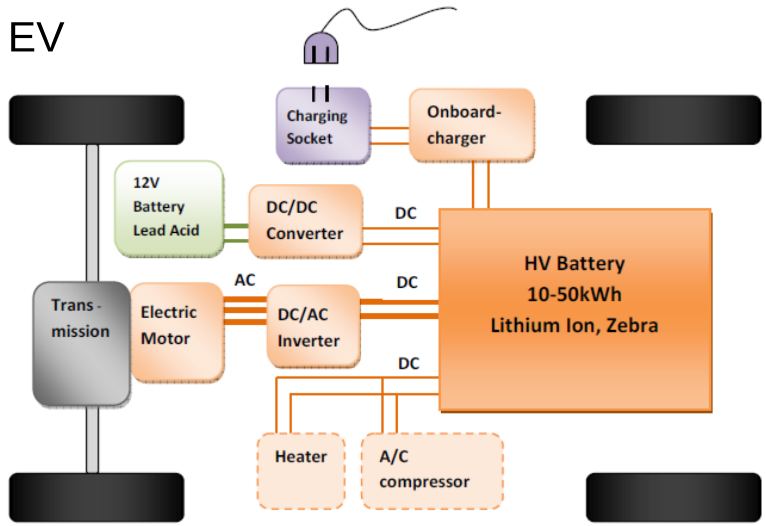
- Optional
- A/C compressor
- Heater
- Supercap-Package + DC/DC

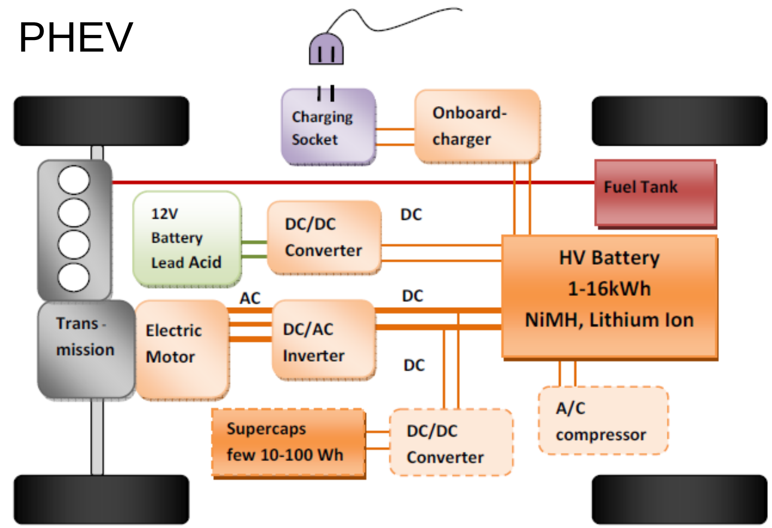


possible architecture of a battery electric car

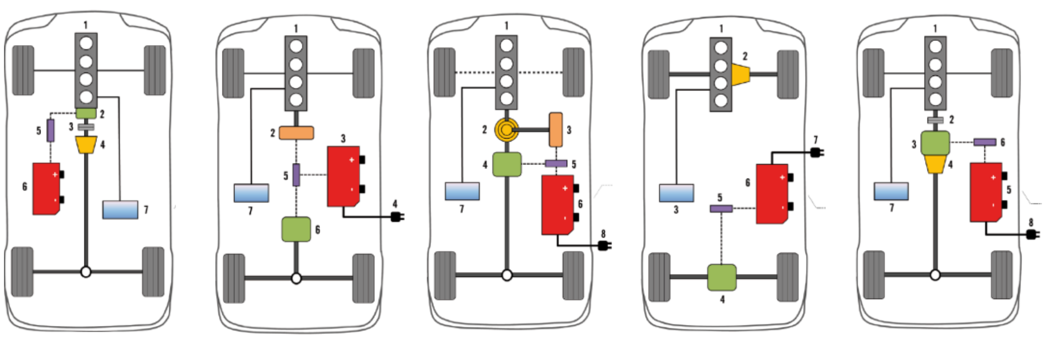
ORANGE = High Voltage

Difference between pure EV and (P)HEV





Huge variety of architectures and topologies.



source: Informationsreihe MTZ Wissen / Die Elektrifizierung des Antriebsstrangs

- Potential Hazard depends on stored energy in the system

Legislation, Regulations, Standards – Damage on batteries in real life crash scenarios

- Testing of cells/batteries or full scale vehicles / Norms (example):
  - FMVSS 305
    - Electric Powered vehicles: Electrolyte spillage and electrical shock protection
  - ECE – R 100
    - Uniform provisions concerning the approval of battery electric vehicles with regard to specific requirements for the construction and functional safety
  - ISO 12405-1
    - Electrically propelled road vehicles - Test specifications for lithium- Ion traction battery systems
  - SAE J 2464
    - Electric and Hybrid Electric Vehicle Rechargeable Energy Storage System (RESS) Safety and Abuse Testing

Legislation, Norms – Damage on batteries in real life crash scenarios

- FMVSS 305
  - Electric Powered vehicles: Electrolyte spillage and electrical shock protection
  - Handling:
    - Remove vehicle key – vehicle should be “off”
    - Pretest Requirements for Persons:
      - Example:
      - HV- protection gloves
      - Non-conductive shoes
      - Safety glasses
  - → Follow „manufacturers“ instructions

Legislation, Norms (Testing of EV´s) – Damage on batteries in real life crash scenarios

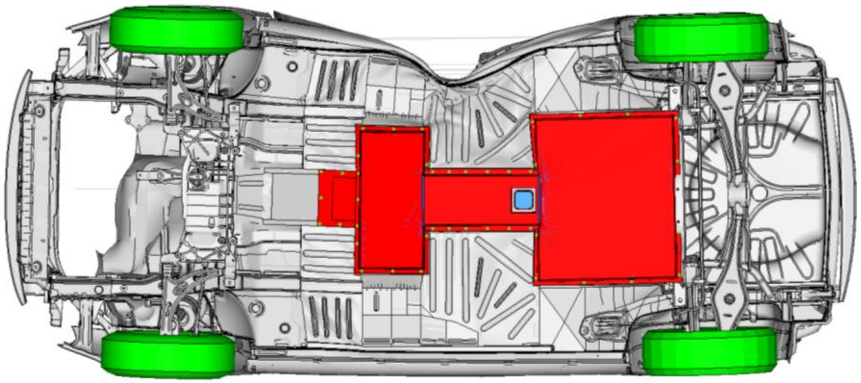
- SAE J 2464
  - Electric and Hybrid Electric Vehicle Rechargeable Energy Storage System (RESS) Safety and Abuse Testing

- Example of tests that have to be conducted
  - Shock Tests
  - Drop Tests
  - Penetration Tests
  - Roll Over
  - Immersion Tests
  - Crush Tests

Legislation, Norms (Testing of EV´s, Cells) – Possible damage on batteries in real life crash scenarios

- Tests, Accidents / Simulation

Source: http://de.euroncap.com

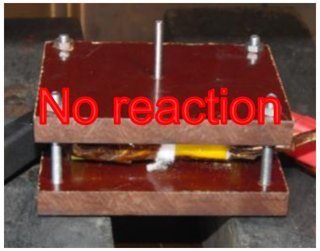


Source: http://www.rp-online.de/regionales/regionale-nachrichten/crash-kurs-nrw-realitaet-erfahren-echt-hart-1.2751867

- Try to fix problems before street use
- But no battery with actual chemistries in a heavy real life accident can be seen as „safe“.

Legislation, Norms (Testing of Cells) – Possible damage on batteries in real life crash scenarios

- Testing of batteries:
  - Nail Penetration
  - Mechanical Shock
  - Over-charching



- Possible reactions:
  - Nothing
  - Warming up
  - Leakage of electrolyte
  - Venting (gas emissions)
  - Burning
  - Exploding

Electric vehicle battery positions

Source: http://www.tunemaster.de/audi-crash-in-zwei-teile-geteilt-t33644.htm

Energy amount of battery: 10-80kWh

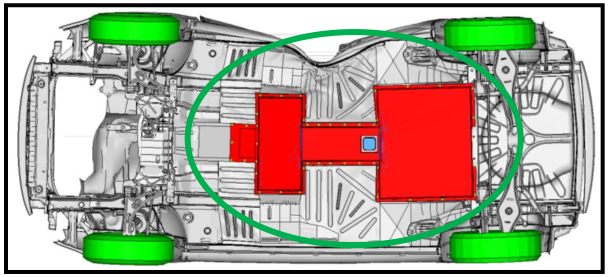
- Petrol tank ~40l ca. 330kWh
- Volume of battery: ~40-80litres

Positioning of battery:

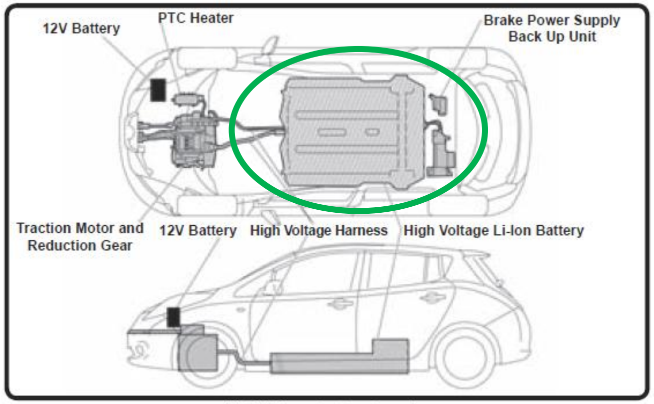
- Mostly due to crash scenarios as seen before and packaging of passenger compartment:
- Also influenced by real life accident scenarios, crash simulations and tests
  - Influenced by the non predictable behaviour of cells/batteries
  - Due to that a „safe space“is preffered. (until a certain limit of force is reached → no safe place for a battery anymore)

Different positions:

- Battery electric vehicles → examples:



- Energy storage: only battery
- Larger battery for higher energy storage capability
- More in the mid-position of a vehicle
  - Away from crash zones

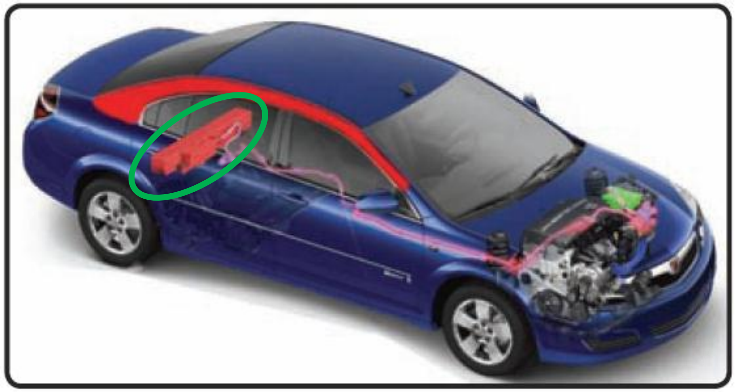


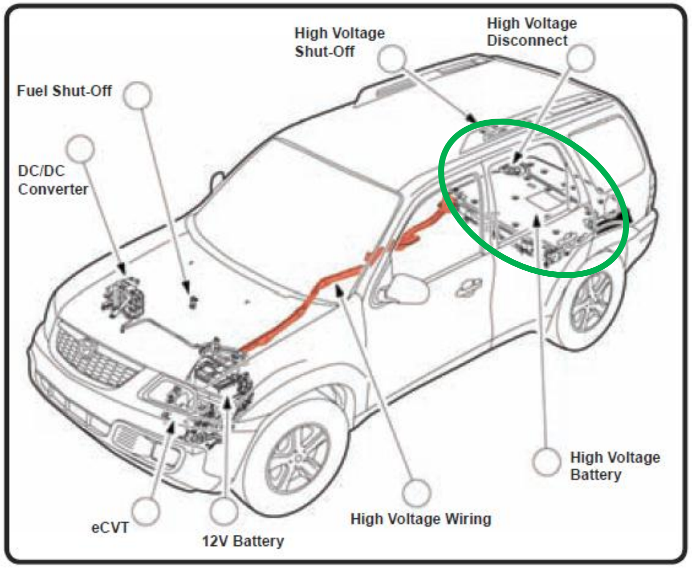
High Voltage System Overview

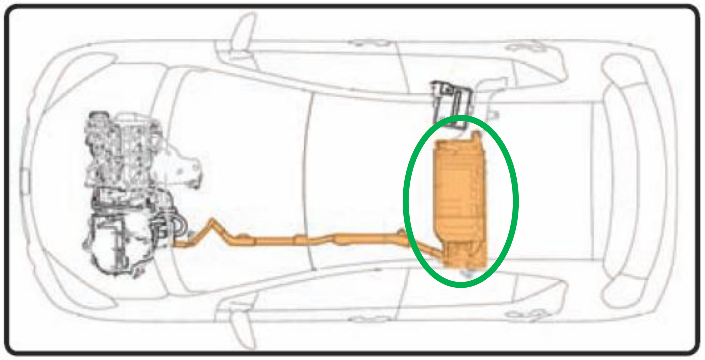
Source: 2012, NFPA, Electric Vehicle Field Guide

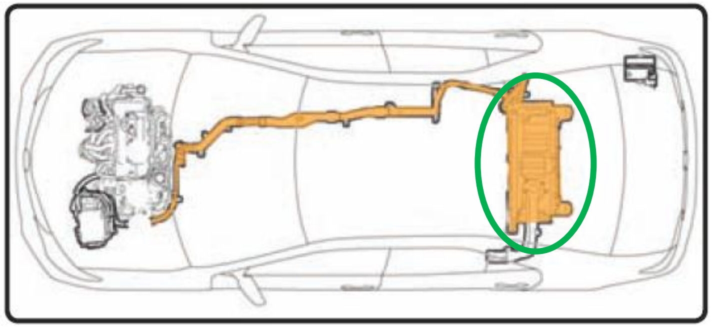
Different positions:

- Hybrid vehicles → examples:
- Energy Storage: battery / „fuel“ tank
- Only small area needed
  - Away from crash zones
  - Beneath rear seats









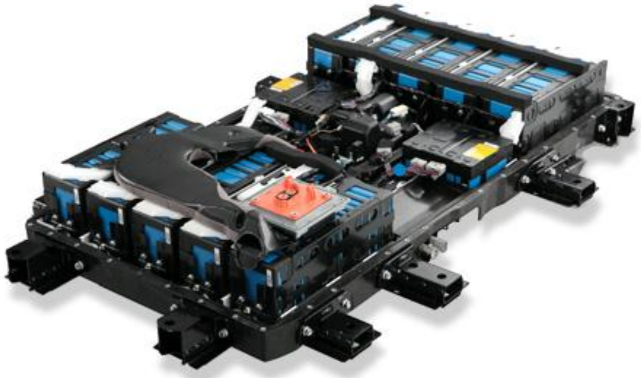
Source: 2012, NFPA, Electric Vehicle Field Guide

Energy storage systems (ESS)

High voltage battery pack

- risks related accordant to cell chemistry
- internal electric, fuse and HV contactors

I MiEV Battery



source: http://www.mmnz.co.nz/imiev/

Supercap pack

- very high short circuit currents due to very low internal resistance
- no self-discharge within days
- zero voltage is possible (capacitor)
- always in combination with separate DC/DC converter

Mazda I-Eloop:
25V 200A
10Wh
fully charged in 7s
6kg

Source: http://www.spiegel.de/fotostrecke/spritsparen-fotostrecke-79909-2.html

Other high voltage electric components

- Generally
  - 2 or more components can be combined in one housing (engine and inverter or inverter and dc/dc converter)
  - no risk if HV-battery is shut off (contactors open) AND sufficient time is passed for self discharge of capacitors in power electronics like inverter
  - **sufficient time: up to 20 min, detailed information from the manufacturer**

- DC/AC inverter transforms DC current into AC current for electric motor
- DC/DC converter charges the 12V lead acid battery
- Engine one ore more electric engines are possible, also act as a generator
- Cabling always orange, double isolated, shielded
- On-board charger turns 230V AC into high voltage DC for the HV battery
- A/C compressor electric propelled compressor for aircondition
- Heater high voltage resistor for water- or air heating
- Electric fan in bigger (P)HEV cars and vans
- Power steering

Inverter and engine

Source: http://www.tm4.com/en/electric_motors.aspx

Cutting high voltage cable in a turned off system

Cutting ONE high voltage cable

- no electrification possible

Cutting PLUS AND MINUS together

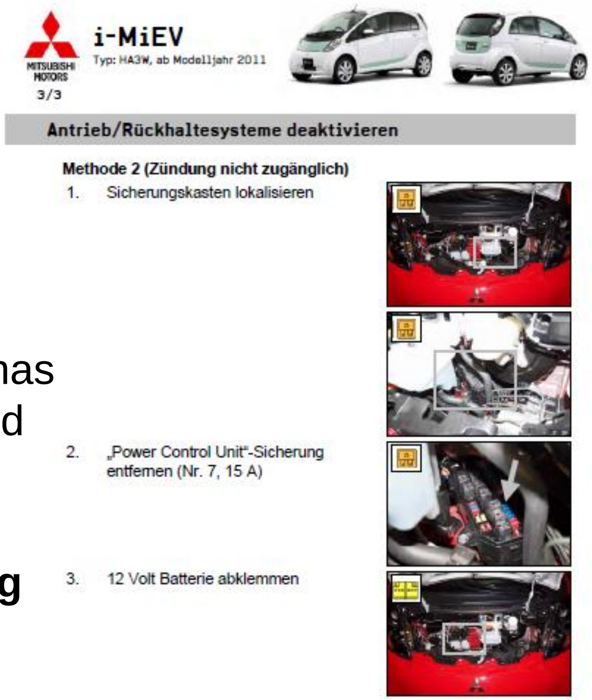
- no electrification possible

except the battery was turned on before and no sufficient time has passed then capacitors in power electronics can be rest-charged

-> short circuiting capacitors will discharge them in ~0.1s

-> causes arcing, heat dissipation, dazzling light and a bang

- can induce fire to the vehicle
- no electrification possible



Source: Mitsubishi Motors, www.mitsubishi-motors.at , 2012

Read the Safety Instruction Card how to turn off the battery system. Discharge time for capacitors could also be found there. (10 min are safe for most of the cars)

Cutting high voltage cable in a turned on system

Cutting ONE high voltage cable will

- make a contact between cable shielding and HV
- trigger an isolation fault
- immediately shut down the system
  - cause no arcing, no short circuit
  - no electrification possible

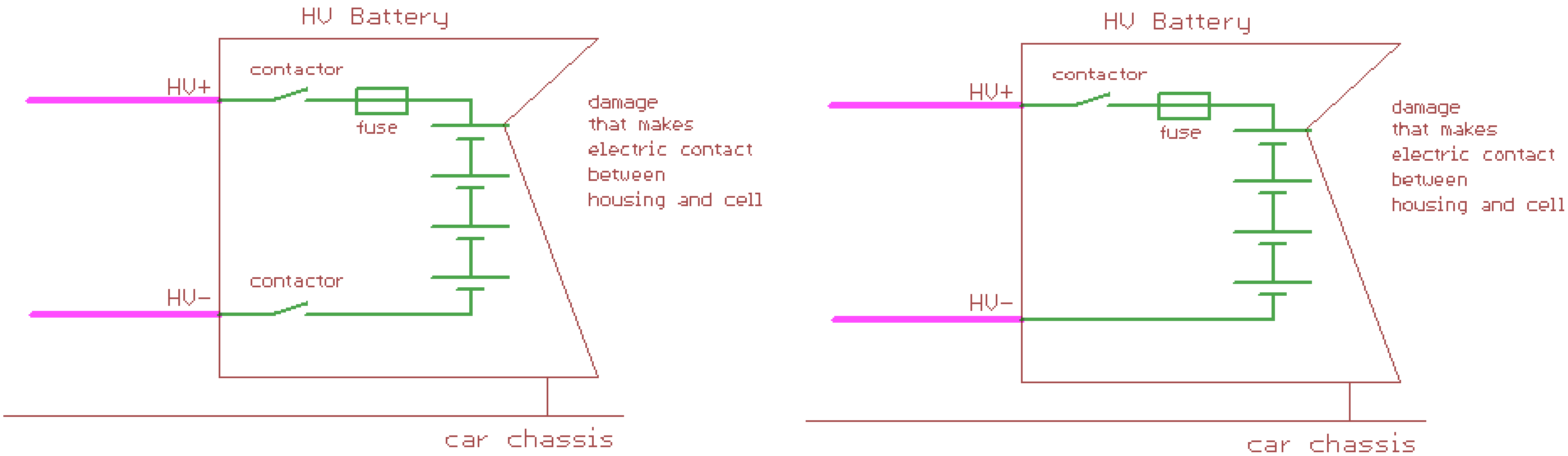
Cutting PLUS AND MINUS together will

- lead to a short circuit of battery and capacitors
- blow the main fuse whithin short time, depending on how „good“ the short circuit is
  - cause strong arc and short circuit current until fuse is blown
  - cause also dazzling light and a bang
  - can induce fire to the vehicle
  - no electrification possible

Cutting high voltage cable in a damaged system

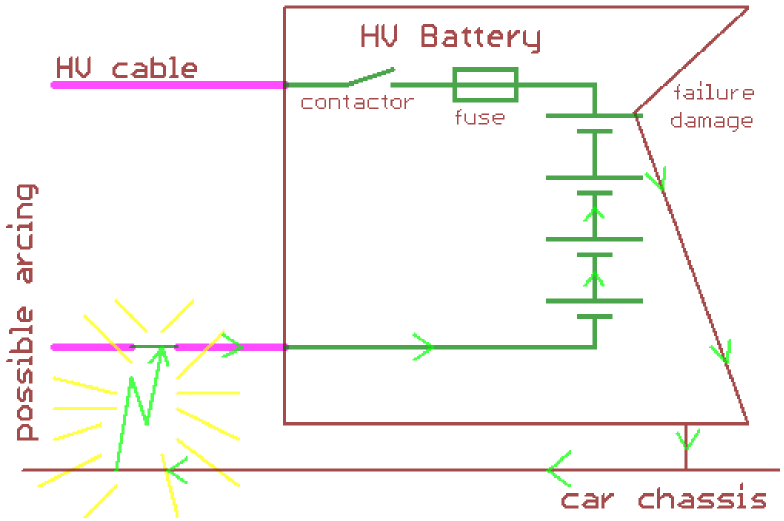
- **An electrically damaged system with no HV contactor on both poles is the only constellation that can cause severe electrical accidents when cutting a HV cable!**

- Almost all HV Battery systems have contactors on both poles like on the left picture



- Note: All the severe hazards on the next 3 slides assume this very unlikely case on the right picture

Electric arc



Fact

- hot, ionized gas that conducts current
- 5000 C° and more (electric welding)
- power:
  - arc voltage x current
  - eg.: 400V x 1000A = 400kW !!

Requirement

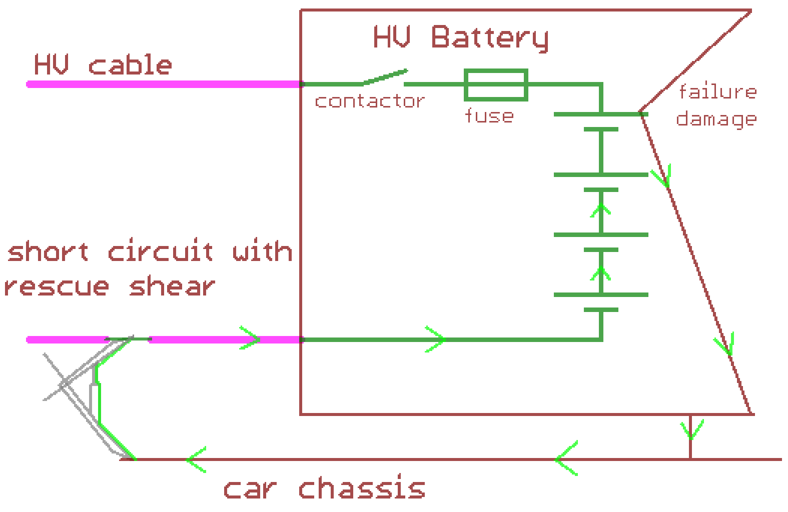
- rescue shear is torn away

Hazard

- extreme heat -> metallization and burning of skin
- extreme bright light -> eye damage!
- poisonous compounds can be evaporated
- loud bang, small compression wave
- movement of the electric arc
- could induce fire to vehicle

Source: http://www.tfritsche.de/news.htm

Electric short circuit

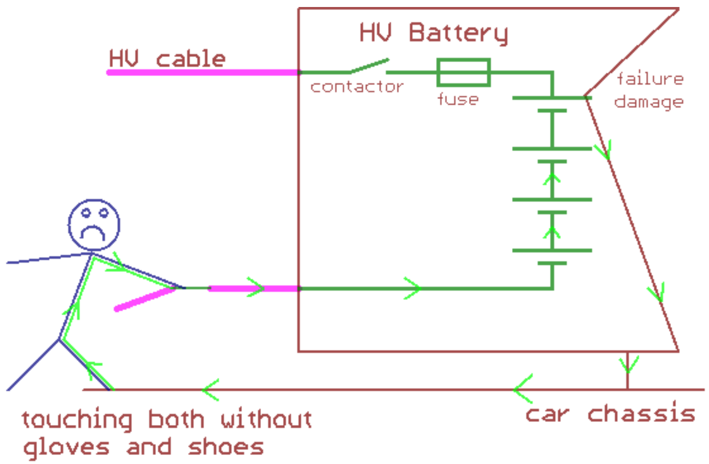


Fact
- very low resistance in a closed electric circuit
- high currents
- power:
  - system voltage x current
  - eg.: 400V x 1000A = 400kW !!

Requirement
- good electrical connection off all parts, otherwise it will melt through -> arcing
- no fuse in the circuit

Hazard
- all the power is converted into heat, but spread on the whole circuit
- melting metal
- risk of arcing after melting away
- electrodynamic forces -> open the short cut -> arcing

Electrification



Fact:

- human body is part of an electric circuit
- currents of 50mA can already be lethal
- Hazardous constellation
  - matter of current AND time

Requirement:

- touching of parts on voltage that are not isolated AND have a possible current path
- in case of accident the cassis can be “activated” but touching the other pole or having path via ground is very unlikely

Hazard:

- burn up, loss of muscle control, pain, respiratory arrest,
- rhythmic pumping of the heart ceases, death

!Rest charge of capacitors is also a severe hazard in case of electrification, whereas it is not such a risk in case of arcing or short circuit!

Laboratory Safety
Systems in Use at AIT for handling Li-Ion Cells

- Explosion-protected climate chamber
  - N_2 based, adjustable variable atmosphere
  - Integrated gas exhaustion system with burst disk

Laboratory Safety

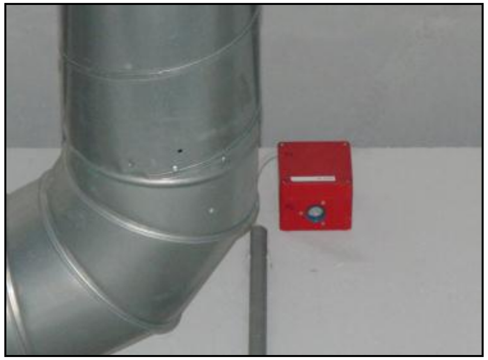
Systems in Use at AIT for handling Li-Ion Cells

- CO_2 extinguisher
- Fire sprinkling system installed in climate chamber
  - Effect: cooling
  - High fog / water mist installation

Laboratory Safety

Systems in Use at AIT for handling Li-Ion Cells

- Installation of gas sensors and controlling unit for detection of
  - CO, CO_2 and H_2
  - Different warning levels /actions
    - Warning
    - Alarm
    - Turn off power supply



- Safe storage of Li-Ion Cells

Laboratory Safety

Systems in Use at AIT for handling Li-Ion Cells

- Abuse chamber
  - Integrated gas (filtered) exhaustion system

BATTERY / CELL RELATED TOPICS

Sources in this chapter partly from :
http://www.evsafetytraining.org/,
www.nhtsa.gov, NHTSA 2012

Content

- Overview: Different Cell technologies, Lead-acid, Li-Ion, NiMH, Ultracapacitors, Zebra.
- Power and Energy for different applications (EV, PHEV, HEV)
  - Types of batteries used for different applications
- Hazards and differences from today's lead-acid batteries
- Examples
  - BMW Mini-e "Emergency Response Quick reference guide"
  - Toyota 2012 Plug in Prius emergency response guide

Typical construction

- Positive plates (+Connector)
- Seperator
- Negative plates (+Connector)

- More plate area means more stored energy and higher power (see next slide)

- Separator avoids plates touching, while allowing flow of ions

NiMH chemistry

NiMH chemistry	
Location	**Reaction**
Anode	$MH + OH^- \rightarrow M + H_2O + e^-$
Cathode	$NiO_2H + H_2O + e^- \rightarrow Ni(OH)_2 + OH^-$
Overall	$NiO_2H + MH \rightarrow Ni(OH)_2 + M$

Discharging reaction shown

- The anodes used in these cells are complex alloys containing many metals, such as an alloy of V, Ti, Zr, Ni, La, Cr, Co, and Fe. This is just shown as “M” in the above equations.
- Using different metals gives different performances for the cell in terms of stored energy, but overall the basic equation is always the same, as is the cells voltage (~ 1.2V).

Li-Ion chemistry

Li-Ion chemistry	
Location	**Reaction**
Anode	$Li_xC_n \rightarrow xLi^+ + xe^- + nC$
Cathode	$Li_{1-x}CoO_2 + xLi^+ + xe^- \rightarrow LiCoO_2$
Overall	$Li_xC_n + Li_{1-x}CoO_2 \rightarrow nC + LiCoO_2$

Discharging reaction shown

- Many materials can be used for example $LiCoO_2$, $LiFePO_4$ for the cathode, or Si instead of carbon for the Anode.
- In this case using different materials gives a slightly different reaction giving a different voltage as well as a different energy.
  - Voltages range from ~ 2.3V to over 4V per cell
- All the reactions involve the transfer of Lithium Ions, which gives this class of batteries their name.

Example cell construction - cylindrical

- Different shapes of packaging exist, but the basic construction is always the same

- Packaging is independent of the chemistry.
    - An EV or HEV battery pack consists of (for example) 100's to 1000's of cells.

Ultracapacitors/Supercapacitors

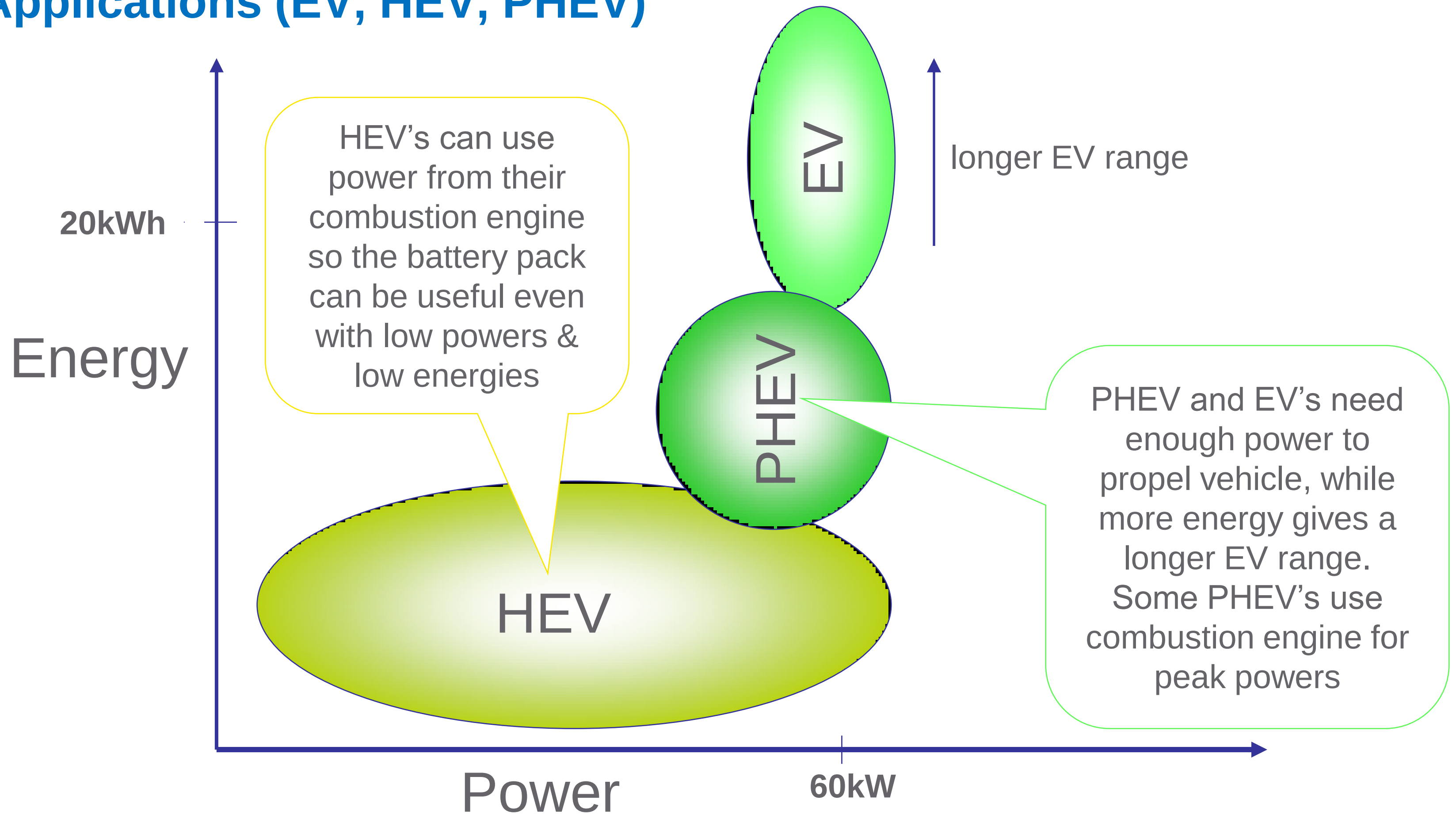
- Ultracapacitors and Supercapacitors are the same device
- The are physically almost identical to batteries, but the material of both the "anode" and the "cathode" is the same (normally carbon)
  - No chemical reactions take place with a capacitor
    - Energy is stored in the "electric field" between the plates.
      - The structure is the same as the last slide, 2 metal plates (coated with carbon) with a separator/electrolyte in-between.

Zebra batteries

- A "Zebra battery" is a high temperature Sodium Nickel Chloride cell that operates between 270 and 350oC.

- In operation the anode consists of molten sodium, while the cathode consists of Nickel Chloride combined with Molten Sodium tetrachloroaluminate ($NaAlCl_4$).
  - $NiCl_2 + 2Na \rightarrow 2\,NaCl + Ni$ (discharge reaction)
- This type of cell have been used in the Th!nk city EV, Modec EV, etc.
- In 1998 NREL (National Renewable Energy Research Lab) published an independent safety study on the Zebra battery which concluded
  - when subjected to extreme external influences simulating vehicle accidents, (Zebra) batteries do not appear likely to add additional significant hazards to occupants or emergency response personnel
  - None of the tests conducted by NREL released any sodium, but clearly there is at least a theoretical risk that sodium could be released.

Overview of Electrical Energy Storage Requirements for Different Applications (EV, HEV, PHEV)



- The energy defines the amount of active material in the cell (which depends on the chemistry)
- Power is largely defined by the chemistry but can be reduced by using thinner metal conductors (which makes the cells lighter & cheaper).

Comparison of Energies vs. Gasoline

- A typical small car has ~ 250kWh of energy stored in its fuel tank (for 400 mile range).
  - This is ~ 30kg of fuel.
    - Note a combustion vehicle has a much higher Wh/km that an EV.
      - combustion engine wastes a lot of energy as heat
- A typical small EV has a 20kWh battery (giving ~ 100 mile range).
  - The 20kWh is the "electrical energy" stored in the battery
  - In some fault conditions (eg fire) energy is released from the battery other than electrically
    - In a lithium ion battery the electrolyte is flammable
      - The total electrolyte content for an EV pack could be exceed 10kg.
        - » Given the electrolyte is normally "trapped" in the mesh of the separator it would be extremely unlikely for all the electrolyte to escape the cells.
    - In some situations, eg with a coolant leak, then more flammable gas may be created by electrolysis (using electrical energy from the battery to create oxygen & hydrogen from coolant "water"), but this is a relatively slow process.

What types of Batteries are used today?

- Almost all cars have a lead-acid battery (as they have for the past 50+ years).
- Hybrid cars may use:
  - a larger lead-acid battery
  - NiMH battery as well as a smaller lead-acid battery
  - a Li-ion battery as well as a smaller lead-acid battery
- PHEV's are similar to hybrids but with bigger batteries
- EV's are similar to PHEV's (but with even bigger batteries)
  - A few EV's just have a large li-ion battery (without a lead-acid battery).
  - Some (especially large) EV's also use Zebra batteries.
- Some cars also have some "supercapacitors" (also called "ultracapacitors") as well.
  - Eg most Toyota hybrids use
    - NiMH battery for the hybrid system
    - A smallish lead acid battery for starting the engine when its cold and "key off loads"
    - Ultracapacitors as a backup power source for the braking system

Hazards

- Lead-acid batteries have the most hazardous contents in their normal state
  - sulphuric acid is used as the electrolyte
    - but these are very well known of the emergency services.
  - newer VRLA/AGM lead-acid batteries also have a thermal run-away mechanism which is similar to that of li-ion batteries.
- NiMH and Li-ion batteries & ultracapacitors normally have no hazardous contents in their normal state.
  - Zebra batteries were discussed earlier (no issues were seen in testing by NREL).

- **Every battery is different - you need to check the specific safety information for the battery in question to be sure**.
  - a good source of information is the USA National Fire Protection Association's website at **http://www.evsafetytraining.org/**
    - Note that while its a very good source of information it only covers vehicles sold in the USA and it provides American contact information.
    - Emergency response guides are typically 30 to 80 pages long and normally provide very specific information for a particular vehicle.
      - see the examples later.

Hazards

- All batteries for HEV's and EV's will be sealed
  - if heated the internal pressure will increase and at some point the contents will "vent" to the atmosphere to avoid an explosion
  - The venting mechanism is different for every cell/pack but is designed to vent to the outside of the vehicle.
  - What vents is likely to be flammable and may be hazardous
    - eg a lead-acid battery will vent hot sulphuric acid
    - for a li-ion battery its the electrolyte that normally vents from the battery
      - this is normally very flammable but if not on fire appears as a "fog".
      - The electrolyte is hazardous itself, it's corrosive and flammable. Also not only the electrolyte, but also a large amount of decomposition product will vent. And they are toxic and flammable (eg. HF, CO).

Emergency response guide

- On arrival, emergency responders should follow their standard operating procedures for vehicle incidents.
- Emergencies involving the Hybrid or battery propelled vehicles may be handled like other automobiles except as noted in these guidelines for:
  - Extrication, Fire, Overhaul, Recovery, Spills, First Aid, and Submersion.

Recovery

- Last year a GM Volt PHEV caught fire ~ 2 weeks after a NHTSA crash test
  - The initial crash caused a leak in the battery packs cooling system
    - the coolant is conductive and combined with the high voltage in the battery eventually caused a significant fire which destroyed the vehicle and several others in the vicinity.

Source: NHTSA Report, 2012, Chevrolet Volt Battery Incident Overview Report

SAFETY RELATED TOPICS

Content

- EV on Fire
- Toxic gases
- Explosion Testing
- Extinguishing
- Risk Analysis – Timeline of a crash event
- Very toxic gases – occurence vs. Temperature
- Battery under Water
- Example for battery failure

EV on fire

- There is very little data available on complete burns of EV´s. (and only a limited number of fires has occurred so far)
- Two papers at FIVE 2012 presenting the results from complete burns of Ev´s
  - one from Japan where the maximum Heat Release Rate was twice the Heat Release Rate from the corresponding ICE vehicle
  - And one from France in which two different EVs were compared with two ICE vehicles, in this paper the Maximum Heat Release rates were about the same for all vehicles (slightly higher for one of the ICE vehicles)

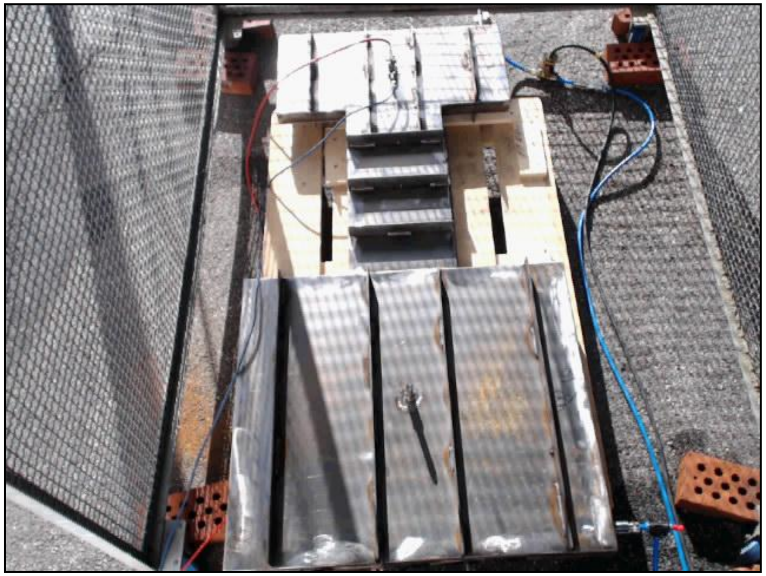
Toxic gases

- A fire in an EV will release toxic gases as all vehicle fires do. One gas that has been discussed a lot is HF. The amount of HF produced can increase with adding water. Research is currently ongoing in e.g. Sweden to investigate how large this effect is.

- Emission data from complete vehicles is scarce. A recent experiment in France compared the emissions from an EV with an ICE vehicle and found higher emissions of HF from the EV than from the ICE vehicle in a late stage of the fire. Both vehicles showed however a larger spike of HF at an early stage of the fire.

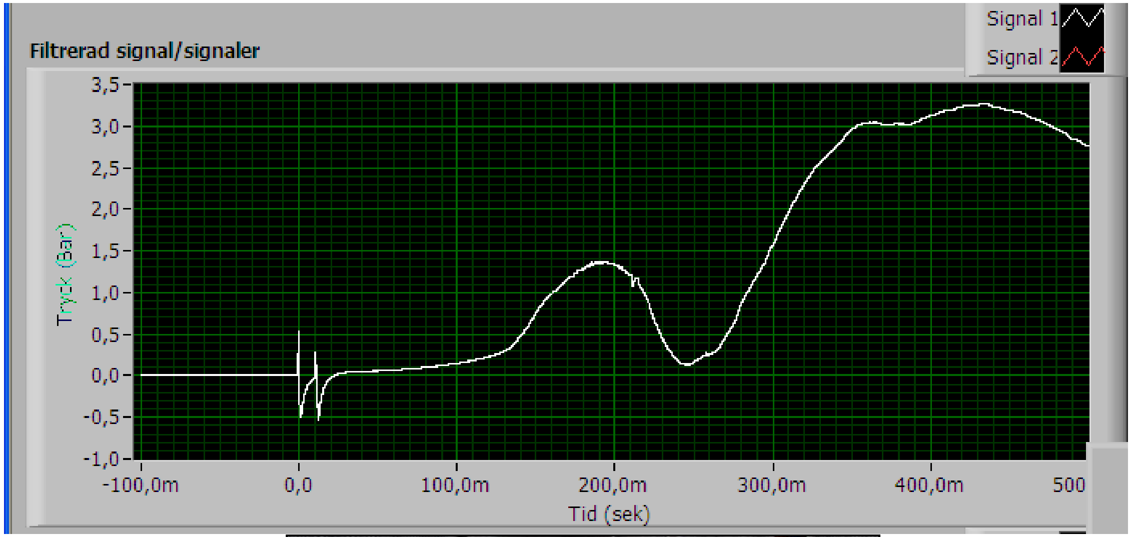
Explosion Testing

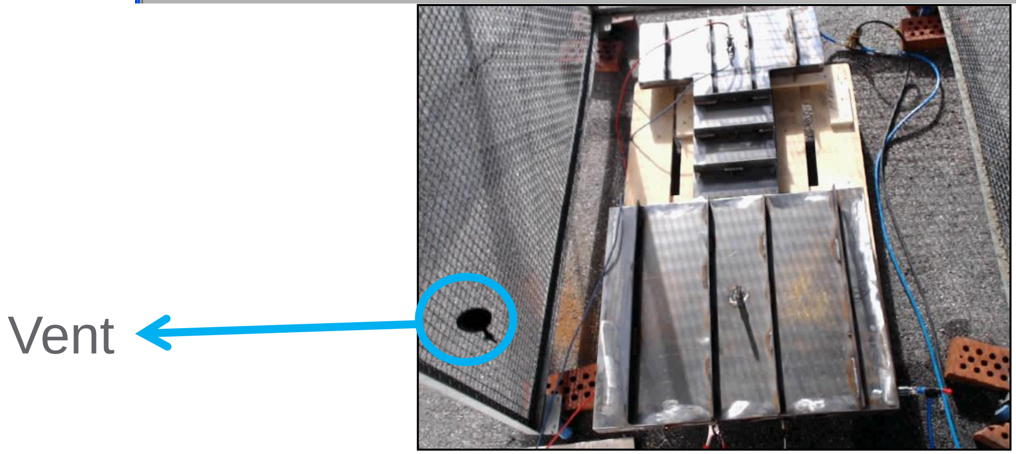
- Built a casing with same dimensions as Smartbatt casing except height that was lowered to equal the amount of air available in casing
- Three explosion vents as designed by AIT
- Tests conducted using propane with similar ignition properties as DMC
- Pressure was measured
- Tests were videorecorded



Test 1

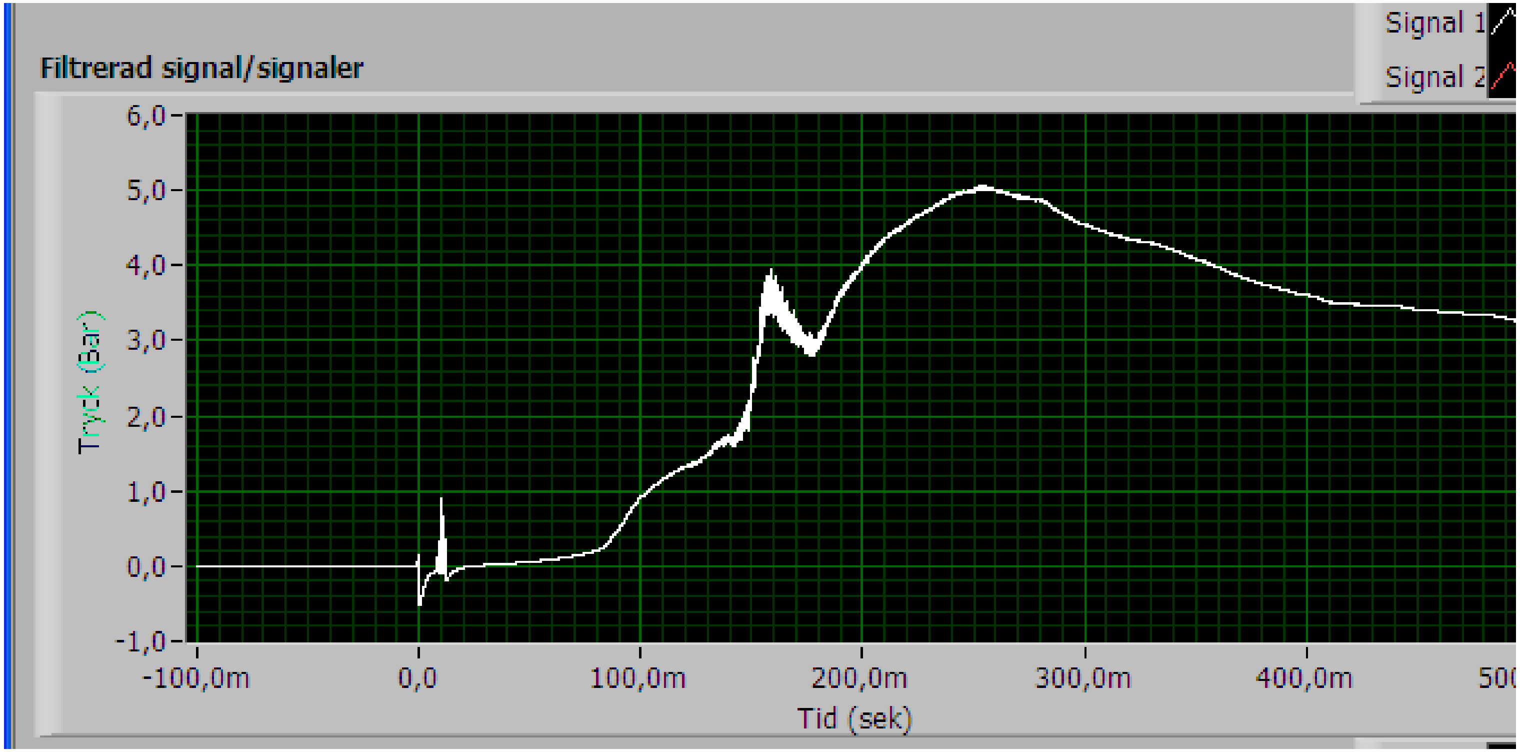
- 3.4 % propane. Ignition in front part, pressure measurement in rear.





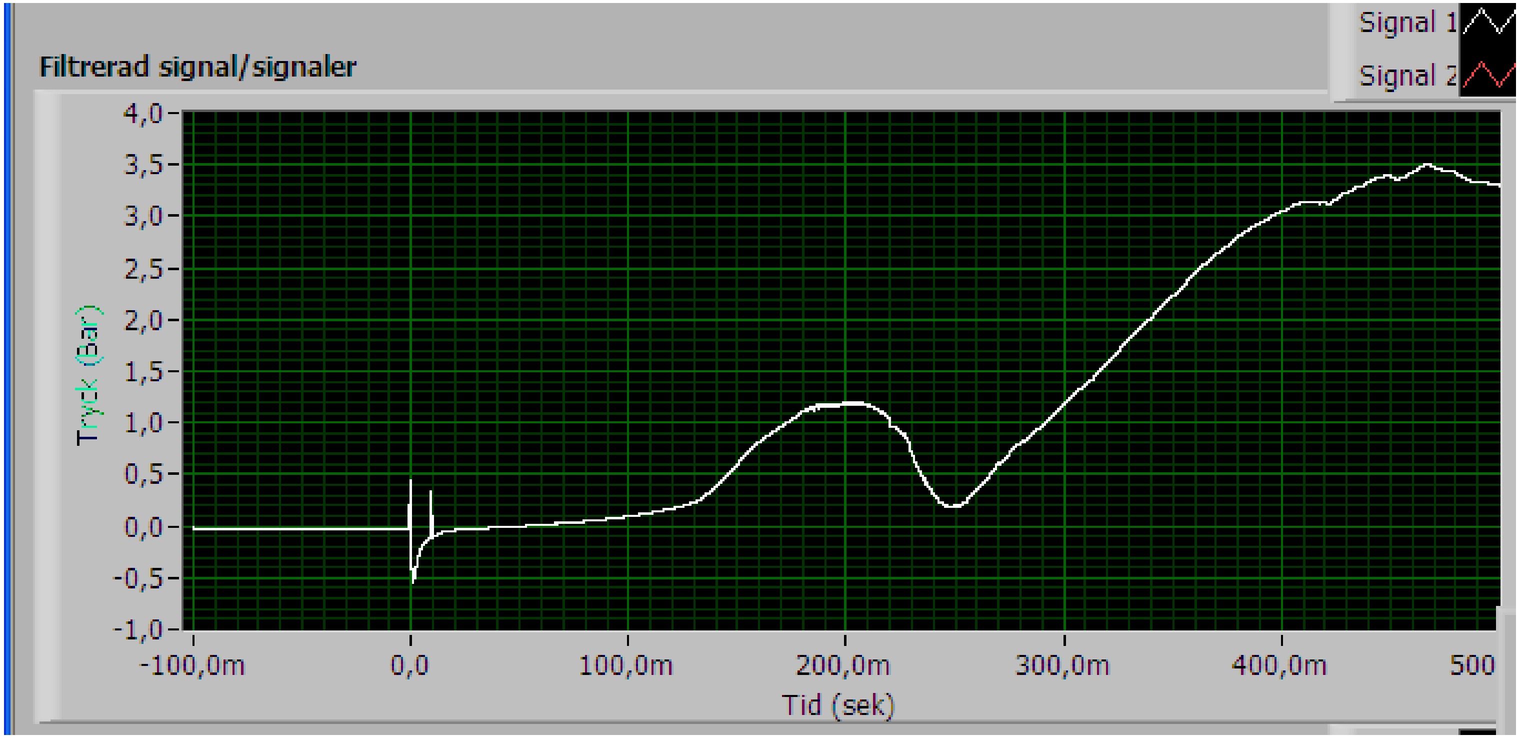
Test 4

- 4.7% propane Ignition in front part, pressure measurement in rear.



Test 5

- 2.7% propane, Ignition in front part, pressure measurement in rear.



Conclusion of Explosion Testing

- The explosion tests represents a worst case scenario with low probability.
- The tests were conducted within Smartbatt as the aim of the project is to construct a casing with high safety

- If explosion vents are needed or not depends on the design of the battery system, no general rules can be given.
- No statistics available on how often such vents are used.

Extinguishing

- Battery and cell manufacturers give different advice on how to extinguish a fire including:
  - Use water
  - Use sand
  - Do not extinguish only cool the surroundings
- There are however many cases where it is not possible to allow it burn

Extinguishing

- The material burning in the battery is mainly electrical components (plastic) and electrolyte. The electrolyte is a hydrocarbon
- Most extinguishing media works in principle so there is no need for extinguishing media for metallic fires. However…
- The heat produced by the battery itself by e.g chemical reactions or arcing calls for large prolonged cooling
- High Voltage levels
- Difficult to get access to the fire with the extinguishing media

Extinguishing

- Water is the extinguishing media that has the highest cooling potential compared to all other extinguishing media.
- Normal procedures when using water is to turn the power off to any high voltage systems. This is not possible in many cases when it comes to EV´s as it might not be possible to reach the main connector/fuse.
- How to extinguish fires in batteries is one of the satey gaps that has been identified of the Fire Protection Research Foundation in USA and a research program has just been initiated on this. Research is also ongoing in e.g. Sweden.

Chevrolet Volt - Failure

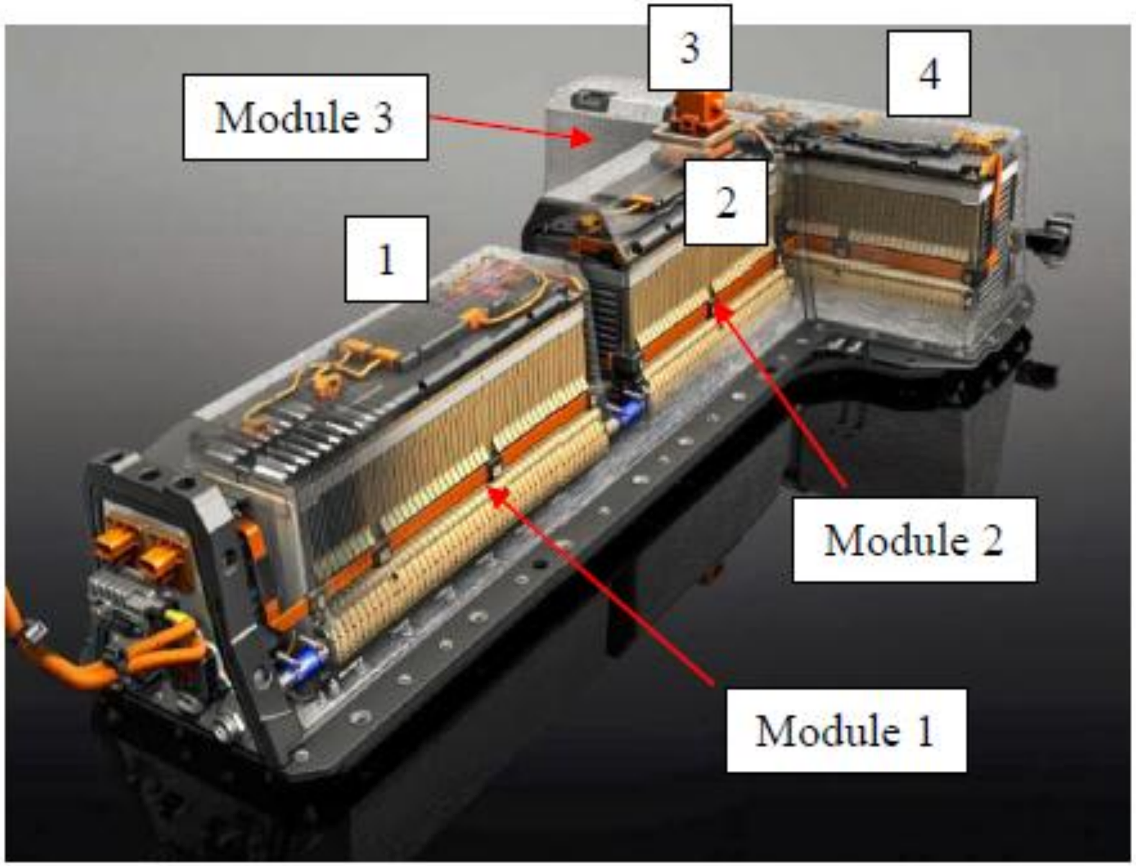
Data from the NHTSA Report

Source: NHTSA Report, 2012, Chevrolet Volt Battery Incident Overview Report

Chevrolet Volt NCAP Pole Test - Pretest	Chevrolet Volt NCAP Pole Test – Post-test
	

0 degrees	90 degrees	180 degrees	270 degrees	360 degrees
				

Photo:NHTSA 2011



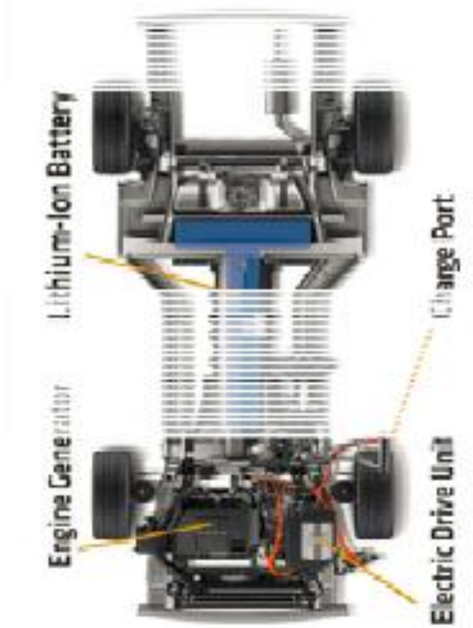


Photo:NHTSA 2011

Photo:NHTSA 2011

Intrusion into the tunnel section

Opening between the battery and occupant compartments

Photo:NHTSA 2011

Photo:NHTSA 2011

Rescue Team Teaching Program
Deliverable 8.2

Source:E-Vehicle Safe Rescue Please see below

E-Vehicle Safe Rescue

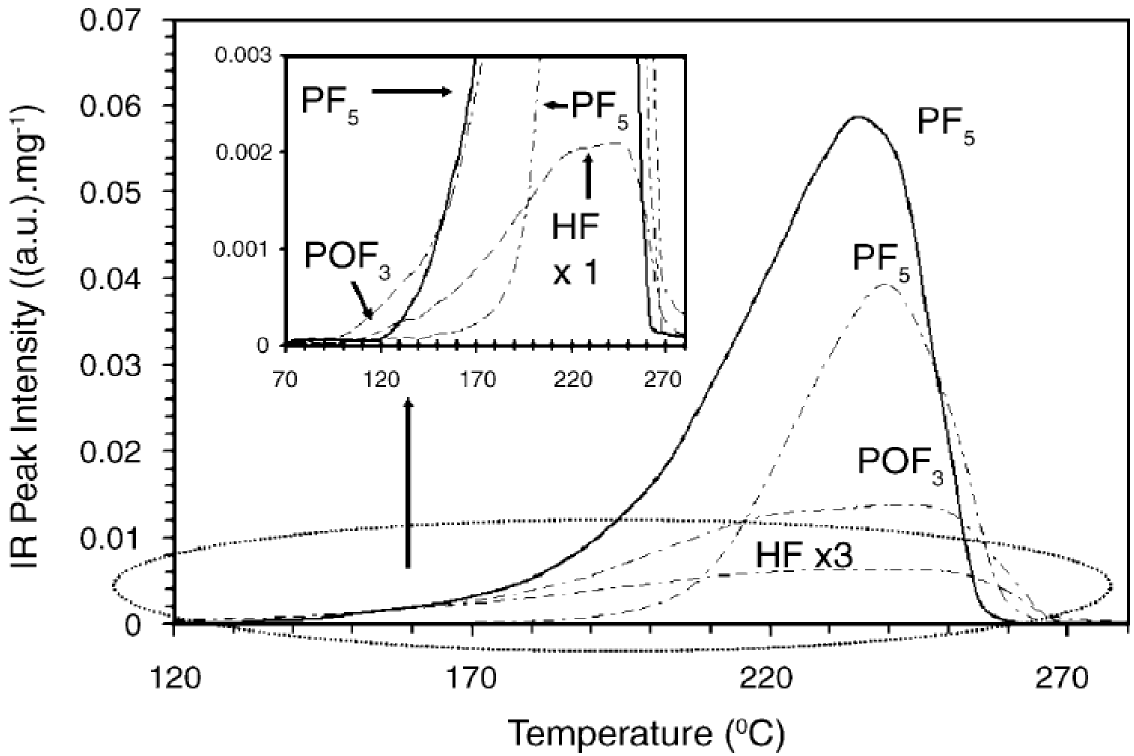
Traction Battery Safety Research and Development of Rescue Strategies for Swedish emergency personnel

Project Sponsors:

VINNOVA, the Swedish Governmental Agency for Innovation Systems

Trafikverket (the Swedish Transport Administration)

Very toxic gases – occurence vs. temperature



- Occurernce of those toxic gases are strongly related to the battery cell's internal temperatur throughout ventilation

References: *Thermal stability of LiPF6 salt and Li-ion battery electrolytes containing LPF6.* Yang, Hui, Zhuang, Guorong V and Ross Jr., Philip N. s.l. : J. of Power Sources, 2006, Vol. 161, pp. 573-579. doi: 10.1016/j.jpowsour.2006.03.058.

Battery under Water

Source:E-Vehicle Safe Rescue Please see below

- Water test with:
- 375 Volt battery 2,4 kWh
  - in freshwater and
  - in 3% salt synthetic seawater.

- No harm for persons who
  - dive down to an electric vehicle in water
  - or firefight an electric vehicle with water

→ if the traction system have free floating electric energy system.

- No other systems seen on market
- But, you never know when it comes to homemade electric vehicles.
- No problem if you know what you are doing, when a vehicle isn’t connected to the grid and when its running out on the street or dive in water.

Battery under Water

- Even in this case no issues regarding personal safety, when it comes to diving down to an electric vehicle in water or firefight an electric vehicle with water. Even if voltage level will be higher, depending of system voltage, the voltage in water is the same but voltage between pole / chassis and water will be higher depending of conductivity in the water.

- Fire fighters protection wear:
  - safety clothes and gloves
  - they will not be harmed
  - closed circuit needed to be electrocuted!

- Conductivity:
  - 5 Volt per meter in fresh water and in salt water it’s even lower!

Battery under Water – possible Hazards

- Damaged battery:
  - If any conductivity pol connect to chassis ground, it‘s BMU (Battery Management Unit) will disconnect the battery due to an detected isolation fault. If not you still will need a closed loop to be electrocuted. Don’t ever cut any cables under water.
- What has to happen with the battery that there could be a dangerous combination.
  - If the battery systems flushers with conductive salt water inside the pack the plus pole will produce hydrogen gazes and the negative pole will produce chloride gazes. If a arcing then starts inside it can start a fire with hydrogen and when the temperature is high enough the hole battery can go for a thermal runaway. This is a risk if the battery only get a half fill with salt water inside the pack.

Conclusions

- No harm to apply water to an electric vehicle as long the vehicle it self isn't connected to the grid.
- Don’t ever never cut any orange cables, specially not under water when diving.
- You need a closed loop to be electrocuted.
- Beware of a “half filled” battery pack with salt water, it has the potential to start a fire.
- Take care when electrolyze starts, it can produce hazardous vapors and gases.

ADDITIONAL INFORMATION ABOUT ONGOING PROJECTS

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E-Vehicle Safe Rescue

A research project on electric and hybrid electric vehicle system-specific risk factors in the event of a crash or electric system failure, in order to develop a training program for rescue personnel.

Co-Funding

Sweden's Innovation Agency
www.vinnova.se

Partners

Autoliv Development AB
www.autoliv.com

Volvo Car Corporation
www.volvocars.com

SP Technical Research Institute of Sweden
www.sp.se

Presto Brandsäkerhet AB
www.presto.se

Swedish Civil Contingencies Agency (MSB)
www.msb.se

Traffic Safety Centre North,
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Rescue Team Teaching Program

Overview

In the event of an E-vehicle crash, quick and competent rescue of the vehicle occupants requires new knowledge and training to minimize the time to final treatment for those injured.

By 2020, several millions of electric and hybrid electric vehicles are expected to be rolling on roads throughout the world. At present, however, there is considerable uncertainty among rescue personnel concerning preferable actions and priorities when responding to accidents involving these new types of vehicles. Novel vehicle battery systems not only offer high voltage, electric capacity, power density and energy density, but also carry significant amounts of combustible contents, raising concerns about safety in first response teams. Consequently, a need for new risk analysis in post crash situations is evident.

The core aim of the E-Vehicle Safe Rescue research project is to develop a training program for Swedish rescue personnel based on a revision of existing recommendations as well as abuse tests and traffic related crash tests on battery systems.

Based on assessments of crash patterns, documented E-vehicle crashes, and technical fundamentals, accident scenarios presenting significant damage inflicted onto the battery systems and its subsequent failure response will be investigated.

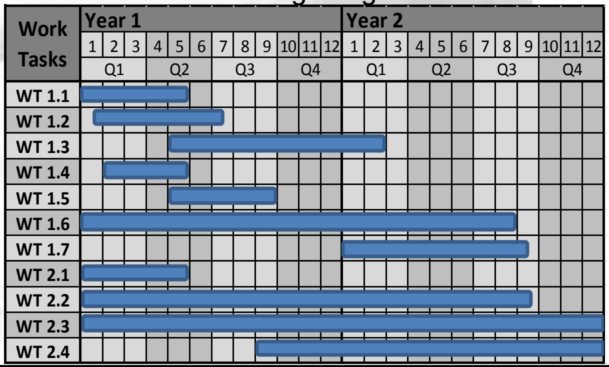
A range of commercial battery chemistries will be abuse tested with an emphasis on Li-ion battery cells and systems. Besides crash tests replicating traffic accident impact loadings, related abuse tests will be investigated – short circuit (internal/external), immersion in water (varying salt conc.), isolation resistance, arcing, fire/combustion energy, gas analysis, and assessment of fire suppression agents.

Work Packages

The training program will be developed through two work packages: *WP1 Technical* and *WP2 Educational.*

WP1 covers technical fundamentals, crash pattern study, crash simulations, physical crash tests, electrical abuse tests and thermal abuse tests on battery systems, while WP2 develops the training program based on results and conclusions from WP1 together with study of documented E-vehicle crashes and review of existing recommendations.

WT 1.1 – E-Vehicle Technical Fundamentals
WT 1.2 – Risk Analysis on Potential Battery Failure Scenarios
WT 1.3 – Compendium on Tech. and Chem. Risk Analysis
WT 1.4 – Study of German GIDAS Crash Statistics and Crash Patterns
WT 1.5 – Crash Scenario Simulations on Vehicle and Battery Systems
WT 1.6 – Physical Abuse Testing on Battery Systems
WT 1.7 – Result Evaluations and Conclusions
WT 2.1 – Real World E-Vehicle Crashes from US NASS
WT 2.2 – Review of Existing Tactics and Recommendations
WT 2.3 – Web Based Interactive Study Material
WT 2.4 – E-Vehicle Safe Rescue Training Program



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The Rescue Chain

Safe rescue in case of a crash or system break down with electric- and electro hybrid vehicles.

A study of vehicle and system specific risk factors.

This is a Sweden's Innovation Agency (FFI/Vinnova) project with the following parties:

Autoliv Development Inc.

Volvo CC

Institute Sweden,

SP Technical Research Borås

Presto Brandsäkerhet AB

Agen

Swedish Civil Contingencies

Departr f

Traffic Safety Centre North, Surgery, Umeå University

Background

- Million of cars/vehicles, with some type of electric drive train, are currently out on the roads in the world
- New types of vehicles and components generates new risks
- Traction batteries with large stored chemical and electrical energy plus high voltage (200-700 V) electrical lines and components
- Quick and competent rescue in case of a crash requires new knowledge and training to minimize the time to final treatment for victims

Aims

- Study of representative crash and breakdown mechanisms
- Technical testing at component and vehicle level for risk and non-risk evaluation
- Develop a state of the art document
- Develop a training program for rescue personnel

Content of project

Industrial parties representing advanced knowhow in technique and testing are working together with rescue personnel and organizations in an iterative process aiming at optimal rescue of injured and safety for the rescue personnel.