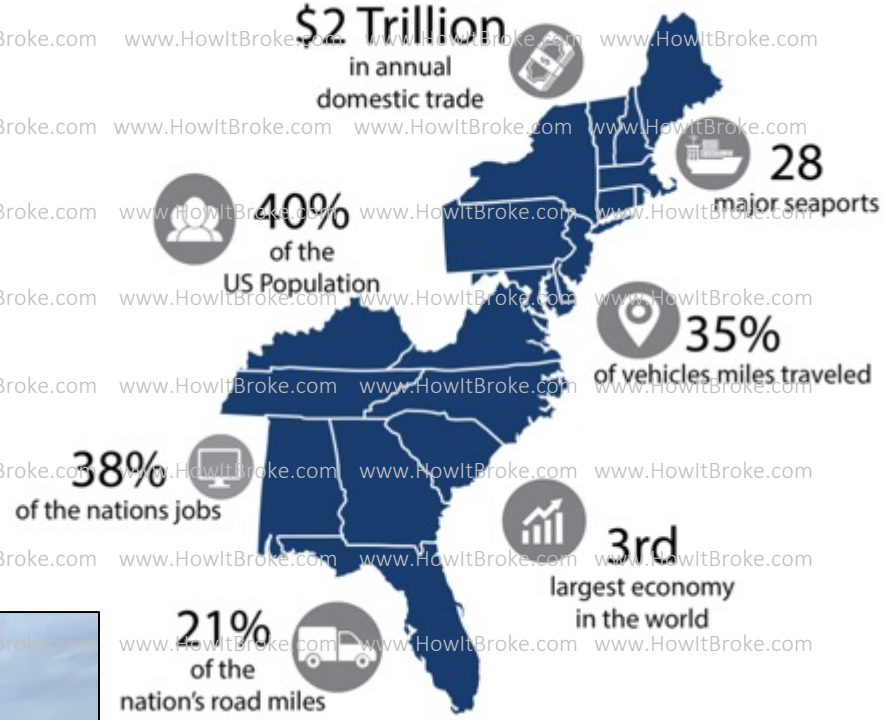
LITHIUM-ION BATTERY CHALLENGES FOR THE EASTERN TRANSPORTATION COALITION

June 3, 2024 at

University of Maryland

Fire on I-95
Source: Wakefield MA Fire Dept, 1/21/2023



Source: Birmingham Fire and Rescue Service, 3/31/2023

Robert L. Swaim

NTSB Accident Investigator – Retired

www.HowItBroke.com

301-359-1399 240-444-5730

HowItBroke.com

Bob Swaim – Accident Investigator

Worked with firefighters around the world since 1980s

32 Years as NTSB accident investigator in multiple roles,

- Investigator in Charge, US Accredited Representative, Systems Engineering

2013 Launch investigator for JAL 787 fire investigation

- Lithium-Ion battery work at UL labs, vehicle, and battery manufacturers

Electric vehicle investigator since 2017

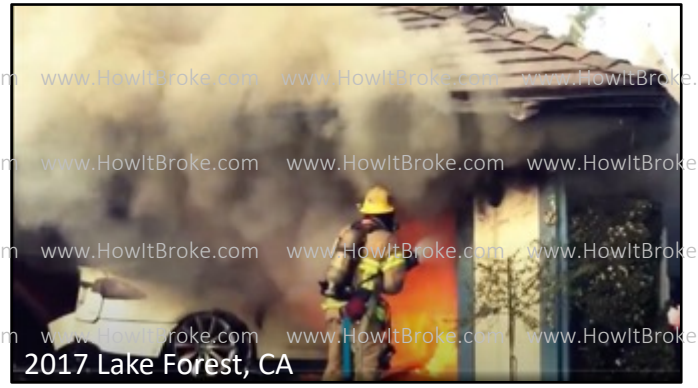
European Joint Research Council (JRC) Registered Expert

Member, SAE First Responder Safety Committee, J2990

SAE Corporate Lithium-ion Battery & Electric Safety Instructor


2014 Gaithersburg jet crash

2013 Boeing 787 Boston, MA


2017 Lake Forest, CA

Topics to Cover For a Common Baseline

What is an EV?

- Low versus high voltage
- How does a battery work?

EV market penetration

- In sales and compared to ICE
- Numbers of highway fires by State

EV vs ICE Rates

- Vehicle identification can be hard!
- ISO 17840 and SAE J3108/1

Unrecognized Issues

- Lithium-Ion in commercial vehicles and trains

Fire, smoke, and flammable gas

- Explosion risks – Don't rush ventilation
- Basic firefighting concepts and tools

Structures and charging stations

- Tunnels

ICE and EV fire exposures have different risks

- Cleaning turn out gear and PPE (NFPA 1851)

Resource list

Four Versions of Lithium Ion Battery Power Vehicles

BEV

BATTERY ELECTRIC VEHICLE

EREV

EXTENDED RANGE ELECTRIC VEHICLE

PHEV

PLUG-IN HYBRID ELECTRIC VEHICLE

HEV

HYBRID ELECTRIC VEHICLE

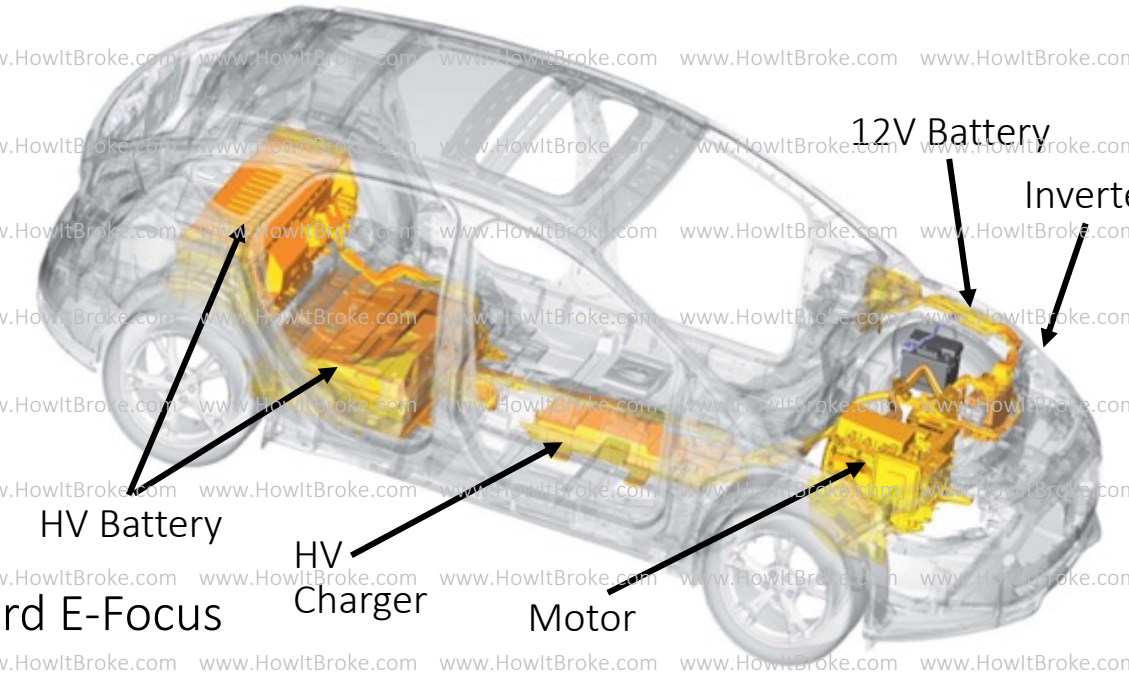
Yellow Low Voltage – Orange High Voltage

Orange denotes high voltage >30 VAC or 60 VDC

Electric vehicles move by power of a traction battery

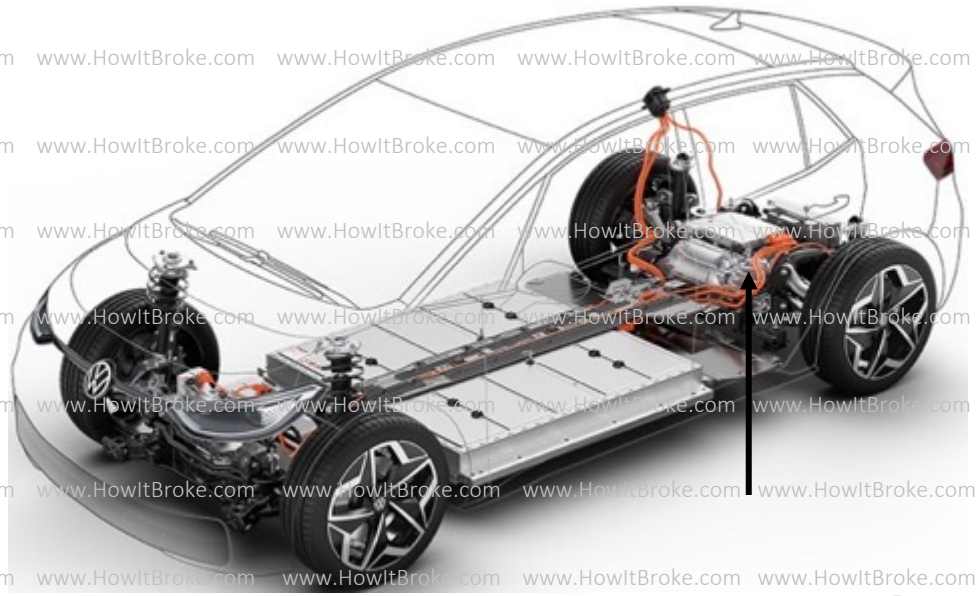
Normally have TWO batteries,

1. Cabin, Airbags, Restraints, etc 12V
2. High Voltage (HV) Traction typically 350 to 900+ V



Ford E-Focus

OLDER "INTEGRATED" STYLE



BATTERY/MOTOR "ROLLER SKATE"

VW ID.3

HowItBroke.com

A Hybrid or EV May Have Three Fuels

Tesla Model 3 Electric Vehicle

Interior fire

Toyota Prius Hybrid

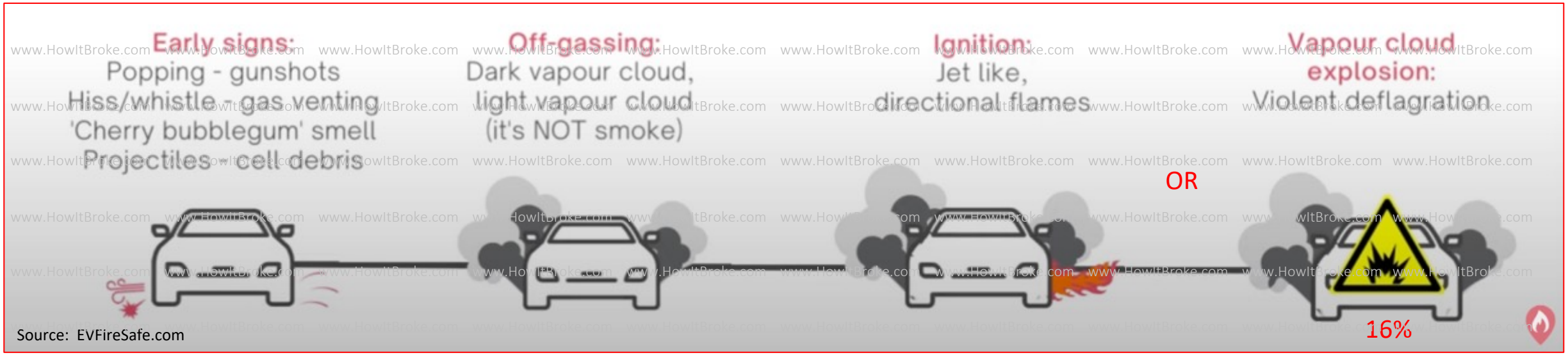
Gas engine fire

Tesla Model S Electric Vehicle

Battery fire

EV Fire Progression

SIGHT - SOUND - SMELL

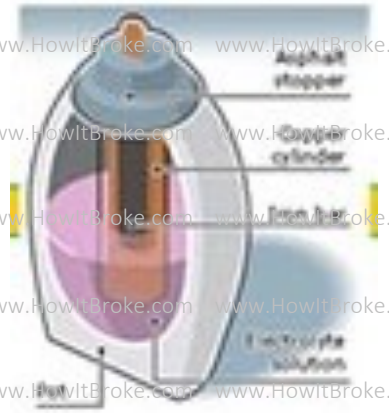


Battery Basics

Batteries Are Not New

https://www.helios-h2020project.eu/news/batteries-long-history-powerful-future

First Batteries
~200 BC



Cu/Fe
vinegar/wine

Dry Cell
1886

Zn/MnO_2/C
NH_4Cl or $ZnCl_2$

Alkaline
1949

Zn/MnO_2/C
Zn in KOH

Li-ion
1980

Li/Ni/Co/Mn/Fe
Li in carbonate

Solid State
K-ion

Na-ion
Metal-Air
Al-S
....

HowItBroke.com

Common Chemistries Of Lithium-ion Batteries In EV Use

Source: https://nordkyndesign.com/lithium-battery-banks-fundamentals/

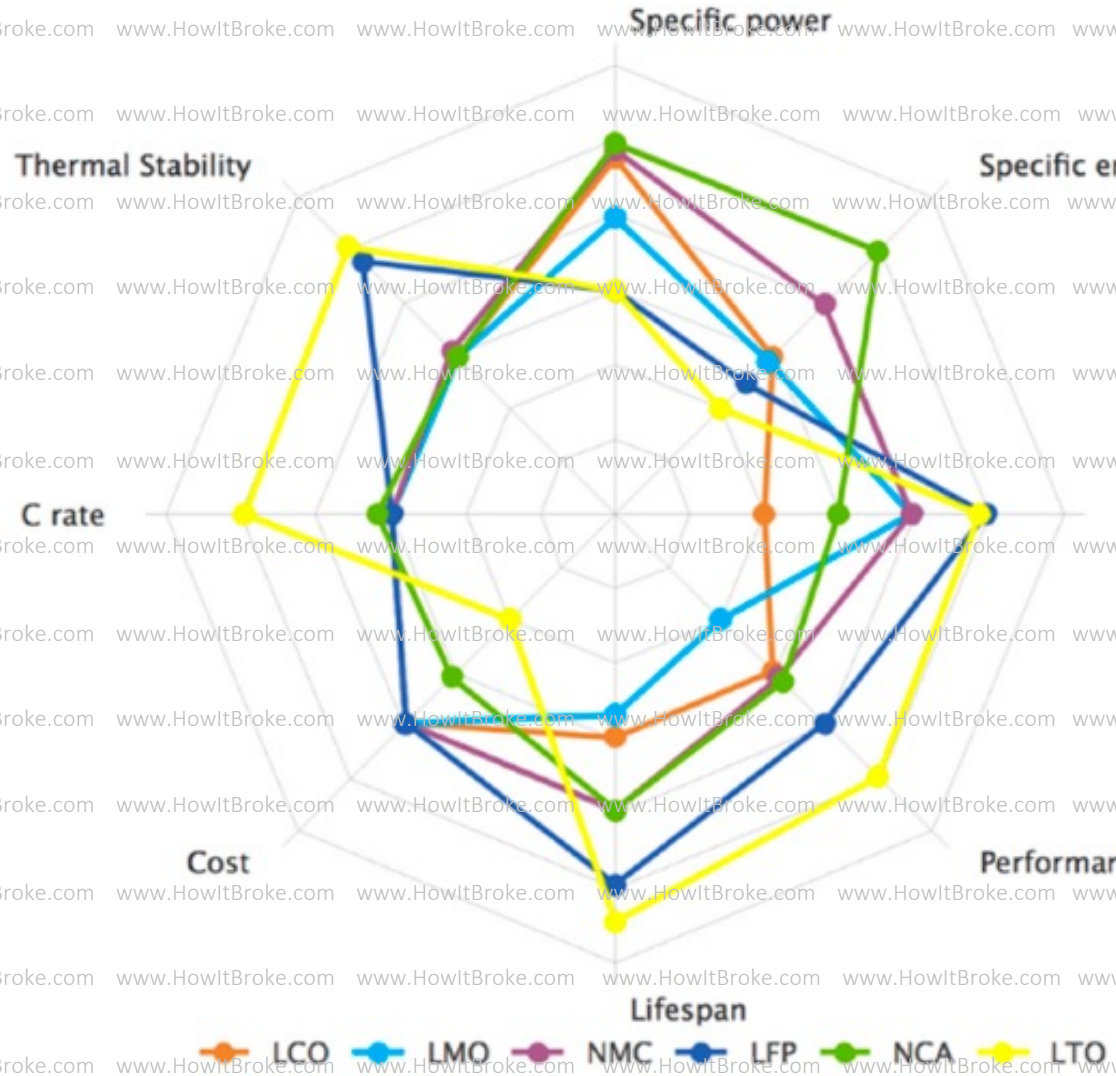
Other non-lithium chemistries exist, such as NiMh in Toyota C-HR and Nissan Leaf

NCA – lithium nickel cobalt aluminium oxide (1999),
NMC – lithium nickel manganese oxide (2008),
LFP – lithium iron phosphate (1993) (aka $LiFePO_4$),
LCO – lithium cobalt oxide (1991),
LMO – lithium manganese oxide (1996),
LTO – lithium titanate oxide (2008).

NCA - Highest energy. Low mfg cost. TR history.
Source issues [Russia Nickel, Congo Cobalt]
Early Tesla models

NMC - High energy. TR history.
Source issues [Russia Nickel, Congo Cobalt]
Rivian
Jeep 4xe
BMW iX3
Hyundai Ioniq 5

LFP - Longer life. Thermal stability. Lower energy density
Rivian (new)
Tesla 3 (new CATL)
Hyundai Ioniq 5



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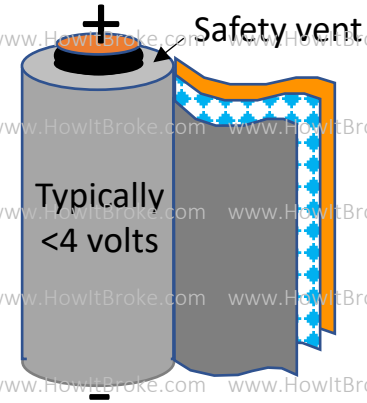
How A Lithium-ion Battery Functions

Four Components



Anode (-)

Copper foil with porous carbon coating

Separator

Porous **polypropylene** membrane

Cathode (+)

Aluminum foil with porous oxide coating

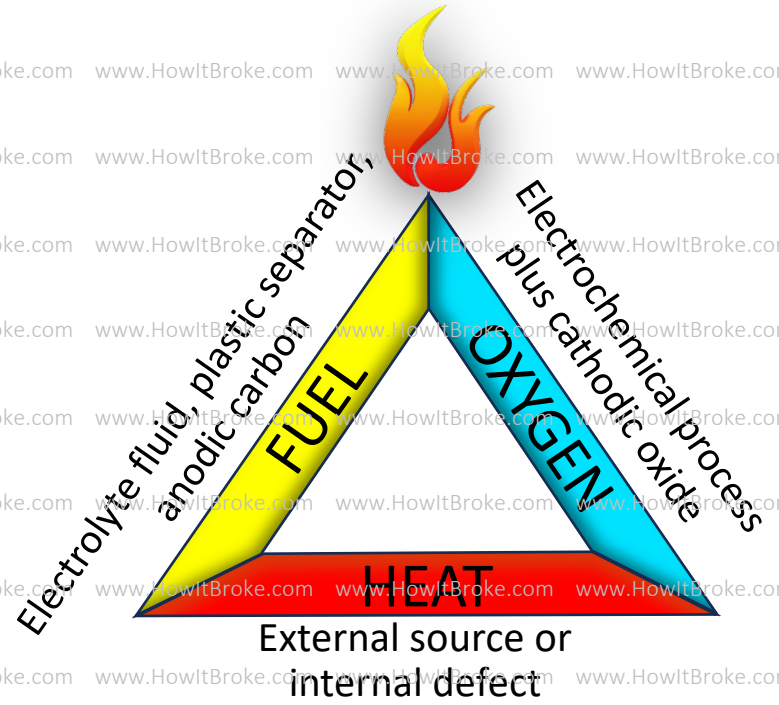
Electrolyte (typically oil) contains lithium ions (salt)

Lithium salt ions move in electrolyte

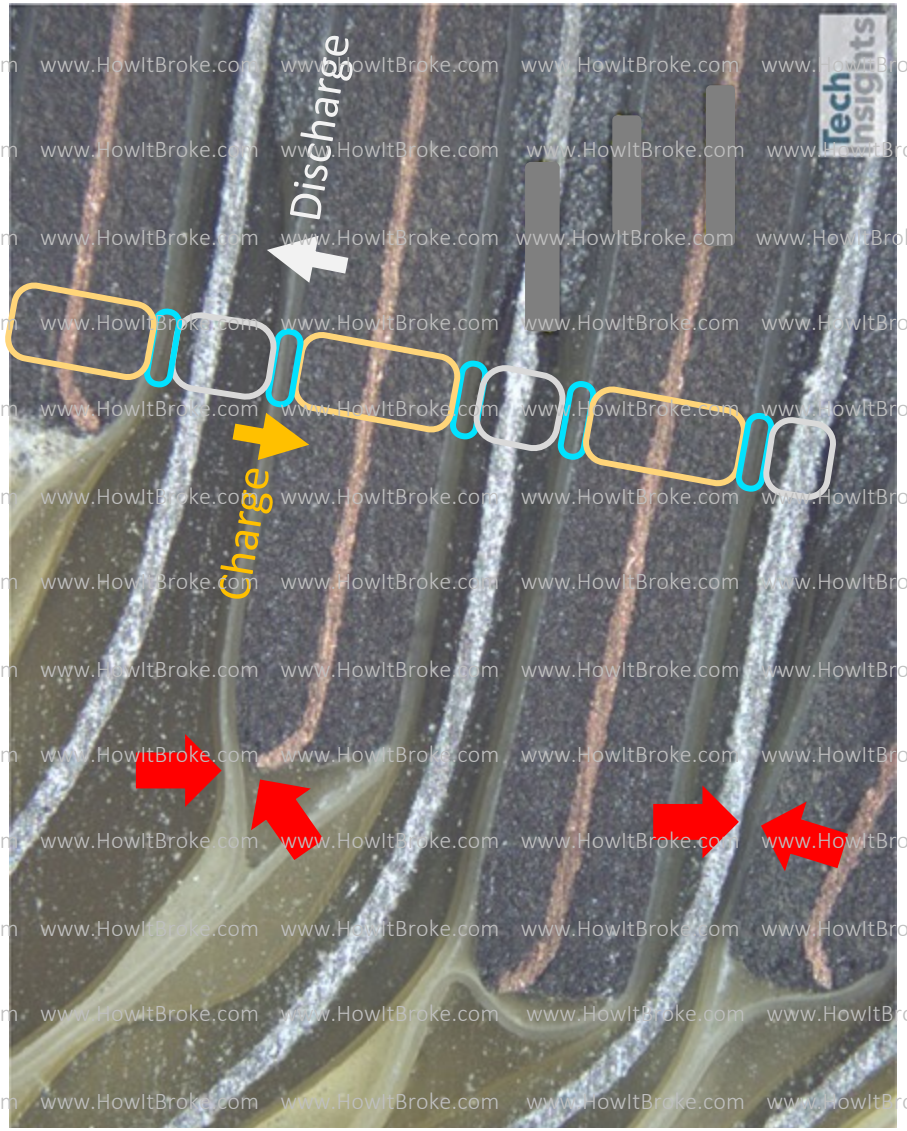
HowItBroke.com

Potentially vulnerable points

Each cell has BOTH electrical (30%)
AND chemical energy (%70)



Each cell contains a complete fire triangle

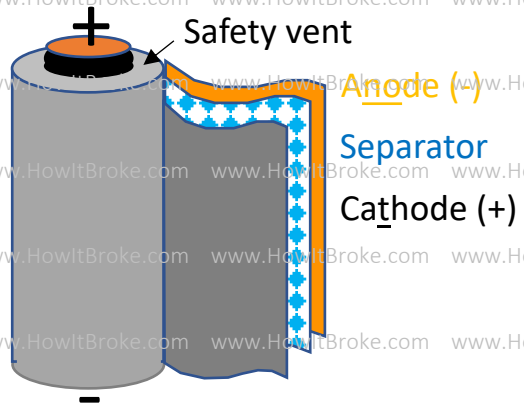


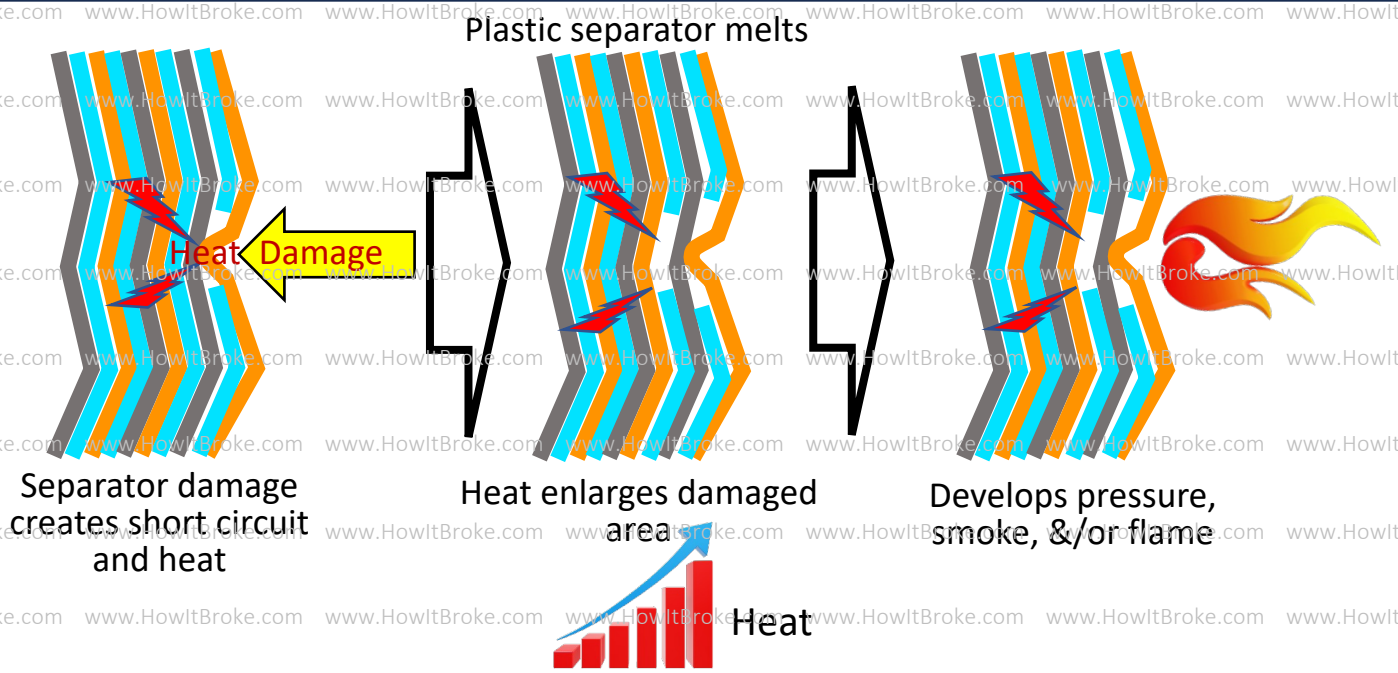
Potential to damage separator

LG Electronics SB035Z6 Ion Battery SEM Cell Cross Section from a Chevrolet Bolt

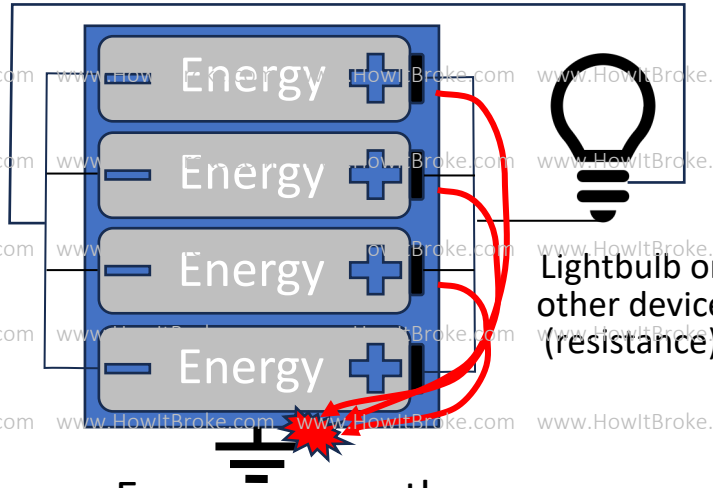
HowItBroke.com

Thermal runaway process





Temp <100C can stop thermal runaway process



Cell venting

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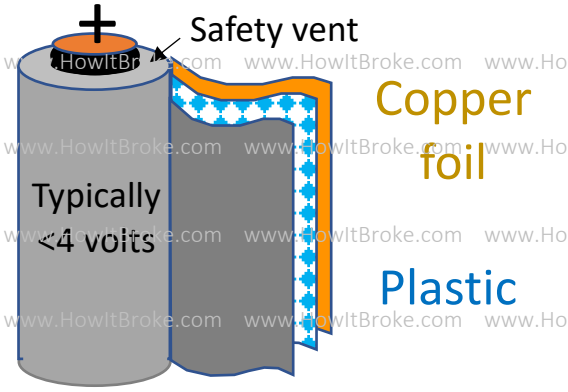
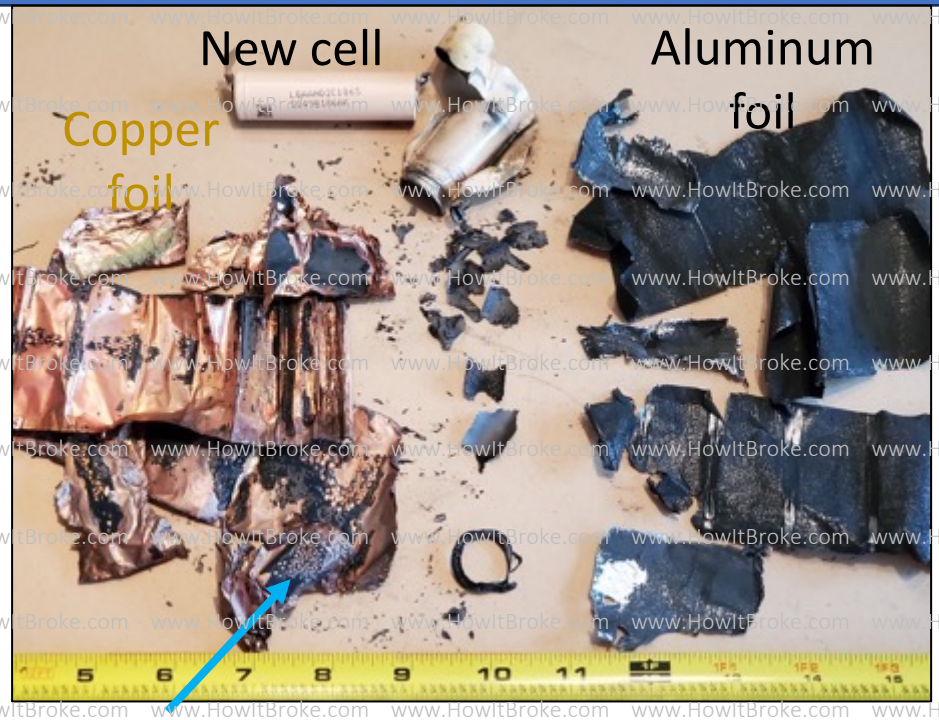
Vapes Cause Injuries And Fatalities





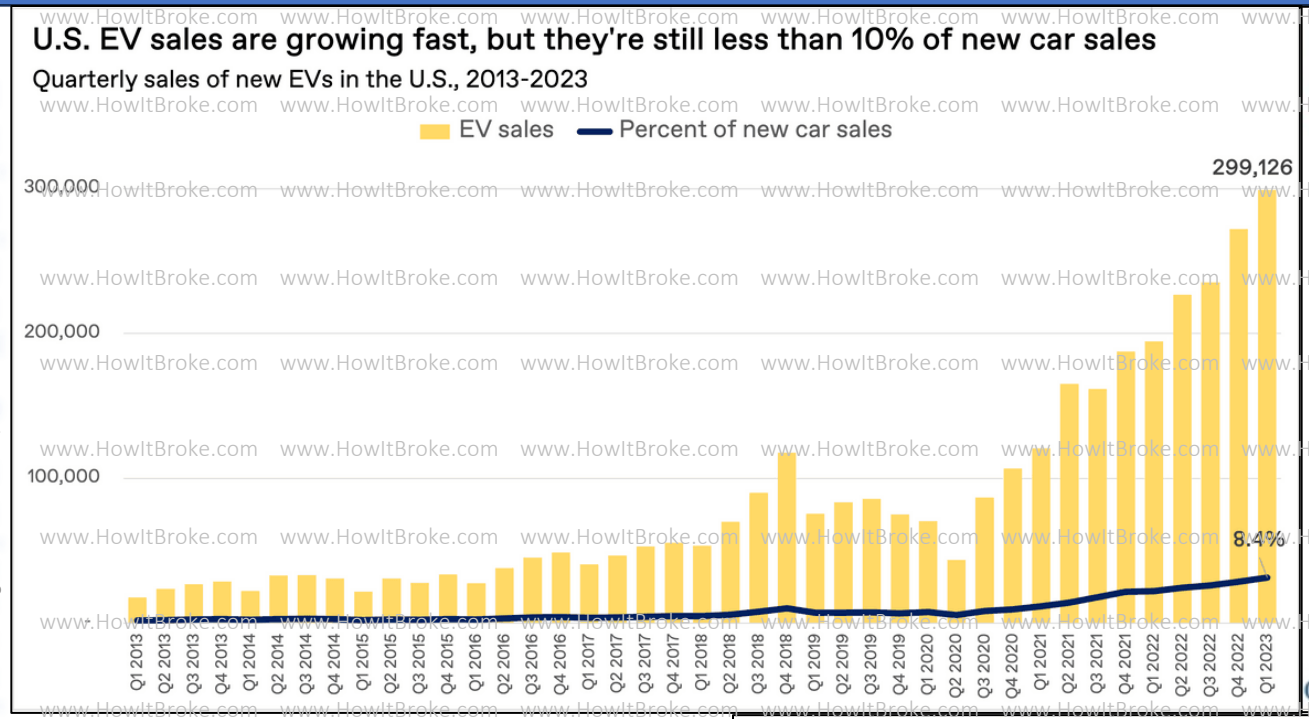
Bursting case becomes shrapnel

Witness: "It sounded like gun shots."

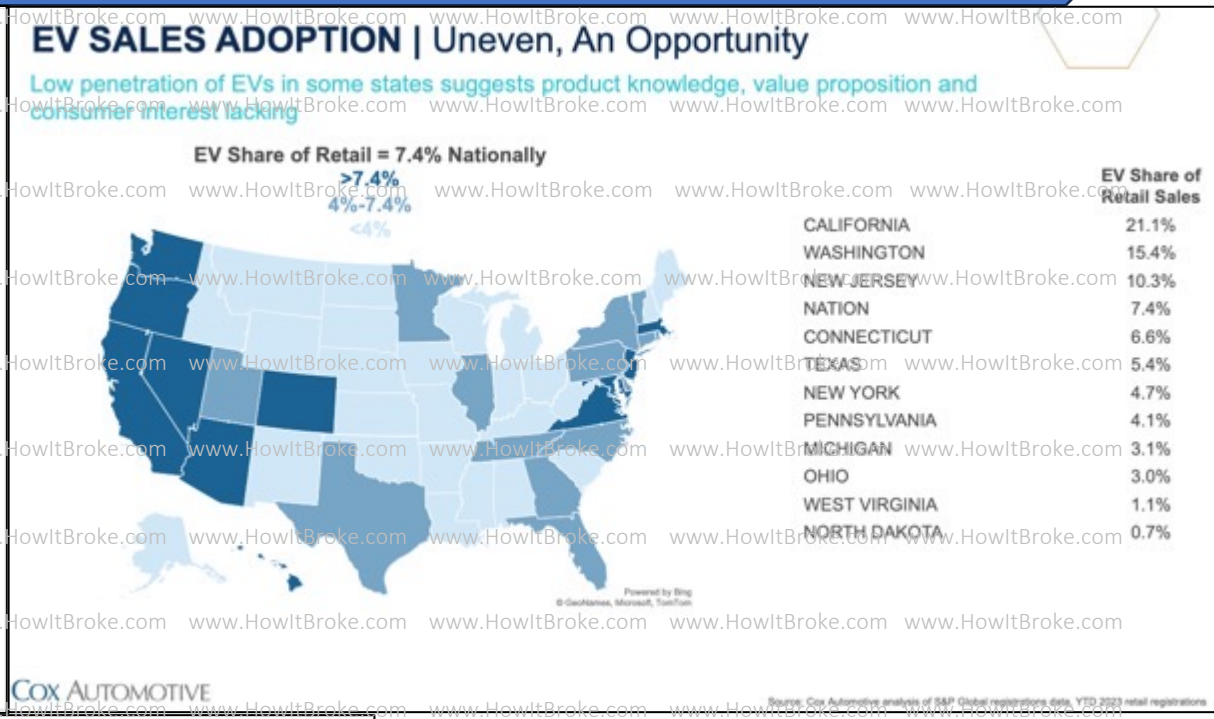
HowItBroke.com

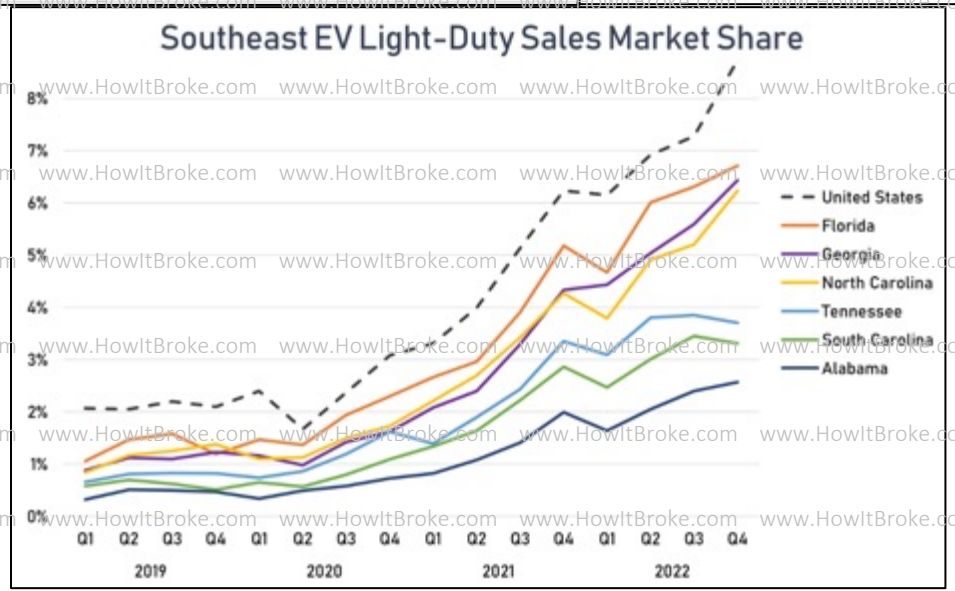
EV Market Penetration

EV Sales And Penetration

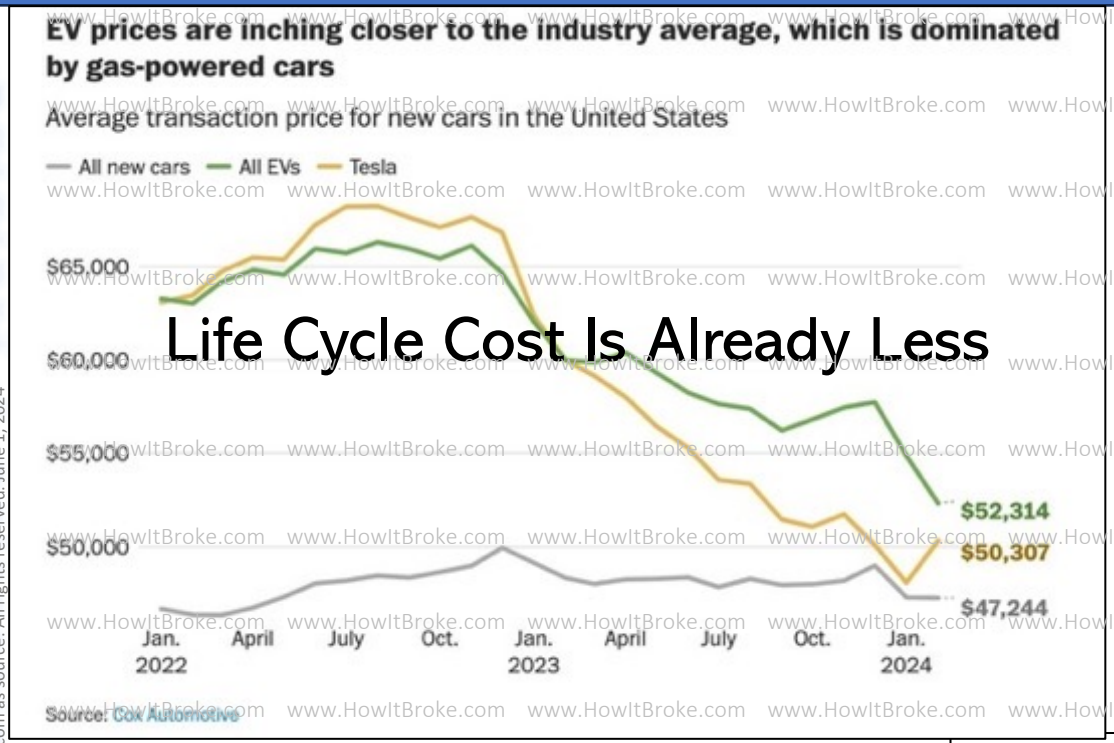


Source: Argonne National Laboratories

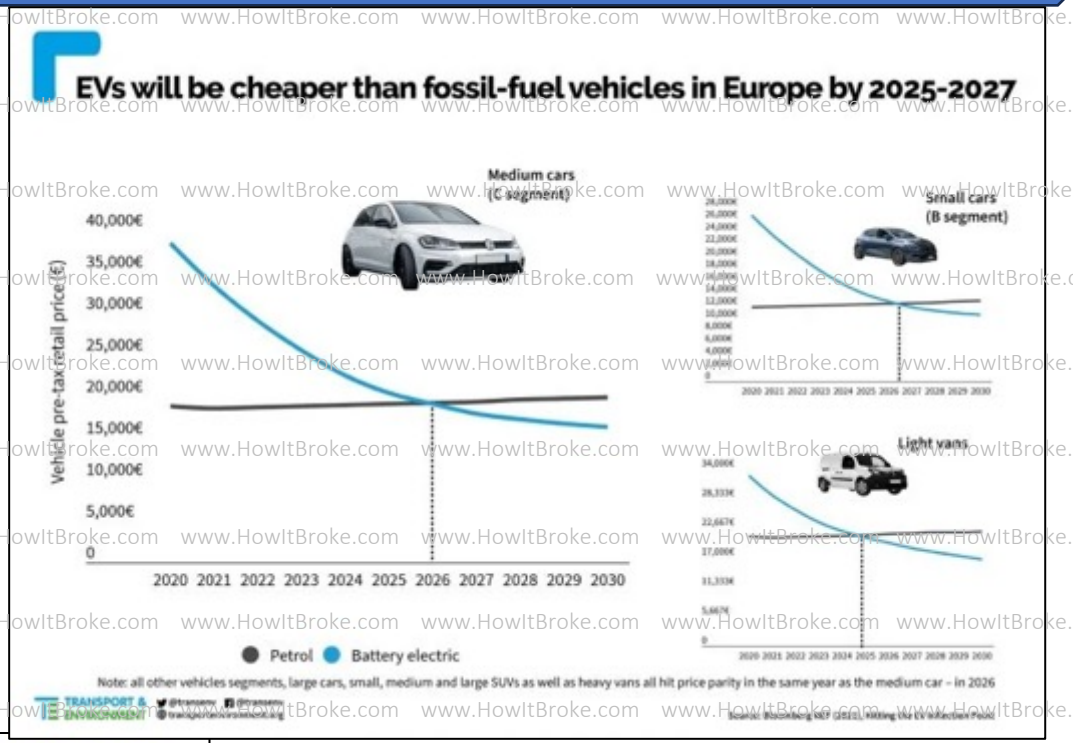




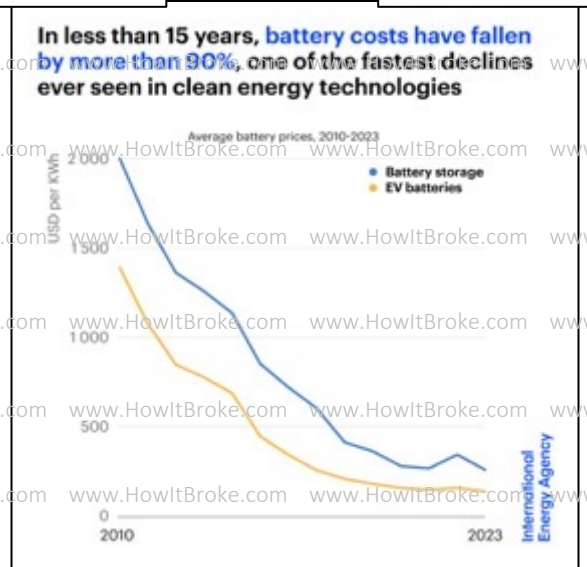
Cost To Build Approaching ICE



Life Cycle Cost Is Already Less



The reason is the falling price to make batteries



Tesla Continues To Dominate Sales – And Fires

Make	2019	2020	2021	2022	2023	2024 Jan-Feb
Tesla	79.9%	76.6%	66.2%	58.6%	56.2%	55.8%
Ford	0.0%	0.0%	7.0%	8.6%	6.7%	6.8%
Mercedes-Benz	0.0%	0.0%	0.0%	1.3%	3.9%	5.0%
Rivian	0.0%	0.0%	0.1%	3.5%	3.8%	4.6%
Hyundai	0.6%	2.9%	2.8%	4.8%	5.0%	3.9%
Chevrolet	7.3%	8.9%	6.4%	5.3%	5.8%	3.8%
Kia	0.5%	1.3%	1.6%	5.0%	2.3%	3.7%
BMW	0.0%	0.0%	0.0%	1.1%	1.8%	2.5%
Volkswagen	2.2%	0.3%	4.3%	2.9%	3.5%	2.5%
Cadillac	0.0%	0.0%	0.0%	0.0%	0.8%	2.4%
Nissan	5.5%	4.1%	3.7%	1.7%	1.9%	2.0%
Audi	2.4%	3.0%	3.4%	2.2%	2.0%	1.7%
Volvo	0.0%	0.0%	1.1%	1.1%	1.1%	1.1%
Porsche	0.1%	2.0%	2.2%	1.2%	0.7%	0.7%
Toyota	0.0%	0.0%	0.0%	0.2%	0.9%	0.7%
GMC	0.0%	0.0%	0.0%	0.1%	0.3%	0.6%
Lucid	0.0%	0.0%	0.0%	0.6%	0.5%	0.5%
Lexus	0.0%	0.0%	0.0%	0.0%	0.5%	0.5%
Subaru	0.0%	0.0%	0.0%	0.1%	0.8%	0.4%
Genesis	0.0%	0.0%	0.0%	0.2%	0.6%	0.4%
Polestar	0.0%	0.0%	0.8%	1.3%	0.6%	0.3%

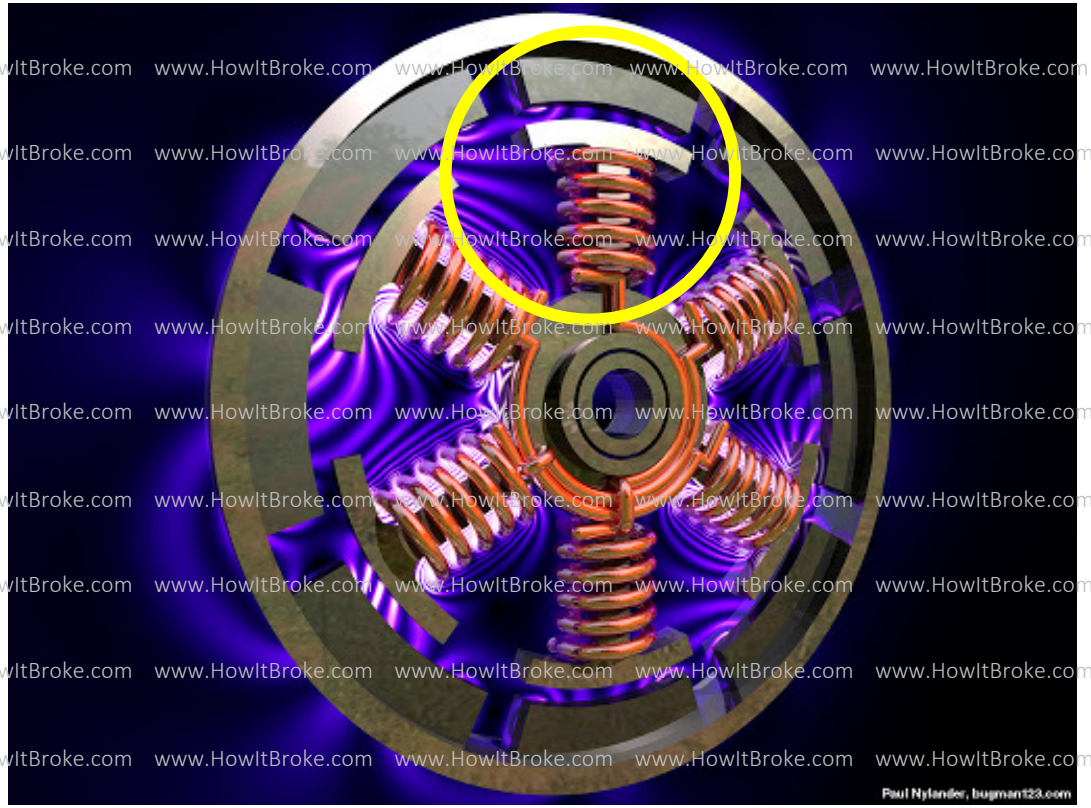
Should influence training

44.1% Combined

Source: Edmunds sales data as of March 6, 2024

Why This Emblem For Tesla?

One coil winding and stator of an electric motor



The Biggest Reason EVs Sell Is Personal

Actual examples:

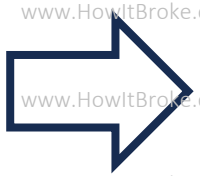
	2023 Hyundai Tucson	2020 Chevrolet Bolt	2016 Ford Transit
Cost	$27,000 (new)	$27,000 (new)	$16,000 (used)
MPG	28 mpg	136 e-mpg	16 mpg
Cost to fill/charge 12,000 mi/year	$ 45	**$ 6.85 (home)**	$ 80
Yearly Cost $3.50 gas $.146 kWh	$ 1,500	**$ 316**	$ 2,625

HowItBroke.com

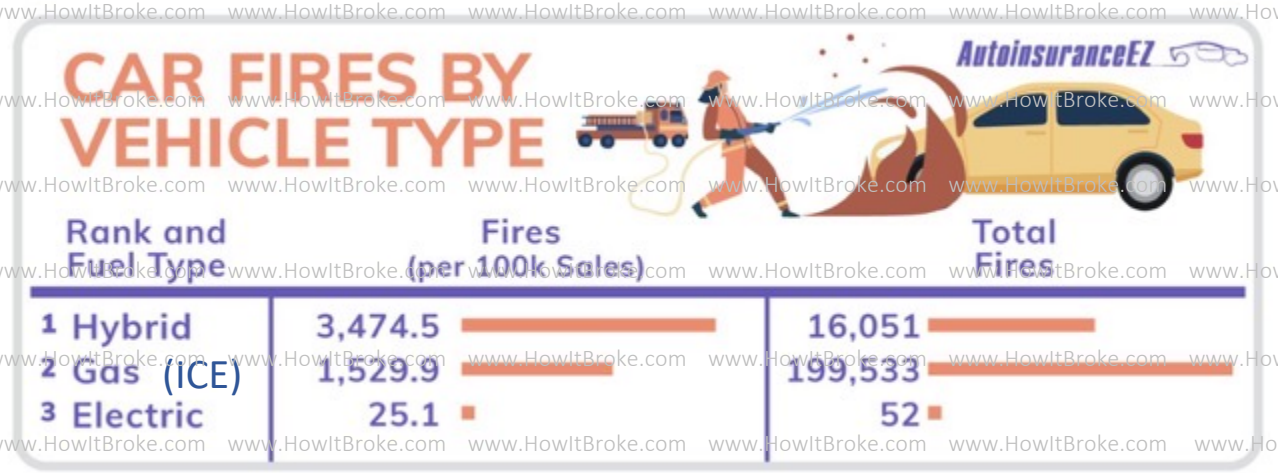
Rates and Recognition

Expectations vs Reality of ICE vs EV Events

ICE



ICE fires: 8.5+ years old and occupied

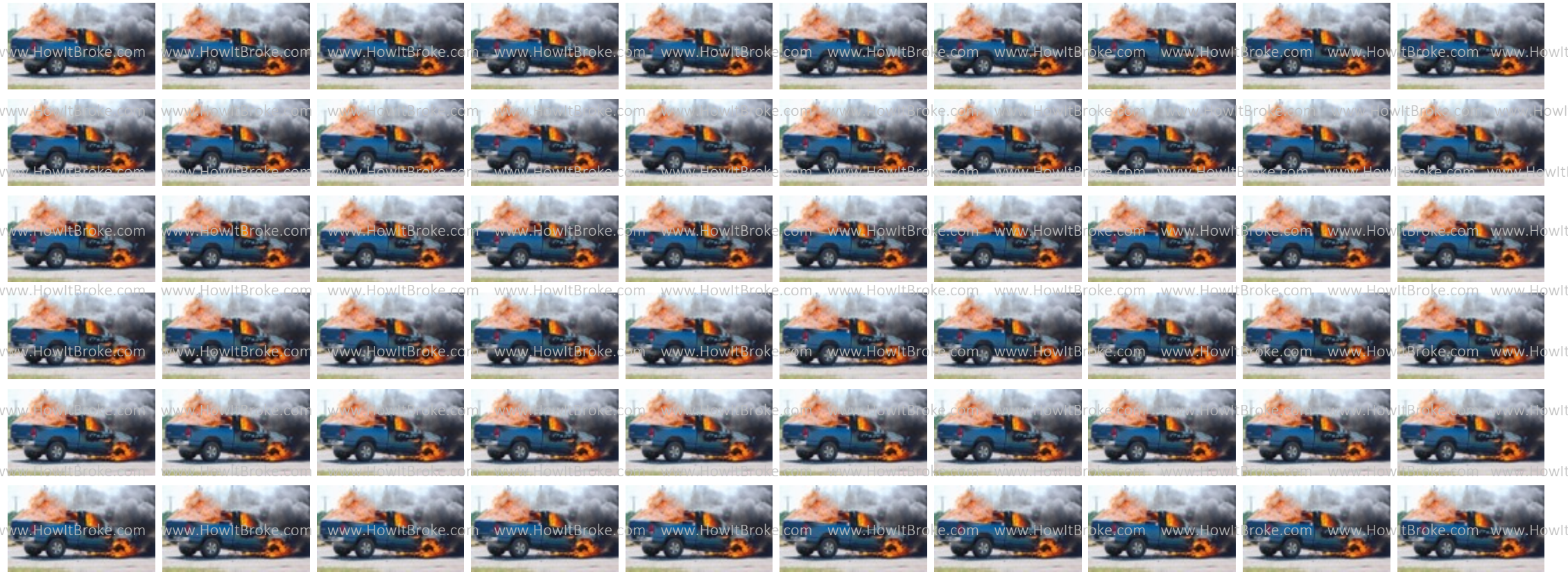


EV fires: Initial 18 months

44% Parked or charging, generally unoccupied

HowItBroke.com

~60.9 ICE Fires Per EV



Estimated Total EV Highway Fires Per Year By State

	State highway EV fires per day (60.9:1) all highways*	**State highway EV fires per year (60.9:1) all highways***	I-95 portion of all highway fires?	Based in: State portion of national total 222,000 vehicle highway fires per year (2022)	Total State registered vehicles 2021	EV % of State vehicle registrations (2021)	State EVs (2021)	Extra Info I-95 miles	State % of total I-95 miles
FLORIDA	0.39	**142**	Would need to know I-95 percentage of all highways in State	8640	19180165	0.0093	178376	382.15	0.20
PENN	0.22	**81**		4922	10927881	0.0047	51361	51	0.03
NEW YORK	0.19	**70**		4238	9408796	0.0075	70566	23.5	0.01
GEORGIA	0.19	**68**		4118	9142656	0.0063	57599	112	0.06
NO.CAROL	0.18	**64**		3922	8707506	0.0051	44408	181.36	0.09
VIRGINIA	0.16	**57**		3447	7652036	0.0074	56625	178.73	0.09
NEW JERSEY	0.13	**46**		2815	6249905	0.0122	76249	97.76	0.05
MASS	0.11	**39**		2346	5207052	0.0091	47384	91.95	0.05
SO.CAROL	0.10	**38**		2294	5091679	0.0027	13748	198.76	0.10
MARYLAND	0.10	**36**		2212	4910674	0.0091	44687	110.01	0.06
CONN	0.06	**20**		1242	2756485	0.0075	20674	111.57	0.06
MAINE	0.03	**10**		625	1387656	0.0041	5689	303	0.16
NEW HAMP	0.03	**10**		639	1417949	0.0051	7232	16.11	0.01
RHODE ISL	0.02	**6**		361	801654	0.0049	3928	42.36	0.02
DC	0.01	**3**		164	363287	0.0185	6721	0.11	0.00
DELAWARE	0.01	**3**		213	472175	0.0059	2786	23.43	0.01

* FIRS Data does not break-out causes for EV vs ICE.

* Does not account for other EV fires involving residences or other non-highway events

HowItBroke.com

Identification Can Be Hard!

HowItBroke.com

Hybrids With Minimal Or No Badging May Surprise Responders

BMW 530i

Ford Hybrid Explorer Interceptor

Jeep Grand Cherokee

Volvo XC60 PHEV

Exploded while doing 360

March 30, 2024, Boulder, CO, 6:38 am

HowItBroke.com

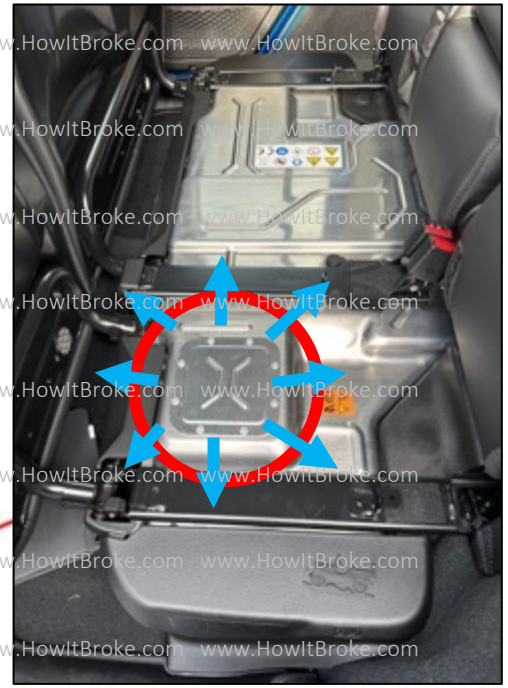
Mis-Identification Can Be Hazardous

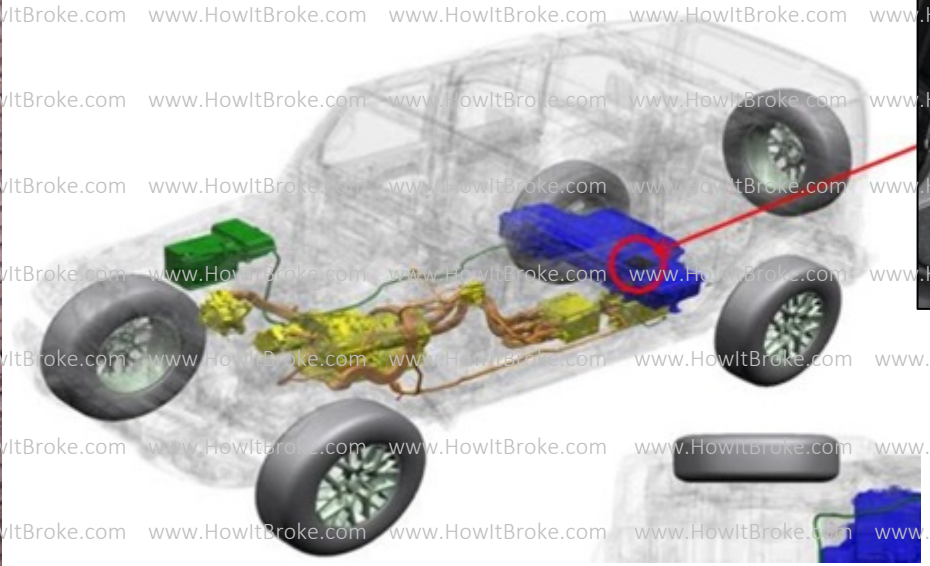
Samsung SDI cell lot found defective

96 prismatic cells, Samsung SDI 2700,

94 Ah nickel manganese cobalt NMC cells, 3.7v cell

Each can generate 109 liters of gas/smoke





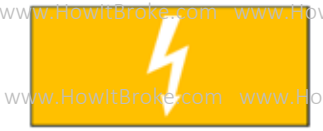
HowItBroke.com

New York First State With Legislation To Mark Vehicles Per SAE

SAE Issued Recommended Practice J3108/1 on March 1, 2024

Examples:

Battery Electric



Hybrid

Natural Gas

Dual fuel
LPG / Gasoline

Hydrogen fuel cell

In-work symbol revisions shown to better harmonize with ISO17840

HowItBroke.com

Electric Vehicle Firefighting Has Differences

Call Center
Location, general details, ask for vehicle

Need to adapt existing formal written risk management plans

While driving: Find Rescue Sheet → Assess scene ID vehicle → Evaluate hazards Fire/chem/elect (Assume Li-Ion) → Command decision Active or Passive

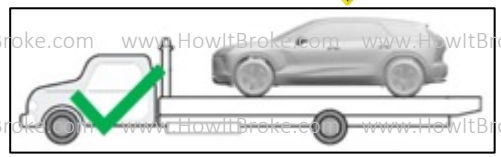
(If possible with Li-Ion)
Passive (Let it burn):
No occupants
Isolated
No smoke threat
Water unavailable

Active: Stabilize vehicle Chock-Park-Park-Off

Occupant Rescue

Oversight Person

Firefighting → Cool (Monitor) → Tow → (Do not turn wheels)



Li-Ion: 13% Re-Ignite so be ready
https://www.evfiresafe.com/ev-fire-reignition
Prepare and equip driver

Procedures are changing fast

Previously called for universally cutting cut-loops

Tesla & GM now – Only cut firefighter loops if necesssary

Tesla was silent on submerging – Now recommend against

GM – Flooding cabin can cool some batteries (Ultium)

HowItBroke.com

Adapted from https://www.fmcsa.dot.gov/sites/fmcsa.dot.gov/files/training-high-voltage/story_html5.html

HV Disconnects Are Not Standardized

1. Pull plugs by hand (typically hidden)
2. Cut loops requiring cable cutter
3. Cut loops requiring circular saw
4. Twist knob by hand (typically hidden)
5. Fuse - hard for gloved hand

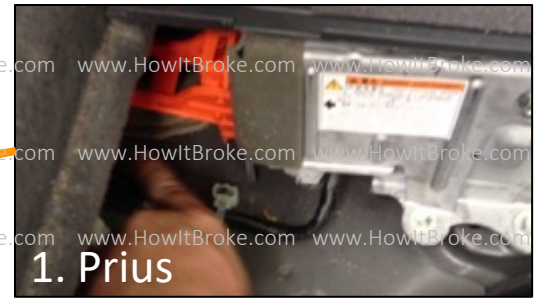

1. Chevy Tahoe

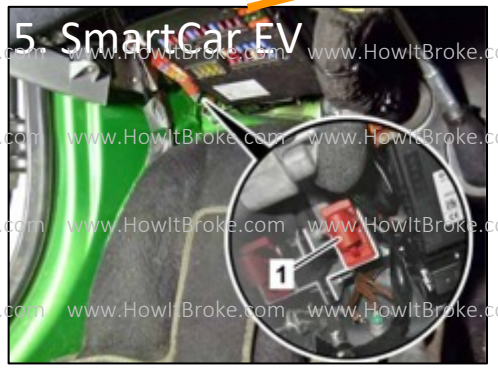
Chevy Volt

Ford Focus


4. Ford Escape


2. Tesla forward cut loop


1. Prius


5. SmartCar EV


2. Mercedes


1. Highlander

HURST or saw

3. Tesla secondary structural cut loop

International Standard ISO 17840 Provides Standardized Info

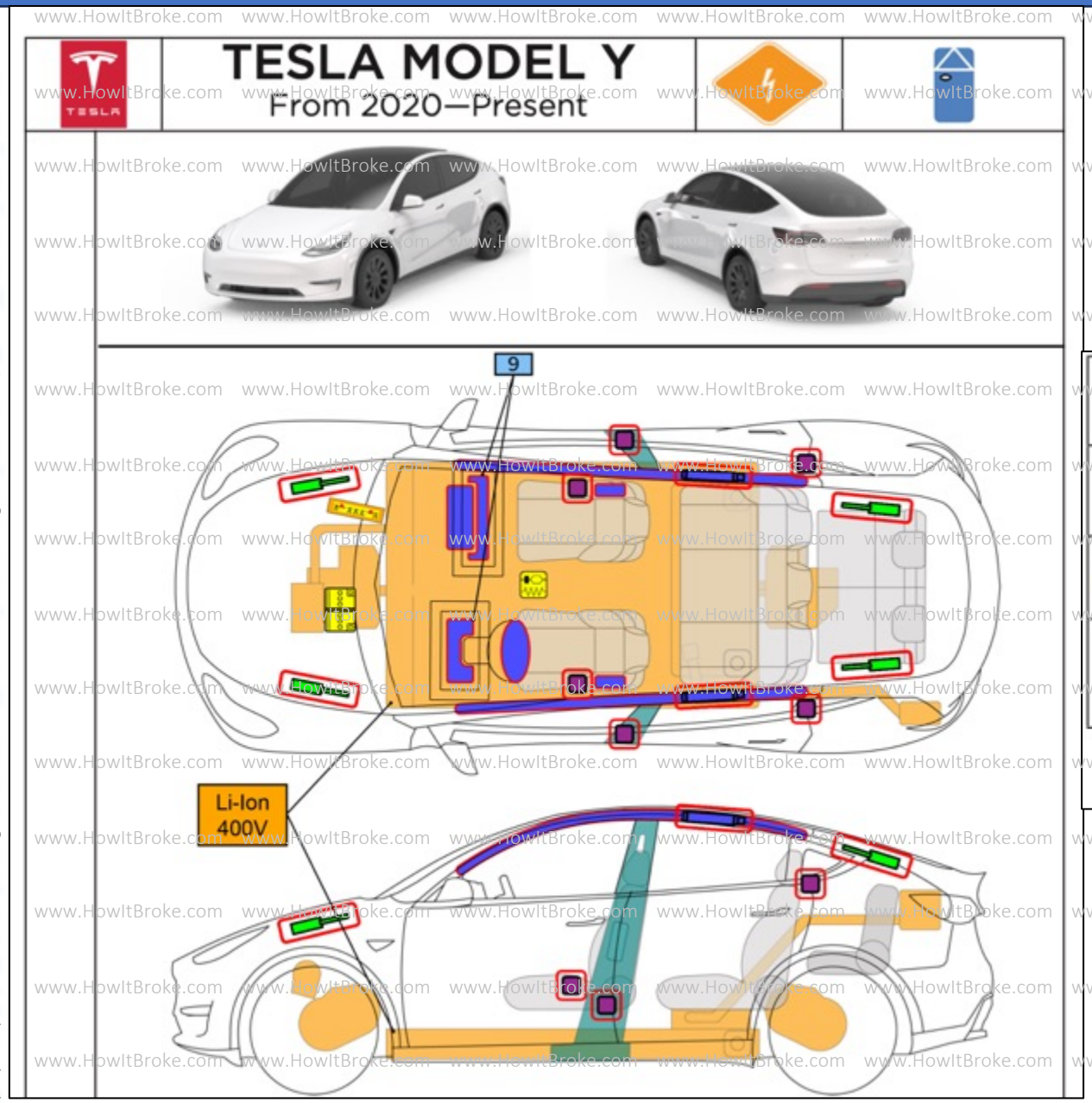
Standardized Info For Procedures

CONTENTS

Standardized Colors & Symbols For Fuels

GREY	DIESEL
RED	GASOLINE
GREEN	GAS
WHITE	CRYOGEN LNG
BLUE	HYDROGEN
ORANGE	HIGH VOLTAGE

ISO-17840 Standardized Graphics, Pictograms, And Colors



	Airbag		Stored gas inflator		Seatbelt preten-sioner		SRS Con-trol Unit		Pedestrian protection active system
	Automatic rollover protection system		Gas strut/ pre-loaded spring		High strength zone		Zone requiring special attention		
	Battery low volt-age		Ultra ca-pacitor, low voltage		Fuel tank		Gas tank		Safety valve
	High voltage battery pack		High volt-age power cable/com-ponent		High voltage discon-nect		Fuse box disabling high voltage system		Ultra capaci-tor, high voltage
	Cable cut								

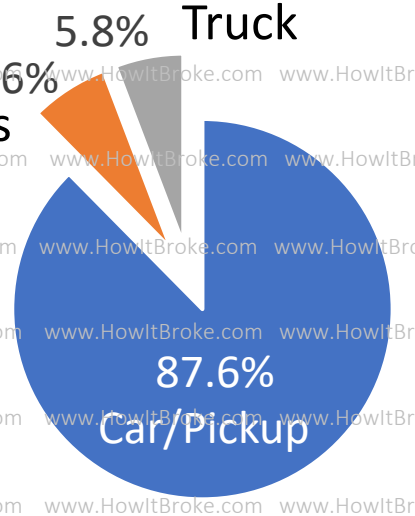
Less Recognized Battery Fire & Explosion Threats

1 in 8 EV Fires Are Commercial Vehicles – Fleet Is Increasing

Trucks and busses

Bigger batteries operating with or near greater numbers of people

Diesel electric hybrid



Volvo modular chassis for tractors, box, refuse

Built in Dublin, VA

= Up to 8 Model 3 Tesla

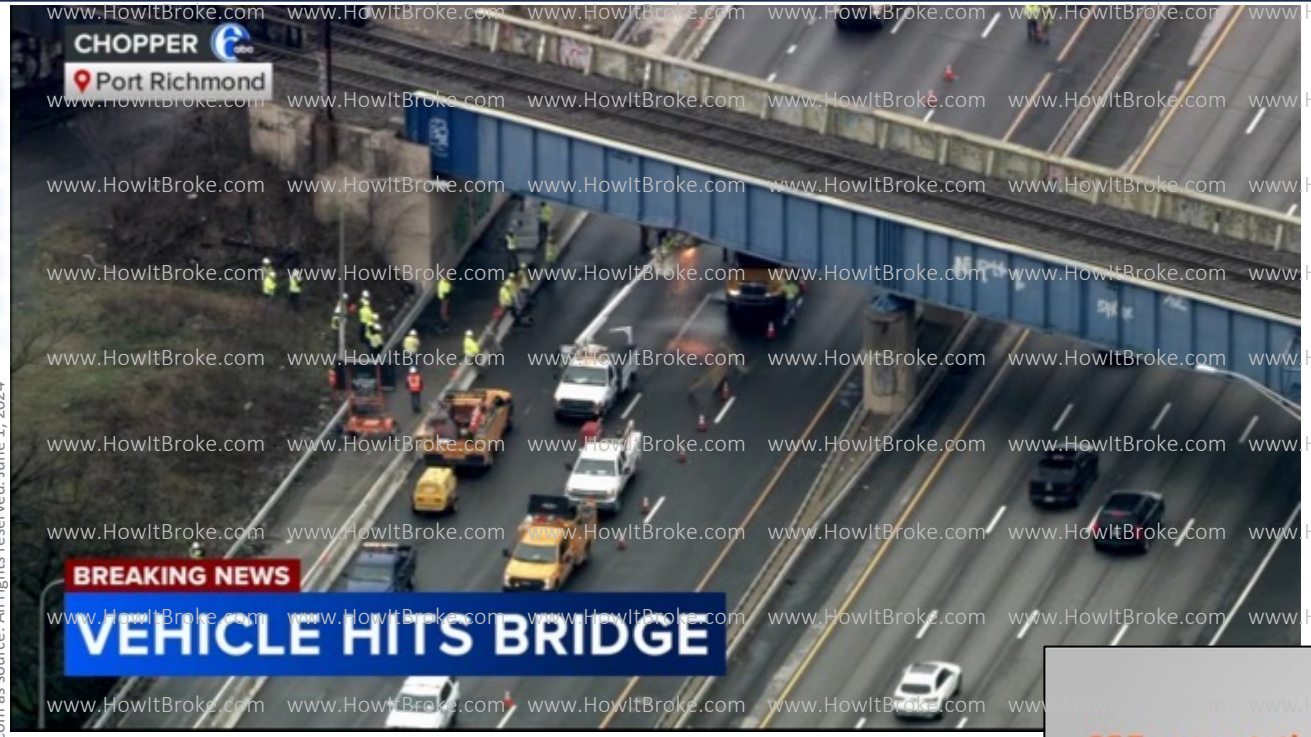
BIG batteries

Kenworth

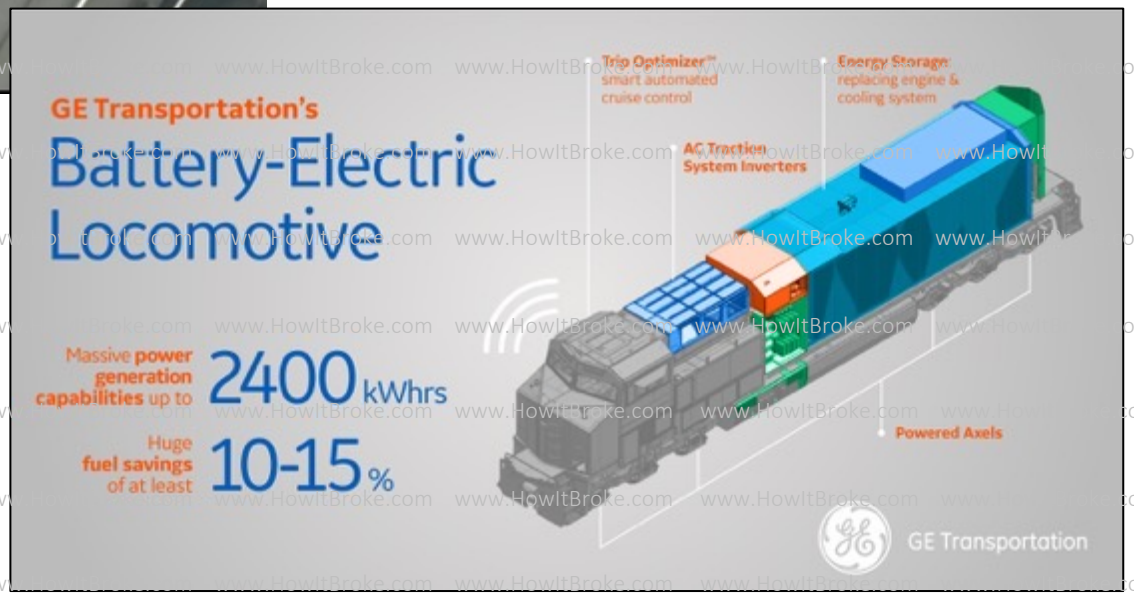
= Up to 6 Model 3 Tesla

HowItBroke.com

Rail Could Interupt I-95



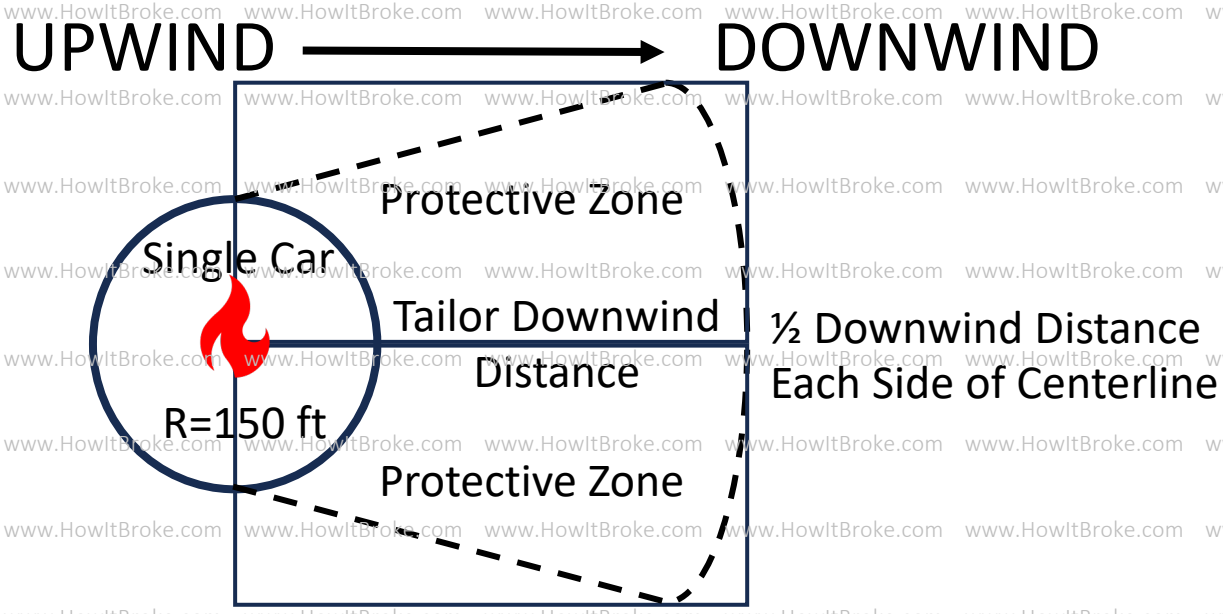
New York Transit Hybrid

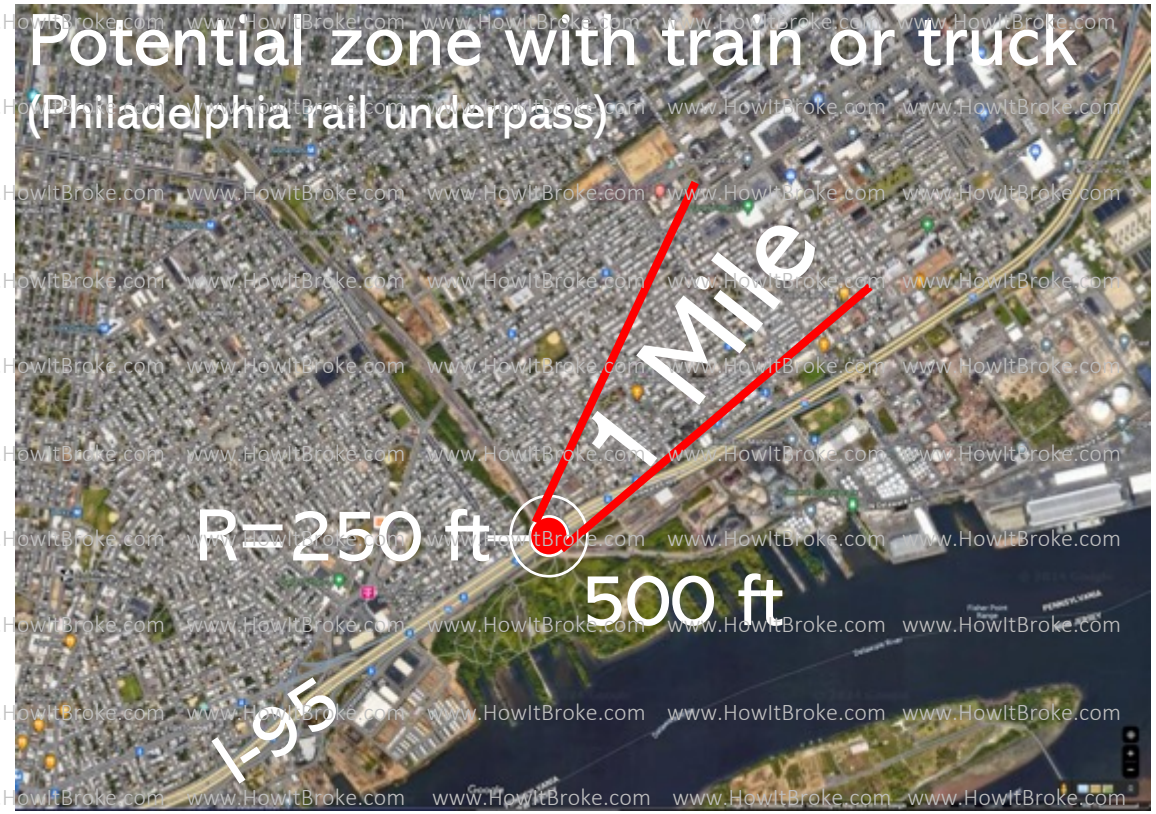


Isolation Zones Must Increase For Rail and Commercial Vehicles

For single car establish 150 ft radius
Alter for wind and other conditions

Increase for commercial and rail vehicles
to the smoke affected area





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Li-Ion Battery Transport Fires/Explosions Now Occur Monthly

Birmingham, AL, 3/31/23

(PHMSA Database)

Livermore, CA, 12/23

Norfolk, VA, July 19, 2023

Columbus, OH, 4/18/24

HowItBroke.com

Recycling Transport Lithium-Ion Fire Losses Occur Daily

Fires Vastly Outnumber Explosions

Trash trucks and collection point fires experience fires daily
California found 65% waste facility fires started by lithium-ion batteries.
Seattle FD responded to 79 lithium-ion fires in the last two years.

Result: In January 2024 Seattle joined others banning **all** batteries in trash.

Ventura, Cal. 9/9/23

Staten Island, NJ. 3/17/22

HowItBroke.com

External Markings Frequently Not Applied To Inform Firefighters

Required Hazard Communication - § 172.102, Special Provision 389 (see Guide 10 diagram for additional details):

- The batteries inside the cargo transport unit are not subject any marking or labeling requirements.
- The cargo transport unit must display the UN ID number (3536) on an orange panel, white square on point, or a Class 9 placard.
- The three options for displaying the UN ID number are displayed in the diagram below.
- The cargo transport unit must be placarded on two opposing sides with the Class 9 placard.
- Transportation by aircraft is forbidden, unless approved by the Associate Administrator.

PACKAGING AND HAZARD COMMUNICATION DIAGRAM

https://www.phmsa.dot.gov/sites/phmsa.dot.gov/files/2021-09/Lithium-Battery-Guide.pdf Guide 10

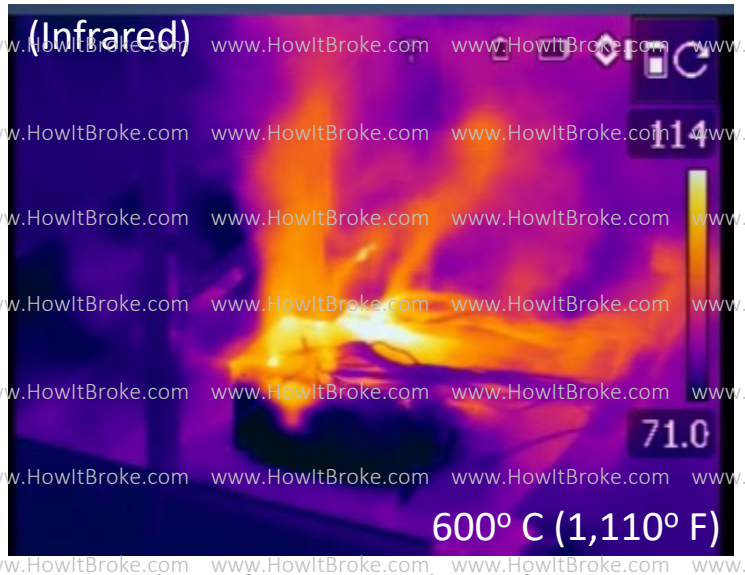
Individual packaging

Fires, Smoke, Flammable Gas

Four Types Of Battery Fire Or Explosion Hazard

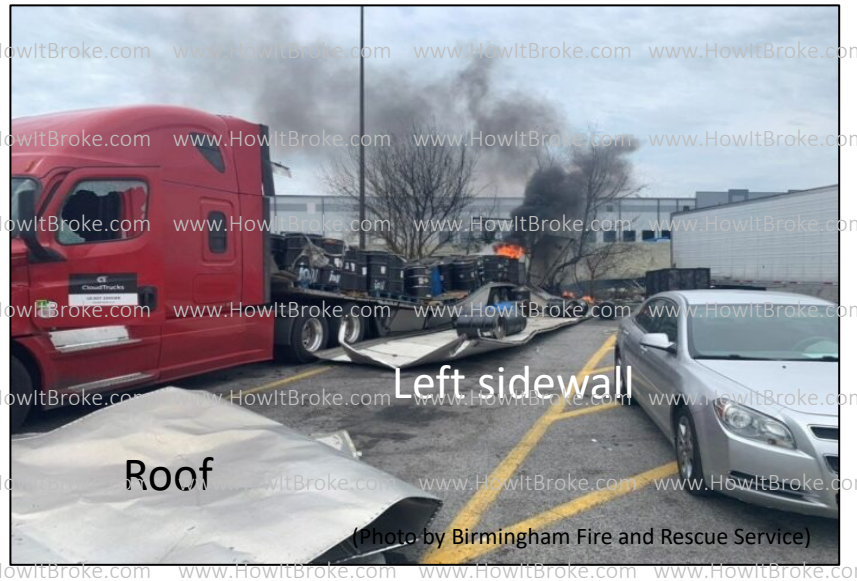
1. Free burning fire. Flammable gas finds igniton source
2. Jet fire. An example would be electric vehicle vents
3. Flash fire. Sub-sonic flame front through flammable gas cloud
4. Vapour cloud explosion. Vented gas in flammable range ignites and develops pressure. May be supersonic flame front or may be pressure build-up in an enclosed space.

Free burning cell phone on hot dashboard



Jetting 787 Battery in NTSB test

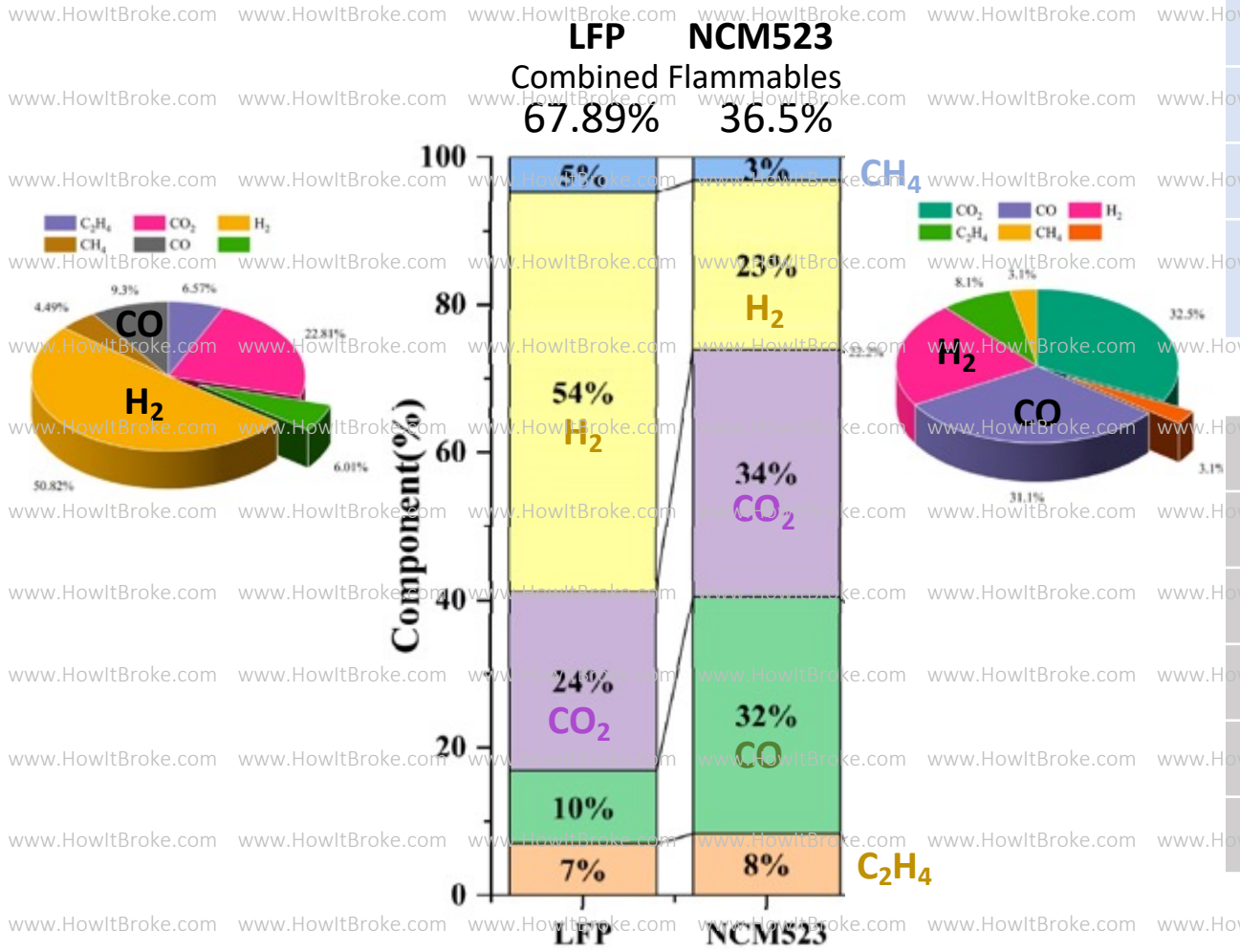
Vapor cloud exploded in parked box trailer



Some Gas/Smoke Constituents Heavier Some Lighter

Combined LiB gas/smoke by battery type and volume

(100% SOC)



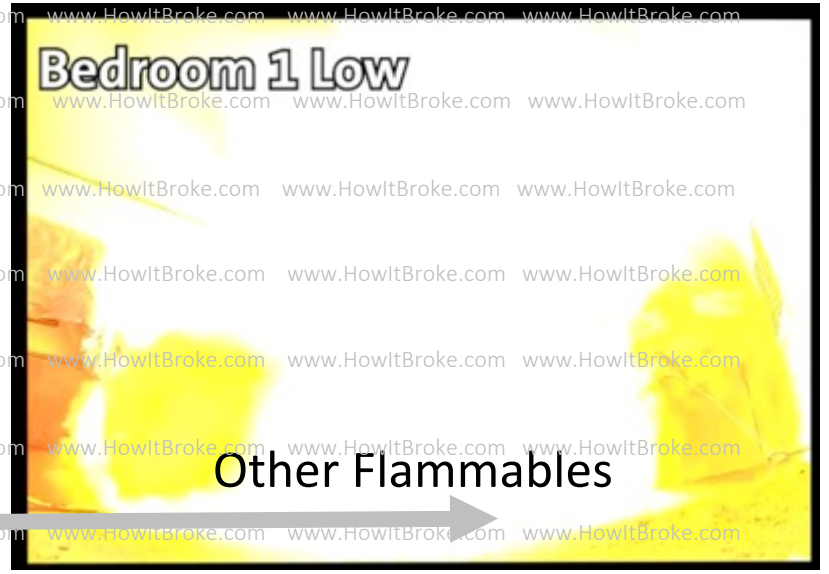
	Gas	Than Air	Flamm
CH_4	Methane	Lighter	5-17%
H_2	Hydrogen	Lighter	4-75%
C_2H_4	Ethylene	Lighter	2.7-36%
C_2H_2	Acetylene ($LiCoO_2$ FAA)	Lighter	2.5-100%
CO	Carbon Monoxide	Diffuses	
C_3H_6	Cyclopropane ($LiCoO_2$ FAA)	Heavier	2-11.1%
C_2H_6	Ethane ($LiCoO_2$ FAA)	Heavier	3-12.4%
C_4H_8	Isobutylene ($LiCoO_2$ FAA)	Heavier	1.8-9.6%
C_3H_8	Propane ($LiCoO_2$ FAA)	Heavier	2.2-9.5%
C_4H_{10}	Butane ($LiCoO_2$ FAA)	Heavier	1.8-8.5%
C6H6	Benzine	Heavier	1.2-8.6%

Source: *Thermal Runaway Characteristics and Gas Composition Analysis of Lithium-Ion Batteries with Different LFP and NCM Cathode Materials under Inert Atmosphere*
https://www.mdpi.com/2079-9292/12/7/1603

HowItBroke.com

Smoke Colors, Flammability, Stratification

UL FSRI Test: Intentional E-Scooter Overcharge in Bedroom



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Explosive Force Is Created In Contained Spaces

14 Ga Steel (0.75")

20 lb Barbecue propane container has explosive force of about 100 kg (220 lbs) of TNT

BBQ Propane Tank, Vancouver, BC

Batteries underway to recycle may fill space with hydrogen gas

Lithium batteries, Houston, TX

Volume of Gas Production In Enclosed Space?

	Size	Gas	
Propane Tank	20 Gallon = 167 ft³	167 ft³	= 220 Lbs TNT
55 Gallon Drum	7.35 ft³ holds up to 8,589 cells (2170)	864 (50% SOC) to 2,729 ft³	= 396 Lbs TNT

Drum

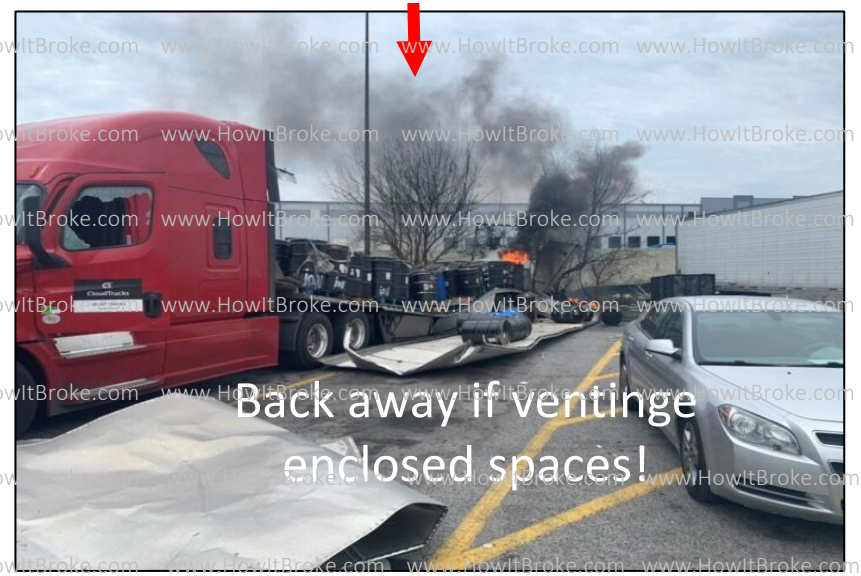
Each cell can generate gas for 45 minutes

27-84% Trailer Volume

One cell

=

Up to 9 Liters at 100% SOC
2.85 L @ 50%



Note: NCM = 3.3 L/ Ah
NMC = 1.2–2.5 L/Ah

https://www.mdpi.com/2313-0105/9/6/300

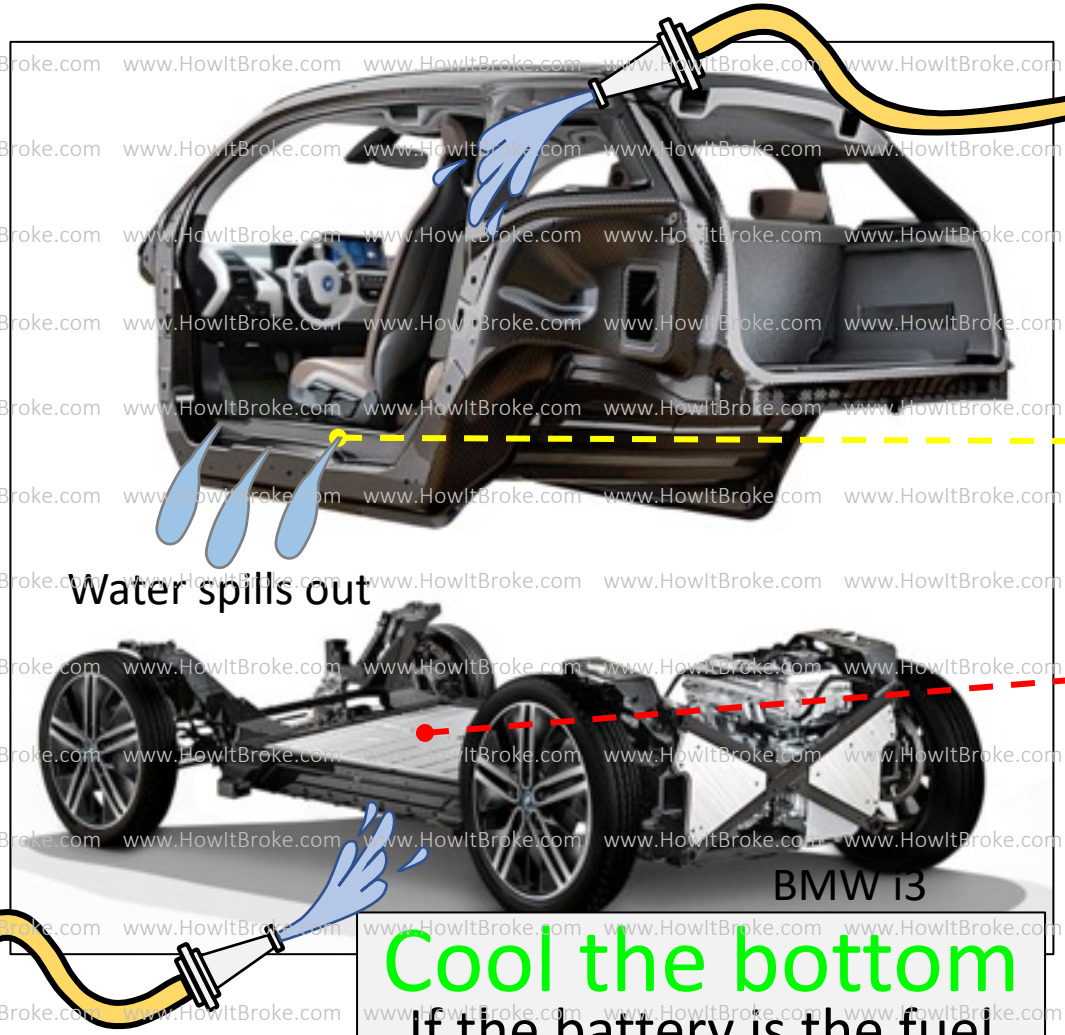
HowItBroke.com

Firefighting and Tools

Water Is Best Resource BUT Plan For 3,000+ Gallons

Water in vehicle cabin typically does not reach cells

The body is like a boat and separated from the sealed battery beneath



This will address the body plastics fire (Class B)

Because water will not reach cells

Layers are between cabin floor and top of sealed battery case

Cool the bottom

If the battery is the fuel

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Tools: Do NOT Puncture Or Damage Battery Case

No vehicle manufacturers endorse tools being marketed to inject water

Submerging The Battery

European city method for fast extinguishment which addresses both battery and plastics

Some ERGs permit this while **Tesla and other makers state not to**, due to hydrogen and re-ignition risk

- Water electrolysis may create flammable gas on surface or after removal, salt water worse than fresh
- No electrical risk

Whether intentional or due to floods - Recover to open area and isolate to dry out

NOTE: Water becomes haz-mat after submerging vehicle

Purpose built

Ad hoc using a dumpster

Tools: Emergency Plugs

Available from multiple manufacturers
Roughly $800+

Consider for EMS calls when integrity of vehicle itself is not in question.

Not for use in fires or when orange HV circuits are exposed.

PRO:
Immobilizes vehicle by going into charging mode

CONS:
1. HV circuits may be energized outside of battery case
2. Does NOT work on all EVs

Source: eDarley

Parking Garages, Commercial

- Beware vapor clouds and potentially flammable smoke
  - Beware entrapment due to smoke or flashover from vehicle to vehicle
- A means to vent smoke is required. Building power may fail due to short circuits.
- Prepare for vehicle to vehicle spread unless countermeasures are taken (blankets, panels, copious water)
- Plan minimum 3,000 gallons water for EV versus 1,000 for ICE
- Overall fire size in heat release is roughly equivalent to ICE, peaking at about 8 MW per vehicle
  - Each flashover results in adding again this amount of heat energy
  - EVs take approximately 6 to 49 minutes to extinguish compared to 5 minutes to extinguish a typical ICE. About 13% of EVs re-ignite.
- ICE tends to have a single peak heat release rate (HRR), followed by a steady reduction as the fuel and combustible components of the vehicle are burnt. EV fires tend to have two peaks: one when the combustible materials in the car ignite; and another when the battery becomes involved in the fire.
- **Loadbearing elements of the structure may have fire resistance periods of only 15 minutes**, increased to 30 minutes where those elements were designed to protect means of escape.
  - Chains may be used to drag out vehicle or create fire breaks

Ref: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1168956/covered-car-parks-fire-safety-guidance-for-electric-vehicles.pdf
Ref: NFPA 88A Standard for Parking Structures
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1168956/covered-car-parks-fire-safety-guidance-for-electric-vehicles.pdf

Tools: Car fire blankets are tools for specific tasks

PROS:

May use to isolate vehicles in enclosed spaces or next to other vehicles

Can contain or be used to redirect flames

May smother burning plastic and other materials to reduce temps

CONS:

For smoldering cases a blanket can trap hydrogen to create explosive environment beneath

Does not halt an EV battery fire

HowItBroke.com

Source: Bridgehill

Charger Hazards:

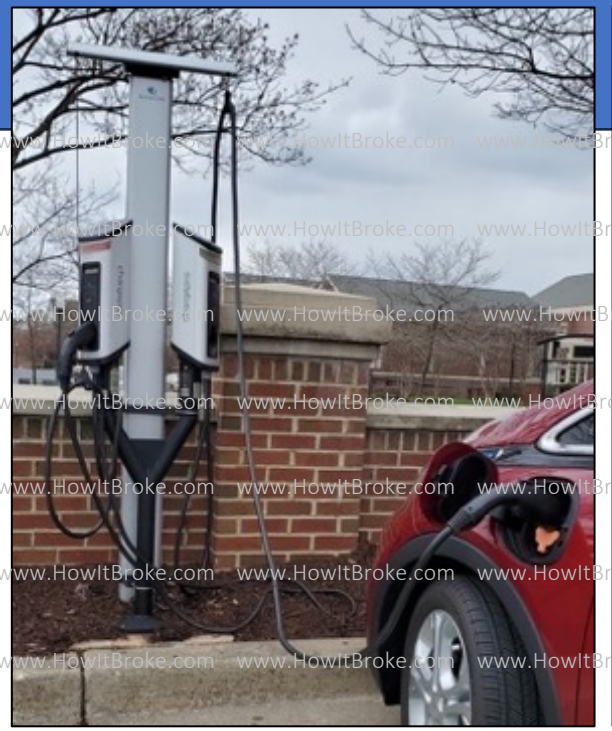
No protective vehicle barrier for many

HV source enters base, below contactors

Housing can energize – HV SHOCK HAZARD

No visible emergency "panic buttons"

Must find power source and shut it off



Use "Hot Stick" voltage detector

HowItBroke.com

Tunnels – Need Both Plans and Tests

The "fuel" will not burn off as fast as petroleum fuels

The smoke will be both toxic and flammable

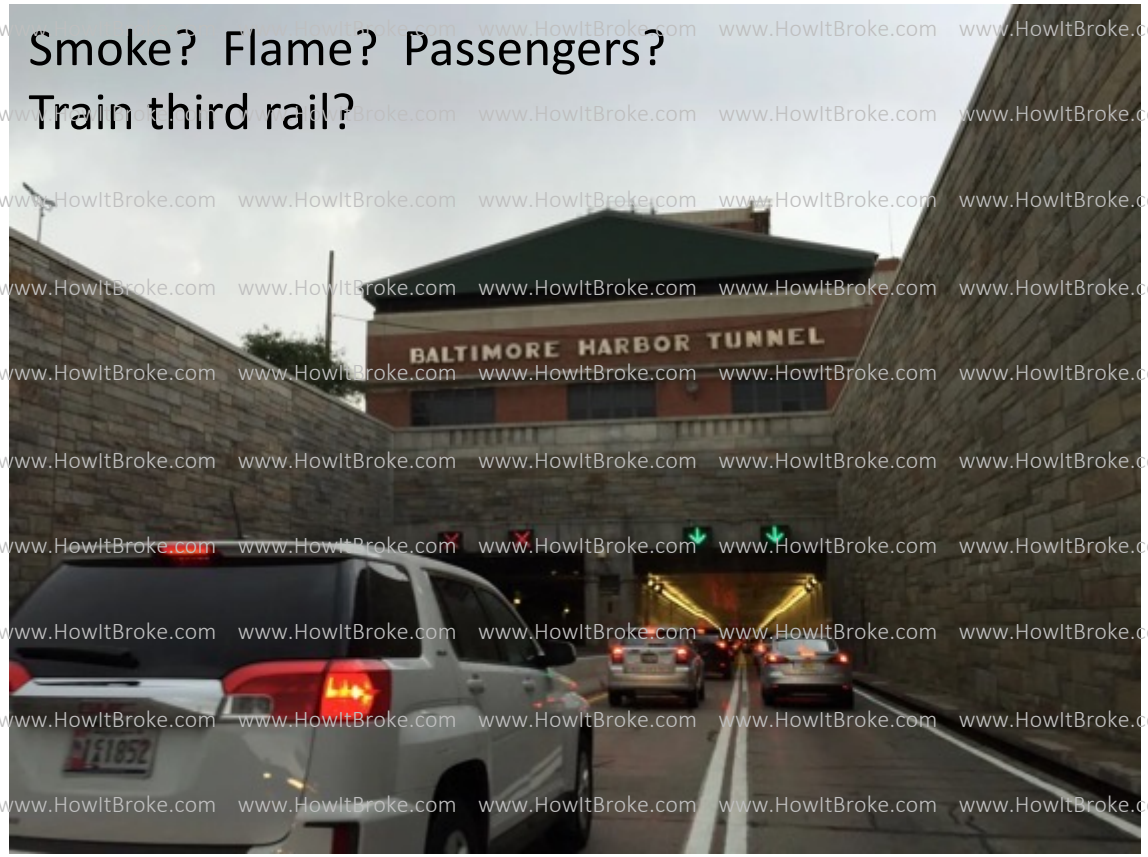


Table 16. Observations made during the tests with regard to the fuel tank and batteries.

ICEV A		BEV A		BEV B	
5:00	External fire ignition	5:00	External fire ignition	5:00	External fire ignition
9:44	Fuel tank rupture	24-27	Continuous and intense gas release from underneath	27-32:30	Battery venting and popping (most intense)
16-18	Diesel pool fire almost gone	30:30	Gas release from underneath almost gone	44-47	Gas release from underneath almost gone

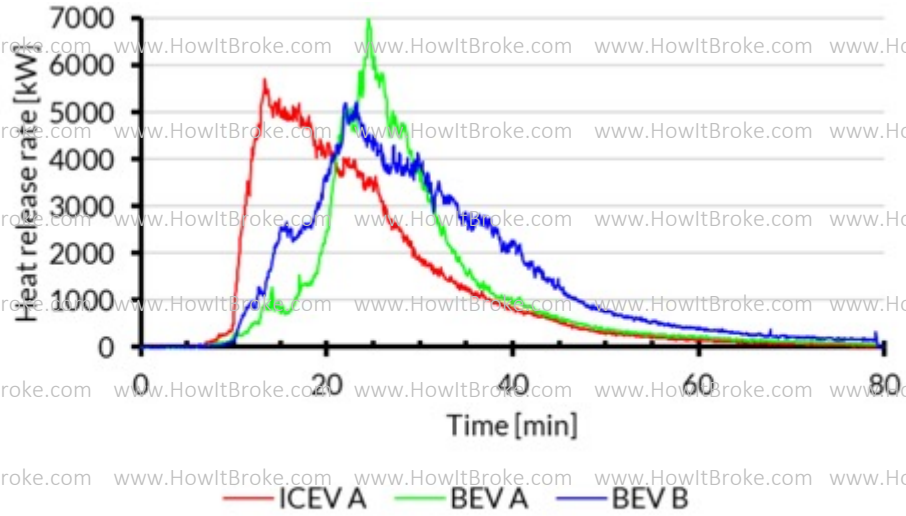


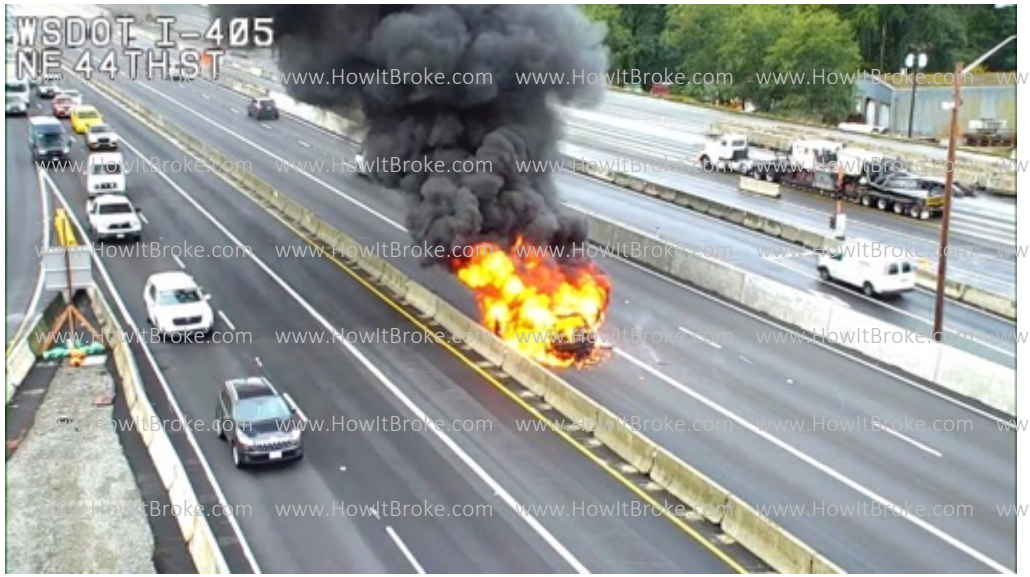
Figure 11. Heat release rate (oxygen consumption calorimetry) for the three vehicles.

Differences in ICE/EV Smoke Hazard

Toxic AND Flammable

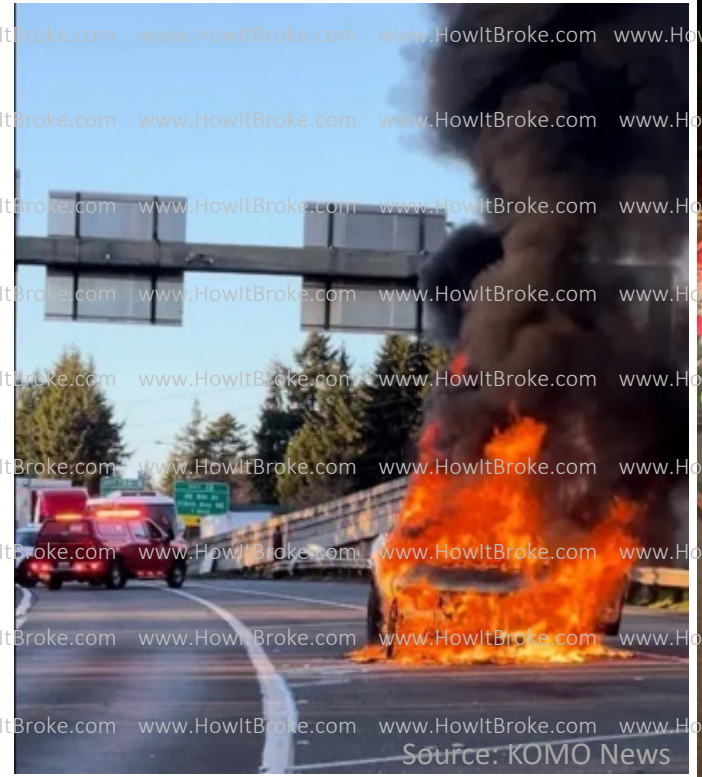
Two Fires On I-495 near Seattle

ICE fire, 10/3/2023

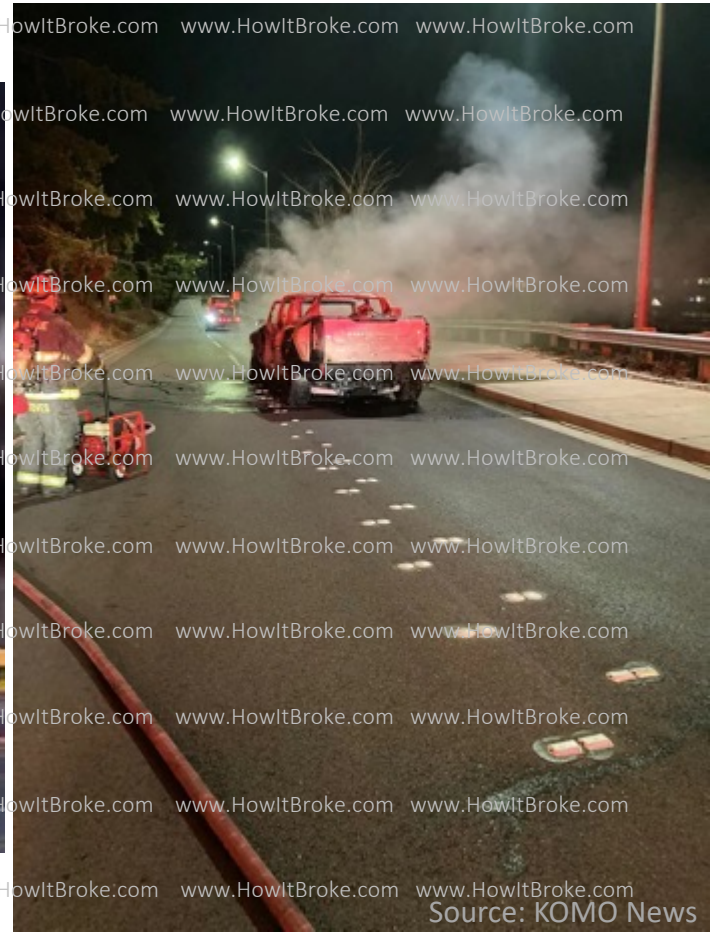


13% of EVs reignite

EV Hummer fire, 2/22/2024
Caused during hit and run



Reignited 3 times



HowItBroke.com

ICE and EV Gases Similar In Burn Tests

Table 4: Gaseous emissions data, ratio of produced mass to the total produced mass of those gases.

Relative emission [% of total]	Car 1	Car 2	Car 3
Acid gases			
Hydrogen chloride (HCl)	0.38%	0.29%	0.33%
Hydrogen fluoride (HF)	0.12%	0.11%	0.07%
Hydrogen cyanide (HCN)	0.03%	0.02%	0.05%
Carbon and nitrogen oxides			
Carbon dioxide (CO_2)	96.54%	96.95%	97.33%
Carbon monoxide (CO)	2.29%	2.11%	1.94%
Nitrogen oxide (NO)	0.13%	0.1%	0.15%
Nitrogen dioxide (NO_2)	0.06%	0.06%	
Sulfur dioxide (SO_2)	-	-	0.13%
Hydrocarbons			
Total hydrocarbons	0.45%	0.37%	-

ICE and EV both are now up to 40% plastic

HF is a strong inorganic acid found in smoke for Li-ion battery fires at levels approaching 600 ppm.

The immediately dangerous to life and health (IDLH) concentration for hydrogen fluoride is 30 ppm.

Table 18. Gas compounds measured from the exhaust duct.

Gas measurements	ICEV A	BEV A	BEV B
CO_2, [kg] / [g/lost g]	344 / (1.4)	335 / (1.4)	438 / (1.1)
CO, [g] / [mg/lost g]	6 420 / (25.5)	7 790 / (31.5)	9 510 / (23.8)
THC, [g] / [mg/lost g]	2 370 / (9.4)	3 130 / (12.7)	2750 / (6.9)
HF, [g] / [mg/lost g]	11 / (0.04)	573 / (2.3)	859 / (2.1)
HCl, [g] / [mg/lost g]	1100 / (4.4)	1590 / (6.4)	1800 / (4.5)
HBr, [g] / [mg/lost g]	18 / (0.1)	115 / (0.5)	88 / (0.2)
HCN, [g] / [mg/lost g]	-	-	155 / (0.4)
SO_2, [g] / [mg/lost g]	479 / (1.9)	575 / (2.3)	645 / (1.6)
NO, [g] / [mg/lost g]	452 / (1.8)	371 / (1.5)	617 / (1.5)
NO_2, [g] / [mg/lost g]	44 / (0.2)	25 / (0.1)	76 / (0.2)
PAH, [g] / [mg/lost g]	112 / (0.4)	29 / (0.1)	334 / (0.8)

https://ineris.hal.science/ineris-01853334/document

Heavy Metal Hazards in EV Smoke Embed in Soft Tissues

Conductive lithium Ions and metals make smoke conductive

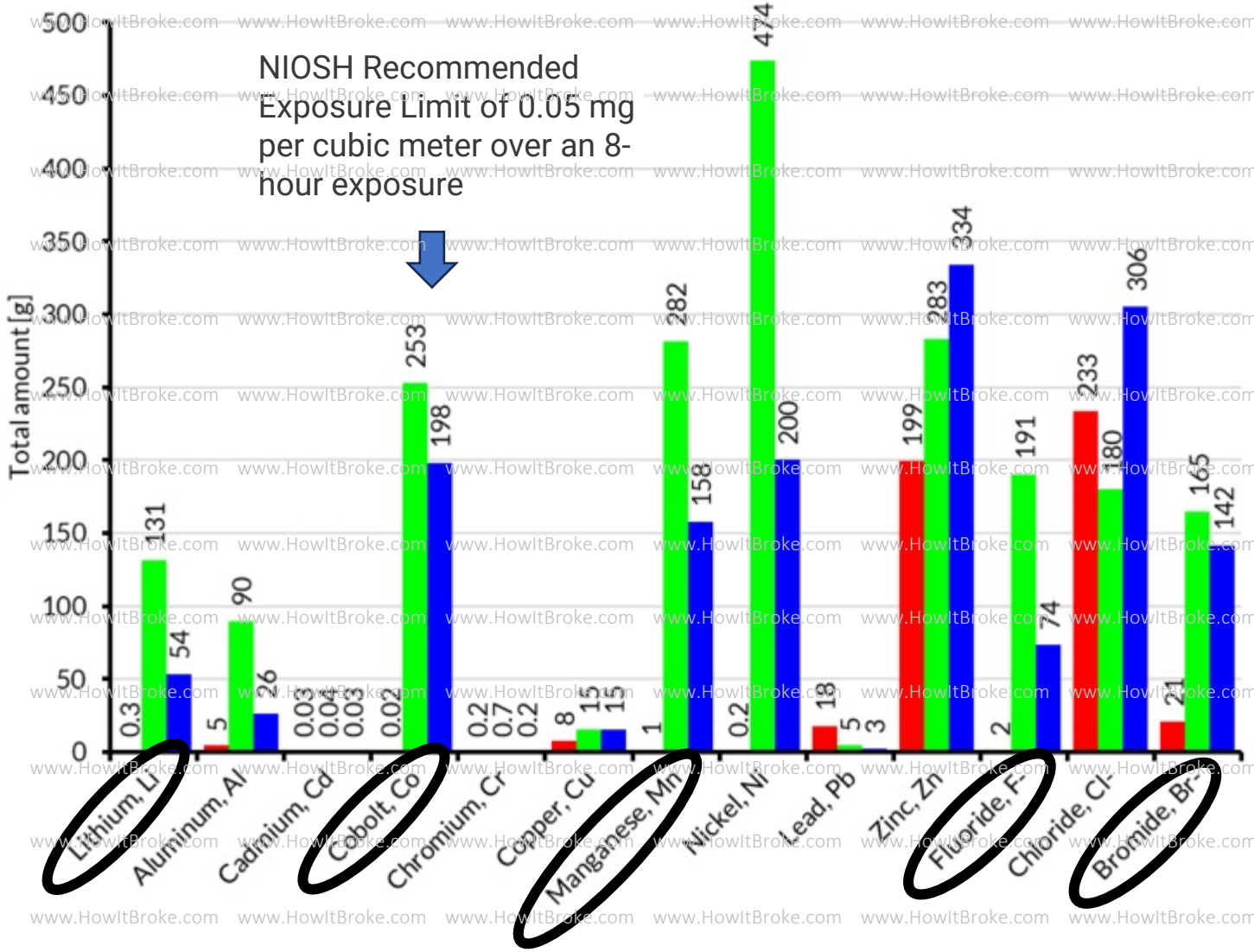


Figure 13. Total amounts of metals and anions on soot particles.

Table 19. Soot particles and substances on these particles measured from the exhaust duct, and ash analysis from the burnt vehicles. Results expressed as weight of substances per total weight of particles.

Soot		ICEV A	BEV A	BEV B
Particles	Dry, [kg]	9.0	10.7	17.0
Metals	Lithium, [mg/g]	0.03	12	3.2
	Aluminum, [mg/g]	0.5	8.5	1.5
	Cadmium, [mg/g]	0.003	0.004	0.002
	Cobalt, [mg/g]	0.003	24	12
	Chromium, [mg/g]	0.03	0.07	0.01
	Copper, [mg/g]	0.9	1.4	0.9
	Manganese, [mg/g]	0.1	26	9.3
	Nickel, [mg/g]	0.03	45	12
	Lead, [mg/g]	2.0	0.4	0.2
	Zinc, [mg/g]	22	27	20
Anions	Fluoride, [mg/g]	0.2	18	4.3
	Chloride, [mg/g]	26	17	18
	Bromide, [mg/g]	2.3	16	8.3
Organic compounds	PAH, [mg/g]	1.0	0.03	0.5
Ash		**ICEV A**	**BEV A**	**BEV B**
Anions	Fluoride, [mg/g]	0.02	0.2	0.1
	Chloride, [mg/g]	31	62	16
	Bromide, [mg/g]	0.4	0.07	0.5

NFPA 1971 technical committee is currently considering an Restricted substnaces List of chemicals and specific levels for those chemicals

http://ri.diva-portal.org/smash/get/diva2:1522149/FULLTEXT01.pdf

HowItBroke.com

Initial Battery Smoke Content (Think plastic fire with nasty additives)

Some variation with constituent materials

NTSB spectrum analysis by UL of release from burning batteries found:

Carbon Monoxide
Carbon dioxide
} Can not breath

Hydrogen (up to 36%)
Methane
Ethylene
Acetylene
} Can ignite

H_2O

Dimethyl carbonate
Ethylmethyl carbonate
Eye & lung irritating acids
} Hazardous Materials

SCBA MANDATORY

COVER ALL SKIN

PROTECT BYSTANDERS

Soot may contain cobalt oxide, nickel oxide, manganese oxide, and other heavy metal skin irritants

Source: https://www.ntsb.gov/investigations/AccidentReports/Documents/NTSB_Battery_Tests_Report_Nail_Penetration_15C_Grounded%20(29May14)_Redacted.pdf

Cleaning Gear (NFPA 1851) Is A Major Challenge

Prevention is best - Try to remain upwind

Heavy contaminants bond to fibers

Inorganic acids attack materials

(example: Hydrogen Flouride becomes hydroflouric acid)

EPA/UCLA Testing not yet published. Found antimony, lead, etc

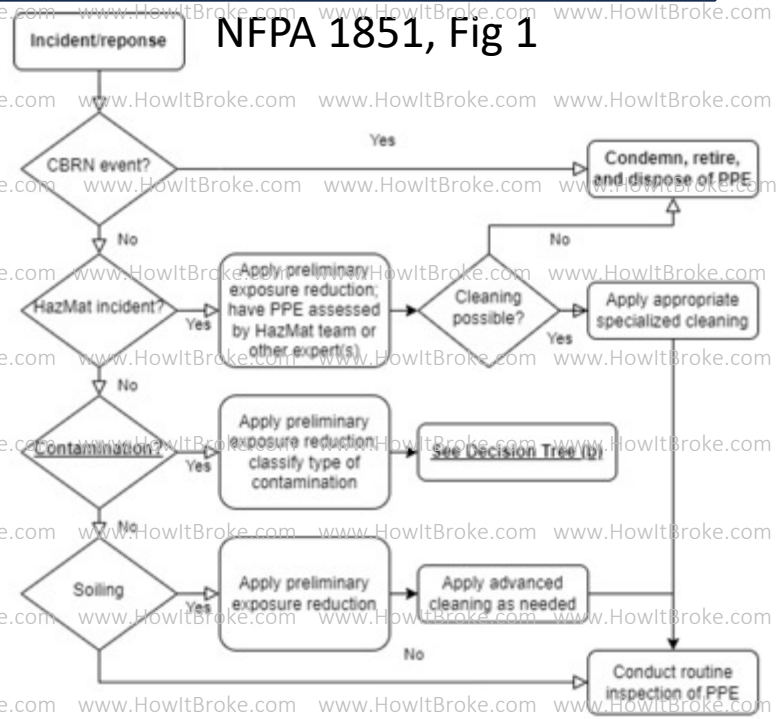
There is not a good or tested method for cleaning PPE and gear

Typical extraction and wash methods do not remove heavy contaminants

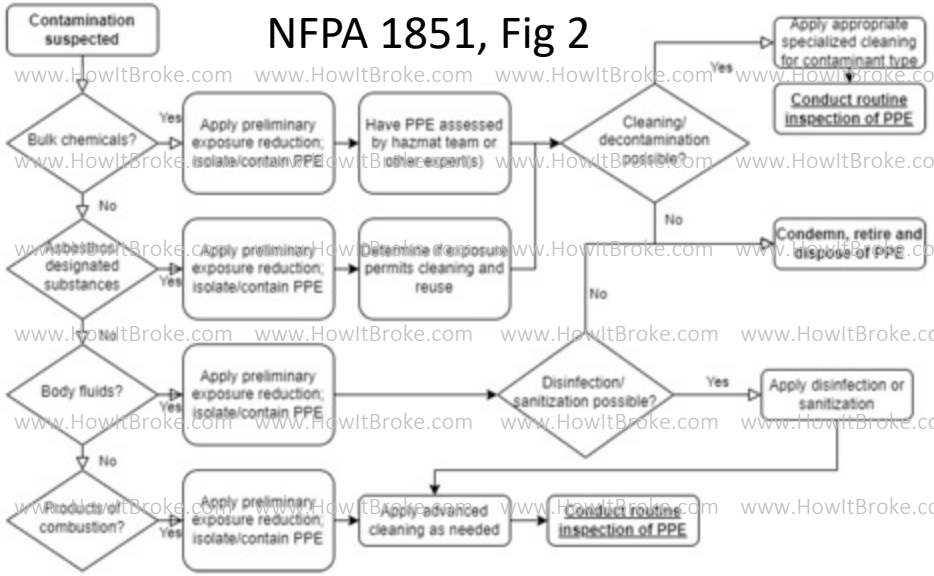
LCO2 is currently best method per testing at SWRA with TEEX (Texas A&M)

Test results to be published July 2024

NFPA 1851, Fig 1



NFPA 1851, Fig 2



Ref for more info: https://www.mdpi.com/1660-4601/19/19/12442

HowItBroke.com

Resources

NFPA www.EVSafetyTraining.org

Training developed with manufacturers, agencies, and organizations

Extensive resources

Online info, classes online & in person, field emergency guide

Energy Security Agency 855-ESA-SAFE (855-372-7233)

24/7 Call center while working on site (no charge), online info, classes on-site

Emergency Response Guides (Free on pc, phone, or tablet) www.autorescueapp.com

UL FSRI www.ulfirefightersafety.org

Firefighter Safety Research Institute

Firefighter research and training is online and free

RAIL www.askrail.us

Lists contacts and cargo in each rail car

Australian Government EV data and training resource website www.EVFireSafe.com

Battery recycling with instructions https://www.call2recycle.org

SAE J2990

Hybrid and EV First and Second Responder Recommended Practices