Hello WA Hazmat Symposium - This handout contains some good stuff on Li-ion batteries as well as white papers for our discussion about toxicity to include the metal problem that is rarely discussed. I briefly covered a few of these in the presentation (briefly), but this format will allow you to look for yourself. Do your own searches and you will find many more. As stated, I have far more questions than answers!

I cannot vouch for all of the content so if something is wrong, please let me know. I believe the other presentations also had some valuable links and resources such as UL FSRI, RISE, NFPA, etc, that I encourage you to look at as well.

If you want to dive deeper into the white papers and various lectures they are here (and there are many more). Usually, the abstracts or conclusions are enough to get the relevance without diving too deep in the weeds, but don't take my word for this – look at it yourself. Control click the link and you are off and running.

Most importantly, please be safe and keep those around you safe!

Again, full disclosure, I am not a toxicologist, doctor, engineer, or industrial hygienist. I am a fire and explosion investigator on the tail end of a 30 year career in law enforcement. I also have a keen interest in this subject born out of my shock when we conducted our own testing when my original interest was how can I tell if a battery caused the fire or was a fire victim.

My opinions are mine and not those of my employer.

My understanding is that the immediate toxic by-products produced during a Li-ion battery (LIB) fire will depend slightly on which of the 6 main LIB chemistries is involved. Suppression water, SOC (state of charge), size of the battery system, type of batteries, geometry of the batteries within the pack, the type of containment, confined space, etc., can all impact what is produced during either venting or combustion. These things will also influence the subsequent fire behavior and the potential for a rekindle if suppression is successful.

The gases produced, both asphyxiants and irritants, are nasty, but many of these appear to dissipate quickly so the threat posed by them is more immediate to the incident so staying out of the plume, direct smoke, and remaining upwind while wearing good PPE and protecting our respiratory system should provide good protection. I know this is not always possible so if you are exposed like this please be mindful of gear contamination, consider writing an exposure report, and also consider getting blood testing from your health department or provider.

This brings us to the metals and my concerns. Keep in mind that the same recommendations to prevent hazardous exposures apply to this threat. The metals will be more persistent as particulates and may pose the larger threat in or on the burned appliance, at the fire seat, and downwind of the fire seat in the event of a fire. Remember that some of these particles can be quite small. Nanoparticles or particles less than 10 micrometers are more easily absorbed, ingested, breathed, or possibly ionized (highly reactive). Here are a few papers if you wish to look and I have included excerpts and highlighted relevant portions.

As stated, there is much we do not know about exposures or contamination of our PPE or to the scene but the amounts observed in the few published studies far exceed permissible limits. As we scale up the size of the battery system (best measured in kWh), it is reasonable to believe the threat scales up as well. I am not as concerned about smaller batteries unless you are in a confined space, vape (direct exposure), or you encounter a fire with dozens of them (add up the kWh) but caution is always our friend.

Due to the expense of testing, we are currently left with "theoretical yields" or suspicion of the same for large systems, but we are following our hazmat training to recognize this threat!

There is some research on the toxicity of cobalt dusts but very little research into how these materials behave at temperatures as high as 4000 degrees F (according to some but usually 2k or better) or in the presence of other volatile compounds such as the solvent chemistries. Manufacturers are just trying to design a better battery and not much thought is given to possible toxic combustion by-products and their impact on human health because they are designed to store energy, not for combustion. The industry is very focused on energy density and economics so don't assume they have looked at this subject comprehensively or that they would publish the information.

*side note – if these links do not open or give you access to the full paper copy the title and look it up on google, you should be able to access the full copy if all you get is a summary or excerpts – some sites charge and others do not but you can usually find it and I have access to some you may not. There are many dozens of published (peer-reviewed) white papers on this subject as you will see if you simply google lithium-ion battery toxicity, etc.

Experimental determination of metals generated during the thermal failure of lithium ion batteries - Energy Advances (RSC Publishing) DOI:10.1039/D2YA00279E

Here are excerpts from this study published in January 2023 that directly reference metal particulates as toxins produced in these fires:

"Metal residues must also be considered as a source of exposure following a battery release; potential routes of exposure could occur through both dermal uptake and any inhalation or ingestion of metals as a result of direct or indirect transfers."

"Each metal determined in this study has its own associated hazard. Nickel and cobalt are known sensitisers, both are known to cause respiratory issues including 'asthma like' allergic reactions. In addition, nickel and nickel compounds are classified Group 1 carcinogens as defined by IARC and nickel can cause skin irritation and allergic dermatitis at sometimes low concentrations.[32]

Elevated exposure to cobalt can affect heart, thyroid, liver, and kidneys. Repeated exposure to cobalt dust can cause scarring of the lungs (fibrosis) even if no symptoms are noticed.

Aluminium compounds have been linked to asthma, obstructive pulmonary disease, and heart disease, however it is better known for causing adverse neurological effects.[33]

With manganese compounds the central nervous system is the primary target of manganese toxicity, specifically causing detrimental neurological effects, since inhaled manganese is often transported directly to the brain before it is metabolised by the liver.

"The methods of analysis used here do not allow the comprehensive determination of the metal containing compounds/species; this is the subject of further work. However, it is not unreasonable to expect metal oxides to be formed from a combustion event, and some of the oxides of cobalt, manganese and in particular nickel are known to be hazardous to human health. The health impact of such an exposure depends not only on the species present, but also to the bioavailability of the compounds, influenced by solubility and, for inhaled absorption, particle size. Certainly, initial effects from exposure to the aforementioned metal oxides would present as skin and inhalation irritations. More long-term health effects can include cancer and neurological issues."

*some of these metals if inhaled can stay in your lungs for months or even years according to some toxicologists and papers (again, doublecheck anything I say if you question it), but we don't seem to have good answers on this or any understanding of potential bio-accumulation from multiple exposures.

Here is another paper from 2020 that specifically looks at LiFePO4 (LFP) or lithium iron phosphate with excerpts (the current favorite chemistry for larger systems such as EV's or ESS). Sadly, I don't think we are far ahead in our understanding than we were in 2020 when this was published and it does NOT focus on the metal particulates -

A comprehensive investigation on the thermal and toxic hazards of large format lithium-ion batteries with LiFePO4 cathode - ScienceDirect

"Toxic gases released from lithium-ion battery (LIB) fires pose a very large threat to human health, yet they are poorly studied, and the knowledge of LIB fire toxicity is limited…

"The major toxic gases detected from the online analysis are CO, HF, SO_2, NO_2, NO and HCl."

"Results show that the effects of irritant gases are much more significant than those of asphyxiant gases. HF and SO_2 have much greater toxicity than the other fire gases. The maximum FEC value is approaching the critical threshold in such fire scenarios."

"Until now, few studies have been done on evaluating the fire effluents of LIB and the knowledge of their toxicity is very limited. "

*Fractional Effective Dose (FEC) is basically the dose at which really bad stuff happens to human beings – see this link for further understanding: 130_A2016_FKT-AAA_CIReport.pdf (nfpa.org) – i.e. - we use this for fatal fires for CO or HCN when we get victim bloodwork back.

*Here is a 2017 paper on toxicity specifically looking at Cobalt – as we discussed cobalt is a key ingredient in the most popular battery chemistry NMC (nickel manganese cobalt) and two other

primary chemistries nickel cobalt aluminum (NCA) and lithium cobalt oxide (LCO) with excerpts. I don't mean to pick on cobalt because nickel, manganese, titanium, iron, aluminum, and the rest also have toxicological profiles. Again, OSHA/NIOSH and the Euros generally reference permissible limits of these metals for "dusts" and those are much larger particles than you will find in batteries. Again, the smaller the particle the more toxic it is to humans (more easily absorbed).

Cobalt toxicity in humans Leyssens et al Toxicology 2017.pdf (imperial.ac.uk)

"Although cobalt has a biologically necessary role as metal constituent of vitamin B12, excessive exposure has been shown to induce various adverse health effects."

"The systemic health effects are characterized by a complex clinical syndrome, mainly including neurological (e.g. hearing and visual impairment), cardiovascular and endocrine deficits.

"toxic reactions at lower doses have been described in several cases of malfunctioning MoM hip implants, which may be explained by certain underlying pathologies that increase the individual susceptibility for Co-induced systemic toxicity. This may be associated with a decrease in Co bound to serum proteins and an increase in free ionic Co^{2+}. As the latter is believed to be the primary toxic form, monitoring of the free fraction of Co^{2+} might be advisable for future risk assessment.

*MoM refers to metal on metal joint replacements – a source of lots of class action lawsuits right now for adverse outcomes. I included a link at the end for a Ted Talk by Dr. Tower talking about his experience with a cobalt hip. It is very interesting, but keep in mind his exposure (and others) was very direct.

*a few notes here about this 56 pages of text – it is NOT specifically looking at lithium-ion batteries, only other exposures to "cobalt". The last quoted excerpt above is the scariest because these are LITHIUM-ION batteries so would it not be possible that we might have ionized cobalt emitted from the battery during venting (pre-fire) and combustion? I don't know, but it should be studied further and remember as we discussed an EV battery may contain 5, 10, 15, or more kg of cobalt along with other ingredients that have toxicological concerns such as nickel, manganese, aluminum, copper, iron, etc. There can be over 150kg of metals in the larger batteries for EV's and we now have ESS that are the equivalent of 40 EV batteries inside one vented Conex style box with buses or other appliances such as heavy equipment that will equal 5 or more large EV batteries. It is not common and best practice to evacuate downwind for these larger incidents.

***I will repeat this again, keep in mind that most of the toxicology studies are for dusts in a manufacturing setting and not ionized particles (possibly) or nanoparticles that may be encountered in a fire or present afterwards so it is reasonable to assume that metal particulates from a battery fire will be worse than metal dusts in an industrial setting.**

*Here is another paper from 2022 that looked at "contamination" post-fire. It is relevant although it's not directly applicable to contamination of humans specifically as that was not the goal of the research. This corroborates my assertion and fear that the dusts or soot (post-fire and

during the fire) are something to be concerned about. I disagree with their assertion that an ICE and EV vehicle burn at the same temperatures, but that is an argument that continues (most researchers believe it burns hotter).

*On a good note, it looks like the auto industry is beginning to engineer better separation and insulation between modules within a pack to minimize rapid fire progression with some good effect so this might reduce previously observed temperatures and rapid/violent fires.

The key take-away for me from this paper as I presented is:

Thermal runaway and fire of electric vehicle lithium-ion battery and contamination of infrastructure facility - ScienceDirect

"The results of experiment 3 indicate that with active ventilation, soot is transported over long distances and is deposited on surfaces. The amounts of soot found were much lower e.g. about 0.5 g/m^2 at 100 m distance compared to 17–20 g/m^2 in the enclosed space of experiment However, the quantities of the heavy metals nickel, cobalt and manganese as well as lithium are still high, which is why professional decontamination is also required here."

"3.1.1. Contamination of infrastructure and textiles (*PPE or turn-outs?*)

"Inorganic pollutants which are toxicological and corrosion chemical relevance were present in the form of large amounts of the elements Co, Ni and Mn, each amounting to approximately 150–400 μg/cm^2, and of the element Li amounting to around 30–70 μg/cm^2 , see Table 5. Water-soluble fluorides in amounts of 40–52 μg/cm^2 were detected on the collector plates and textile, see Table 6. Therefore, the usual background levels for non-contaminated surfaces are exceeded by factors up to approximately 2000–4000 (Co, Ni), 500–700 (Mn), 400–700 (Li) and 50 (fluorides).

"Conclusion Using the scalable experimental design, a contamination with soot in the range of 20 g/m2 can be expected when a lithium-ion battery of 32 kWh capacity burns down in an enclosed parking space for 30 cars. Thermal runaway and fire of a battery of type NMC 111 produced soot consisting mainly of heavy metal-oxides of nickel, manganese and cobalt (each 18–20% by mass) as well as, to a lesser extent, of lithium (3–4% by mass), fluorides (appr. 2.5% by mass) and chlorides (appr. 0.2% by mass)."

*30 car garage? What about a two-car garage? We don't know, but these are very high numbers for permissible exposure limits or PEL as we discussed. I will include some SDS sheets if you want to look at them below or look up your own. They don't always tell you what the exact chemistry of the battery is (proprietary special sauce).

Remember, combustion of LIB's may also cause other compounds to be formed so don't assume these are high school chemistry class questions that follow typical oxidation-reduction formulas. Again, we really don't know enough about this stuff or the long-term health consequences of exposures or contamination.

Firefighters PPE contamination PV (solar) and EV - https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9566750/

It also contains test results showing that firefighters' clothes accumulate harmful substances after fighting these types of fires. Pilot tests for the presence of polycyclic aromatic hydrocarbons (PAHs) and formaldehyde showed that levels exceeded limits in all clothing samples. For example, the cobalt level was 24 times higher than that considered safe in the test carried out with car battery fire. Although it is recognized that liquid carbon dioxide (LCO_2) methods of cleaning may be more effective than traditional water washing, further research on cleaning efficiency for clothing containing substances emitted from car battery and PV modules fires is required.

Here is an old but decent representation of the "content" of a 60kWh EV battery pack (NMC chemistry) but keep in mind that the amounts of materials vary. Tesla is trying to get away from cobalt and it may contain very little but other manufacturers use more cobalt.

Visualizing an EV battery https://elements.visualcapitalist.com/the-key-minerals-in-an-ev-battery/

SDS for lithium nickel manganese cobalt oxide https://www.sigmaaldrich.com/US/en/sds/aldrich/761001

SDS for lithium nickel cobalt aluminum oxide https://loradchemical.com/data/sds/SDS-Lithium-Nickel-Cobalt-Aluminium-Oxide.pdf

SDS for lithium nickel oxide https://www.ltschem.com/msds/LiNiO2.pdf

6 most common lithium battery types https://dragonflyenergy.com/types-of-lithium-batteries-guide/

Look these up yourself simply by searching things like lithium cobalt oxide SDS – .02mg per cubic meter TWA for PEL

https://www.fishersci.com/store/msds?partNumber=AA4209022&productDescription=LITH+CBLT%28III%29+OXID+99.5%25+100G&vendorId=VN00024248&countryCode=US&language=en

*Iron is used in LFP batteries (lithium ferrous phosphate or LiFePO4) – Iron is "less toxic" than other cathode metals for LIB's but as I stated, we don't really know much about nanoparticle toxicity and most reference "not studied" when you read a straight SDS for Lithium Iron Oxide or Iron Oxide (rust) and there is possibly a threat of iron fume similar to what welders may experience. The last paper I link at the very bottom of this book states that combustion may produce other hazardous compounds with even higher toxicity, but we don't know. https://www.continentalbattery.com/assets/Lithium_Safety_Data_Sheet.pdf

* Let us break this "soot" down further from the testing above with what we discussed about SDS and OSHA/NIOSH limits…. .5g/m2 is well over .02g per cubic meter and this was measured at 100m away (! Think about the old guys like me NOT on SCBA at the end of the driveway) with 17-20g per meter squared in the enclosure for 30 cars. It is logical that this might be far worse in a two-car garage or in a smaller semi-confined space. Not to make a math lesson about this, but if permissible limits of dusts are .1mg, 5g, .02mg, .05mg per cubic meter over a 40 hour work week, that is a LONG way from 17g per square meter! As the "plume" (containing these metals) cools the particulates will drop to the ground or on you, your PPE, and your apparatus. This is the contamination that will remain present post-fire in and around the fire seat, on the appliance or container, and on our PPE. Remember, average size EV is around 60kWh and these measurements were in a far larger space than a garage so 20g per sq meter may be far lower than an incident you might respond to or less in an open parking lot.

Remember, these things are fully expelled with little to no copper or aluminum left (often just empty battery casings) so all of this stuff goes somewhere!

Another from 2017 - Toxic fluoride gas emissions from lithium-ion battery fires - PMC (nih.gov)

"Lithium-ion battery fires generate intense heat and considerable amounts of gas and smoke. Although the emission of toxic gases can be a larger threat than the heat, the knowledge of such emissions is limited."

"While the fire itself and the heat it generates may be a serious threat in many situations, the risks associated with gas and smoke emissions from malfunctioning lithium-ion batteries may in some circumstances be a **larger threat**, especially in confined environments where people are present, such as in an aircraft, a submarine, a mine shaft, a spacecraft or in a home equipped with a battery energy storage system.

Full article: Lithium-ion battery explosion aerosols: Morphology and elemental composition (tandfonline.com)

"Aerosols emitted by the explosion of lithium-ion batteries were characterized to assess potential exposures. The explosions were initiated by activating thermal runaway in three commercial batteries: (1) lithium nickel manganese cobalt oxide (NMC), (2) lithium iron phosphate (LFP), and (3) lithium titanate oxide (LTO)."

"The abundance of elements from the anode, cathode, and separator in respirable aerosols underscored the need for the selection of low-toxicity battery materials due to potential exposures in the event of battery thermal runaway."

"Aerosols emitted by lithium-ion battery thermal runaway have not been characterized to the authors' knowledge. In particular, information is lacking on the size, composition and morphology of explosion aerosols in the respirable size range (e.g., ≤4 μm). However, the powder deposited after lithium-ion battery thermal runaway has been studied for 8.5–300 μm particles (Chen, Wang, and Yan Citation2020). The study was carried out for a single battery type with an NMC cathode and showed that powder samples contained carbon, organic compounds, carbonates, and transition metals. The transition metal content of mixed aerosols can especially influence toxicity. In mixtures with carbonaceous particles, transition metals mediate the

production of reactive oxygen species that cause oxidative damage, such as **DNA strand breaks** and inflammation"

*Full disclosure, I am not a doctor, but DNA strand breaks are NOT good and we are now in the realm of cancer, birth defects, and a whole list of other bad stuff. As stated in the presentation, we don't know but until we do…….

One of my favorite papers that I referenced because it focuses on the metal particulates - Full article: Detailed characterization of particle emissions from battery fires (tandfonline.com)

"Lithium-ion (Li-ion) batteries that are becoming ubiquitous in various applications may be susceptible to thermal runaway when subjected to certain abuse factors. Fire ensuing from such a thermal runaway event results in significant release of gaseous and particle emissions that **pose a critical safety risk to human health**."

> "there have been limited studies reported in the literature that examine particulate emission characteristics in detail"
> "Thermal runaway resulted in very high particle emissions."

- "Battery fires emanating from thermal runaway events can result in significant particle and gaseous emissions. Both overcharge tests of LFP modules, and the nail penetration test of the NMC module resulted in PM2.5 emissions exceeding 375 g/h and total PN emissions of the order of 2E + 17 part./h. These emission rates are 5 to 6 orders of magnitude higher than those typically emitted from the exhaust of a modern heavy-duty diesel engine. It is to be noted that the aforementioned statement is primarily to provide a contextual comparison with a well-documented particle emitter.

  * my note - particles are metal particulates, oxides, etc as discussed above – gases are generally asphyxiants and irritants. Not to bore anyone with statistics but an "order of magnitude" is generally 10x more than the subject of comparison so we are talking about 50-60 times the particulates that are emitted from a diesel exhaust. Diesel can be nasty but remember that they are designed to reduce particulate emissions from the exhaust and those particulates are NOT as toxic nor are they in the same quantities (especially for metals) as batteries. My opinion.

Nickel toxicity and environmental concerns – nickel is often the main metal cathode ingredient in NMC batteries – - https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7037090/

Human exposure to highly nickel-polluted environments may cause a variety of pathological effects [34,35]. Accumulation of nickel and nickel compounds in the body through chronic exposure may be responsible for a variety of adverse effects on the health of human beings, such as lung fibrosis, kidney and cardiovascular diseases and cancer of the respiratory tract [36,37]. High incidence of nasal and lung cancer in workers exposed to nickel and nickel compounds was observed [37,38,39,40,41,42]. A small fraction of nickel is dermally absorbed, and Ni^{2+} ions and nickel particles penetrate the skin at sweat ducts and hair follicles. Moreover, dermal absorption of this metal is affected by solubilizing agents, such as detergents, and clothes and gloves that behave as a barrier to the skin.

*Remember, the warmer the particle the more easily it is absorbed through your skin.

Nickel nanoparticles are associated with reproductive toxicity.

Potential toxicity of nickel and nickel compounds is dependent on their physico-chemical characteristics, as well as the amount, duration of contact and route of exposure. Nickel can enter the body via inhalation, ingestion with food and dermal absorption; however, the route for this element to enter cells is determined by its chemical form. The riskiest route of exposure to nickel is by inhalation.

Insoluble nickel sulfide (Ni_2S_3) is a carcinogen agent for the respiratory tract: When it is inhaled, particles of nickel sulfide accommodate themselves in the lungs of human beings, where they remain in contact with epithelial cells. These nickel particles are removed by macrophages in the digestive tract. Under high exposure to nickel, the macrophage activity of removal could be perturbed, and Ni_2S_3 particles may be taken into epithelial cells by endocytosis. In this way, nickel particles are delivered to the nucleus of lung epithelial cells, causing a heritable change in chromosomes, inducing lesions of both double- and single-stranded DNA in cultured human cells.

Here are the random articles, YouTube videos, and other stuff you may find interesting and educational.

A MUST WATCH is Dr. Christensen's presentation (up top). He has trained hundreds or thousands of firefighters in Europe and Australia and he specifically talks about the vapors NOT being smoke and VCE's or vapor cloud explosions being a threat like Captain Clare shared with us in the two incidents he presented. The amount of gas produced by these things is scary and I believe he now puts that at 500-3000L per kWh (I think this older presentation states 300L-3000L of gas per kWh). The potential of major explosions (like that in AZ) is definitely real!

I recommend that your family watch this too so they recognize a vapor cloud, hissing, and the sound of pressure relief caps popping.

For reference, many e-mobility devices are .5 kWh or 1 kWh, Residential ESS systems can be 10-40 kWh, and EV's and larger grid or industrial ESS systems can be much larger. He also points believes the black smoke from initial venting of the cell(s) are the cathode metals and these do NOT dissipate so we are at risk of contamination, inhalation, or ingestion while conducting a scene exam, during a fire, or post-fire.

You may see references to carbon black or black carbon in the batteries (instead of graphite) – look it up – it's also a suspected carcinogen. Yes, I am a joy to have at dinner.

Something new I learned – a CO detector may well react to a venting battery that is heating but has not or does not catch fire because CO is a big part of the vapor cloud put out to relieve pressure inside the cell when thermal runaway begins. Keep this in mind if you are running a

truck and answer a CO alarm or a witness references a CO alarm activation prior to the fire. If you have batteries in your house I would have a CO detector even if you don't have gas appliances. You should always have a smoke detector in your garage. Just a recommendation from a fire investigator!

29 minute version:

SWFRS webinar with Prof Paul Christensen. Lithium-Ion Batteries and electric vehicles - YouTube

https://www.youtube.com/watch?v=rvRCz-2zcmM 41 minute version of same presentation (mostly)

Christensen video – "the new asbestos" – 13 minutes – he makes some great points about the lack of regulations https://www.youtube.com/watch?v=GfZPNSOGjgE&t=10s

What is a lithium-ion battery? Dr. Billy Wu – great introduction and overall view of the technology - https://www.youtube.com/watch?v=DBLHaLhyo2w&t=24s

Why do they catch fire? Dr. Billy Wu – I showed part of this during the presentation but it is very good and it is not long, you can forward through the graph portion where he talks about combustion properties of specific batteries so probably 9 minutes worth and watch the conclusion - https://www.youtube.com/watch?v=VWMfeseybt4&t=689s

YT – ABC Australia EV fires – references cobalt poisoning and vapor barrier and this is where the union president mentions firefighters medically retired from exposures (to cobalt). Australia is having a lot of battery fires. https://www.youtube.com/watch?v=NWvI1daNils

YT – EV fire in garage – newer model loaner Mercedes totals a house (it was NOT charging) and I am still impressed with the knockdown on this fire - https://www.youtube.com/watch?v=SIpXkQhq1ps

YT – EV fire in driveway with not a single SCBA being used – this kills me! https://www.youtube.com/watch?v=rItu9FIBsKE

YT – E-bike battery catches fire on video in garage - https://www.youtube.com/watch?v=2ex7Qf0j7Rw

YT – Phoenix Fire puts Tesla in container with wet sand – this is not an endorsement, but just throwing it out there in case you are interested but few fire agencies have as much experience as Phoenix with these fires – batteries don't like warm temperatures? https://www.youtube.com/watch?v=LUGu30hR_kU

YT – fire blanket news story - https://www.youtube.com/watch?v=3db6Wyl9CSQ

YT – EVFireSafe – EV van on fire in London – good educational presentation https://www.youtube.com/watch?v=mIIdMkwKLp4

YT – EV fire blanket demo – short https://www.youtube.com/watch?v=n_JINtx08iA

Toxic fluoride gases from fires – white paper - https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5577247/

Cobalt toxicity in humans – white paper - https://pubmed.ncbi.nlm.nih.gov/28572025/

Lithium ion battery research – storage systems – ORNL – good stuff - https://www.osti.gov/servlets/purl/1963149

ECHA SDS cobalt oxide – Europeans believe it to be a carcinogen and impact reproductive health and lungs? - https://echa.europa.eu/substance-information/-/substanceinfo/100.013.777

CDC report on manganese toxicity - https://www.atsdr.cdc.gov/toxprofiles/tp151-c2.pdf

Comprehensive investigation of thermal and toxic hazards LIBs - https://www.sciencedirect.com/science/article/abs/pii/S0304389419308696

Toxic gas emissions from damaged LIBs - https://www.mdpi.com/2313-0105/2/1/5

Ecotoxicity of extinguishment water – always consider aquatic toxicity as a major threat to your community. We have to do what we have to do, but may come in handy to explain to the public why you chose to let it burn rather than flow a lot of water - https://pubs.acs.org/doi/10.1021/acs.est.2c08581

Particle emissions from battery fires - https://www.tandfonline.com/doi/full/10.1080/02786826.2021.2018399

LIB explosion hazards/aerosols - https://www.tandfonline.com/doi/full/10.1080/02786826.2021.1938966?src=recsys

Thermal runaway and EV contamination - https://www.dora.lib4ri.ch/empa/islandora/object/empa%3A29507/datastream/PDF/Held-2022-Thermal_runaway_and_fire_of-%28published_version%29.pdf

https://www.youtube.com/watch?v=rvdb1ce7hGo – StacheD M18 battery burns down truck – this is a good one to be aware of because tool pack battery fires happen and we are moving away from 2-cycle gas powered lawn equipment or snowblowers to battery powered equipment and that is very hard usage often with temperature extremes during use or storage. We will see more fires from these in the future and most of the time these are found in the garage.

Headline – 2 firefighters killed in China https://www.pv-magazine.com/2021/04/21/two-firefighters-killed-and-one-missing-after-beijing-battery-blaze/

Rivian Factory – 3 fires in a year (believe its 4 now) for local fire dept - https://insideevs.com/news/589006/rivian-normal-fire-battery-pack/

Scooter fire and explosion – BBC - https://www.bbc.com/news/uk-england-leeds-64881631

Recall fire for vacuum battery off Amazon - https://www.nbcchicago.com/consumer/explosions-fires-and-injuries-know-the-risks-behind-lithium-ion-batteries/3133300/

AZ ESS explosion and legal fights - https://spectrum.ieee.org/dispute-erupts-over-what-sparked-an-explosive-liion-energy-storage-accident

Fire investigators have battery explode during investigation – a good one to be aware of! https://www.denver7.com/news/local-news/close-call-lithium-ion-battery-explodes-in-adams-county-fire-investigators-face

EV in China explodes during suppression https://www.dailymotion.com/video/x7vpbzl

Australia 2 firefighters cobalt poisoned https://7news.com.au/lifestyle/motoring/firefighters-union-calls-for-government-action-on-ev-fire-risks-c-8827258

Australia original source for 2 firefighters….. https://www.carexpert.com.au/car-news/firefighters-union-calls-for-government-action-on-ev-fire-risks#article_comments

*Again, I don't know what happened to these firefighters but the source of this is the President of their firefighters union and he has never retracted or corrected the quote which has been widely used in the media. I really fear stories like this may become MORE common because of a lack of training and awareness within the fire service.

Scooter battery blows out wall into hallway https://www.linkedin.com/feed/update/urn:li:activity:7108327644307353601/

Tesla into garage FF in smoke and one on the roof - https://www.nbcnews.com/business/autos/federal-regulators-warn-risks-firefighters-electrical-vehicle-fires-n1271084

Overall news story good stuff https://www.youtube.com/watch?v=WKBDNtMlRfI

Toxicity of cobalt and nickel nanoparticles https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3501377/

Heavy metals and cancer - https://www.intechopen.com/chapters/76911

Cobalt exposure white paper - https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7410254/ talks about inhalation hazard and dermal absorption

Ebikes Australia rekindle https://www.youtube.com/watch?v=fyY-tnohLiY

Mutagenity/carcinogenity of cobalt dust and oxides - https://pubmed.ncbi.nlm.nih.gov/2195331/

45000g of water for a Nissan Leaf? - https://www.wkrn.com/news/local-news/electric-vehicle-fire-in-franklin-requires-thousands-of-gallons-of-water/?ipid=inline-link

Followup story talks about the US Fire Admin - https://www.wkrn.com/news/local-news/electric-vehicle-fires-continue-to-fuel-concerns-among-first-responders/

Pollution in Congo – Spina Bifida and limb abnormalities - https://www.theguardian.com/global-development/2020/may/06/pollution-causing-birth-defects-in-children-of-drc-cobalt-miners-study

UK report on e-mobility fires – good product - https://www.electricalsafetyfirst.org.uk/media/sgyikuwb/esf_batterybreakdown_report_2023_v7_-final.pdf

Waste and Recycle Fires - https://www.linkedin.com/pulse/waste-recycling-fire-report-achieving-best-case-from-ryan?trk=news-guest_share-article

Thermal imaging of overcharge failure - https://www.youtube.com/watch?v=RedHpzZesPs&t=4s

Professor Guillermo Rein Twitter thread on innovation blind spots and stats – he has some good stuff on YouTube and I will try to link others - https://twitter.com/GuillermoRein/status/1552812305242521600

Recent lecture on LIB's by Professor Rein - https://www.youtube.com/watch?v=BUVw85SZciU

E-scooter fire on London subway BBC - https://www.youtube.com/watch?v=m24ZQ0SjriQ

Tesla First Responders Guide to ESS - https://www.tesla.com/firstresponders/industrial-energy-emergency-response-video

Energy Wall Fires Oct 23 – Recalls – Europe - https://www.pv-magazine.com/2023/10/10/germany-austria-hit-by-multiple-solar-battery-fires-in-september/

Recall on LG ESS Oct 23 - https://www.news.com.au/technology/accc-urgent-recall-on-lg-solar-storage-system-battery/news-story/283a4eb58dc011ababf2da6c687fb4e9

BESS fire problem – San Diego Oct 23 - https://www.sandiegouniontribune.com/business/story/2023-10-11/battery-storage-is-a-key-piece-of-californias-clean-energy-transition-but-theres-a-problem-with-fires

Update on fighting EV fires Denmark – new design and recommendations - https://cfpa-e.eu/new-knowledge-about-battery-fires-in-electric-cars-on-ferries/#:~:text=Jul%202022-,DBI%20%E2%80%93%20The%20Danish%20Institute%20of%20Fire%20and%20Security%20Technology%20has,consisting%20of%2040%2Dfoot%20containers

Electric buses under high rise apts Europe – bad idea? - https://www.telegraph.co.uk/money/net-zero/electric-bus-fire-threat-risks-tower-blocks-volcano/

CPSC recall on 550 sets of pajamas for flammability risks – irony? - https://www.cpsc.gov/Recalls/2023/Childrens-Pajamas-and-Nightdresses-Recalled-Due-to-Violation-of-Federal-Flammability-Standards-and-Burn-Hazard-Imported-by-Little-Cotton-Clothes-Recall-Alert

*I include this recall because this is the standard we have established to keep children safe from fire(s) so this goes directly to the risk/benefit analysis of school buses or mass transit. The failure can be quite sudden and violent, the venting can generate large vapor clouds of metal particulates, and an explosion or violent fire can occur. It is reasonable to believe that airplanes, submarines, ships, and other people movers greatly increase the risk of catastrophe with this

technology from an explosion, fire, or toxic exposure regardless of "how" or "why" a fire is started. These things should require the most stringent safety engineering to prevent venting into the passenger compartment as well as stringent maintenance and monitoring.

San Diego writing local codes after losing 4 trash trucks and for BESS - https://www.activistpost.com/2023/10/city-to-write-laws-for-regulating-storage-disposal-of-lithium-ion-batteries-for-evs-etc-after-losing-4-trash-trucks-to-fires-many-injuries.html

White paper on lithium battery contents - https://www.sciencedirect.com/science/article/pii/S2405844019347012

French LIB submarine – bad idea? - https://www.navalnews.com/naval-news/2023/10/france-offers-new-scorpene-evolved-li-ion-submarine-to-indonesia

20 ton electric excavator with batteries by Proterra - https://www.mequipment.ro/en/noi-excavatoare-electrice-komatsu-cu-baterii-in-clasa-20-de-tone/

Proterra bankruptcy filed – the battery management system is apparently being updated by the company that took that portion over and I hope that continues – https://techcrunch.com/2023/08/09/what-led-to-ev-darling-proterras-bankruptcy/ This is a real concern because quality manufacturers often update the BMS to make them safer, but if a company goes bankrupt the engineers are not working on this (think transit or school buses) so if a problem exists within the BMS the software remains the same

FDNY commissioner letter to Amazon for only UL or certified products sold – this is really becoming a big problem because the discount or knock-off market is not regulated for safety with no UL testing on products. Please always pay close attention to these products in your home and follow best practices! https://twitter.com/FDNYFC/status/1712949020379803937/photo/1

Aqueous rechargeable batteries – a solution? – no flammable electrolyte – I include this because you constantly hear about new battery tech that will change the game and lower risks. This is an example as are the solid state batteries, sodium ion, silicon, and others. I think we will get there eventually, but not any time soon as it often takes a long time to field new chemistries https://thedebrief.org/lithium-ion-batteries-could-soon-be-replaced-by-new-green-aqueous-rechargeable-batteries/

IPO listing for 2022 stats – 65% growth in demand – NMC vs LFP - https://twitter.com/IPOACADEMY01/status/1713860353413759041

NSW – scooter fire with video of aftermath – blew out window - https://www.fire.nsw.gov.au/incident.php?record=rec3hvFSdo2qjZKyh

Gulf clubhouse burns down – cart batteries? - https://www.youtube.com/watch?v=GekYcU-s9YI

Best study on cobalt toxicity? Jan 23 – Agency for Toxic Substances (CDC) - tp33.pdf (cdc.gov)

Cobalt toxicity and ionized cobalt – 2012 - Cobalt metabolism and toxicology--a brief update - PubMed (nih.gov)

Scooter battery explodes on Madrid subway - https://batteriesnews.com/explosion-madrid-metro-carriage-left-destroyed-after-faulty-e-scooter-battery-causes-blast/

Francesco Retuccia lithium battery fires lecture – https://www.youtube.com/watch?v=rJsoWD0J7bQ&t=522s

Lithium batteries a clear and present danger to CT with stats - https://ctbythenumbers.news/ctnews/lithium-ion-batteries-a-clear-and-present-danger-in-connecticut

Francesco Retuccia – Fire Science Show - https://www.firescienceshow.com/118-different-batteries-different-challanges-with-francesco-restuccia/

Why Tesla, GM And Other EV Companies Have A Fire Problem – CNBC https://www.youtube.com/watch?v=XWq-Mq1Uqpw

Science and technology of battery fire safety from Imperial College – some really good stuff on this one. Discusses the importance of heat dissipation and how that impacts larger scale systems AND the FACT that most research on battery fires have been done with single cells. Behavior (and risks) change as the packs become larger and this is VERY important to understand. The bigger the battery the higher the risks due to heat dissipation influence and more failure points? https://www.youtube.com/watch?v=LVSPbbXFd5g

Cobalt hip transplant failure/poisoning? This is the one I mention above. He also references the epidemic of cobalt in beer foam in the 60's (this really happened to beer drinkers). It's an interesting Ted Talk - https://www.youtube.com/watch?v=ksuFfbic6tA

Mike Abraham's (ATF electrical engineer) presentation on DCARI (great YouTube channel for fire investigators by the way) – let's get his hits up there! https://www.youtube.com/watch?v=ZWc0Gf07MU8

London Fire Brigade scooter - https://www.youtube.com/watch?v=Ka2hMktqoCY

UL testing of scooter in news story with rapid flash and explosion - https://www.youtube.com/watch?v=cC0t7foqr8k&t=29s

"It scares the daylights out of me:' Florida's top firefighter fears more lithium-ion battery fires" - https://www.youtube.com/watch?v=CC0KyXkJPlA

https://www.youtube.com/@evfiresafe7330/videos link to the EV Fire Safe videos on YouTube

Electric bus fire in downtown Paris – this is crazy. From other sources it sounds like the bus driver thankfully reacted to warnings and he evacuated the bus earlier to the bus behind this one in the video – There were over 100 of these very expensive buses that were pulled from service after this fire and one other (I believe from other sources) – I believe they are now back in service - https://www.youtube.com/watch?v=uA7SoM2DWuM

2 mechanics hurt after VTA bus fire (Proterra) – they dispute that it was the batteries but that is not what is important – fires will happen - https://www.youtube.com/watch?v=VmK8NpstKi0

Electric bus crash in Italy – media does not use word electric, but witnesses who rescued survivors were unable to get to survivors who were screaming due to the subsequent fire – any bus can catch fire and they do, but a LIB bus may pose some unique challenges https://www.youtube.com/watch?v=Id2CvnUVtBk

Chinese parked buses catch fire – we showed this one in presentation – consider this if you have e-buses in a bus barn or parked next to one another – rapid spread but remember this video is sped up a bit https://www.youtube.com/watch?v=T71cVhxG_v4

CT transit bus fire news story – we showed this during presentation - https://www.youtube.com/watch?v=_8YClwsWTyU

Bus fire in China that we showed – it's not funny but try to count how many people were on the bus! - https://www.youtube.com/watch?v=wzwqLekgDSc

Another bus barn fire that could have been much worse! https://www.youtube.com/watch?v=O8p4JUwb680

Lithium battery fire in a backpack – a lot of backpacks now contain charging banks of questionable quality (see how cheap they are on Amazon) or people are getting on planes with charging banks - https://www.youtube.com/watch?v=2cKVgaynEuA

Battery storage system fire in Idaho recently – these are happening more frequently as the number of these systems greatly increase and more are in transportation - https://www.youtube.com/watch?v=wmVCc_nKNu8

Battery fires in London and the UK – it's not just in NYC that is having many more of these - https://www.youtube.com/watch?v=9OvkNbbHGnQ

Lithium battery fire in a hostel in Australia - https://www.youtube.com/watch?v=j15GowW5f_g

Hotel fire caused by charging battery - https://www.youtube.com/watch?v=Ho_e6cDyjvQ

Great video showing how much gas these things can put out – Australia again, New South Wales Fire is estimating 1/3 fires they run on now are batteries – remember, these are ignitable vapors! https://www.youtube.com/watch?v=2AvBs3CI8pg&t=36s

Firefighter cancer report Canada – this is an excellent product - https://www.occupationalcancer.ca/wp-content/uploads/2024/01/FFCRPW-Report-Jan-2024.pdf

How are EV batteries recycled - https://blog.ucsusa.org/jessica-dunn/how-are-ev-batteries-actually-recycled/

Concerns about e-mobility fires – very good https://www.youtube.com/watch?v=G665T8eGAn8

Toxicity of metallic nano-particles paper - https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9822575/

Li-ion batteries cause scrapyard fire - https://www.newshub.co.nz/home/new-zealand/2024/02/lithium-batteries-may-have-caused-large-t-huhu-scrap-yard-fire.html

Carbon black and cancer - https://www.ncbi.nlm.nih.gov/books/NBK326509/

Metals generated during thermal failure - https://pubs.rsc.org/en/content/articlehtml/2023/ya/d2ya00279e

ESS trends global 2023/2024 - https://www.energytrend.com/research/20231218-41985.html

Toxicity, Emissions and Structural Damage from Lithium-Ion Battery Thermal Runaway

https://www.mdpi.com/2313-0105/9/6/308

GC-MS was used to qualitatively detect and analyze the thermal runaway gaseous products of the battery. Dozens of toxic substances can be detected in thermal runaway products of LIBs with different cathode materials and SOC, among which six very toxic substances such as 2-propenal, methyl vinyl ketone, propanedinitrile, propanenitrile, 1,2-dimethyl-hydrazine and thiocyanic acid ethyl ester could be detected and analyzed. For NMC and LCO, high-SOC batteries had more types of products than low-SOC batteries. For LFP, most types of toxic products were detected in 30% SOC battery samples. At the same time, it was found that certain substances used as electrolyte solvents or additives may react with electrode materials or thermal runaway products during the thermal runaway process, **generating new products with higher toxicity**. Therefore, when choosing electrolyte solvents and various functional additives containing elements such as N, S, Cl, etc., more serious concern is needed.

*Academics are the best source we have right now to define the possible threats to health and safety, but as we saw in our EV battery burn and testing you can measure a lot of stuff but it does not tell you how much is present. However, we need to demand testing to quantify our exposures and the best source may be our PPE, bloodwork, and health. The statement that is bolded above is the biggest problem I see with these batteries.

Respiratory hazards of LIB's - https://dial.uclouvain.be/pr/boreal/object/boreal%3A196570/datastream/PDF_01/view

Janus Electric converted 16 semi-trucks to electric with 2 fires - https://bigrigs.com.au/2023/12/18/why-electric-truck-caught-fire-on-the-west-gate-freeway/

Nikolai Trucks in Phoenix – semi's – 209 built with 4 fires and now recalled

https://electrek.co/2023/09/08/nikola-trucks-cant-stop-catching-fire-4th/

Hummer fire on I-405 while we were at symposium – this is a very large battery for an EV (246kWh NMCA battery or about 4 average EV's)

https://www.king5.com/video/news/local/hit-and-run-crash-causes-hummer-ev-to-reignite-three-times/281-45bcf6f3-6667-47b4-b8f7-a8bb0198d919

Morris, IL (talked about in EPA presentation) accumulator mixed battery fire suspected to be between 100-200 tons abandoned in a warehouse. EPA cleanup still active I believe.

https://www.nbcchicago.com/news/local/nearly-100-tons-of-lithium-batteries-involved-in-large-morris-industrial-fire/2543694/

Battery recycling fire in France. Fires are not uncommon at these facilities that take in large amounts of unknown and possibly damaged batteries. 900 tons present allegedly

https://www.reuters.com/world/europe/french-recycling-plant-fire-housing-900-tonnes-lithium-batteries-2024-02-18/

Toronto e-bike fire on the subway – good points from the Chief about codes and regulations

https://www.youtube.com/watch?v=J22mbd70DxU

Another e-bike fire and explosion that will really get your attention!

https://www.youtube.com/watch?v=vJ4ODDLhjvI

Lithium battery fire in Harlem high-rise kills young man – rope rescue

https://www.youtube.com/watch?v=s356Y0hX6P8

The next asbestos or PFAS? https://www.pbs.org/newshour/show/what-we-know-about-toxic-forever-chemicals-and-how-to-reduce-our-exposure

Firefighters exposure to PFAS - https://www.frontiersin.org/articles/10.3389/fmats.2023.1143411/full

This is not all inclusive, but I hope you take what you learn(ed) and pass it on to others and I apologize for sounding like Dr. Doom but we deserve better answers about these things and all of us (and our families) should be very careful until we get some.

*Again, all ***opinions*** are mine and not those of ATF but I sincerely hope you develop your own "informed" opinions and ideas based on credible science and not the prevailing narratives or "tradition". This is new technology and it is going to take us a awhile to get our feet under us with it. We need to keep pushing for answers because this is important!

Feel free to reach out if you have any specific questions and if you come across something interesting, I always appreciate a note about it or a link! I will keep my phone number when I retire if the email does not work.

Stay safe and best wishes!

C. Todd Smith

Christopher.smith@atf.gov

509-342-0652

“I would rather have questions that can't be answered than answers that can't be questioned.” — **Richard P. Feynman**

Where is your battery fire?

