

Analysis of emitted gases from Li-ion LFP and NMC batteries at elevated temperatures

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Summary

A study on gases vented from Li-ion cells at the event of thermal runaway in an inert environment is presented. Automotive Li-ion pouch cells of LFP and NMC cathode chemistry were exposed to heat-up in a nitrogen environment, and by means of analytic instruments such as Gas Chromatography-Mass Spectrometry a screening of known and unknown constituent gaseous species was performed. This study was funded by the Swedish Civil Contingencies Agency in order to investigate the contents of vent gases from automotive E-Vehicle batteries, based on the demand from Swedish first responders for more knowledge.

Keywords: Lithium battery, Safety, EV, HEV

1 Introduction

In the event of an E-Vehicle (i.e. any vehicle with electric propulsion and carrying traction batteries; e.g. EV, HEV, PHEV etc.) crash, quick and competent rescue of the vehicle occupants requires new knowledge and updated training to minimize the time to final treatment for those injured. This was the conclusion drawn by the Swedish Civil Contingencies Agency (MSB) in 2011 after analyzing the results of a survey that they had sent out to Swedish first responders. This led to the initiation of a Triple Helix research project, E-Vehicle Safe Rescue (2012-2014), where abusive testing on E-Vehicle batteries (cells/modules/packs) were conducted by Swedish partners from the industry, research institutes and academics and the results were compiled by MSB into a free web-based educational material for first responders [1]. Amongst mechanical, electrical and thermal abuse tests, bonfire tests on LFP and NMC Li-ion battery cells were conducted, analyzed and published [2]. In January 2015 MSB identified that a remaining task to be investigated was the composition of gases that can be vented without fire from a critically damaged automotive battery such as the LFP and NMC Li-ion batteries. Those two types of Li-ion chemistries were chosen due to the fact that they currently are the two most common ones found in commercialized automotive HV batteries. The results of the present investigation will provide MSB with further material to be added to the existing education for first responder rescue routines at the event of a traffic incident involving E-Vehicles.

The present study was conducted during autumn of 2015 by Swedish Defense Research Agency (FOI) based on battery material provided from E-Vehicle Safe Rescue and Autoliv Development AB.

The team of researchers at FOI investigated the ventilated emittants such as gases, aerosols and particles from Li-ion pouch cells of the mentioned chemistries by means of Gas Chromatography-Mass Spectrometry (GC-MS), Dräger tubes for detection HF, and metal analysis using ICP-SFMS and EPA Method (based on metals collected in the particulate phase), in order to the screen for unknown and known chemical compounds. Examples of known gases or vapors that can be generated during critical thermal failure of Li-ion cells are carbon dioxide, carbon monoxide, hydrogen fluoride, fluorocarbons, hydrogen, and vaporized or aerosolic electrolyte alkyl carbonates [3] [4] [5] [6] [7] [8] [9] [10] [11].

The aim of the present investigation was to identify previously unknown and known chemical compounds with potential toxicity. Therefore, this paper presents a table summarizing the toxicity of the chemical compounds identified by means of all three analytic methods utilized, i.e. GC-MS, Dräger tubes and metal analysis. However, besides that table, this paper will primarily focus on the GC-MS analysis method and results derived thereof, while methods and detailed results of the other two analytical instruments remains available in the original and public FOI test report [12].

2 Methods and Data Sources

2.1 Safety and setup

The tests were conducted in a well ventilated 65 m³ room with stainless steel walls and with filtered air supply from the outside. Exhaust air from tests passed through aerosol and carbon filters before released to surroundings. For safety a separate control room was used and personal protection equipment for operators included protective mask, suit, gloves and boots to ensure minimum exposure through inhalation or skin contact with known and unknown harmful substances.

The battery cell to be tested (Figure 1) was placed inside a stainless steel box (Figure 2) (hereafter referred to as the “battery box”) which was mounted on top of a flameless heat sources. This arrangement was installed in a glove box (Figure 3). The glove box, carrying the battery box, was defined as the test chamber. The battery box received an inflow of nitrogen gas (regulated by a mass flow controller, 0-100 L/min) at 20°C and 63% RH; consequently, all tests were performed in a nitrogen atmosphere in order to prevent any gases or aerosols to burn. The outflow from the battery box was released into the glove box. During the tests all gases, particles and aerosols accumulating in the glove box were sampled by equipment mounted inside the box (Figure 4).

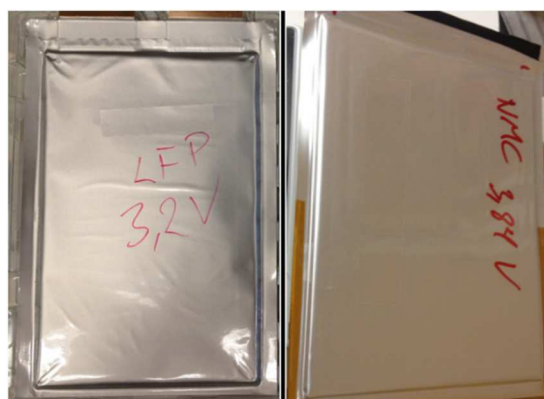


Figure 1 The study focused on vent gases from two types of Li-ion pouch cells designed for E-Vehicles with similar physical dimensions but different electrical capacity: 7 Ah LFP (LiFePO₄) and 14 Ah NMC (Li(Ni_{1/3}Mn_{1/3}Co_{1/3})O₂).



Figure 2 The battery cell was placed inside the battery box that has connections for inflow of nitrogen and an opening in the lid for the outflow. The lid also carried connections for temperature and pressure probing of the box's inside.



Figure 3 The glove box (0.38 m³) located in the test room (65 m³).



Figure 4 Inside the glove box with all sampling equipment setup and the battery box on the heat source.

2.2 Sampling methods and analysis protocol

2.2.1 Filter and absorbents

Air sampling with Tenax tube (PerkinElmer, USA), Carbosieve tube (PerkinElmer, USA) and 25 mm GF filter (PALL, USA), connected to a sampling train, was done with Pocket Pump's (SKC Inc., USA) at a flowrate of 100 mL/min. The GF filter was used to protect the gas sampling tubes of Carbosieve and Tenax. The sampled air passed the Tenax tube first, removing semi volatile compounds, volatile compounds passed the Tenax tube and were collected on the Carbosieve tube. Particulate aerosols were collected on 37 mm PVC filter (PALL, USA) and a set of 47 mm GF filter and an Anasorb 747 adsorbent tube. The sampling rate for the PVC filter was 5 L/min (Leland Legacy pump, SKC Inc., USA) and 2 L/min for the 47 mm GF filter with Anasorb 747 tube (AirCheck2000, SKC Inc.).

2.2.2 GC-MS

The adsorbent tubes (Tenax and Carbosieve) were analyzed by thermal desorption gas chromatography (TD-GCMS). The instrumentation used were: TD – TurboMatrix 350 ATD (Automated Thermal Desorption), Perkin Elmer; GC – Agilent 7890A Gas Chromatograph; MS – Agilent 5975C MSD. Adsorbent tubes were desorbed at 250°C during 3 min using a split ratio of 1:10 (inlet split 200 mL/min, tube desorb 20 mL/min). The cold trap used to refocus the analytes was set to 2°C for Tenax adsorbent tubes using a Thermal Desorber Trap, Packed with Tenax (M041-3535, Perkin Elmer, CT, USA). The analytes from the Carbosieve adsorbent tubes were refocused onto an Air Monitoring Trap (M041-3628, Perkin Elmer, CT, USA) kept at a temperature of -30°C. After the initial desorption stage the trap was rapidly heated to 250°C to introduce the analytes to the GC after a second split of 1:10. The temperature of the valve and transfer line were 180°C and 200°C respectively. Chromatographic separation was performed using DB-5 MS analytical column (Agilent J&W scientific, USA) with a length of 30 m x 0.25 mm and a film thickness of 0.25 µm. The GC profile was as follows: initial temperature was kept at 40°C for 1 min, then increased to 100°C at a rate of 5°C/min and then ramped at 15°C/min until 300°C. The mass spectrometer was operated in full scan mode (mass 29-400) to allow identification. Samples were quantified against calibrations generated using toluene in methanol spiked onto an adsorption tube. The raw data files were evaluated using the software AMDIS.

2.2.3 Thermocouple

The expected soft spots of the tested pouch cells were the seams by the tabs. The thermocouple measuring the battery box temperature was therefore mounted next to the tabs, through the lid of the battery box. The temperature readings were primarily used to indicate the start of venting.

2.3 Test procedure

Prior to tests, the empty battery box was conditioned at over 250 °C to degas possible interfering substances. Background measurements were acquired with an empty battery box in a similar fashion as sharp measurements.

Totally four experiments were done on a single cell per test; referred to as LFP1 (3.2 V), LFP2 (3.26 V), NMC1 (3.84 V), and NMC2 (3.84 V). Total amounts of degassed substance was determined from battery weights before (236 g/LFP and 386g/NMC) and after the experiment.

The battery was placed inside the battery box, and in order to ensure optimal thermal conductive surface connection between the battery cell tested and the heats source below, a perforated metal U-profile was

clamped in between the battery cell and the ceiling of the battery box so as to prevent the pouch cell from swelling.

After the battery box and battery cell had been prepared and placed on top of the electric heater, the nitrogen supply and the temperature probe was connected to the battery box. Air samplers were placed inside the glove box. The door to the glove box was closed and the humidified nitrogen flushed the test chamber until the carbon dioxide concentration inside the glove box was reduced to a low value ($< 1/3$ of initial concentration).

During the test, the battery box was heated until battery cell vented and gases, aerosol and particles were released to the glove box. At that point in time the power to the heater was shut down. Sampling started immediately and proceeded for 10 min.

Following the 10 min, the humidification of nitrogen ended and the nitrogen flow increased to 50 L/min to evacuate the glove box to minimize the risk of open flame when the door was to be opened and volatile electrolyte gases were exposed to oxygen in surrounding air. After about another 10 min the glove box was visually clear and filter and adsorbents were collected and sealed.

Between the experiments the battery box and glove box was cleaned with moistened paper towels.

3 Results

3.1 Chemical analysis

Substances identified from adsorbent tubes by means of ATD-GCMS are summarized in Table 1 for LFP and NMC batteries. Compounds were identified using AMDIS software (Automated Mass spectral Deconvolution and Identification System). The selection criteria for a positive identification was a match factor above 90.

The most abundant compounds emitted from the batteries were carbonates. Diethyl carbonate (DEC) and ethylmethyl carbonate (EMC) found in the LFP battery and dimethyl carbonate (DMC) and EMC in the NMC battery. In addition, both battery types contained large amounts of 1,3-dioxolan-2-one.

Similar compounds are detected for the two different battery types. However, in the tests on NMC batteries phosphonofluoridates were detected; those species were not found in the tests on LFP batteries.

The volatile compounds previously reported with FT-IR such as phosphorylfluoride, pentafluorophosphate and hydrogenfluoride were not detected by means of the GC-MS analytic method presented [8] [10].

Table 1 Emittants from LFP respectively NMC battery cells (GC-MS). Light grey table cells presents compounds found in tests of both chemistries. Yellow cells are compounds from LFP only; orange cells are compounds from NMC only. [12]

LFP Chem. compound	Structure	CAS#	Conc. (µg/m³)	NMC Chem. compound	Structure	CAS#	Conc. (µg/m³)
1,3-dioxolan-2-one		96-49-1	300	1,3-dioxolan-2-one		96-49-1	100
1,4-dioxane		123-91-1	0.2	1,4-oxathiane		15980-15-1	2
1,4-oxathiane		15980-15-1	10	2-methyl-1,3-dioxolane		497-26-7	10
1-methylpyrrolidin-2-one		872-50-4	5	Diethyl carbonate (DEC)		105-58-8	30
1-phenylethanone		98-86-2	1	Diethyl phosphorofluoridate		358-74-7	10
2-methyl-1,3-dioxolane		497-26-7	2	Dimethyl carbonate (DMC)		616-38-6	300
2-methylcyclopent-2-en-1-one		1120-73-6	0.2	Ethyl ethylphosphonofluoridate		650-20-4	0.2
6-methyloxan-2-one		823-22-3	0.1	Ethyl methylphosphonofluoridate		673-97-2	0.5
Benzoic acid		65-85-0	0.1	Ethyl propyl carbonate		35363-40-7	0.01
Diethyl carbonate (DEC)		105-58-8	1000	Ethylbenzene		100-41-4	0.1
Diethyl phosphorofluoridate		358-74-7	0.5	Ethylmethyl carbonate (EMC)		623-53-0	1000
Dimethyl carbonate (DMC)		616-38-6	1	Methyl methylphosphonofluoridate		353-88-8	0.02
Ethyl prop-2-enyl carbonate		1469-70-1	0.1	Styrene		100-42-5	5
Ethyl propyl carbonate		35363-40-7	0.1				
Ethylbenzene		100-41-4	2				
Ethylmethyl carbonate (EMC)		623-53-0	1000				
Styrene		100-42-5	5				

Table 2 Toxicological assessment summary of compounds identified by GC-MS, Dräger tubes and metal analysis [12]

Chemical compound	CAS no. ¹	TOXNET ² Skin eyes, respiratory tract	Hygienic limit values ³	Labelling of chemicals according to ECHA ⁴ : Hazard codes for chem-phys & human health
1,3-dioxolan-2-one	96-49-1	Irritating to eyes, skin and airways.	---	NA
1,4-dioxane	123-91-1	Very irritating to eyes, skin and airways. Possibly carcinogenic. LC ₅₀ mice inhalation. 37 g/m ³ /2 h LC ₅₀ rats inhalation. 46 g/m ³ /2 h	Limits (1996) LLV 35 mg/m ³ STV 90 mg/m ³ (H) The substance can easily be absorbed through the skin. (C)The substance is carcinogenic	Highly flammable liquid and vapor (H225), Causes serious eye irritation (H319), May cause respiratory irritation (H335), Suspected of causing cancer (H351), May form explosive peroxides (EUH019), Repeated exposure may cause skin dryness or cracking (EUH066)
1,4-oxathiane	15980-15-1	NA	---	# Flammable liquid and vapor (H226), Causes skin irritation (H315), Causes serious eye irritation (H319) May cause respiratory irritation (H335)
1-methylpyrrolidin-2-one	872-50-4	Irritating to eyes and skin. Headaches and chronic eye irritation have been reported at levels of 2.9 g/m ³ .	Limits (2015) LLV 40 mg/m ³ STV 80 mg/m ³ (H) The substance can easily be absorbed through the skin. (R) The substance may impair fertility.	Causes skin irritation (H315), Causes serious eye irritation (H319), May cause respiratory irritation (H335), May damage fertility or the unborn child (H360D)
1-phenylethanone	98-86-2	Irritating to eyes and skin	---	Harmful if swallowed (H302), cause serious eye irritation (H319)
2-methyl-1,3-dioxolane	497-26-7	Induce muscle weakness LC ₅₀ mice inhalation.:59 g/m ³ LC ₅₀ rats inhalation.:80 g/m ³ (ChemIDplus)	---	# Highly flammable liquid and vapor (H225), Causes serious eye irritation (H319).
2-methylcyclopent-2-en-1-one	1120-73-6	NA	---	# Flammable liquid and vapor (H226)
6-methyloxan-2-one	823-22-3	NA	---	# Causes serious eye irritation (H319)
Benzoic acid	65-85-0	Vapors may induce irritation to eyes, skin and airways. (Mild irritant)	---	Causes skin irritation (H315), Causes serious eye damage (H318), Causes damage to the lungs through prolonged or repeated exposure (H372)
Cobalt (Co)	7440-48-4	Cough, shortness of breath, wheezing, asthma. May induce itching at skin exposure.	Group limit values (2011) LLV Inhalable dust 0.02 mg/m ³ (C) The substance is carcinogenic (H) The substance can easily be absorbed through the skin. (S) The substance is sensitizing.	May cause an allergic skin reaction (H317). May cause allergy or asthma symptoms or breathing difficulties if inhaled (H334)
Diethyl phosphofluoridate	358-74-7	An organophosphorus chemical. Old studies indicate that the chemical is toxic after exposure via skin or inhalation (ChemIDplus).	---	NA
Diethyl carbonate (DEC)	105-58-8	Very irritating to eyes, skin and airways.	---	# Flammable liquid and vapor (H226)
Dimethyl carbonate (DMC)	616-38-6	Irritating to eyes, skin and airways. LD ₅₀ rats inhalation. ≥14 mg/m ³ /4h	---	Highly flammable liquid and vapor (H225)
Ethyl ethylphosphonofluoridate	650-20-4	NA, but is an organophosphorus chemical	---	NA

Chemical compound	CAS no. ¹	TOXNET ² Skin eyes, respiratory tract	Hygienic limit values ³	Labelling of chemicals according to ECHA ⁴ : Hazard codes for chem-phys & human health
Ethyl methylphosphonofluoridate	673-97-2	NA, but is an organophosphorus chemical	---	NA
Ethyl prop-2-enyl carbonate	1469-70-1	NA	---	Flammable liquid and vapor (H226), Causes skin irritation (H315), Causes serious eye irritation (H319)
Ethyl propyl carbonate	35363-40-7	NA	---	NA
Ethylbenzene	100-41-4	Irritating to eyes, skin and mucous.	Limits (2015) LLV 220 mg/m ³ STV 884 mg/m ³ (H) The substance can easily be absorbed through the skin.	Highly flammable liquid and vapor (H225), May be fatal if swallowed and enters airways (H304), Harmful if inhaled (H332), May cause damage to organs (hearing) (H373)
Ethylmethyl carbonate (EMC)	623-53-0	NA	---	# Flammable liquid and vapor (H226), Causes skin irritation (H315), Causes serious eye irritation (H319), May cause respiratory irritation (H335)
Hydrogen fluoride (HF)	7664-39-3	Highly toxic and highly corrosive. Dermal exposure leads to severe burns. HF is adsorbed through skin. Inhalation can lead to pulmonary edema and pneumonia. Skin or inhalation may provide high risk of hypocalcemia.	Limits (2015) LLV 1.5 mg/m ³ STV 1.7 mg/m ³ For exposure to a mixture of fluorides and hydrogen fluorides, the level limit value for fluorides shall be applied.	Fatal if swallowed (H300), Fatal in contact with skin (H310), Causes severe skin burns and eye damage (H314), Fatal if inhaled (H330)
Lead (Pb)	7439-92-1	Both skin and respiratory exposure can lead to systemic effects including effects on the nervous system (CDC). Suspected carcinogen.	Group limit value (2011) LLV Inhalable dust 0.1 mg/m ³ Respirable dust 0.05 mg/m ³ (B) Exposure approaching existing professional hygienic limit values and simultaneous exposure to noise levels approaching the action value of 80 dB can cause damage to hearing. (M) Medical supervision may be required for handling of this substance. (R) The substance may impair fertility.	NA
Lithium (Li)	7439-93-2	Corrosive with risk for serious effects on eyes, skin and mucus. Risk for edema and corrosive damage on the respiratory tract.	Group limit value (2011) STV Inhalable dust 0.02 mg/m ³	In contact with water releases flammable gases which may ignite spontaneously (H260), Reacts violently with water (EUH014), Causes severe skin burns and eye damage (H314)
Manganese (Mn)	7439-96-5	Can be neurotoxic chemical	Group limit values (2000) LLV Total dust 0.2 mg/m ³ Respirable dust 0.1 mg/m ³	NA
Methyl methylphosphonofluoridate	353-88-8	NA, but is an organophosphorus chemical	---	NA

Chemical compound	CAS no. ¹	TOXNET ² Skin eyes, respiratory tract	Hygienic limit values ³	Labelling of chemicals according to ECHA ⁴ : Hazard codes for chem-phys & human health
Nickel (Ni)	7440-02-0	Nickel may sensitization of the skin.	Group limit value (1978) LLV Total dust 0.5 mg/m ³ (S) The substance is sensitizing.	Refers to dust of nickel (<1mm in diameter) May cause an allergic skin reaction (H317), Suspected of causing cancer (H351), Causes damage to organs through prolonged or repeated exposure (H372)
Styrene	100-42-5	Irritating to eyes, skin and mucous. Health effects include changes in color vision, fatigue, reduced alertness, concentration and balance.	Limits (2011) LLV 43 mg/m ³ STV 86 mg/m ³ (H) The substance can easily be absorbed through the skin. (B) Exposure approaching existing professional hygienic limit values and simultaneous exposure to noise levels approaching the action value of 80 dB can cause damage to hearing. (M) Medical supervision may be required for handling of this substance.	Flammable liquid and vapor (H226), Causes skin irritation (H315), Causes serious eye irritation (H319), Harmful if inhaled (H332), Suspected of damaging fertility or the unborn child (H361d), Causes damage to organs (hearing) (H372)
Tin (Sn)	7440-31-5	Irritating to eyes, skin and respiratory system.	Group limit value (2011) LLV Inhalable dust 2 mg/m ³	NA

¹CAS no.: Chemical number according to Chemical Abstract Service

²TOXNET: Toxicology data network at NIH (<http://toxnet.nlm.nih.gov/>). The Hazardous Substances Data Bank was used as the database if not otherwise stated. The information presented here focuses on toxicity after exposure via the skin, respiratory tract and eyes.

³Hygienic limit values. Information from (www.av.se; AFS 2015:7 in Swedish).

⁴Labelling according to CLP. Information from ECHA (<http://echa.europa.eu/>). Labelling of chemical, physical and human health hazards are presented giving an indication of possible effects.

The chemical does not have a harmonized classification and labelling. Labelling is presented in the table when most companies have registered the same phrases.

LD₅₀: Lethal dose where 50% of the individuals die.

LC₅₀: Lethal concentration where 50% of the individuals die.

LLV: Level limit value (Nivågränsvärde in Swedish).

STV: Short-term value (Korttidsvärde in Swedish). These values are used for toxic chemicals that do not have Ceiling limit values.

NA: Not available

3.2 Toxicological assessment

The identified organic chemicals emitted by cell-venting from LFP and NMC pouch battery cells were evaluated for toxicological assessment by using data from the databases TOXNET and ECHA. Table 2 provides a summary of potential hazards related to single exposures via air to these chemicals. However, the potential consequences caused by exposures to mixtures of these compounds are not considered in this analysis.

In brief, many of the toxic compounds presented in Table 2 range from mildly to severely irritating to the eyes, respiratory system, and to the skin. For instance, both ethylbenzene and styrene are harmful to the airways.

Several chemicals can be taken up by the skin, including 1,4-dioxane, ethylbenzene, styrene, and 1-methylpyrrolidin-2-one, of which 1,4-dioxane is classified by the Swedish Work Environment Authority as carcinogenic.

Three of the chemicals are phosphonofluoridates or phosphorofluoridates. Their structural similarity to some organophosphorus compounds (e.g. pesticides and nerve agent sarin) indicate that they potentially could be highly toxic, but no or limited toxicological data on those species are currently available in the databases utilized.

4 Discussion and Conclusions

The primary goal of this investigation was to determine the existence of unknown and known chemical species that may present health risks to people in the proximity of an E-Vehicle traffic accident that involves venting automotive Li-ion batteries. Pouch cell batteries of LFP and NMC chemistries were provoked into venting and the results presented in this paper derives from GC-MS screening of the large range of compounds emitted. In these screening tests compounds are foremost identified, rather than quantified. Positive identification is based on a selection criteria for a match factor above 90 using AMDIS software.

This study was conducted on a single cell per test, and most gaseous compounds were detected in low concentrations. The concentrations registered cannot offer a statistical significant material because of the number of tests conducted. To evaluate the quantitative relation between airborne concentrations in the proximity of a traffic accident and the risk for toxic exposures during first responder rescue, a larger or even full scale E-Vehicle battery experiment is necessary.

Among the detected compounds that ventilated from the tested li-ion cells during critical thermal exposure, this investigation confirmed the existence of species such as HF, alkyd carbonates and derivatives thereof previously presented in literature, but most interesting is the identification of some species that to our knowledge are not previously reported as emittants from venting Li-ion battery cells. Some of these can be considered toxic presenting health consequences such as being irritating to the skin, eyes and respiratory system. For some of the previously unknown substances there were no or limited toxicological data available in the databases used. Three of these previously unknown compounds – ethyl ethylphosphonofluoridate, ethyl methylphosphonofluoridate, and methyl methylphosphonofluoridate – are structurally very similar to pesticides but lack toxicological data. Consequently, their potential quantities that could be emitted need to be further evaluated as well as their actual toxicological risk level. A first step towards evaluating the toxicity of these chemicals would be to analyze their potential to inhibit the enzyme acetylcholinesterase. If these chemicals can inhibit this enzyme to a relevant degree, it should be followed up by an *in vitro* screening of medical countermeasures.

Besides determining the existence of unknown and known chemical species, this study intend to offer researchers guidance for subsequent test series aiming at investigating the potential health risks, or lack thereof, associated with the now detected but previously unknown emittants from venting automotive Li-ion batteries.

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Lars Hägglund is a senior research scientist at the Swedish Defense Research Agency with many years of experience in chemical analysis.



Christian Lejon, M.Sc. Engineering Physics, started working in 2008 at the Swedish Defense Research Agency in multidisciplinary projects with vibrational spectroscopy, aerosol characterization, multivariate data analysis and mathematical modelling.



Tobias Tengel has an MSc in chemistry and a PhD in biophysics from Umeå University. He has been working as an analytical chemist at FOI since 2014.



Åsa Gustafsson has a M.Sc. in ecotoxicology and a PhD in lung medicine. She has been employed by the Swedish Defense Research Agency since 2002 and currently also perform Post.Doc. studies at Swetox focusing on health effects related to indoor air pollution and endocrine disrupting chemicals. Previous work include lung related injuries and immunological effects following inhalation exposures to chemicals or nanoparticles