**UNIVERSIDAD INTERNACIONAL DE LAS AMÉRICAS**
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# TRANSLATION AND ANALYSIS OF SOME DOCUMENTS FROM ENGLISH INTO SPANISH AND VICE VERSA

**Thesis Submitted to Obtain the Bachelor Degree in English**

**FABRIZIO CALVO CHAVARRÍA**

**M.Sc. CATALINA GUERRERO TROYO**

**SEDE ARANJUEZ**

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# Abstract

The purpose of this research project is to translate some documents using the various translation methods and procedures that have been thoroughly analyzed in order to provide a precise and complete target text that is as accurate and natural as the source text. The following research question determined the realization of this research project in order to achieve the desired goal: What is the effect of the procedures and methods used to translate the documents *Programa para bomberos dentro del proyecto avanzando con un enfoque regional para movilidad eléctrica en América Latina* from Spanish into English, *Research, and Development of Fire Extinguishing Technology for Power Lithium Batteries*, and *Best Practices for Emergency Response to Incidents Involving Electric Vehicles Battery Hazards: A Report on Full-Scale Testing Results* from English into Spanish for the Academia Nacional de Bomberos? As stated in the research question, the Academia Nacional de Bomberos is the institution that provided the documents to be translated and will benefit with the complete and translated documents, which will be crucial and useful for the respective department that needs them.

Moreover, this research project was carried out with the implementation of the qualitative method, including the implementation of the text analysis of the documents, a glossary with some vocabulary collected during the translation process, and a color coding that highlights the translation procedures used in both the target and source texts. Furthermore, by following these procedures and the objectives stated for this research project, it led to concise findings, such as the proper implementation of the translation procedures in the target text, which maintained the naturality and sense in the source text. This includes the implementation of color coding, which revealed that there were some translation procedures that were more noticeable and utilized due to the naturality of the text. In addition, the implementation of the glossary in the translation

process was considered a key and important aspect due to its utility to get a deeper look and understanding of the context of the text through the vocabulary presented in both documents. Undoubtedly, the realization of this research project opens up a different and more complete perspective on how to translate properly by using the multiple tools at hand. The use of these tools will only bring good effects in the translator's work and students should take advantage of them in their early professional stage because it will improve their skills and point of view before, during and after the translation process.

## Resumen

El objetivo de este proyecto de investigación es traducir algunos documentos utilizando varios métodos y procedimientos de traducción que se han analizado exhaustivamente con el fin de proporcionar una traducción precisa y completa que sea tan exacta y natural como el texto original. La siguiente pregunta de investigación determinó la realización de este proyecto de investigación para alcanzar el objetivo deseado: ¿Cuál es el efecto de los procedimientos y métodos utilizados para traducir los documentos Programa para bomberos dentro del proyecto avanzando con un enfoque regional para movilidad eléctrica en América Latina del español al inglés, Research, and Development of Fire Extinguising Technology for Power Lithium Batteries, and Best Practices for Emergency Response to Incidents Involving Electric Vehicles Battery Hazards: A report on Full-Scale Testing Results del inglés al español para la Academia Nacional de Bomberos? Como se indica en la pregunta de investigación, la Academia Nacional de Bomberos es la institución que proporcionó los documentos a traducir y va a ser beneficiado con los documentos completos y traducidos, que serán cruciales y útiles para el departamento respectivo que los necesite.

Este proyecto de investigación se llevó a cabo con la aplicación del método cualitativo, incluida la aplicación del análisis textual de los documentos, un glosario con el vocabulario recopilado durante el proceso de traducción utilizados tanto en el texto traducido como el original. Además, al utilizar estos procedimientos y los objetivos establecidos para este proyecto de investigación, se obtuvieron conclusiones concisas, como la aplicación correcta de los procedimientos de traducción en el texto traducido, que mantuvo la naturalidad y el sentido del texto original. Esto incluye la implementación de la codificación por colores, que demostró que había algunos procedimientos de traducción que eran más notables y usados debido a la

naturalidad del texto. Adicionalmente, la implementación del glosario en el proceso de traducción se consideró un aspecto clave e importante debido a su utilidad para obtener una visión y compresión más profunda del contexto del texto a través del vocabulario presentado en ambos documentos. Sin duda alguna, la realización de este proyecto de investigación abre una perspectiva diferente y más completa sobre cómo traducir correctamente utilizando las múltiples herramientas que tenemos a nuestro alcance. El uso de estas herramientas solo brindará buenos resultados en el trabajo del traductor y los estudiantes pueden aprovecharlos en los inicios de su etapa profesional porque esto mejorara sus habilidades y su punto de vista antes, durante y después del proceso de traducción.

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# Chapter I

# Introductory Framework

Throughout history, translation has been an important part of spreading knowledge about multiple subjects to people worldwide. This linguistic practice mainly focuses on communicating the information to other people, simplifying how they gathered it by providing access to it in their native language. In this case, this study is related to investigating the multiple translation techniques that have been studied and adapted to the multiple scenarios that require a specific form of adaptation of the message from the "source language" to the "target language and vice versa. In addition, the information gathered during the research process will be applied to the translation of documents that were provided by a national institution, with the objective of not only, demonstrating that the translation techniques are reliable during the translation process, but also providing a non-profit service that will facilitate the need to access the information of a certain topic that they will require in their daily duty, in this case, the main topic presented on these documents is related to electric vehicles and how to handle them in an emergency.

Chapter 1 of this study will present elements such as the problem statement that includes the problems that may affect the Costa Rican population due to the lack of information presented in these documents. The objectives presented in the study will show the vision behind the study's realization. The justification will explain the study's importance and the benefits resulting from the investigation. The antecedents provide backup information on this matter covered in other investigations that will complement the study being worked on. Finally, the scope sets out the goals to be achieved by the end of the research.

## 1.1 Problem Statement

The application of the different translation methods studied in this project was extremely helpful throughout the translation process of these documents, from beginning to end. Applying these methods will ensure that the final product will contain a complete and relevant message, which will be extremely useful for the institution that allows working on these documents.

The first document to be translated using the translation techniques is *Programa para bomberos dentro del proyecto avanzando con un enfoque regional para movilidad eléctrica en América Latina* from Spanish into English, which presents interesting information on electric vehicles, as well as for the documents *Research and Development of Fire Extinguishing Technology for Power Lithium Batteries*, and *Best Practices for Emergency Response to Incidents Involving Electric Vehicles Battery Hazards: A Report on Full-Scale Testing Results*, which were translated from English into Spanish, which also address the proper handling of electric vehicles and their components.

Unquestionably, the firefighters need to receive more information about electric cars. In that case, they will not know how to properly respond to an emergency related to this matter, which would be an obstacle in solving the problem in the safest way possible for them and the people either present in or around the situation. An emergency of any kind will always have a negative effect, regardless of the level of risk, and if the lack of knowledge persists, there will not be a higher rate of successful assistance in these situations, and this can put the lives of both the people and the environment around them at risk.

These situations can happen anywhere, and it is almost unpredictable to know when they will receive an emergency. However, they will surely act efficiently with the proper training and knowledge. For this reason, the Academia Nacional de Bomberos must have access to these translations as soon as possible, as well as more information on this matter, so they can extend this knowledge to the entire team, looking forward to providing better and more specialized assistance when emergencies occur that involve an electrical component in the equation, therefore saving the lives and integrity of the Costa Rican population.

The following research question underlies this investigation: What is the effect of the procedures and methods used to translate the documents *Programa para bomberos dentro del proyecto avanzando* *con un enfoque regional para movilidad eléctrica en América Latina* from Spanish into English, *Research, and Development of Fire Extinguishing Technology for Power Lithium Batteries*, and *Best Practices for Emergency Response to Incidents Involving Electric Vehicles Battery Hazards: A Report on Full-Scale Testing Results* from English into Spanish for the Academia Nacional de Bomberos?

## 1.2 Objectives of the Investigation

### 1.2.1 General Objective

To analyze the effect of the procedures and methods used to translate the documents *Programa para bomberos dentro del proyecto avanzando con un enfoque regional para movilidad eléctrica en América Latina* from Spanish into English Research and *Development of Fire Extinguishing Technology for Power Lithium Batteries* and *Best Practices for Emergency Response to Incidents Involving Electric Vehicles Battery Hazards: A Report on Full-Scale Testing Results* from English into Spanish for the Academia Nacional de Bomberos

### 1.2.2 Specific Objectives

- To translate the documents “Programa para bomberos dentro del proyecto “avanzando con un enfoque regional para movilidad eléctrica en América Latina” from Spanish into English, “Research and Development of Fire Extinguishing Technology for Power Lithium Batteries from English into Spanish, and “Best Practices for Emergency Response to Incidents Involving Electric Vehicles Battery Hazards: A Report on Full-Scale Testing Results” from English to Spanish for the Academia Nacional de Bomberos
- To apply various translation techniques to the documents in order to achieve natural and accurate target texts
- To evaluate the effect of the translation techniques applied to the documents

- To create a glossary with the most relevant terminology found in both texts

## 1.3 Justification of the Study

This study aims to investigate the different translation methods that different translators have used over the years and to learn and understand the meaning behind the application of these methods according to the context, the cultural influence, and the relevance of the subject that has been translated. In addition, these methods will be applied to the translation from English to Spanish and from Spanish to English of some official documents provided by an institution that will benefit from a voluntary and non-profitable translation; in this case, the beneficiary institution is the Academia Nacional de Bomberos de Costa Rica.

These documents mainly focus on information on electric cars that use lithium batteries and how to handle situations involving this type of vehicle properly. Translating these documents will greatly benefit the institution's staff in their daily labors. In addition, it will provide more knowledge that will facilitate the training process related to the topic presented in the documents for the current staff of firefighters and the new and future arrivals at the institution.

Throughout this process of developing the study, the institution will be assured of receiving a correct translation for each document that will be processed using the translation methods that were analyzed in this study. Certainly, the Academia Nacional de Bomberos is actively training and educating great firefighters who need the greatest amount of information related to this matter, as they will ensure the country's safety. They must be as prepared as possible for any eventuality. Providing this contribution to the institution will be extremely helpful as they will acquire a new and updated tool to implement in their labor.

## 1.4 Antecedents

Newmark stated that “a hundred years ago, the majority of translated texts were religious, literary, scientific and philosophical” (1991), and only the educated people of each country read these translations. In the 19th Century, translators began to emphasize accuracy rather than the style of the text in their translations because of globalization, which increased the demand for translations, especially the ones in which technical translation was implemented. According to Byrne, the translation of scientific and technical knowledge has played a tremendous role in the development of human civilizations and the advancement of science and technology throughout history because it was a very valuable commodity. (2009) Furthermore, Byrne pointed out that technical translation is a key part of the translation industry.

The publication of the most important theories on technical translation began in 1960, and one of these first publications took place in Europe. This document was a guide on translating scientific and technical texts, including examples in German and English. These texts covered the fields of science and technology and other subjects related to technology development, such as economics, law, and business.

Without any doubt, generations of translators have translated many written works that have theorized and applied multiple techniques in their translations, seeking to provide the correct translation for each word, expression, and meaning. According to George Steiner, the history of translation is divided into four periods, beginning with the first period, which goes from the Roman translators Cicero and Horace to Alexander Fraser Trytler, followed

by the second period, which goes up to Valery. The third period was from Valery to the 1960s, and the fourth and final period was after the 1960s.

Significant translations took place during these four periods. However, an important example of these works is the translation of the Bible, which has been a work in progress for centuries, and it has taken more than two thousand years to translate the Bible from its original language into two thousand others around the world. The Bible has been translated into 2400 of the 6900 languages spoken around the globe, and its translation is available to ninety-eight percent of the world's population, which were accurately adapted into a language that they can understand properly and fluently. These figures prove that there is much work behind translating a book of such importance in the history of humankind. The translation of this book has even reached the point that in the Twentieth Century, the translation of the Bible was considered a social action by religious and political organizations that aspired to implement the translation of the Bible into unique languages spoken in primitive and tribal societies. It is important to highlight the translation of this book because, as mentioned before, it was a work in progress in which many people have put their knowledge and effort into translating all the contents as accurately as the original work.

The translation in the Arab world can be traced to the times of the Assyrians in the first half of the second century AD. Assyrians translated a large amount of heritage into Arabic, a Semitic language belonging to the Semitic language family whose origin has a history of about a thousand years. Some of the first Arabic transcriptions were presented around the Fourth Century, and one of this region's most important pieces of literature was established in the first half of the seventh Century: the Koran.

The translation of the Koran was the most remarkable moment in the history of the Arabic translation, and the first official translation into Persian was carried out during the Abbasids. Like the Bible, the Koran has been translated into different versions in every language worldwide. The main purpose of the translation of the Koran was to provide the specific meaning of the message of Islam to non-Muslims and Muslims who either speak Arabic or not, making it an important era for the Arab world because it provided the holy Koran for those who did not speak Arabic. Some of these translations are preserved in Western libraries because there was an extreme interest in translating this book. In addition, it is interesting that the Muslims reached an agreement stating that the Koran's style was inimitable, making it impossible to transfer this aspect into translation. As a result of this declaration, the translations cannot be used as a substitute for the original, which requires access to the original Arabic version. This Islamic rule was strongly supported to the point that the government-sponsored this movement, and seminars were set up during the Islamic empire to organize the Koran's translation flow.

In 1605, “El ingenioso hidalgo Don Quijote de la Mancha," written by Miguel de Cervantes Saavedra, was published in Madrid by Juan de la Cuesta, and a couple of years later, the first part of the play was translated into English. Jacob Tonson was honored to publish in England a special edition of the "Quixote de la Mancha" in their mother tongue, delivered with such dignity as if it had been composed by the Spanish writers themselves. This edition includes the extended version of Cervantes' bibliography, which Don Gregario Mayans and Siscar originally wrote. According to James Fitzmaurice-Kelly (1905):

> England was the first foreign country to mention Don Quijote, the first to translate the book, the first country in Europe to present it decently garbed in its native tongue, the first to indicate the birthplace of the author, the first to provide a biography of him, the first to provide a biography of him, the first to publish a commentary on Don Quixote, and the first to issue a critical edition of the text (p. 2).

In addition, around six translators added their vision to this work of literature, reaching a total of fifty-three editions between 1612 and 1800. Of all the translations of Quixote into English presented from the first publications, the most relevant translation that caught the attention of the Cervantes scholars from Spain and other foreign countries was the one translated by Thomas Shelton. This translation was concluded in 1607, but it was not published until five years later, and its relevancy not only, comes from the fact that it is the only version created by a contemporary of Cervantes but also, from the fact that it was translated into the same English spoken in the same era from Shakespeare.

Costa Rica and its literary works are important in its cultural history and have been in extreme danger. Costa Rica lacks cultural image because its literary works, such as "Su Quijongo," appear non-existent in the National Library of France. Similarly, "The Segua," written by Alberto F. Cañas, does not appear in the German catalogs because only about twenty records of this important writer in the history of Costa Rica are recognized in that country. This is proof that if the works of the author of a literary work are not translated, they are marked as inexistent by humanity. Unfortunately, a biology book has more relevance and interest nowadays than an almost extinct book due to the lack of recognition.

Believe it or not, this lack of recognition causes the "death" of these books, which threatens literature as a whole, which, in this case, is extremely dangerous for Costa Rican literacy. The existence of national literature requires a worldwide representation through the translation of these literary works to increase the number of readers or writers willing to consume these contents.

The small number of Costa Rican authors who have taken their works overseas is very rare, and the lack of merits in their own country is a key factor. For this reason, it is important to keep these written works alive in the minds of the current and future generations and to promote the importance of keeping these literature pieces alive by working on more translations to increase knowledge about Costa Rica and its culture presented on paper.

## 1.5 Scope

1. To provide a proper and complete translation that will be useful for the institution and the people related to it
2. To consider the multiple aspects related to the different translation techniques that can be applied during the translation process of the documents provided by the institution
3. I look forward to the study's complete and relevant final product to work efficiently and take advantage of the time invested in this investigation.

# Chapter II

## Theoretical Framework

Chapter 2 of this study will cover some aspects that must be taken into consideration by translators before, during, and after the translation process. Some of these aspects will be presented by starting with the text analysis and the text styles, which are mainly focused on guiding translators in a technical way on how to get to know the style of the document to be translated and also the getting to know the document by doing the previous look of what they might encounter prior or getting right into the translation. Another key point covered is the Stylistic scales that can be developed in translation, which are divided into formality, generality, difficulty, and emotional tone. These types of stylistic scales have characteristics that will change the way of expression of ideas that the translators have to translate documents. Following the stylistic scales, the text function, which is divided into informative, expressive, and vocative, will be covered to provide information on how translators have to transfer and adjust the ideas and the context from the source language into the target language of the translation.

Furthermore, the most important aspects, in my opinion, are the translation methods, divided into semantic and communicative, as well as the translation procedures that have been used and developed by translators in order to make the translation process more personalized for each document, because each translation method or procedure will have different characteristics that can be applied in different types of documents, depending on the context and the way the source language or even the author expresses its ideas. Without a doubt, there are many translation procedures, but this chapter will be focused on developing the procedures of transposition, modulation, omission, amplification, explicitation, literal translation, and punctuation changes. As mentioned before, this procedure can be applied in different scenarios; however, some of them can work together as well due to some similarities that make translators have a handful of variants that can be applied in their works.

Finally, the last aspect of this chapter mentions the use of the glossary as a tool that will gather information presented during the translation. The use of the glossary provides multiple benefits for the translator, as well as for the translation process, and this information is covered alongside the information on how to properly develop and take advantage of this tool as a translator.

## 2.1 Text Analysis

Before translating a document, book, text, or even an expression, it is important to analyze the text to get a first look at what you might encounter during the translation process. The first thing a translator has to do is to read the text first, focusing on understanding both the general and the close reading. In the case of the general reading, the translator will be focused on understanding the subject and the concepts related to the document that is going to be translated.

The translator might opt to access encyclopedias, articles, textbooks, and specialist papers that provide information that guides the context regarding the document's topic. As for the close reading, the translators might find it useful when the text is challenging and requires a closer analysis to understand its context. Sometimes, the context or the words used by the author might not make sense at first sight; that is why it is important to analyze if the information presented in the text has been applied figuratively, technically, colloquially, even musically, and translators need to figure out what is the relation of this information with what was the purpose of the message written by the author.

It is also important to mention that it all depends on the intention of the text as well as the intention of the translator because it all reaches the same end, providing the same message in both situations. The intention of the text is related to the point of view provided by the author, and the author intends to adopt that point of view and properly convert it into another language without changing the original intention of the author into another language. According to

Newmark (1988), the translation process can be compared to an iceberg. The tip of the iceberg shows what can be seen at first sight on the document, and the iceberg contains all the information behind the message, which can be ten times as much as what cannot be seen until the translator goes deeper into the text. (pag.12)

### 2.1.1 Text Styles

Four texts, either literary or non-literary, are distinguished: the narrative, which is related to the sequence of events, and the dynamism of the verbs applied to the text. The description is considered static, and its emphasis is on linking verbs, adjectives, and adjectival nouns. Discussion, which is how the ideas are treated in the text, focuses on abstract nouns, verbs of thought, mental activity, logical argument, and connectives—lastly, the dialogue, with empathies on the colloquialisms and phaticisms.

### 2.1.2 Stylistic Scales

The stylistic scales Newmark presents are the scale of formality, the scale of generality or difficulty, and the scale of emotional tone. Each scale has its point of view that can be used in the translation methods to modify and properly apply the expressions from one text to the other so as not to lose their complete meaning during the translation process.

#### 2.1.2.1 Scale of Formality

The scale of formality uses different ways of expressing the meaning of a word by adapting it into the expressions: officialize, official, formal, neutral, informal, colloquial, slang, and taboo. These expressions will provide the same meaning as what is presented in the text but expressed according to their point of view.

#### 2.1.2.2 Scale of Generality or Difficulty

Similarly, as the scales of formality, the scale of generality or difficulty uses simple, popular, neutral, educated, technical, and opaquely technical expressions to describe the meaning of what is written in the text.

#### 2.1.2.3 Scale of Emotional Tone

As for the scale of the emotional tone, implement expressions such as intense, factual, and understatement when explaining the meaning of words and expressions. In addition, there is some correlation between formality and the emotional tone; the official style tends to be factual, and some colloquialism is emotive, but in translation, it is important to consider that in different languages, these expressions might not be similar in different countries.

### 2.1.3 Text Function

Newmark (1988, p. 39) thought the translation process was implicitly based on the theory of language. Every translation is an exercise in which linguistics should be applied. Newmark considers the theory of language, presented by Buhler and adapted by Jakobson, which presents the expressive, informative, and vocative as the main functions of language and the main purposes of language use (1988, p. 39).

#### 2.1.3.1 Informative

As for the informative function, it is important to mention that its core is related to the external situation, the facts, and the reality outside the topic. Translators must be aware that informative texts are related to any knowledge written works, such as a textbook, a technical report, a newspaper or periodical author, a thesis, and scientific papers.

Most translators who translate these texts work in international organizations, multinationals, private companies, and translation agencies. It is quite normal that these texts need to improve written skills. However, translators have to make corrections not only, to accommodate the ideas in the text, but also to the style that was originally written in. They look forward to adapting it for readers to understand properly. In addition, nowadays, many translations of this document are better than the original, or it should be this way.

#### 2.1.3.2 Expressive

According to Newmark (1988), the core of the expressive function is the mind of the speaker, the writer, and the originator of the utterance, which was considered a way to express feelings irrespective of any response (p. 39). As for translation, the expressive function is divided into some types: serious imaginative literature, which expresses that out of the principal types of literature, lyrical poetry is the most intimate way of expression, and plays address literature to a large audience. In these scenarios, translation helps when it comes to cultural expressions to keep their meaning and expressiveness.

The authoritative statement is the second type on this list, which is any text that derives its authority from the high status or the reliability and linguistic competence of its authors. Authoritative statements are present in political speeches, political documents, legal documents, scientific works, and academic works written by recognized authorities. These texts, despite having the personal signature of the authors, are denotative, meaning that the feelings or ideas are not presented in these written works. The third on the list are autobiography, essays, and personal correspondences, which are expressive only if the readers are from a remote background, converting them into a personal effusion.

#### 2.1.3.3 Vocative

In the vocative function, the content and the form of the text are subordinate to the extralinguistic effect, and by using this function during the translation process, its overall purpose is to bring the same reaction in the audience. However, this involves changing the content and the stylistic features from the original to the target text.

Newmark (1988) considers that the vocative function is “calling upon” how the readership will act, feel, think, and feel in the way the reader intends to react to the text (p. 41). A couple of factors are present in this function. The first one refers to the fact that vocative text is the relationship between the writer and the readership, and the second one states that these texts must be written in a certain way so that the readership clearly understands the language used in the text. For this reason, during the translation process, the translators must review the linguistic and cultural level of the source language before jumping right into the pragmatic part.

### 2.1.4 Translation Methods

There has always been a debate about whether translators should translate in a literal way or if they should opt to translate with complete freedom. This argument has existed among translators from the first century before Christ to the nineteenth century. Many translators wanted the truth to be read and understood, that is why they created a sort of translation tree that expresses the relevant factors while translating, such as the spirit, not the letter, the sense, not the words, the message rather than the form, the matter not the manner.

This argument was theoretical, and aspects such as the purpose of the translation, the nature of the readership, and the type of text were not discussed since the writer, the translator, and the reader worked together, but Newmark (1988, p. 45.) considered that "the context has changed, but the basic problem remains." In addition, he considered there are eight types of translation methods: word-for-word translation, literal translation, faithful translation, semantic translation, communicative translation, idiomatic translation, free translation, and adaptation. Two of these methods will be covered, which are the semantic and the communicative translation, following the descriptions provided by Newmark itself.

#### 2.1.4.1 Semantic Translation

According to Malmkær (2018), the definition of semantics in translation is “the study of meaning and to the extent that the translation concerns the conveyance of a message in one language that means the same as a message previously conveyed in another language, meaning is a central concept in translation theory” (p. 31).

The semantic translation method differs from the "faithful translation" as it mainly focuses on the aesthetic value of the text, which considers how natural and beautiful the sound of the source language is in the text. However, the semantic translation is more flexible than the faithful translation when reproducing words in the target language. In addition, it is also used to translate cultural words into a neutral equivalent state in the target language. According to Newmark (1988), the semantic translation looks back to the formal values of the start text and is focused on retaining as much information as possible (p. 31). This might put the meaning in danger of getting lost throughout the process. This method seeks a change of meaning of the source language, ending up being more complex, and translators tend to translate, ending up as more specific than the original text.

#### 2.1.4.2 Communicative Translation

The communicative translation renders the contextual meaning of the original text to make the content and the language as comprehensible as possible by the readership. This translation method is free and idiomatic, and it must be focused on being smoother, simpler, and clearer rather than being mainly focused on the content of the text. The translators have to attempt to produce the same effect on the readers of the target language as it was intended to have that impact on the source language readers. This can be possible by considering the linguistic, cultural, and pragmatic conventions of the target language instead of using the words from the source text as closely as possible, infringing the norms of the target language and affecting the message's meaning.

## 2.2 Translation Procedures

Translators have developed multiple translation procedures that fit the different texts. Depending on the text and its context, translators must apply one or multiple translation procedures to provide the most accurate target text. To find a suitable procedure, the translator is not only, required to know the differences and similarities of the language systems, but also to have enough understanding of the register of the target text. By using these procedures, translators manage to transfer complex ideas and cultural elements and adapt unique grammatical functions from one language to another, taking into consideration that all this information must be translated properly in order to avoid the mishandling of key information that may affect the final product. Further in this chapter, translation procedures such as transposition, modulation, omission, amplification, explicitation, literal translation, and punctuation changes will be developed from a personal understanding of their usage in translation, as well as the point of view from different authors that have developed the theory on this translation procedures.

### 2.2.1 Transposition

The technique of transposition is related to transposing the grammatical structure of source language text into the structure of the target language in order to convert the messages as accurately as possible. Transposition is an alternative language that involves the sense of the expressions from the source text into a grammatical change in the target text, affecting the parts of speech, the word order, the voice, the mood, and the tense of the verb in the sentence. Chiara Grassilli (2016) considered that the transposition procedure is related to free translation, in which the translator can proceed with the translation completely. However, it follows grammatical and stylistic basics that keep the translator on track to developing a proper and organized translation. About the grammatical part, transposition works as finding a replacement of a word or expression with another word of expression without changing the meaning of it.

As for the stylistic perspective, transpose expressions do not have the same relevancy as long as they maintain the same meaning and if the form used properly fits with the context as well. In other words, this is a process in which the expressions change their sequence when translated; for example, blue ball in English will be translated into boule bleue in French. You can see that it maintains the same grammatical idea, and it fits well with the expression without changing the meaning. Of course, it is easier to detect within two words, but it creates an overall idea of how to identify this procedure.

According to Newmark (1988), a shift or transposition is a translation procedure involving a change in the grammar from the source language to the target language (p. 55). Newmark (1988, p. 55) considered that this translation method is divided into four types; the first one is related to the change from singular to plural or the position of the adjective that changes automatically from one language to another, giving the translator no choice to follow these grammatical differences. An example of this type can be represented using the English word "advice," a singular word. However, if we translate this same word into French, it will be "des consents," meaning the same as the English word, but written and expressed in plural. The second type is mainly required when the grammatical structure from the source language is not the same or does not exist in the target language.

If we compare English and French, most of their expressions can be directly translated with slight changes without putting the context at risk, but this might not be the case with German and Greek, for instance. Both languages may have completely different ways to express their ideas, and translators have to convert this from one language to another, seeking coherence between texts. As for the third type, there could be occasions where the literal translation is grammatically possible; however, it may affect the naturality of its usage in the target language. Furthermore, the fourth type of the transposition method is related to the virtual lexical gap in the grammatical structure.

Newmark (1988) stated that certain transpositions appear to go beyond linguistic differences and can be regarded as general options available for stylistic consideration (p. 87). This can be seen when a complex sentence can be converted into a coordinate sentence or even two simple sentences, for example: “Si lui est amiable, safemme est arrogante" which is a complex sentence from the source language. "He is (maybe) very pleasant, but his wife is arrogant," which is the coordinated version of the target language, and "He is pleasant; his wife, however, is arrogant.", representing the same idea but in two sentences. Transposition is the only procedure in translation that is concerned with grammar. Most translators apply this translation method intuitively, but Newmark considers that the comparative linguistic research and the analysis of the corpora of the texts in both the original and the translation will uncover more serviceable transpositions.

### 2.2.2 Modulation

What first comes to mind when speaking of the modulation technique can be related to mediation or comparison between the different ways of conveying the message in the translation. For example, depending on the information in the source text, we, as translators, have to decide whether the document should be delivered in a literal or coherent form.

According to Elena Croitoru and Antoanela Duminitrascu (2006), modulation focuses on the events and state of affairs the words refer to. It is also related to how the speaker of the target language conceives a word, phrase, structure, or text span (p. 32). This translation procedure is often compared with the Transposition procedure. The basic principle of the modulation technique is the change of the point of view in the same situation. However, the transposition consists of changing the grammatical structure but always keeping the same meaning of the context presented in the text.

Due to this comparison between the two, Van Hoof (2006, p. 33) described modulation as "a type of transposition at the global level, applying to categories of thought, not grammatical categories," which confirms that this procedure is a manner of point of view and perspective of the situation, not completely guided by what is written on the text and how its ideas must be transferred into the target language. In addition, modulation provides a major contribution when it comes to offering a new perspective between semantics and pragmatics, and it is also related to contrastive linguistics because it helps clear out both the source text and the target text. The same situation can be equated with the same meaning of a sentence, for instance, a modal verb or phrase in the source text can be rendered by another modal or verb form with the exact same meaning in the target language.

Newmark (1988) pointed out the definition provided by Vinay and Darbelent on modulation, which is a variation through a change of viewpoint, perspective, and very often a category of thought (p. 88). The two modulation types are straightforward: the standard modulation is used in bilingual dictionaries, and the free modulation is mainly used by translators when the target language is not adaptable to the literal translation technique.

According to Newmark (1988, p. 88), modulations are divided into eleven categories, but in his opinion, only one of them is the most relevant, which is the negated contrary. The negated contrary or positive four double negatives can be applied to any action that is determined by a verb, quality, adjective, or adverb that is present in the sentence. Using the examples of n'a pas hesite (He acted at once) and n'est pas lache (He is extremely brave), you can notice that the translation is completely free in both scenarios. However, as for the negated contrary, these two expressions depend on their tone of voice to formulate the context since they might look and sound quite similar.

### 2.2.3 Omission

As far as the omission technique is concerned, its function is related to its name: to omit or eliminate expressions or words from the source text in the target to adapt properly and convert the correct message in the translation. Vipin Kumar Sharma (2015) stated that the addition and the deletion accompany the omission, and they are used in translation to ensure the correct use of dissemination of the current knowledge and the information that facilitates the translation studies as well as helps to keep the pace of both globalization and localization factors (p. 1).

Dimitrios (2004) stated the vital term of the Omission procedure, considering that this procedure has been neglected. He stated:

> Whereas it has been amply demonstrated that many translators, at least between Indo-European languages, exceed their sources in length, comparatively fewer studies have approached instances in which, for various reasons, translators have not translated, 'omitted' something from the source text in their translation. Many recent dictionaries of translation studies do not have any particular entry for the term 'omission,' or (at least) for some of its partial synonyms, 'implication,' 'subtraction,'

> 'economy,' 'condensation,' or 'deletion.'" Moreover, books on translation studies that incorporate translation strategies briefly mention omission, mainly in close connection with its more 'positive' counterparts, i.e., addition and explication (p.7).

Newmark (2015, p. 5) also considered that the source language is full of idioms, phrases, and foreign words that could differ in meaning while translating, and the translator is justified to eliminate those words that are redundant or simply unnecessary to be translated. Translators work hard to translate the same or at least an equivalent number of ideas from the source text into the target text. However, there are some scenarios in which it is necessary to use the omission to avoid the redundancy and the awkwardness of ideas.

This procedure is often used when the source language tends to be redundant. In this case, the omission procedure is used to "drop" words usually placed in the source language text that are not used in the target language during the translation process. Zethsen (2018) stated that well-known translation strategies, such as omission, are more commonly applied to intralingual translation (translation or rewording within a language) since the overall purpose is to involve a degree of simplification. (p. 370)

Furthermore, some of these words are often encountered due to the cultural differences between both languages. As mentioned, translators often neglect the use of omission because they think this "costs and lacks an effective communication" instead of being useful words for the transition of meaning in the target language. It was considered that the omission, despite being avoided even if the information is not important for the understanding of the text, will have a positive impact on the quality of the translation.

### 2.2.4 Amplification

Let us take a look at the name of the technique. It seems that the idea of amplification is to extend or amplify the statements written in the source text into the target text, to convey the message in a more complete and complex way, always retaining all the information that must not be omitted when translating a document, no matter how sensitive it is.

The meaning of amplification in literature refers to making something stronger, bigger, louder, or more important. In other words, to make an exaltation on words and expressions or add an extra meaning to what already is. As for the implementation of amplification in the translation process, this procedure is mainly used to add more information to the target language to make the translation more comprehensible and coherent for the readers.

Using this procedure, a translator should provide as much information on the target language as it was received from the original text; however, sometimes, the final translation requires more words to convey the message than originally presented in the source text. For example, the expression "the change against him" is composed of four words, but when it is translated to French, for instance, it will become "I'accusation portée contre lui," ending up being "the charge brought against him" a five-word expression (p. 52). The amplification is required in this scenario since the naturality of both languages requires either more or fewer words to adapt the whole idea. This does not mean that the target language will end up with more information when using this procedure since this is focused on providing enough information to fulfill what is required to convey the message as completely and naturally as possible.

The amplification method can be used in three scenarios while translating a text. The first one is related to the implicit into the explicit information, expressing that the implicit information can be naturally comprehended in the source language. However, the readers from the target text will need help understanding the same way. Due to this difference between one language and another, the amplification procedure is used to add up explicit information in order to eliminate this gap between both languages. The second one is related to the grammatical differences between the target and the source language and the target language that can affect the meaning of the message by the naturality of the language. As for the third and last one, the cultural terms presented in the source language require a description that explains the meaning behind it in order to transfer it into the target language properly. This information can be gathered and explained in the translation glossary. By implementing the amplification procedure, this can be converted for the readers to understand what the author was referring to in the original text.

### 2.2.5 Explicitation

The explicitation technique may be related to making some key or delicate information in the source text more explicit, which needs to be treated differently in the final product in the target language in order to avoid any confusion or misunderstanding in the final version of the translation. The proper way to define the functionality of the Explicitation is when the source language has a more general and non-complex meaning and will be translated into the target language but convert that original meaning in a more specific way. Vinay and Darbelnet described this translation procedure as a "stylistic translation technique," making the explicit context of the target language the implicit context that is only present in the source language. However, it can originate from the context or the situation presented in the text.

Renata Kamenická (2007) stated that the explicitation method is one of the translation procedures that attracted translators of both source languages and the target languages. Since the formulation of the explicitation hypothesis, it has become very lively (p. 2). The explicitation hypothesis was formulated by Blum-Kulka, who suggested that explicitation “may be an inherent feature of the translation process” (Kulka, 1986, p. 81). Furthermore, this hypothesis is a historical development considering "a translation will be more explicit than a corresponding non-translation form either the source text or a parallel text in the target language."

The explicitation procedure is useful when the translator wants readers to understand the information they are reading. In addition, it can be used as a bridge for both the source language and the target language when both have different cultural backgrounds or multiple language differences. For example, the informative text uses the explicitation procedure when the information translated on the target text should be plain and without redundancy when the source text is fully referential and conceptual. Translators are the ones who work as an intermediary and the ones who have to be able to conduct intercultural communication and provide a target text that makes readers understand with clarity the context without encountering aspects that may cause a hard time understanding the context translated.

### 2.2.6 Literal Translation

Literal translation is one of the easiest techniques to understand its main function when translating any text. This technique works by translating every word, phrase, and format from the source text to the target text. This could be used well when the translator is asked to translate the text as similarly as possible without worrying about adapting the message or idea to another language. This does not mean copying and pasting from one language to another but simply translating what is written. Let us compare literal translation to free translation, according to Barr (2017). Literalism is a technique, and free translation is not a concrete method, making it impossible to develop an exact principle of what is "free" beyond not meeting the "literal" criteria that define if a translation can be free one way and literal in another (p. 3).

The word-for-word translation is another name that translators use to refer to the literal translation, and its main purpose is to directly transfer the source language text into an appropriate target language that follows the grammatical and idiomatical procedures. This procedure is most commonly used when translating two languages that share the same idiomatic structure, for instance, French and Italian, or if they share the same cultural ideology because both languages have the same principals and have more similarities than differences, simplifying the process of either understanding the context and translating that context into the target language.

In the case of English and Spanish, not always the literal translation conveys the same meaning of the expression, for example, with the Spanish idiom of “Te estoy tomando el pelo" which means that the person is messing around or joking around with another person. If we translate this expression into English, it will end up saying, "I'm just pulling your hair," which is the same format as the words used in the expression, but the proper way to translate this expression while maintaining the same context of the idiom is "I'm just pulling your leg," in other words, in messing around or joking with you.

Furthermore, Newmark (1988) considered that the excessive emphasis on linguistic discourse analysis created the idea that the only unit of translation is the text. If a translator uses the literal translation procedure, it can be appealed as an overriding authority (p.69). In other words, literal translation was rejected as a legitimate translation procedure. However, he also stated that the literal translation is correct and must not be avoided by translators as long as it secures referential and pragmatic equivalence to the original.

### 2.2.7 Punctuation changes

This translation procedure could consider more the fact that the way punctuation is implemented in the text may need to be changed in the target text in order to create fluency for the reader, as well as provide guidance to understand the text without misspelled punctuation symbols that could affect the meaning of the translated message. In the case of the English language, punctuation is often used incorrectly or inappropriately, causing the reader or even the translator to misunderstand the meaning of a segment or a sentence in the text. The punctuation in other languages follows a syntactic structure, and some marks are required in that language, but in English, those marks are not necessary to be implemented. It is important to mention that punctuation has two specific purposes in most languages: one is to regulate the flow of the discourse, and the other is focused on the stylistic effect of the text. Despite these purposes, punctuation still needs to be used correctly. Wrong positioning of the punctuation symbols can dismantle the whole idea of the text, leading to a misunderstanding not only, of the message translated, as mentioned before, but also of the whole point of view presented in the text.

Newmark (1988) considered that punctuation in a text can be powerful but easily overlooked, and the translator must compare and check the punctuation in their version of the text and the original one (p. 58). Punctuation is an essential aspect of contextual analysis because it offers a semantic guide about the relationship between sentences and clauses, which can differ in all languages. For example, the suspension point in French indicates a pause, whereas in English, it indicates an omission of a passage. Another example is the exclamation mark, which is used in German to draw attention to the titles of messages in order to add up an emotional effect, or the use of commas as conjunctions in the French language.

According to Dana Awad (n.d.), punctuation is important in creating a logical sentence to communicate accurate meaning (p. 1). However, only a few studies have highlighted the relevance of this matter while translating. Those studies were based on something other than bilingual analysis to back up their information and put their attention on the grammatical theory of punctuation, discarding the cognitive nature of those marks. Multiple research studies state the importance of punctuation, considering that following a didactic approach will offer a method to teach translation students by comparing the grammatical system of both the source and the target language. This grammatical system should follow the orthographic differences such as the usage of the question or exclamation marks, the typographic differences of when to use the spacing before and after the punctuation, the syntactic differences of the punctuation between connectors, and the textual differences.

Another study on the didactic approach, written by Mogahed, states the importance of punctuation in maintaining or modifying the meaning of the source text. He expressed his theory with the following example; “I have taken several science courses this year; my favorite was neuroscience.” from an English to Arabic translation (Mogahed, 2012, p.3). Mogahed used the semicolon instead of a comma, which normally is something that most people use in this scenario. He explains that using two independent clauses with a comma followed by conjunction produces a slight change in the meaning from the original version because it emphasizes the contrast between the first clause and the single course of the second clause.

These studies provide an important point, which is that sometimes the punctuation marks need to be updated during teaching and practicing translation. The reason behind this may be because the general rules of punctuation are almost similar among languages, being considered universal, and no matter if the punctuation is not followed, the readers of the target language will understand by themselves what is the meaning of the source text.

## 2.3 Glossaries

Throughout this chapter, useful translation procedures that will assist in the translation process have been conveyed. However, there is also another tool that is as useful as this procedure, and that is the glossary. In this section of the chapter, information related to the glossary will be covered, taking into consideration how relevant it is for the translators as well as how it will impact the translation process and the benefits that the translator must take advantage of in order to simplify this process. In addition, information regarding the creation of the glossary is presented in this part since it is important to know how to use and develop this tool properly in different translation scenarios.

The glossary that translators develop is a list of the specific terms that were translated into both the source and target language. Usually, translation glossaries are used in technical texts or even in the marketing area; however, it is also beneficial for any project in which the meaning of the text content is conveyed across languages. Translators can take advantage of this glossary to take a step further in their translation because sometimes it is a difficult process, depending on the topic or the context presented. It is always useful to add some assistance to reduce the complications presented in this process by boosting the translation process. This will provide benefits while translating since it can help the translator clarify doubts encountered during the translation process. It will also provide additional help while trying to understand the context of the original text. Some of the information presented in the text might need to be clarified initially, but a deeper look at the terminology will increase the understanding of the subject. Also, it will help the translator to identify words or phrases that do not have the same meaning in both languages. Another key benefit on this list is that it will reduce the level of risk of being inconsistent during the translation because the development of the glossary will increase productivity and accuracy, making the translator work faster and more efficiently, decreasing or disappearing those unwanted last-minute changes that can cause a complete cool down of the translation while reviewing the information again to look what information was mishandled.

It is also important for a translator to understand how the glossary needs to be created and what information must be considered even before starting the translation process. That is why it is important to know the creation process of the translation glossary. Sherry E. Gapper (n.d) considered that after gathering all the information, it is time to start creating the glossary. However, it is important to define the content that will be developed in this part, as well as the format that will follow (p. 75). Two formats should be evaluated according to the content presented: the macrostructure and the microstructure. When developing the macrostructure, the translator should take into consideration the general organization of the glossary as well as if it is necessary to add aspects such as a preface, user guidance, a table of abbreviations, or even an appendix. In addition, it is also important to consider if the glossary should be divided into sections related to the language (English to Spanish or vice versa) or into sections according to the topic. The microstructure is mainly focused on designing the structure of the preface and the articles according to the information gathered on the topic.

It is not necessary to add all the terms related to the information since not all of them have the same relevance on the topic, or maybe it is not necessary to be included in the glossary due to the lack of recognition in that field. In addition, it is impossible to add all the terms related to the topic because it will overextend the glossary. That is why it is recommended only to gather the fundamental terms that will provide the information that will help in the understanding process of the topic. Once the selected terms are gathered, it is also important to limit the amount of information that will be provided about that term. An excessive amount of information will cause a feeling of "crowdedness" while consulting the glossary, where all this information is packed up with information that might not be necessary to be there in the first place.

Some aspects that can be presented while developing these terms are defining the terms, defining the format used to develop the terms, determining which alphabetic order is the most appropriate, and determining the order of the information presented in each preface. It is also important to check the final product to analyze if the information provided and how it was developed on the glossary is as useful as initially intended.

# Chapter III

# Methodological Framework

Chapter 3 presents multiple aspects that must be followed for proper data collection and how they must be applied in the study. These aspects are that the research approach is related to the approach that must be followed due to the naturality of the study; in this case, since it is a translation study, it is important to implement a specific method of the research approach. The research design explains the theory of descriptive research, its characteristics, and the steps that must be followed to implement it properly in the study. Information sources are another aspect presented in this chapter, which contains the primary, secondary, and tertiary sources that will be used to elaborate on this study. The analysis categories define translation procedures and translation methods. Finally, the data collection instruments and the collection data process and data analysis explain the instruments used for collecting data and how the process collects and analyzes the information gathered.

## 3.1 Research Approach

Three methods can be applied to the research approach: qualitative, quantitative, and mixed. Qualitative research is mainly used when the research is involved in collecting and analyzing non-numerical data, such as texts, videos, or audio messages, to understand its concepts, opinions, or experiences (Bhandari, 2023, p. n.d.). Quantitative research is quite the opposite of qualitative research since it is used to collect and analyze numerical data, making it essential when it comes to detecting trends and averages, making predictions, testing relationships, and generalizing results for large populations (Fleetwood, 2023, p. n.d.). Mixed research combines qualitative and quantitative research, which provides the benefits of both methods that can act as one in the research study (George, 2023, p n.d.). Since this study is focused on translation, the research method that will be used is qualitative research because its characteristics are the most appropriate for translations. According to Bhandari

(2023, p. n.d.), qualitative is used to understand how people experience the world, and it has a variety of approaches that make the process more flexible and emphasize recalling meaning when interpreting data. In addition, when using this research method, it is important to evaluate the approach that will be used to explain why the information was collected and analyzed.

## 3.2 Research Design

According to Bhat (2023, p. n.d.), descriptive research is used for describing the characteristics of either the population or the phenomenon studied, and it mainly focuses on describing the nature of a demographic segment without including why the particular phenomenon happens. Another term used when referring to descriptive research is the research question. One of the characteristics related to descriptive research is quantitative research, which collects and describes the quantifiable information used for statistical analysis of the population. The uncontrolled variables are used to conduct the research. However, none of the variables are influenced—by cross-sectional studies, which analyze the different sections of the same group being studied. Moreover, the basis for further research is analyzing the data collected using the different descriptive research methods. As mentioned before, descriptive research contains different methods: observational, case study, and survey research, which will be useful for data collection.

In addition, Bhat considered that descriptive research can be used in multiple ways (2023, p. n.d), but it is important first to know what steps must be followed to understand the research goal and how to apply it properly. At first, it is important to define the respondents' characteristics by using close-ended questions, looking forward to reaching a concrete conclusion for the respondents. Following this, it is important to measure the data trends, conduct comparisons, and validate the existing conditions to maintain organized information gathered to achieve the main goal of the research. Furthermore, conducting the research at different times is used to evaluate the research variables, which can be conducted to detect any differences or similarities.

## 3.3 Information Sources

The use of different sources is a key factor during the development of a study because it is considered a tool that provides guidance and knowledge that can be implemented throughout the development of this study. These sources are categorized as primary, secondary, and tertiary. The primary sources contain multiple books related to translation, translation methods, and how translation can be applied to transfer cultural approaches or expressions from one text to another. One example of the books that are going to be used on this list of primary resources is *A TEXTBOOK OF TRANSLATION* by Peter Newmark, who is without a doubt the most influential of translators and the one whom plenty of upcoming translators have to get knowledge from his studies and point of view regarding translation and how it must be applied.

Regarding the secondary sources, it is important to consider multiple studies that have been developed previously about translation and how it is applied in multiple scenarios. Throughout the development of chapter two of this study, it is important to investigate and gather knowledge to understand and develop each segment of that chapter. As well as for chapter three, it will also be important to investigate and research more studies that can be functional for developing ideas and understanding of the topic studied, always respecting the authors and avoiding plagiarism. In addition, using a thesis related to translation is a useful source of information since it can be useful for guidance and a better overall idea of how to apply the knowledge gathered from the primary resources.

As for the tertiary sources, the use of the "Mariam Webster Dictionary Online" will always be presented throughout this investigation since it is a great tool to learn about the meaning of non-common or unknown words that will be encountered during the translation process as well as for the development of the glossary.

## 3.4 Analysis Categories

This research project has been developed by following a qualitative analysis due to the naturalness of what has been worked on. For this research project, it is important to provide the following definitions to get to know these aspects and to analyze the data properly.

**Translation methods:** This is a method of learning any foreign language by translating or converting the sentences of the native language into the target language or vice versa (Roma, n.d.).

**Translation procedures:** It refers to a particular course that applies to sentences and the smaller units of language (Newmark, 1988).

**Translation:** Translation is a mental activity in which the meaning of a given linguistic discourse is rendered from one language to another (Osman, 2017).

**Glossary:** A glossary is a collection of words about a specific topic (George, 2023).

**Semantic translation:** Semantic translation is only a slight variation on faithful translation in that it considers aesthetic value. This may often compromise the meaning when needed to have continuity in assonance, repetition, and wordplay in the target language (Lingua, 2020).

## 3.5 Data Collection Instruments

Data collection is the systematic process of gathering, measuring, and recording data for research, analysis, or decision-making (Vaidya, n.d.). A useful way of collecting data from any source is to use a data collection tool. In this project, two charts have been developed as data collection tools to collect key information obtained during the translation process of each document, which will be divided and analyzed from different perspectives.

### 3.5.1 Text Analysis Chart

The first chart focuses on the text analysis, considering the text style and function of the translated documents. The second chart focuses on the stylistic scale, confirmed by the formality, generality, or difficulty, and the emotional tone that can be presented in the documents. Dividing the information collected into these aspects will be useful to gain insight into the information presented in the translated documents.

| ***Text Analysis*** | | | |
|---|---|---|---|
| **Documents Translated** | Programa para bomberos dentro del proyecto “avanzando con un enfoque regional para movilidad eléctrica en América Latina”. | Research and Development of Fire Extinguishing Technology for Power Lithium Batteries. | Best Practices for Emergency Response to Incidents Involving Electric Vehicles Battery Hazards: A Report on Full-Scale Testing Results. |
| ***Text Style*** | | | |
| ***Text Function*** | | | |
| | | | |
| ***Stylistic Scale*** | | | |

| **Documents Translated** | Programa para bomberos dentro del proyecto “avanzando con un enfoque regional para movilidad eléctrica en América Latina”. | Research and Development of Fire Extinguishing Technology for Power Lithium Batteries. | Best Practices for Emergency Response to Incidents Involving Electric Vehicles Battery Hazards: A Report on Full-Scale Testing Results. |
|---|---|---|---|
| ***Formality*** | | | |
| ***Generality or difficulty*** | | | |
| ***Emotional tone*** | | | |

***Table 1. Text analysis chart. Source: Researcher's creation***

### 3.5.2 Color Coding

Color coding is used in this project to highlight the translation procedure presented in the texts presented in the documents. These translation procedures are divided into transposition, modulation, reduction and expansion, exploitation, literal translation. Different colors have been assigned to each procedure to avoid confusion and make it easier for the reader to identify which procedure is being referred to.

| |
|---|
| **Transposition** |
| **Modulation** |
| **Expansion** |
| **Explicitation** |
| **Literal Translation** |
| **Reduction** |

***Table 2. Color coding chart. Source: Researcher's creation***

### 3.5.3 Glossaries

A translation glossary is a list of terms and definitions created by the translator to ensure the accuracy and consistency of the terminology being translated during the translation process. Implementing a glossary in a translation project reduces errors and allows the translator to translate more quickly from one language to another. Two glossaries were created for this project, one for English to Spanish and one for Spanish to English. These glossaries contain at least 25 words per document, collected to provide information on their target word, grammatical category, and definition. This is very important for the translator during the translation process and for the reader to increase their knowledge of the topic presented in the document.

| ***English Glossary*** | | | |
|---|---|---|---|
| ***Word*** | ***Target Word*** | ***Grammatical Category*** | ***Definition*** |

***Table 3. Glossary of the most relevant terms in the document from Spanish into English***

| ***Glosario en español*** | | | |
|---|---|---|---|
| ***Palabra*** | ***Traducción*** | ***Categoría Gramatical*** | ***Definición*** |

***Table 4. Glossary of the most relevant terms in the document from English into Spanish***

***Source: Researcher's creation***

## 3.6 Collection Data Process and Data Analysis

For this research project, the translation of two documents was carried out, and the realization of each translation considered Newmark's point of view and his theory about translation procedures and translation methods. The content of these translations will be analyzed using a text analysis chart and a stylistic scale chart.

In addition, different translation procedures will be given a color to help the reader identify the different methods presented in the text. Furthermore, the implementation of glossaries will be a key factor that will guide both the translator and the reader regarding the vocabulary presented in the translation of each document.

# Chapter IV

## Investigación y desarrollo de la tecnología de extinción de incendios en baterías de litio

Resumen

De acuerdo con estudios experimentales anteriores sobre la extinción de incendios en baterías de litio, se encontraron algunas características esenciales como su larga duración, las altas temperaturas que se desprenden de estos sucesos, el alto consumo de agua y la gran dificultad para extinguir estos sucesos. La aplicabilidad de los agentes extintores de incendios en baterías de litio fue analizada en este trabajo, a través del experimento de acupuntura se compararon las diferentes eficiencias de los agentes extintores de incendios; de modo que se pretende proveer referencias útiles para el futuro diseño de seguridad y mantenimiento preventivo de las baterías de litio.

1. Introducción.

En los últimos años hubo un aumento en la demanda de nuevas fuentes de energía, con esto se incrementaron los problemas ambientales, así como la mayor atención de vehículos de energía nueva, como lo son los vehículos eléctricos. Para finales del año 2015, el total de la producción anual de vehículos de energía nueva fue de aproximadamente 380 000, número que demuestra una tendencia a la alza de manera muy rápida. Se estima que en China la producción y venta de autos eléctricos alcance un millón para el 2017. China está en una etapa crítica del desarrollo de la industria automovilística de nuevas energías, por lo tanto, la seguridad de estos vehículos se vuelve más sensible.

Los accidentes de seguridad en vehículos de energía nueva deben ser manejados con extrema cautela, pues la batería de litio que forma parte de su estructura actúa como un gran portador de energía. En estos casos la fuga térmica ocurre a baja temperatura y eliminar estos accidentes no es fácil, es por esto que los fenómenos de autoignición térmica, incendio y explosión de la batería del vehículo eléctrico hacen que la seguridad de las baterías de iones de litio se convierta en el centro de atención. Así, las preguntas sobre seguridad y fiabilidad de la batería de litio de los vehículos eléctricos presentan nuevos problemas y desafíos para la lucha contra incendios y rescates de emergencias. Recientemente, los académicos de State Key Laboratory of Fire Science llevaron a cabo experimentos relacionados con la extinción de incendios sobre la tecnología de prevención y control de incendios en baterías de litio, pero la investigación aún se encuentra en la fase inicial. Este estudio utiliza baterías de iones de litio #18650 para examinar la eficiencia de agua pura, al 5 % de solución F-5000 y al 5 % de solución creada (anicónico, niónico y surfactantes) en incendios de baterías de litio. Además, el sistema de extinción por agua nebulizada fue aplicada para extinguir los incendios de baterías de litio, proporcionando un método alternativo para estos incendios. Este trabajo revela una percepción fundamental sobre el estudio de la tecnología de extinción de incendios de batería de litio a gran escala.

2. Características de la extinción de incendios para la batería de energía de litio.

Aunque la causa de incendio en vehículos eléctricos es complicada, una de las razones principales es la ignición espontánea causada por la batería de litio. En el estudio de accidentes de incendio por baterías de litio, la Asociación Nacional de Protección contra el Fuego (NFPA) ha llevado a cabo el experimento sobre incendios causados por baterías de litio.

2.1. Quemado rápido y larga duración

La batería de litio causa una serie de efectos debido a que varios incentivos llevan a una fuga termológica. Una vez que la acumulación de calor de una batería de litio esta fuera de control, la batería se quema inmediatamente. La figura 1 muestra el proceso de extinción de un incendio de una batería de litio llevado a cabo por la Asociación Nacional de Protección contra el Fuego. En este caso x a la batería solo le tomó unos segundos transformase en una combustión intensa, mientras que el proceso de supresión duró unos 27 minutos [2].

## 2.2. Temperatura alta

Durante las pruebas de incendio, la NFPA utilizó un termopar para medir la temperatura y para encontrar la temperatura máxima fuera de la batería en un rango entre 283 y 1090 grados, se determinó que la temperatura máxima dentro de la batería se encontraba entre 572 y 1121 grados. Se debe tomar en cuenta que el flujo de calor máximo a una distancia de 5 pies del dispositivo VFT es de 2.2kW/ $m^2$ , y el valor oscila entre 1.5kW/ $m^2$ a 2.1kW/ $m^2$ cuando la distancia es de 15, 20 y 25 pies respectivamente. La temperatura máxima y el flujo de calor medido durante las pruebas ocurrieron después de que el incendio fue controlado, esto indica que la batería aún estaba muy caliente; por lo tanto, la temperatura de la flama es lo suficientemente caliente para encender otros combustibles una vez que la batería de litio del vehículo se quema.

## 2.3. Gran consumo de agua

Durante las pruebas para extinguir el fuego, la NFPA utilizó agua para controlar y apagar el incendio y evitar que la batería de litio reiniciara el fuego; además la extinción del fuego tardó mucho tiempo y el consumo de agua fue mayor que en otros eventos similares pero con materiales diferentes, el exceso de agua puso en peligro la batería por un flujo térmico de temperatura.

## 2.4. Mayor dificultad para extinguir

La reacción de la combustión de las baterías de litio generalmente ocurre dentro de la batería, por esta razón el agua no puede acceder al incendio, pues la carcasa de la batería previene que el agente de extinción de incendios actúe directamente en el núcleo eléctrico; por lo tanto, se convierte en un tema importante que se debe tomar en cuenta a la hora de extinguir un evento de este tipo. Durante las pruebas, el tiempo total dedicado para luchar contra incendios excede el tiempo del suministro de oxígeno de los bomberos y presenta un gran desafío para la seguridad personal de los bomberos; de modo que se evidenció que no hay un método efectivo para luchar contra incendios provocados por las baterías de litio.

### 2.5. La complejidad para extinguir incendios en baterías de litio

Una batería es una unidad de energía de almacenamiento cuyo fuego se transforma a partir de su energía eléctrica y química, cuando estas no se consumen completamente el calor se encuentra en una fase de liberación sostenida. Después de la etapa de expansión del flujo térmico, la supresión del fuego se vuelve muy eficaz. Este es el origen del dicho "por qué los incendios de energía no se pueden extinguir". El desarrollo de los incendios por baterías es muy veloz y violento, especialmente por la batería ternaria de polímero de litio que libera oxígeno por sí sola. Por consiguiente, es muy difícil de extinguir después de que el fuego se haya propagado. El empleo de algunos métodos específicos puede impedir que ocurra y se propague el incendio.

Adicionalmente, para extinguir un incendio abierto, el control de la fase de la fuga térmica también es muy importante, así como el uso de materiales ignífugos, principalmente en electrolitos. Por lo tanto, es más importante desarrollar la tecnología de alerta rápida, gracias a esto la detección inteligente de incendios y de mecanismos ignífugos han sido un avance en relación con las baterías. Sin embargo, hay un avance extraño y eficiente en la investigación básica sobre la tecnología de prevención y control de incendios, su desarrollo se ha enfrentado con dificultades considerables.

## 3. Investigación sobre la extinción de incendios en baterías de litio

Actualmente, las investigaciones sobre incendios en baterías de litio es muy preocupante, anteriormente en Estados Unidos y países europeos se preocupaban [4,5] por la seguridad contra incendios en baterías de litio, entidades como la Asociación Nacional de Protección contra el Fuego (NFPA), la Administración

Federal de Aviación (FAA), y la Dirección General de Aviación Civil (CAA). Recientemente, los académicos de FM Global de Estados Unidos, la Asociación Nacional de Protección contra el Fuego (NFPA) y State Key Laboratory of Fire Science llevaron a cabo experimentos de extinción de incendios en relación con la tecnología de prevención y control de incendios en baterías de litio, pero el modelo de incendio es diferente [1].

### 3.1. Estudio sobre la extinción de incendios de baterías de litio en el extranjero

La FAA ha llevado a cabo experimentos de prueba de un agente extintor eficaz contra los incendios de baterías de litio, se realizó una simulación de incendio, tomando como punto de partida experimentos basados en el enfriamiento de los agentes extintores. Este se comparó el agente extintor de incendios Halon1211 con agentes de extinción acuosos, así como el agua, AF-31, AF-21, A-B-D. También se compararon agentes extintores de incendios de gas, como el FM-200, FE-36, Halotron I con un agente extintor en polvo y un nuevo agente extintor de fuego como el Purple-K y el Novec1230. Los resultados mostraron que el agente extintor a base de agua posee un buen efecto más significativo en relación con el enfriamiento. Al reducir la capacidad de aspersión también se pueden obtener efectos notables en el proceso de enfriamiento; sin embargo, el efecto de enfriamiento de los agentes extintores no acuosos no es evidente, pues con el incremento de la dosis del agente extintor, la capacidad de enfriamiento tiene pequeños cambios. La capacidad de enfriamiento del agente extintor a base de agua se priorizó como AF-31, AF-21, A-B-D y Novec 1230. Con base en la investigación experimental sobre el efecto refrigerante del agente extintor de incendios, la FAA llevó a cabo el experimento de incendio en baterías de litio, en este se usó una batería de iones de litio #18650 (la capacidad de la batería es de 2600mAh, SOC es de 50%). Primero se encendió el calentador del horno tubular, luego se abrió el calentador de hexano cuando la temperatura de la primera batería se calentó a 100 grados Celsius. Una vez que la primera batería estuvo fuera de control, se rociaron los agentes extintores de incendios.

Cuando los agentes extintores de incendios son líquidos a temperatura y presión ambiente, como el agua, AF-31, AF-21, A-B-D and el Novec1230, estos fueron rociados por una botella de 500ml. Otros agentes extintores de incendios, como el Halon1211, Halotron, I, FM-200, FE-36, CO2 y el Purple-K fueron rociados con una botella. Después de que el incendio se apagara, el calentador se cerró, los datos fueron grabados por 20 minutos. Los resultados mostraron que todas las fugas térmicas de las baterías de litio ocurrieron y se propagaron en la ausencia de agentes extintores de incendios, y solo 500 ml de un agente extintor de incendios puede impedir eficazmente la propagación de un incendio de una batería de iones de litio. Además se concluyó que los agentes extintores no acuosos de incendios no hacen efecto en baterías de iones de litio.

A lo largo de la investigación de este proyecto, la FAA encontró que los resultados experimentales del efecto de enfriamiento de los agentes extintores de incendios son similares a los resultados de los experimentos sobre la extinción de incendios en baterías de litio; asimismo se evidenció que la capacidad de enfriamiento de los agentes extintores de incendios es el factor clave para prevenir la propagación de incendios de baterías de litio. Los agentes extintores a base de agua tuvieron un mejor efecto en la supresión de los incendios en baterías de litio, mientras que los agentes extintores de gas y polvo seco no son efectivos al suprimir los incendios en baterías de litio.

3.2. Estudio sobre la extinción de incendios en baterías de litio en China.

Para reducir el riesgo de incendios por baterías de litio, el Wuhan Institute of China Classification Society llevó a cabo una investigación sobre la eficacia de agentes extintores en la lucha contra incendios en baterías de litio. Los investigadores analizaron la eficacia del dióxido de carbono, polvo seco y heptafluoropropano, que impiden los incendios en baterías de litio; asimismo evaluaron su eficacia desde tres aspectos, como el tiempo de extinción del incendio, la tasa de resurgimiento y el efecto del humo sintético. Al respecto el experimento mostró que el efecto extintor del dióxido de carbono fue débil y se produjo un resurgimiento del incendio. El agente en polvo seco presentó un pequeño efecto en la batería de litio, y se presentó una explosión durante el experimento, entre todos estos agentes extintores el que tuvo un mejor efecto extinguiendo el incendio de la batería de litio fue el heptafluoropropano.

En la misma línea la Universidad de Ciencia y Tecnología de China llevó a cabo una investigación sobre la eficacia del polvo seco, dióxido de carbono y heptafluoropropano en la extinción de incendios en baterías de litio. Se descubrió que el efecto del heptafluoropropano es bueno, pero también se produjo un resurgimiento del incendio. Taijin Fire Station of Ministry of Public Security realizó un experimento sobre la extinción de incendios en baterías de litio utilizando el polvo, el dióxido de carbono y con el agente extintor de incendios AFFF y la tecnología de agua nebulizada. Los resultados demostraron que el dióxido de carbono, el polvo seco y el 3 % de AFFF pueden extinguir el incendio de una batería de iones de litio #18650. Debido a una fuga térmica, la batería de litio siguió liberando calor, gas combustible y oxígeno; sin embargo, con ninguno de estos agentes se puede extinguir completamente el incendio.

En todos los casos mencionados anteriormente se presentó el fenómeno de resurgimiento, pero se debe tomar en cuenta que con el incremento de la capacidad de enfriamiento de los agentes extintores de incendios, se prolonga el tiempo de aparición de un resurgimiento. Para extinguir completamente el incendio de baterías de iones de litio #18650 se necesita mejorar la capacidad de enfriamiento y de absorción de calor de los agentes extintores de incendios. En estos casos la tecnología de aspersión de agua no puede inhibir con eficacia los incendios de la batería de iones de litio #18650. Algunos estudios mostraron que el agua nebulizada con un agente superficial activo es una tecnología de extinción de incendios eficaz y amigable con el ambiente. Se concluye que la extinción de los incendios en las baterías de litio requiere más estudios.

### 3.3. Aplicación de la tecnología de microcápsulas F-500 y del sistema de agua nebulizada con aditivos en la extinción de incendios de baterías de litio.

Existen pocos estudios en la literatura sobre la tecnología de microcápsulas de hidrocarburos explosivos y los resultados de las investigaciones existentes se concentran principalmente en países desarrollados. La tecnología avanzada existente es la tecnología de materiales de las microcápsulas F-500, que es una nueva tecnología altamente eficaz para la extinción de incendios, prevención de explosiones y protectora del medio ambiente desarrollada por American Dangerous Goods Control Arts Inc (HCT). En 2009, Bosch probó el efecto extintor de agua, espuma, polvo y F-500 en incendios de baterías de litio. Las pruebas revelaron que el F-500 es la primera opción como agente extintor de incendios en baterías de litio.

En abril de 2013, la German Motor Vehicle Inspection Association (DEKRA) seleccionó tres tipos de agentes extintores de incendios e investigó el efecto de extinción de los incendios en baterías de litio de vehículos eléctricos. De acuerdo con la estructura de la batería de litio del vehículo, DEKRA utilizó n-heptano para encender la batería de litio y crear un modelo de incendio. Se compararon los efectos del agente extintor F-500 con el agua y el del agente extintor en polvo en relación con la extinción de incendios en baterías de litio. Los bomberos comenzaron a luchar contra el incendio por alrededor de 20 minutos después de la combustión de n-heptano. En este experimento de simulación DEKRA descubrió que el agua puede extinguir con éxito el incendio en batería de litio de vehículos eléctricos. Sin embargo, hay muchos otros problemas, como el gran consumo de agua y el largo tiempo de extinción. Se demostró que el agente extintor F-500 puede mejorar la eficacia de la extinción de incendios en baterías de litio. El tiempo de extinción de este agente con tan solo un 1 % de F-500 es de solo catorce segundos, de esta manera el consumo de agua se redujo considerablemente; así, el F-500, como un tipo de agente microcelular, puede inhibir eficazmente un incendio clase D (metal) en el que no exista una explosión. Cuando el agua se aplica a un incendio clase D (metal), esta se puede convertir en hidrógeno y oxígeno, de modo que la postcombustión y la explosión se producirá fácilmente, se debe tomar en cuenta que el agente extintor en polvo no puede calmar el fuego y el incendio puede iniciar de nuevo. Por su parte el F-500 puede reducir la tensión superficial del agua, así la formación de pequeñas gotas puede penetrar en el interior de la batería de litio, de modo que rápidamente extinguen el fuego y el incendio no ocurrirá de nuevo. El F-500 forma una capa protectora en la superficie del agua, es una especie de microcápusla esférica "capullo químico", de manera que los elementos combustibles de combustión fueron envueltos en la microcápsula inhibidora de combustión, en este caso la capacidad de enfriamiento rápido del F-500 puede extinguir el fuego y evitar que el incendio ocurra de nuevo. Estas características hacen al F-500 no solo sea aplicable al magnesio metálico, titanio metálico y otros incendios clase D, sino también que se aplique a los incendios de baterías de litio.

4. Experimento de extinción de incendios con baterías de litio.

4.1. Muestras de experimentos

La muestra es una batería comercial de iones de litio de fosfato de hierro. La capacidad total de la batería es de 80A-h. Esta está conectada en serie por cuatro celdas de 20A-h, y el peso de cada batería es de 2375±3g.

4.2. Método de experimentación

Para poder simular el estado de carga común de cada día, el preciclo de la batería se llevó a cabo entre 3~4.5V antes de las pruebas; el radio de circulación fue de 0.2 C. Cuando estaba en un estado de carga deseado (50%SOC), la batería se pinchó. El experimento de acupuntura se llevó a cabo en una etapa especial de extrusión de acupuntura, esta se encontraba equipada con termopares instalados en el dispositivo de punción. El diámetro de la aguja de acero fue de 5mm y penetró una sola batería de 50 % SOC a un ritmo de 30mm/s. Los termopares fueron adheridos a la superficie de la batería y midió la variación y la distribución de la temperatura. Las pruebas fueron aplicadas a dos grupos, uno fue usado para observar el fenómeno del incendio de batería de litio, y el otro se usó para realizar la prueba de extinción del fuego cuando ocurrió la fuga térmica de la batería. El efecto de extinción del agua pura se comparó con el de la solución F-500 al 5 % y la solución casera de 5 % (tensioactivos aniónicos no iónicos), esto con el fin de evaluar la tecnología de extinción de incendios del agua nebulizada con aditivos. El tensioactivo aniónico no iónico combina muchas ventajas de los tensioactivos aniónicos y no iónicos. Estos experimentos arrojaron excelentes resultados como una buena solubilidad del agua, resistencia a altas temperaturas, fácil degradación y una alta capacidad espumante.

4.3. Fenómenos y resultados de los experimentos

El SOC (estado de carga) tuvo una gran influencia en los resultados del experimento de acupuntura. El SOC se controla al 50 % para poder repetir las pruebas. Después de que se pinchó la batería, se roció un poco de líquido inmediatamente para producir mucho humo blanco. La temperatura de la superficie de la batería se incrementó rápidamente; tal como se muestra en la figura 3, esta alcanzó una alta temperatura de 813,7°C en 29 segundos. Después de que la fuga térmica ocurriera, el comportamiento del incendio de las baterías de litio se dividió en las siguientes etapas: (1) La expansión de la batería se presentó después de la acupuntura, por su parte el gas y el material interno fueron rociados desde el orificio pequeño, para este momento la batería estaba gravemente deformada y se pudo observar una gran cantidad de humo. (2) A los 14s, la batería emitió una siseante explosión y expulsó una gran cantidad de aerosol blanco, probablemente compuesto de gotas de electrolitos. El aerosol blanco se encendió al instante y salió una llamarada. (3) La batería entró en estado de combustión estable y tardó unos 15s. (4) A los 29s, la flama de la batería se realzó. (5) Después de un tiempo, la llama se apagó gradualmente y el incendio finalizó a los 1637s.

Con base en la figura 4, se descubrió que el 5 % de la solución F-500 y el 5 % de la solución casera tienen un efecto extintor significativo en las pruebas de incendios en baterías de litio, esta efectividad se comparó con el agua pura, evidenciando que el tiempo de extinción se acortó a más de la mitad. Ambas soluciones pueden reducir rápidamente la temperatura de una batería de litio y extinguir las llamas rápidamente; sin embargo, existe una pequeña diferencia entre los tiempos de extinción de ambas soluciones, pues la solución casera es un poco mejor que la solución de F-500. Asimismo, se debe agregar que el agua pura es muy inestable en la primera fase de supresión de las llamas, en este caso la estabilidad en el efecto de supresión de las llamas en ambas soluciones es mucho mejor que la de agua pura. En comparación, al rociar agua pura y rociar 5 % de solución casera y solución F-500 se demostró que se debilita la intensidad de combustión de las llamas producidas por un incendio en una batería de litio. Después de rociar por 4s se pudo inhibir bien la combustión de la batería de litio. Los resultados de los experimentos infieren que las moléculas de combustible son absorbidas y envueltas por una solución después de ser rociadas por solución casera o solución F-500. Así es como la reacción de combustión se termina. Al comparar el efecto de las llamas, se obtuvo que el efecto inerte de la solución F-500 se acerca al de la solución casera. Mientras tanto, el control de humos de la F-500 es un poco mejor que la solución casera después de la ignición y es mejor controlada la intensidad de las llamas después de la ignición, se evidencia que es superior al del agua pura. Según el experimento de eficacia de extinción de incendios, el uso de agua pura tiene sus defectos como agente extintor para extinguir incendios en baterías de litio, así como el largo tiempo de extinción y los componentes dañinos como el humo negro.

Mientras que el escenario de cierto porcentaje de aditivos es agregado al agua, el tiempo de extinción se acorta en gran medida, el aumento del fuego se suprime eficazmente y una gran cantidad de humo negro se convierte en humo blanco al mismo tiempo. En cuanto a la solución casera y F-500 se evidenció un excelente efecto extintor de incendio en los experimentos. En el proceso de extinción de incendios de baterías de litio, la solución casera y la solución F-500 absorbieron y envolvieron moléculas de hidrocarbono rápidamente, estas moléculas producidas por combustión fueron envueltas y aisladas del oxígeno, por cuanto la combustión puede evitarse y ser inerte, de modo que la intensidad de las llamas y el tiempo de combustión fueron reducidos. Los productos dañinos de la combustión se reducen y la visibilidad en el incendio aumenta; por consiguiente, se consigue finalmente un efecto de extinción rápido y seguro.

5. Problemas y perspectivas

(1) Actualmente, los medios de extinción de incendios de las baterías de litio incluyen principalmente agua, espuma, polvo seco, haluro de alquilo,  dióxido de carbono, entre otros. El sistema de extinción de incendio de agua nebulizada posee características como el bajo consumo de agua, medio de extinción

barato, poco daño al objeto protegido y protección ecológica al medio ambiente. En los últimos años se ha concentrado en el área de la protección contra incendios; sin embargo, hay muchos problemas en el sistema de extinción de incendios de agua nebulizada, pues no se puede garantizar la uniformidad del agua nebulizada, debido a que las gotas líquidas alcanzan la superficie de la combustión con una cierta cantidad de impulso y es muy difícil que el sistema de agua nebulizada extinga un incendio en bloque, le es fácil extinguir un incendio clase B (líquido) y difícil extinguir un incendio clase A (sólido), por lo cual. no se garantiza que no exista ningún tipo de daño causado por el agua a los objetos. El sistema de extinción de agua nebulizada no es movible. Las propiedades de la extinción de incendios son afectadas por el tamaño de las gotas, distribución de la velocidad, el impulso y las características geométricas de la boquilla. En los últimos años, el estudio de la tecnología de extinción de agua nebulizada se ha llevado a cabo ampliamente. Sin embargo, el sistema de extinción de incendios de agua nebulizada que contienen aditivos aún se encuentra en fase de investigación. Los resultados muestran que la eficacia del sistema de extinción de incendios de agua nebulizada que contiene aditivos es claramente mejor en comparación del método ordinario. El estudio de material extintores de incendio y las tecnologías de prevención de incendio en baterías de litio se han convertido en una parte importante en el área de la ciencia contra incendios.

(2) Los estudios experimentales han demostrado que las baterías de iones de litio tienen un gran riesgo de incendio, pues la oxidación del metal de litio se acaba en un instante cuando la batería se calienta, en estos casos la energía es eléctrica y química contenida en otras sustancias. Por supuesto hay más sustancias tóxicas y dañinas dentro de la batería como el pentafluoruro de fósforo cinco, fosfina, fluoruro de hidrógeno e hidrógeno, todas ellas son la raíz de la combustión y la reignición de las baterías. Uno de los gases más tóxico y dañino producido por los incendios de batería de litio es el fluoruro de hidrógeno. Se investigó el uso de los agregados orgánicos del agente de superficie activa para absorber el gas de fluoruro de hidrógeno y la viabilidad para reducir la concentración de este gas; asimismo, se estudió la absorción de mezclas surfactantes de fluoruro de hidrógeno. A través de un análisis exhaustivo del rendimiento de absorción y estabilidad, se seleccionó el sistema absorbente con un buen efecto de absorción del gas de fluoruro de

hidrógeno. Esto revela que se debe dar mayor relevancia al uso de agregados orgánicos del agente activo superficial para absorber pentafluoruro de fósforo cinco, fosfina, hidrógeno y otros gases.

(3) China aún no ha formulado o promulgado las especificaciones o pasos a seguir para una emergencia de rescate de vehículos eléctricos; por lo tanto las normal nacionales chinas existentes para rescates de emergencia en caso de incendios no han cubierto los contenidos específicos en eventos de este tipo. Es muy difícil para los bomberos tratar los incendios de vehículos eléctricos; de manera que, según el experimento de extinción de incendios en baterías de litio, la investigación fundamental sobre la lucha contra incendios debe ser combinada con el rescate de emergencia. Por lo tanto, es necesario establecer un manual técnico o de especificaciones estándar, con el fin de satisfacer las necesidades del trabajo contra incendios; además, se debe normalizar el funcionamiento de los bomberos y el rescate de emergencia.

**Mejores prácticas, respuestas de emergencia a incidentes relacionados con riesgos de las baterías de vehículos eléctricos: un informe sobre las pruebas a escala real.**

2.1 Visión general de Li-ion

Las celdas de baterías de iones de litio (Li-ion) se utilizan mucho en la actualidad. Al evolucionar esta tecnología y aumentar las densidades energéticas su uso se ha aplicado en muchos productos de consumo, incluyendo la industria automovilística. Las celdas de baterías de iones de litio colocadas en un gran volumen de las baterías de iones de litio se están utilizando para alimentar varios tipos de EDV. Cuando los EDV entran en el mercado estadounidense se anticipa un fuerte aumento del número y tamaño de las baterías tanto almacenadas como en uso. Un estudio reciente de la FPRF de la NFPA destaca los posibles peligros y los usos de las celdas de baterías de litio durante el ciclo de vida del almacenamiento y su distribución. También se incluye un punto de vista sobre la tecnología de iones de litio y sus modos de fallo. A continuación, se presenta un breve resumen de la tecnología de iones de litio.

Los iones de litio se han convertido en la batería recargable dominante en dispositivos electrónicos de consumo y está a punto de convertirse en la batería industrial, de transporte y de almacenamiento de energía. En varios aspectos, la química es diferente de las baterías recargables populares, como por ejemplo el níquel metal hidruro, níquel cadmio y plomo ácido. Desde un punto de vista tecnológico, debido a su alta densidad energética, la tecnología de iones de litio ha habilitado la alimentación a vehículos eléctricos de transporte (EDV). Desde un punto de vista de seguridad y de protección contra incendios, la alta densidad de energía juntada con un electrolito inflamable orgánico, en lugar de uno acuoso, ha creado un gran número de retos con respecto al diseño de las baterías que contienen celdas de iones de litio y a la extinción de incendios.

El término de iones de litio (Li-ion) se refiere a una familia entera de la química de las materias. Está fuera del alcance de este informe describir todas las químicas utilizadas en las baterías comerciales de iones de litio. Además, debe de tenerse en cuenta que la química de las baterías de iones de lito es un área de investigación activa y muchos materiales se siguen desarrollando constantemente. La información detallada adicional con respecto a las baterías de iones de litio está disponible en varias referencias y en un gran volumen de publicaciones de investigación y actas de congresos sobre el tema.

En el sentido más básico, el término de batería de iones de litio se refiere a cuando los materiales de un electrodo negativo (ánodo) y un electrodo positivo (cátodo) actúa como anfitrión para los iones de litio (Li+). Los iones de litio se mueven del ánodo al cátodo durante la descarga y se intercalan (insertan entre los huecos) en la estructura cristalográfica del cátodo. Los iones van en sentido contrario mientras se carga, así como se muestra en la figura 1. Los iones de litio al estar intercalados en los materiales del anfitrión durante la carga y la descarga, no hay metal de litio libre dentro de una célula de iones de litio, por lo tanto, si una célula se inflama debido a la incidencia de una llama externa o un fallo interno las técnicas de extinción de incendios con metal no son apropiadas para controlar el fuego.

En la celda de iones de litio, las capas alternadas de ánodos y cátodos están separados por una lámina porosa. Un electrolito compuesto por un disolvente orgánico y una sal de litio disuelta proporcionan el medio para el transporte de iones de litio. Una celda puede construirse apilando capas alternas de electrodos (típico de las celdas primaticas de alta capacidad), o enrollando largas tiras de electrodos en una configuración de "rollo de gelatina" típica de las celdas cilíndricas, así como se muestra en la figura 2. Las celdas o rollos de electrodos pueden construirse apilando los electrodos o enrollándolos, también pueden introducirse en carcasas rígidas selladas con juntas (la mayoría de las pilas cilíndricas comerciales), así como se muestra en la figura 3, en carcasas rígidas soldadas con láser, así como se muestra en la figura 4, o en bolsas de aluminio con costuras termoselladas (denominadas comúnmente como celdas de polímero de iones de litio), así como se muestra en la figura 5. Una variedad de mecanismos de seguridad puede también ser incluidos en el diseño mecánico de las celdas, así como los dispositivos de interrupción de carga y los interruptores de coeficiente de temperatura positivo.

Una batería de iones de litio está hecha de muchas celdas individuales empaquetadas junto con su sistema electrónico de control y protección asociado, al conectar las celdas en paralelo, los diseñadores incrementaron la capacidad del paquete; al conectar las celdas en series incrementaron el voltaje del paquete; por lo tanto, muchas de las baterías van a ser marcadas con una nómina de voltaje que puede ser usada para inferir el número de elementos de series y junto con la energía total de la batería (en vatio-hora [Wh]), pueden usarse para determinar la capacidad (en Amperios-hora [Ah]) de cada elemento (tamaño de las celdas individuales o número de celdas conectadas en paralelo).

Para un formato 69 más amplio de baterías, las celdas deben ser conectadas entre ellas (en series y/o en paralelo) en módulos. Los módulos deben ser conectados después en series o en paralelo para formar un paquete de baterías completo, estos fueron usados para facilitar el cambio de configuraciones y la sustitución de partes defectuosas de las baterías más grandes; por eso, la arquitectura de las baterías de gran formato puede ser compleja.

Las baterías EDV usan típicamente celdas individuales compuestas en módulos. Los módulos serán ensamblados para formar un gran formato de baterías. El gran formato de baterías típicamente contiene un sistema de seguridad activado para monitorear la corriente eléctrica, el voltaje y la temperatura de las celdas para optimizar el rendimiento y mitigar los fallos potenciales, incluyendo incendios. Un gran número de estándares y protocolos están disponibles para estas baterías, incluyendo, pero no limitando a: Underwriters Laboratorios (UL) Asunto 2580: Baterías para uso en vehículos eléctricos; SAE J2464: Sistemas de Almacenamiento de Energía Recargable (RESS) para Vehículos Eléctricos e Híbridos, Pruebas de seguridad y abuso; y SAE J2929: Norma de seguridad del sistema de baterías de propulsión de vehículos eléctricos e híbridos – Baterías recargable a base de litio.

Está fuera del alcance de este estudio analizar todas la posibles normas y protocolos; sin embargo, ya se ha publicado anteriormente un resumen de muchos protocolos de ensayo para celdas de iones de litio.

4. Descripciones de la batería

En colaboración con la FPRF de la NFPA y el Panel Técnico del Proyecto, Exponent adquirió baterías de dos fabricantes de automóviles para realizar pruebas, denominadas batería Y, batería B. Las dos baterías adquiridas se basan en tecnología de iones de litio que son utilizados actualmente en vehículos de producción en Estados Unidos. La batería A es una batería 4.4kWh que está instalada en el compartimiento trasero de carga del vehículo. La batería B es una batería 16kWh que está instalada debajo del piso del vehículo y se extiende a lo largo de este, desde el eje trasero hasta el delantero en una configuración en forma de "T". La batería A y la batería B abarcan un amplio espectro de tamaños de baterías y posiciones de instalación en el vehículo para simular los posibles peligros a los que los equipos de emergencias podrían enfrentarse sobre el terreno durante incidentes reales de incendio de un vehículo EDV.

Parte del acuerdo con los fabricantes de vehículos, que donaron las baterías, consistía en que las baterías EDV no fueran abiertas, alteradas o manipuladas antes, durante y después de las pruebas de incendio. Los diseños, descripciones y detalles de las baterías en las siguientes secciones fueron facilitados por Exponent, fabricantes de vehículos eléctricos, además de las fuentes de información de acceso público.

#### 4.1.1 Batería A

La batería A está diseñada para un PHEV y posee un conjunto de batería de vehículo híbrido (HV) de alto voltaje y una gran capacidad que contiene celdas de batería de iones de litio selladas. El paquete de baterías HV de 4.4kWh está encerrado en una caja metálica (ver la figura 6) y está montada rígidamente en la parte inferior del maletero trasero, detrás del asiento trasero, así como lo muestra la figura 7. La caja metálica está aislada de la alta tensión, oculta y separada del compartimiento de los pasajeros por una cubierta de plástico moldeado con moqueta, así como se muestra en la figura 8. El electrolito utilizado en las celdas de la batería de iones de litio es un compuesto orgánico inflamable.

#### 4.1.2 Batería B

La batería B está diseñada para una EREV y cuenta con un conjunto de batería que contiene celdas selladas de iones de litio. El conjunto de baterías de 16kWh se asienta sobre una placa de acero y está encerrada en una carcasa de fibra de vidrio, así como se muestra en la figura 9. La batería en forma de T ocupa casi toda la longitud del vehículo, desde el eje trasero hasta el delantero, y está montada de forma rígida debajo de la bandeja del suelo del vehículo, así como se muestra en la figura 10. La bandeja del suelo del compartimiento de pasajeros separa el conjunto de la batería del compartimiento de pasajeros del vehículo. El electrolito utilizado en las celdas de la batería de iones de litio es un electrolito orgánico inflamable.

**Program for Firefighters Within the Project "Advancing a Regional Approach to Electric Mobility in Latin America"**

**Reference material – June 2022**

1. Introduction

As the use of alternative energies proliferates, the Santiago de Cali Fire Department has identified a number of areas of concern regarding risk mitigation and the response to emergencies. This includes electric and hybrid vehicles that present new and unexpected dangers for firefighters and other emergency responders.

Nowadays, it is very common to see electric vehicles on all types of roads. The number of vehicles of this kind, including hybrids, is constantly increasing. In statistical terms, this means that there is a greater chance that, if an accident occurs, it will involve an electric vehicle. Therefore, it is relevant to access information on managing risk situations and emergencies related to this technology in order to create capabilities of alertness. This reference material gathers the best practices that are being disseminated by manufacturers and other relevant actors on electric mobility safety. The document is intended reference for first responders, in this case, firefighters; therefore, commercial usage is not allowed.

2. Type of alternative fuel vehicle

Multiple definitions of the term electric vehicle can be found in the common literature, as well as in consensus codes and standards. The following are the ones taken for this reference material:

a. Hybrid-electric vehicle (HEV)

A hybrid electric vehicle (HEV) uses two energy sources: an internal combustion engine (ICE) and an electric/battery engine combination. In contrast to a plug-in hybrid vehicle, it does not provide the ability to connect to an external source to charge the batteries. However, the batteries are charged by the internal combustion engine or a regenerative braking system.

b. Plug-in hybrid electric vehicle (PHEV)

A plug-in hybrid electrical vehicle can recharge its batteries by using a connection to an external electrical power source such as a wall outlet. A PHEV shares the characteristics of a hybrid electrical vehicle (an electrical engine and an internal combustion engine) and an all-electric vehicle (the ability to connect to a charging station).

c. Electric vehicle (EV)

An electrical vehicle (EV) only uses one or multiple electrical engines for propulsion and it must be connected to a charging station in order to recharge the battery that transmits power to the engine.

d. Especial electric vehicle (NEV)

A special subclass of an EV is the NEV, a special-purpose electric vehicle. These are electric vehicles that are not intended or designed for long-distance travel or highway speeds. A NEV is a low-speed, four-wheeled, battery-powered vehicle that is typically recharged on normal electric circuits.

3. Warning icons and identifiers

a. Warning Icon

b. Lithium Ion Battery

c. Warning Icon

4. Best practices for emergency responses

Each emergency incident, to which the fire department responds, is unique. Despite the differences, however, there are common characteristics that allow the fire department staff to better understand the tasks they must perform and prepare for their roles. This section provides a review of the common elements of most interest to firefighters when handling emergencies involving EV and HEV. The main scenarios of emergency in which the firefighters might expect to respond to an emergency involving an EV or HEV are illustrated in the figure below. Key emergency scenarios for EV and HEV.

This figure considers the four basic possibilities: (1) Extrication/Rescue; (2) Fire; (3) Water Immersion; and (4) 0ther Scenarios.

5. General response

This reference material is intended to provide a "general response." It presents an initial response, as well as a guide for scenarios that are not specific to any particular vehicle (fire, submersion, spills, etc.). The safety of the firefighters and any other emergency first responders depends on understanding and properly handling this guidance through proper training and preparation.

Take into consideration that this reference material is generic and it is applied to the majority of vehicles. However, there is always the possibility of contradiction between generic orientation and the specific instructions of the vehicle provided by the manufacturer. In such cases, always follow the specific instructions of the manufacturer of the vehicle.

a. Vehicle specific data

This information is organized alphabetically by manufacturer and then by the model of the vehicle for each manufacturer's label. Each vehicle entry is presented in a two-page format with critical information to assist with the identification, immobilization, disablement, and extraction.

All of the primary deactivation procedures, such as most of the alternative procedures, are designed to deactivate both the fuel or high-voltage electrical system and the SRS (airbags, etc.). The partial performance of any of the procedures will not guarantee that both systems will shut down.

Note: Whenever possible, the locations of components such as the ignition, the 12V battery, the parking brake, and the gear selector are indicated. However, it is always possible that these components may be located elsewhere due to the manufacturer's model updates or secondary market modifications.

b. Release information

The automobile manufacturers voluntarily colored the wiring for these high-voltage systems bright orange for easy and consistent identification. In some recent models, blue and yellow color-coded cables have appeared, which also present a dangerous shock hazard; even though, they are not specifically considered to be high voltage. In addition, the high-voltage wiring in vehicle designs is often protected in protective conduit channels, making it difficult to locate them visually. In terms of vehicle release, perhaps the most significant difference between a conventional vehicle and an EV or HEV is the high-voltage electric system.

The EVs and HEVs generally include high-voltage batteries and the presence of high-voltage components creates a possible electrocution hazard (between 36 and 600 volts of electricity) for emergency staff, especially before they realize that the vehicle is a hybrid model. While it is understandable that the high voltage in electric vehicles and hybrids generates not only, concerns among firefighters that demand a higher degree of caution, but also certain misconceptions that deserve to be addressed.

For example, electrocution is not a real danger just by simply touching the exterior of a crashed EV or HEV. This should not be different from a conventional engine vehicle since the stop system is completely isolated from the chassis/bodywork of the vehicle. However, the only obvious exception to an exterior electrocution danger, and one that would apply to any vehicle, is a crash situation that involves an exterior electrical power source, such as when the dropped power lines are placed over the crashed vehicle.

6. Generic Procedures of Initial Response for hybrid-electric Vehicles

**Identify – Immobilize – disable**

a. Identify the vehicle

Always assume that the vehicle is any type of hybrid, electric, or alternative fuel until proven otherwise.

- Search for external logos that indicate an alternative fuel vehicle.
- The identification can be hidden in a crash or fire so that alternative identification methods can be used.
- Determine the brand, model, and year of the vehicle to access a vehicle more specific vehicle information is found in this guide.
- It is possible that some hybrid and electric models do not have external marks in order to identify them, but they still have high-voltage warning labels and other secondary indicators like the distinctive “zero emissions.”

b. Immobilize

All the vehicles should be immobilized before working around them. The hybrid and electrical vehicles can seem to be off even when they are not, due to the potential lack of engine noise.

- Get close to the vehicle from a 45-degree angle to stay off the projection axis and: block the tires, put the hand/emergency brake, and put the vehicle in parking mode.

c. Disable

Primary shutdown method (for the majority of vehicles)

1. Turn off the vehicle's ignition (if it is on).
2. Disconnect the 12V battery (according to the vehicle instructions).

<u>Some vehicles use a proximity key</u>

If the key can be located, remove it, and move it at least 16 feet (5 meters) away from the vehicle. If it cannot be quickly located, proceed by inhabiting the vehicle. Once the vehicle is turned off and disconnected from the 12V battery, the proximity key system is deactivated.

Alternate power off method (if the ignition is not accessible)

- Consult the vehicle-specific page for more information.

Note: The majority of hybrid and electric vehicles are equipped with security systems that are designed to shut down automatically the vehicle in case of a crash. Therefore, in the majority of collision incidents, the vehicle should be off by then. Check the condition of the vehicle in order not to inadvertently restart a vehicle that has already been shut down.

Note: All the principal deactivation procedures, such as the majority of alternative procedures, are designed to deactivate the fueling system and/or the high-voltage vehicle and the SRS (airbags, etc.). The partial realization of any of the procedures does not guarantee that both systems will shut down.

7. General procedures and considerations for the response to incidents in hybrid / electric vehicles.

Always follow and refer to all the proper procedures when responding and releasing in a vehicular accident.

7.1. Accidents

Follow the initial response procedures:

- Perform an evaluation of the scene, and after that locate, immobilize, and disable the vehicles.
- If the vehicle can be identified, consult the corresponding pages of the response guide from the manufacturer.

- If the vehicle cannot be identified, use the common shutdown method from the Initial Response section.

7.2. Release

Immobilized and disabled the vehicle before initiating the extraction operations.

**Always stabilize the vehicle before starting the release whenever possible.** (see Stabilization). Before cutting or levering, visually check to determine the location of: the SRS and Occupant Protection System, HV High voltage components and wiring, fuel gas lines, and cylinders/tanks.

- The HV wiring and the components are primarily routed along the bottom of the vehicle from the HV battery to the under-hood compartment (engine); therefore, they are not located at the typical removal cut points.
- The locations of the HV batteries and components could stop advanced techniques such as the backbone tunneling and through-ground extraction.

7.3. Stabilization

- Use standard brackets and stabilization methods, the same that is used in conventional vehicles.
- Do not place the shoring in a location that will trap or tangle high-voltage wires or gaseous fuel between the shoring and the vehicle frame or structural points. Visually check before placing the shoring.

**Always stabilize the vehicle before performing the extraction.**

**Ultra-High Strength Steels [UHSS]**

- Strength/low-weight metals are being used extensively in newer vehicle designs.

- The hydraulic cutting tools that are not designed for ultra-high strength steels may be inappropriate.
- It is possible that tools such as alternative saws cannot cut these metals. Alternative extraction techniques may be required.
- Some cutting tools cannot cut new ultra-high-strength steel.
- It is highly recommended that the firefighter department review the abilities of their cutting equipment against ultra-high strength steel prior to encountering these materials in the field.

7.4. Warning

- Avoid contact with high-voltage wiring and components. Always assume the HV system is energized.

**Never cut the orange high-voltage wiring or penetrate high-voltage components with tools.**

- The shutdown procedures of the HV system are designed to deactivate the HV system of the vehicle, not to discharge the HV battery.

**The HV battery will remain with energy.**

- If the vehicle's 12 V system is not accessible and cannot be deactivated, the occupant protection systems, such as the airbags or pretensioners, may remain active even if the HV system is turned off.

7.5. Note

Hybrid-electric vehicles

The blue and yellow medium/intermediate voltage wiring is treated the same as the orange high voltage (HV) wiring. All references to HV practices also apply to medium/intermediate voltage systems.

<u>Damaged high-voltage (HV) batteries.</u>

- If they are damaged, the HV batteries may emit noxious and/or flammable gases.
- If unusual odors are detected or you experience eye, nose, throat, or skin irritation, put on the complete personal protective equipment with SCBA.
- If you detect fluid leaks, sparks, smoke, or bubbling noises coming out of the HV battery, ventilate the vehicle by opening the trunk to avoid vapor accumulation.

The sparks, smoke, or bubbling noises coming from the HV battery are signs that the battery is overheating, which may provoke a delayed fire. The content of the HV batteries should be considered corrosive, toxic, and/or flammable. Consult SPILL/LEAK HAZARDS if the battery contents are exposed or leaking.

**<u>Avoid contact with a damaged HV battery. There may be a significant risk of electric shock.</u>**

Disconnections Service Guide

- The majority of hybrid and electric vehicles. If you experience eye, nose, throat, or skin irritation, put on the complete personal protective equipment with SCBA.
- Consult the specific pages of the vehicle or response guides from the manufacturer before using a manual or service disconnection.
- Any manufacturer recommends insulated electrical disconnecting equipment when disconnection services are used.
- The majority of departments do not have it or carry them regularly.

- Take into consideration that taking off a disconnection service will deactivate the HV system; however, in the majority of vehicles, the SRS (airbags) will remain active until the 12V CC systems get deactivated. Removing a manual disconnect does not discharge the HV battery.

7.6. Post-incident

All the hybrid and electric vehicles have to be transported in a platform. If this is not possible, be sure to tow with the drive wheels off the ground [varies by model].

**<u>The trailer with the drive wheels on the ground represents a fire hazard in the electrical system.</u>**

- If the damage to the battery is observed or suspected, notify the dealer or manufacturer's representative.

It is possible that they may have procedures to de-energize a battery.

- Due to the possibility of a delayed fire, do not store a severely damaged vehicle that contains an HV lithium-ion battery within at least 50 feet (15 meters) of a structure or another vehicle. It is possible that it is necessary to increase the distance, depending on the size of the vehicle.
- After a fire or accident, communicate with the fleet service staff or the manufacturer for assistance in removing and storing the vehicle.

**<u>Notify the truck/towing operators, who remove the vehicle, that it should be on a flatbed, or without having to roll its tires. The staff should be trained to inspect it and provide recommendations for final parking.</u>**

8. General procedures for fire extinguishing on alternative fuel vehicles.

All the staff must use full personal protective equipment and SCBA a required at all vehicle fires.

**Use full personal protective equipment and SCBA.**

8.1. General

Hybrid and electric vehicles

Use extinguishing equipment and tactics of standard vehicles according to the operational procedures and guides from the firefighting department. Hybrid and electric vehicles do not require special equipment for fire suppression/extinguishing.

- Size and location of the battery
- Fire range inside the battery
- Access and capacity of the extinguishing agent to be applied to the battery mounting box.

Possible openings in the battery box which allow the extinguishing agent to be placed directly on the burning cells.

8.2. Extinguishing agents

Use water or any other standard agents for vehicle fires. The use of water does not present an electrical danger for the firefighting staff.

- If an HV battery ignites, it will require a high and sustained volume of water.

**Tests have indicated that it may require more than 2600 gallons, depending on the size and location of the battery. Be sure to establish a sustained supply of water through a hydrant or static water source.**

### 8.3. Warnings

If you use water to extinguish/suppress an HV battery, use a large amount. Using a small amount of water could allow the release of dangerous toxic gases. If a lithium-ion HV battery is involved in the fire, there is a possibility that it will reignite after the extinguishment. If they are available, use thermal images to monitor the battery. Do not store a vehicle with a damaged or burnt lithium-ion HV battery from 50 feet (15m) from a structure or another vehicle until the battery can be discharged. The reignition of fire in a pack of HV batteries is usually accompanied by "hissing" or popping" sounds, followed by the release of white smoke gases and/or electrical arcing/sparks that are kindled by visible flames/fires. Reignition can occur at any time from several hours to a day or more after the extinguishment.

### 8.4. Note

Since HV batteries are in protective cases, it is very difficult for an extinguishing agent to reach directly to the burning cells. The application of large volumes of water can cool the HV battery sufficiently to prevent the spread of the fire to adjacent cells. Continuous application of water over a located area of the battery for an extended period of time before moving to another section of the battery, provides a faster extinguishment. Continue applying water even after the visible flame is no longer present in order to properly cool an HV battery and prevent/reduce the re-ignition risk.

To anticipate longer fire suppression times once the HV battery is involved due to the difficulty of accessing the burning materials inside the battery cage. Tests have shown that it can take an hour or more depending on the size and location of the battery, as well as the extension of the fire.

### 8.5. Tactic

Do not blindly pierce the hood with tools such as a Halligan bar to access. This tactic could penetrate the HV components in the engine compartment, creating a serious risk of electrical shock. Never pierce, cut, leverage, or disassemble any vehicle structure in an effort to introduce water directly into the battery. You may touch an HV component and be at risk of injury.

Offensive attack: It is recommended where exposures are present or the HV battery is not involved.

Defensive attack: It is recommended if the HV battery is involved, there are no exposures present, and there is a limited water supply available. Due to the difficulty of reaching the burning cells inside the battery with the extinguishing agent, the incident commander may opt to let it burn on its own. Any individual without SCBA should remain upwind of the fire and avoid inhalation due to the toxic compounds in the smoke. If water is not applied directly, the HV battery could take 90 minutes or more to self-extinguish.

### 8.6. Fires at charging stations

Locate the power supply for the charging station and turn it off.

- Until the power of the charging station is cut off, treat the fire as you would with an energized electrical fire.
- If a vehicle is connected to the charging station, it should be disconnected as soon as it is safe to do so. If possible, switch off the charging station first.

### 8.7. Review and recovery

- Immobilize and disable the vehicle if not already done.
- Never disconnect or be in contact with any exposed high-voltage components or wiring.

- Attempt to contact a dealer or manufacturer’s representative as soon as possible for assistance with post-incident vehicle disposition and the de-energization of the HV battery if necessary.
- Never break or remove the HV battery. If you do so, it can cause severe electrical burns, electric shock, and/or electrocution.
- Do not store a vehicle with a damaged or burned lithium-ion battery inside a structure or other vehicle within 50 feet (15 meters) until the battery can be discharged.

9. General procedures for water immersion of hybrid-electric vehicles

9.1. General

- The hybrid-electric vehicles are designed to be safe in water, even when fully submerged.
- The HV system is isolated from the chassis and is designed so that it does not present a shock danger when touching the vehicle body.
- The system is designed to not energize the surrounding water.
- The system is equipped with short-circuit failure detectors designed to shut the HV system in the event of a short circuit.

9.2. Response practices

Avoid contact with HV components, wiring or service disconnects on a submerged vehicle.

- Follow your standard practices and procedures for patient access and removal of the vehicle from the water.
- It may be necessary to wait until the vehicle is safely on the ground and clear of water to perform the deactivation procedures.

9.3. Microbubbles

- Microbubbles are bubbling or fizzing reaction that comes from a submerged HV battery.
- It does not indicate an electric shock danger. This process is internal to the battery case and does not energize the surrounding water.
- Microbubbles are the result of electrolysis, where the electric current travels between the positive and negative terminals inside the battery and breaks water molecules into hydrogen and oxygen gases.

When the microbubbles cease, the high-voltage battery has discharged.

9.4. Warning

This process produces inflammable hydrogen and oxygen gas, that can be potentially explosive in confined spaces. It should be necessary to ventilate the passenger compartment to reduce the gas accumulation.

**Never remove a submerged service disconnection!**

Partial immersion in water, such as during a flood, can provoke a short circuit in the internal components and a possible fire.

9.5. Examples of manufacturer's specific recommendations

Some manufacturers could have a specific guide od the model for the submerged vehicles. Consult the appropriate vehicle response guide found further in this document for handling and shutdown procedures.

FORD/MERCURY: (Escape, Fusion, Mariner, Milan Hybrids): Ford recommends that a submerged vehicle should not be removed from the water until the HV battery is completely discharged (when the microbubbles have stopped completely).

MITSUBISHI (Mitsubishi i): After getting the vehicle out of the water, flush the HV battery by following this procedure: remove the service cap (under the front driver's seat) while wearing an insulated PPE (400 V minimum resistance gloves) and pour at least 8 gallons (30 liters) of non-saline water into the service cap hole.

10. General procedures for spill/leak dangers

High voltage batteries (HV), whether nickel metal hydride (NiMH) or lithium-ion (Li-Ion), are essentially considered dry cell batteries, and if damaged or ruptured, electrolyte leakage should be minimal.

10.1. General

Follow your department's procedure for common automotive fluids. Hybrid and electric vehicles can contain many of the same common automotive fluids as conventional vehicles.

- Secure the area and keep non-emergency personnel out of the danger zone.
- Use appropriate respiratory and structural personal protective equipment for firefighting when working near the filtered content of a hybrid or electric vehicle battery.
- When possible, try to contain the leaked electrolyte and avoid its introduction into the environment.

**Smokes from broken lithium-ion battery cells are often irritating or toxic.**

**Use the appropriate SCBA and EPP**

## 10.2. Note

Some HV batteries are liquid-cooled. If a battery of this type is damaged, there could be a coolant leak. The coolant is similar to what is found in conventional vehicle radiators and should not be confused with the battery electrolyte (although cross-contamination with the electrolyte is possible if the damage is extended.

## 10.3. Warnings

On electrolyte leakage in the high-voltage battery (HV)

- Due to the difficulty in determining the composition of a specific HV battery, the electrolyte in all HV batteries must be considered potentially corrosive, toxic, and/or flammable.
- If it gets damaged, the HV battery can emit harmful or flammable vapors. Use complete personal protective equipment and SCBA and avoid direct contact with the battery since it can also present an electric discharge risk.
- If unusual odors are detected or eye, nose, throat, or skin irritation is experienced, put on full PPE with SCBA and immediately remove occupants and respond staff from the vehicle, if possible.
- If such vapors are present, patients cannot be removed immediately and if there is available equipment, install positive-pressure ventilation (PPV) or a smoke ejector to move vapors away from the interior of the vehicle. If possible, supply oxygen to the patient(s) via a non-rebreathing respirator at a minimum to reduce the possibility of inhalation of dangerous gases.

Any liquid leak should be disposed of in accordance with the fire department’s disposal procedures. Contact your local distributor or manufacturer for guidance on handling and disposal of any spilled electrolyte.

**Consider all battery electrolytes as caustic or corrosive, especially nickel metal hydride (NiMH). Use appropriate PPE.**

11. General first aid procedure for specific dangers

Note: The following practices are not intended to replace local medical directives, protocols or operational procedures.

11.1. General

- Follow the local medical protocols and the first aid procedures for any burn, electrical, or any other type of injury.

11.2. Response to battery electrolyte exposure.

- The exposure to HV battery electrolyte is unlikely except in severe shock.
- Use appropriate EPP if exposure to electrolytes is expected. SCBA is highly recommended due to the possibility of severely irritating vapors.
- The PPE for electrolyte manipulation or a damaged battery which may contain leaks includes:
  - Suitable gloves for organic solvents (rubber, latex, nitrile, etc.).
  - Suitable apron or upper clothing suitable for organic solvents (rubber, Tyvek, etc.).
  - Suitable boots for organic solvents (rubber, etc.).
  - Handling of a damaged HV battery is strongly discouraged. However, if handling is absolutely necessary, HV electrical PPE should be worn.

## 11.3. Warnings

- Handling a damaged HV battery can only be done when is absolutely necessary since it presents a significant potential danger.
- The NiMH battery electrolyte is a caustic alkali (pH 13.5) that damages human tissues. To avoid injuries from contact with the electrolyte, wear appropriate PPE.

## 11.4. Note

Any kind of clothing or personal protective equipment that could have been in contact with electrolytes must be decontaminated or thrown away appropriately.

## 11.5. Skin contact

- Take off the contaminated clothing
- Rinse the skin with water for 20 minutes.
- Seek immediate medical attention.

## 11.6. Contact with the eyes

- Immediately rinse with ware for 15 to 20 minutes. Ensure a proper wash by separating the eyelids with your fingers.
- Seek immediate medical attention.

## 11.7. In case of ingestion

- Allow the patient to drink large amounts of water to dilute the electrolyte (never provide water to an unconscious person).

- Do not induce vomiting.
- If vomiting occurs spontaneously, keep the patient's head down and forward to reduce the risk of choking. In the case of unconsciousness, keep the patient's head to one side and have the suction ready.
- Seek immediate medical attention.
- Contact a healthcare facility for poison control treatment.

### 11.8. Electrolyte vapor inhalation

- If electrolyte leaks and is exposed to air, electrolyte vapors may be released. Even in a non-fire situation, the electrolyte vapors can be toxic or at least irritating.
- If vapors are inhaled, move immediately to fresh air.
- If inhalation exposure is expected, administer the oxygen and transport the patient to an appropriate medical facility.

### 11.9. Inhalation in fire extinguishing situations

- Toxic gases are released as by-products of combustion.
- All the response staff must use the adequate EPP to firefight, including SCBA.

In case of smoke inhaling, regulate the oxygen and transport the patient to an adequate medical center. As vehicle designs increasingly move away from conventional gasoline engines, alternative fuel vehicles are becoming more frequent on the road, particularly in mass transit and last-mile delivery services.

Before fire investigators can properly determine the origin and the cause of alternative fuel vehicle fires, they must understand how these vehicles are designed and fueled. Although, each vehicle is different, as with conventional fuel vehicles, there are many common elements that can inform the investigator's understanding of the basic principles of how alternative fuel vehicles operate, how they convert alternative fuel to energy, and the important implications of these alternative fuel fire research. These good practices share basic concepts for vehicles that function with alternative fuel.

Important safety warning: A fire investigation involving an alternative fuel vehicle must not proceed unless the vehicle has been made safe according to the manufacturer's instructions for that specific vehicle brand/model/year

# Chapter V

# Data Analysis

## 5.1 Analysis and Interpretation of the Results

The results of the data analysis obtained during the realization of the translations of the documents provided by the institution are presented in this chapter. The analysis of these results has been made with the help of the chart of the text analysis and the stylistic scale, the realization of the color coding of some text fragments, and the glossary of the words presented on the translated documents.

### 5.1.1 Text Analysis.

The following chart presents the text analysis based on the aspects formulated by Newmark and presented in chapter two of this research project. Such aspects are composed by the text style, the text function on the text analysis chart, and the formality, generality or difficulty, and the emotional tone regarding the stylistic scale.

| ***Text Analysis*** | | | |
|---|---|---|---|
| **Documents Translated** | Programa para bomberos dentro del proyecto “avanzando con un enfoque regional para movilidad eléctrica en América Latina”. | Research and Development of Fire Extinguishing Technology for Power Lithium Batteries. | Best Practices for Emergency Response to Incidents Involving Electric Vehicles Battery Hazards: A Report on Full-Scale Testing Results. |
| ***Text Style*** | Descriptive | Descriptive | Descriptive |
| | | | |

| | | | |
|---|---|---|---|
| ***Text Function*** | Informative | Informative | Informative |
| | | | |
| ***Stylistic Scale*** | | | |
| **Documents Translated** | Programa para bomberos dentro del proyecto “avanzando con un enfoque regional para movilidad eléctrica en América Latina”. | Research and Development of Fire Extinguishing Technology for Power Lithium Batteries. | Best Practices for Emergency Response to Incidents Involving Electric Vehicles Battery Hazards: A Report on Full-Scale Testing Results. |
| ***Formality*** | Formal | Official | Official |
| ***Generality or difficulty*** | Technical | Technical | Technical |
| ***Emotional tone*** | Factual | Factual | Factual |

***Table 1. Text analysis chart. Source: Researcher's creation***

### 5.1.2 Color Coding.

As for the color coding, the multiple translation techniques such as transposition, modulation, expansion or amplification, explicitation, literal translation, and reduction or omission that were applied to the translation are highlighted with their respective color to identify them in the multiple texts collected from both translations.

| |
|---|
| Modulation |
| Expansion |
| Explicitation |
| Literal Translation |
| Reduction |

Program for Firefighters

Within the project "Advancing a regional approach to electric mobility in Latin America"

Reference material – June 2022

Paragraph 1

**1. Introducción**

A medida que prolifera el uso de energía alternativa, el servicio de bomberos de Santiago de Cali ha identificado una serie de áreas de preocupación con respecto a la mitigación de riesgos y la respuesta a emergencias. Esto incluye vehículos eléctricos e híbridos que presentan peligros nuevos e inesperados para los bomberos y otros respondedores de emergencias.

Hoy en día es común ver vehículos eléctricos en todo tipo de vías. El número de vehículos de este tipo, incluidos los híbridos, está en constante aumento. En términos estadísticos, esto significa que hay mayores probabilidades de que, en caso de ocurrir, un accidente involucre a un vehículo eléctrico.

Así, es relevante acceder a información sobre el manejo de situaciones de riesgo y emergencias alrededor de esta tecnología con el propósito de crear capacidades de atención.

12. Introduction

As the use of alternative energies proliferates, the Santiago de Cali Fire Department has identified a number of areas of concern regarding risk mitigation and the response to emergencies. This includes electric and hybrid vehicles that present new and unexpected dangers for firefighters and other emergency responders.

Nowadays, it is very common to see electric vehicles on all types of roads. The number of vehicles of this kind, including hybrids, is constantly increasing. In statistical terms, this means that there is a greater chance that, if an accident occurs, it will involve an electric vehicle. Therefore, it is relevant to access information on managing risk situations and emergencies related to this technology in order to create capabilities of alertness.

Paragraph 2

Este material de referencia recoge las MEJORES PRÁCTICAS que están divulgando fabricantes y otros actores relevantes sobre la seguridad en movilidad eléctrica. El documento tiene la intención de ser una referencia para los primeros en la escena, en este caso para BOMBEROS, por lo cual NO es permitido su uso comercial.

**2. Tipo de vehículo de combustible alternativo**

Se pueden encontrar múltiples definiciones del término vehículo eléctrico en la literatura común, y en los códigos y estándares de consenso. Los siguientes son los que se han tomado para este material de referencia:

**a. Vehículo híbrido-eléctrico (HEV)**

Un vehículo eléctrico híbrido (HEV) utiliza dos fuentes   energía: un motor de combustión interna convencional (ICE) y una combinación de motor eléctrico/batería. En contraste a un vehículo híbrido enchufable, no brinda la capacidad de conexión a una fuente externa para cargar las baterías.

This reference material gathers the best practices that are being disseminated by manufacturers and other relevant actors on electric mobility safety. The document is intended reference for first responders, in this case, firefighters; therefore, commercial usage is not allowed.

13. Type of alternative fuel vehicle

Multiple definitions of the term electric vehicle can be found in the common literature, as well as in consensus codes and standards. The following are the ones taken for this reference material:

e. Hybrid-electric vehicle (HEV)

A hybrid electric vehicle (HEV) uses two energy sources: an internal combustion engine (ICE) and an electric/battery engine combination. In contrast to a plug-in hybrid vehicle, it does not provide the ability to connect to an external source to charge the batteries.

Paragraph 3

Sin embargo, las baterías se cargan mediante el motor de combustión interna o un sistema de frenado regenerativo.

**Vehículo eléctrico híbrido enchufable (PHEV)**

Un vehículo eléctrico híbrido enchufable puede recargar sus baterías mediante el uso de una conexión a una fuente de energía eléctrica externa como un enchufe de pared. Un PHEV comparte las características de un vehículo eléctrico híbrido (un motor eléctrico y un motor de combustión interna) y un vehículo totalmente eléctrico (la capacidad de conectarlo a una estación de carga).

**c. Vehículo eléctrico (EV)**

Un vehículo eléctrico (EV) utiliza solo un motor o motores eléctricos para la propulsión
y debe conectarse a una estación de carga para poder recargar la batería que transmite la energía al motor.

However, the batteries are charged by the internal combustion engine or a regenerative braking system.

f. Plug-in hybrid electric vehicle (PHEV)

A plug-in hybrid electrical vehicle can recharge its batteries by using a connection to an external electrical power source such as a wall outlet. A PHEV shares the characteristics of a hybrid electrical vehicle (an electrical engine and an internal combustion engine) and an all-electric vehicle (the ability to connect to a charging station).

g. Electric vehicle (EV)

An electrical vehicle (EV) only uses one or multiple electrical engines for propulsion and it must be connected to a charging station in order to recharge the battery that transmits power to the engine.

Paragraph 4

**d. Vehículos eléctricos especiales (NEV)**

Una subclase especial de un EV es un vehículo eléctrico NEV, vehículo Eléctrico para usos ESPECIALES. Estos son vehículos eléctricos que no están destinados ni diseñados para viajes de larga distancia o velocidades de carretera. Un NEV es un vehículo de baja velocidad de cuatro ruedas que funciona con batería y normalmente se recarga en circuitos eléctricos normales.

**14. Iconos de advertencia e identificadores**

Icono Advertencia

Batería iones de Litio

Icono Advertencia

**4. Conjunto de mejores prácticas para la respuesta de emergencia**

Cada incidente de emergencia al que responde un departamento de bomberos es único. A pesar de las diferencias, sin embargo, hay características comunes que permiten al personal del servicio de bomberos comprender mejor las tareas que deben realizar y prepararse para sus funciones. Esta sección proporciona una revisión de los elementos comunes de mayor interés para los bomberos cuando manejan emergencias que involucran EV y HEV.

h. Especial electric vehicle (NEV)

A special subclass of an EV is the NEV, a special-purpose electric vehicle. These are electric vehicles that are not intended or designed for long-distance travel or highway speeds. A NEV is a low-speed, four-wheeled, battery-powered vehicle that is typically recharged on normal electric circuits.

3. Warning icons and identifiers

d. Warning Icon

e. Lithium Ion Battery

f. Warning Icon

4. Best practices for emergency responses

Each emergency incident, to which the fire department responds, is unique. Despite the differences, however, there are common characteristics that allow the fire department staff to better understand the tasks they must perform and prepare for their roles. This section provides a review of the common elements of most interest to firefighters when handling emergencies involving EV and HEV.

Paragraph 5

Los principales escenarios de emergencia que podría esperar el servicio de bomberos que responda a una emergencia que involucre un EV o HEV se ilustran en la siguiente figura. Escenarios de emergencia clave para EV y HEV.

Esta figura considera las cuatro posibilidades básicas de: (1) Extricación/Rescate; (2) Fuego; (3) Inmersión en agua; y (4) Otros Escenarios.

**5. Respuesta general**

Este material de referencia se orienta a dar una "Respuesta general". Presenta una respuesta inicial, así como una guía para escenarios que no son específicos de ningún vehículo en particular (incendio, sumersión, derrames, etc.).

La seguridad de los bomberos y cualquier otro personal de primera respuesta de emergencias depende de la comprensión y el manejo adecuado de estas orientaciones a través de la capacitación y preparación adecuadas.

The main scenarios of emergency in which the firefighters might expect to respond to an emergency involving an EV or HEV are illustrated in the figure below. Key emergency scenarios for EV and HEV.

This figure considers the four basic possibilities: (1) Extrication/Rescue; (2) Fire; (3) Water Immersion; and (4) 0ther Scenarios.

5. General response

This reference material is intended to provide a "general response". It presents an initial response, as well as a guide for scenarios that are not specific to any particular vehicle (fire, submersion, spills, etc.). The safety of the firefighters and any other emergency first responders depends on understanding and properly handling this guidance through proper training and preparation.

Paragraph 6

Tenga en cuenta que este material de referencia es genérico y se aplica a la mayoría de los vehículos, pero siempre existe la posibilidad de contradicción entre la orientación genérica y las instrucciones específicas del vehículo proporcionadas por el fabricante. En tal caso, siga siempre las instrucciones específicas del fabricante del vehículo.

**a. Datos específicos del vehículo**

Esta información está organizada alfabéticamente por fabricante y luego por modelo de vehículo para cada etiqueta de fabricante.

Cada entrada de vehículo se presenta en un formato de dos páginas con información crítica para ayudar con la identificación, inmovilización, inhabilitación y extracción. Consulte la siguiente página para obtener una descripción del diseño.

Todos los procedimientos de desactivación primarios, así como la mayoría de los procedimientos alternativos, están diseñados para desactivar tanto el sistema eléctrico de combustible o de alto voltaje como el SRS (bolsas de aire, etc.).

Take into consideration that this reference material is generic and it is applied to the majority of vehicles. However, there is always the possibility of contradiction between generic orientation and the specific instructions of the vehicle provided by the manufacturer. In such cases, always follow the specific instructions of the manufacturer of the vehicle.

c. Vehicle specific data

This information is organized alphabetically by manufacturer and then by the model of the vehicle for each manufacturer's label. Each vehicle entry is presented in a two-page format with critical information to assist with the identification, immobilization, disablement, and extraction.

All of the primary deactivation procedures, such as most of the alternative procedures, are designed to deactivate both the fuel or high-voltage electrical system and the SRS (airbags, etc.).

Paragraph 7

La realización parcial de cualquiera de los procedimientos no garantizará que ambos sistemas se apaguen.

NOTA: Siempre que sea posible, se indican las ubicaciones de componentes como el encendido, la batería de 12 V, el freno de mano y el selector de marchas. Sin embargo, siempre es posible que estos componentes se encuentren en otros lugares debido a actualizaciones del modelo del fabricante o modificaciones del mercado secundario.

**b. Información de liberación**

Los fabricantes de automóviles colorearon voluntariamente el cableado para estos sistemas de alto voltaje de color naranja brillante para una identificación fácil y consistente.

En ciertos modelos recientes, han aparecido cables codificados en color azul y amarillo que también presentan un peligro de descarga peligrosa, a pesar de no ser considerados específicamente como de alto voltaje.

Además, el cableado de alto voltaje en los diseños de vehículos a menudo está protegido en canales de conductos protectores, lo que dificulta su localización visual.

The partial performance of any of the procedures will not guarantee that both systems will shut down.

Note: Whenever possible, the locations of components such as the ignition, the 12V battery, the parking brake, and the gear selector are indicated. However, it is always possible that these components may be located elsewhere due to the manufacturer's model updates or secondary market modifications.

d. Release information

The automobile manufacturers voluntarily colored the wiring for these high-voltage systems bright orange for easy and consistent identification. In some recent models, blue and yellow color-coded cables have appeared, which also present a dangerous shock hazard; even though, they are not specifically considered to be high voltage.

In addition, the high-voltage wiring in vehicle designs is often protected in protective conduit channels, making it difficult to locate them visually.

Paragraph 8

En términos de liberación del vehículo, quizás la diferencia más significativa entre un vehículo convencional y un EV o HEV es el sistema eléctrico de alto voltaje.

Los EV y HEV generalmente incluyen baterías de alto voltaje, y la presencia de componentes de alto voltaje crea un posible peligro de electrocución (entre 36 y 600 voltios de electricidad) para el personal de emergencia, especialmente antes de que se den cuenta de que el vehículo es un modelo híbrido.

Si bien es comprensible que el alto voltaje en los vehículos eléctricos e híbridos genere preocupaciones entre los bomberos que exigen un mayor grado de precaución, también genera ciertos conceptos erróneos que merecen ser abordados.

Por ejemplo, la electrocución no es un peligro real por simplemente tocar el exterior de un EV o HEV chocado. Esto no debería ser diferente a un vehículo de motor convencional, ya que el sistema de alto está completamente aislado del chasis/carrocería del vehículo.

In terms of vehicle release, perhaps the most significant difference between a conventional vehicle and an EV or HEV is the high-voltage electric system.

The EVs and HEVs generally include high-voltage batteries and the presence of high-voltage components creates a possible electrocution hazard (between 36 and 600 volts of electricity) for emergency staff, especially before they realize that the vehicle is a hybrid model. While it is understandable that the high voltage in electric vehicles and hybrids generates not only concerns among firefighters that demand a higher degree of caution, but also certain misconceptions that deserve to be addressed.

For example, electrocution is not a real danger just by simply touching the exterior of a crashed EV or HEV. This should not be different from a conventional engine vehicle since the stop system is completely isolated from the chassis/bodywork of the vehicle.

Paragraph 9

Sin embargo, la única excepción obvia para un peligro de electrocución exterior, y que se aplicaría a cualquier vehículo, es una situación de choque que involucre una fuente de energía eléctrica exterior, como cuando las líneas eléctricas caídas se colocan sobre el vehículo chocado.

**6. Procedimientos genéricos de respuesta inicial para vehículos híbridos – eléctricos**

Evaluación / escena 360

**IDENTIFICAR-INMOVILIZAR -DESHABILITAR**

**a. Identificar el vehículo**

SIEMPRE ASUMA QUE EL VEHÍCULO ES DE ALGÚN TIPO HÍBRIDO, ELÉCTRICO O DE COMBUSTIBLE ALTERNATIVO HASTA QUE SE DEMUESTRE LO CONTRARIO.

- Busque distintivos logos externos que indiquen un vehículo de combustible alternativo.
- La identificación puede estar oculta en un choque o incendio, por lo que los métodos de identificación alternativos pueden necesitar ser utilizado.

● Determine la marca, el modelo y el año del vehículo para acceder a un vehículo más específico información que se encuentra en esta guía.

However, the only obvious exception to an exterior electrocution danger, and one that would apply to any vehicle, is a crash situation that involves an exterior electrical power source, such as when the dropped power lines are placed over the crashed vehicle.

6. Generic Procedures of Initial Response for hybrid-electric Vehicles

**Identify – Immobilize – Disable**

d. Identify the vehicle

Always assume that the vehicle is any type of hybrid, electric, or alternative fuel until proven otherwise.

- Search for external logos that indicate an alternative fuel vehicle.
- The identification can be hidden in a crash or fire so that alternative identification methods can be used.
- Determine the brand, model, and year of the vehicle to access a vehicle more specific vehicle information is found in this guide.

Paragraph 10

Es posible que algunos modelos híbridos y eléctricos no tengan distintivos externos para identificar ellos, pero todavía tendrán etiquetas de advertencia de

● alto voltaje y otros secundarios indicadores como el distintivo “Cero emisiones”

**b. Inmovilizar**

TODOS LOS VEHÍCULOS DEBEN SER INMOVILIZADOS ANTES DE TRABAJAR ALREDEDOR DE ELLOS.

LOS VEHÍCULOS HÍBRIDOS Y ELÉCTRICOS PUEDEN PARECER APAGADOS INCLUSO CUANDO NO LO ESTÁN, DEBIDO A LA POTENCIAL FALTA DE RUIDO DEL MOTOR.

- Acérquese al vehículo desde un ángulo de 45° para mantenerse fuera del eje de PROYECCIÓN y:

1. **BLOQUEE LLANTAS**
2. **COLOQUE FRENO DE MANO/ EMERGENCIA**
3. **COLOQUE VEHICULO EN PARKING/PARQUEO**

**c. Deshabilitar**

**MÉTODO DE APAGADO PRIMARIO** (para la mayoría de los vehículos)

1. Apague el encendido del vehículo (si está encendido).
2. Desconecte la batería de 12V (según instrucciones del vehículo).

It is possible that some hybrid and electric models do not have external marks in order to identify them, but they still have high-voltage warning labels and other secondary indicators like the "zero emissions" distinctive.

e. Immobilize

All the vehicles should be immobilized before working around them. The hybrid and electrical vehicles can seem to be off even when they are not, due to the potential lack of engine noise.

- Get close to the vehicle from a 45-degree angle to stay off the projection axis and: block the tires, put the hand/emergency brake, and put the vehicle in parking mode.

f. Disable

Primary shutdown method (for the majority of vehicles)

3. Turn off the vehicle’s ignition (if it is on).
4. Disconnect the 12V battery (according to the vehicle instructions).

Paragraph 11

1. ALGUNOS VEHÍCULOS UTILIZAN LLAVE DE PROXIMIDAD.

SI SE PUEDE LOCALIZAR LA LLAVE, QUITARLA Y ALEJARLA AL MENOS 16 PIES (5 METROS) DEL VEHÍCULO.

SI NO LO PUEDE LOCALIZAR RÁPIDAMENTE, PROCEDA A INHABILITAR EL VEHÍCULO.

UNA VEZ APAGADO EL VEHÍCULO Y DESCONECTADA LA BATERÍA DE 12V, SE DESACTIVA EL SISTEMA DE LLAVE DE PROXIMIDAD.

**MÉTODO DE APAGADO ALTERNO** (si no puede acceder al encendido)

- Consulte la página específica del vehículo para obtener más información.

**NOTA:** La mayoría de los vehículos híbridos y eléctricos están equipados con sistemas de seguridad que están diseñados para apagar automáticamente el vehículo en caso de

un choque.

Por lo tanto, en la mayoría de los incidentes de colisión, el vehículo ya debería estar APAGADO. Verifique el estado del vehículo, para que no reinicie inadvertidamente un vehículo que ya se apagó.

Some vehicles use a proximity key

If the key can be located, remove it, and move it at least 16 feet (5 meters) away from the vehicle. If it cannot be quickly located, proceed by inhabiting the vehicle. Once the vehicle is turned off and disconnected from the 12V battery, the proximity key system is deactivated.

Alternate power off method (if the ignition is not accessible)

- Consult the vehicle-specific page for more information.

Note: The majority of hybrid and electric vehicles are equipped with security systems that are designed to shut down automatically the vehicle in case of a crash. Therefore, in the majority of collision incidents, the vehicle should be off by then. Check the condition of the vehicle in order not to inadvertently restart a vehicle that has already been shut down.

Paragraph 12

**NOTA:** Todos los procedimientos de desactivación principal, así como la mayoría de los procedimientos alternativos, están diseñados para desactivar el sistema de combustible

y/o de alto voltaje del vehículo y el SRS (bolsas de aire, etc.).

La realización parcial de cualquiera de los procedimientos no garantizará que ambos sistemas se apaguen.

**7. Procedimientos y consideraciones generales para la**

**respuesta a incidentes en vehículos híbridos / eléctricos**

Siempre siga y haga referencia a todos los Procedimientos propios al realizar la respuesta y la liberación en un accidente de vehicular.

**7.1. Accidentes**

Siga los procedimientos de respuesta inicial:

- Realice una evaluación de la escena, luego identifique, inmovilice y deshabilite los vehículos.
- Si puede identificar el vehículo, consulte las páginas correspondientes a guía de respuesta del fabricante.
- Si no se puede identificar el vehículo, use el método de apagado común del Sección Respuesta Inicial.

**7.2. Liberación**

Inmovilice y deshabilite el vehículo antes de iniciar las operaciones de extracción.

**SIEMPRE que sea posible estabilice el vehículo antes de comenzar la liberación**

Note: All the principal deactivation procedures, such as the majority of alternative procedures, are designed to deactivate the fueling system and/or the high-voltage vehicle and the SRS (airbags, etc.). The partial realization of any of the procedures does not guarantee that both systems will shut down.

7. General procedures and considerations for the response to incidents in hybrid / electric vehicles.

Always follow and refer to all the proper procedures when responding and releasing in a vehicular accident.

7.1 Accidents

Follow the initial response procedures:

- Perform an evaluation of the scene, and after that locate, immobilize, and disable the vehicles.
- If the vehicle can be identified, consult the corresponding pages of the response guide from the manufacturer.
- If the vehicle cannot be identified, use the common shutdown method from the Initial Response section.

## 7.2 Release

Immobilized and disabled the vehicle before initiating the extraction operations.

**Always stabilize the vehicle before starting the release whenever possible.**

Paragraph 13

(ver ESTABILIZACIÓN). Antes de cortar o hacer palanca, verifique visualmente para determinar la ubicación de:

o **SRS** y Sistemas de Protección de Ocupantes.

o **HV** Componentes y cableado de alta tensión.

o **Líneas de combustible** gaseoso y cilindros/tanques

● El cableado y los componentes HV se enrutan principalmente a lo largo de la parte inferior del vehículo desde el HV batería al compartimiento debajo del capó [motor] y, por lo tanto, NO se encuentran en los puntos de corte de extracción típicos.

● Las ubicaciones de las baterías y los componentes HV pueden impedir técnicas avanzadas como la tunelización troncal y extracción a través del suelo.

## 7.3. Estabilización

● Utilice soportes estándar y métodos de estabilización, los mismos que se utilizan en los vehículos convencionales.

(see Stabilization). Before cutting or levering, visually check to determine the location of: the SRS and Occupant Protection System, HV High voltage components and wiring, fuel gas lines, and cylinders/tanks.

- The HV wiring and the components are primarily routed along the bottom of the vehicle from the HV battery to the under-hood compartment (engine); therefore, they are not located at the typical removal cut points.
- The locations of the HV batteries and components could stop advanced techniques such as the backbone tunneling and through-ground extraction.

7.3 Stabilization

- Use standard brackets and stabilization methods, the same that are used in conventional vehicles.

Paragraph 14

NO coloque el apuntalamiento en un lugar que atrape o pueda enredar cables de alto voltaje o líneas de combustible gaseoso entre el apuntalamiento y el bastidor del vehículo o puntos estructurales. Verifique visualmente antes de colocar el apuntalamiento

**SIEMPRE estabilice el vehículo antes de comenzar la extracción. ACEROS DE ULTRA ALTA RESISTENCIA [UHSS]**

- Resistencia/bajo peso los metales se están utilizando mucho en los diseños de vehículos más nuevos

- Las herramientas de corte hidráulicas que no están diseñadas para aceros de ultra alta resistencia puede resultar inadecuadas.

**Es posible que herramientas como las sierras alternativas no puedan cortar estos metales. Puede que se requieran técnicas de extracción alternativas.**

**Algunas herramientas de corte NO PUEDEN CORTAR aceros nuevos de ultra alta resistencia.**

- Se recomienda enfáticamente que los departamentos de BOMBEROS revisen las capacidades de sus equipos de corte frente a los aceros de ultra alta resistencia antes de encontrar estos materiales en el campo.

Do not place the shoring in a location that will trap or tangle high-voltage wires or gaseous fuel between the shoring and the vehicle frame or structural points. Visually check before placing the shoring.

**Always stabilize the vehicle before performing the extraction.**

**Ultra-High Strength Steels [UHSS]**

- Strength/low-weight metals are being used extensively in newer vehicle designs.
- The hydraulic cutting tools that are not designed for ultra-high strength steels may be inappropriate.

It is possible that tools such as alternative saws cannot cut these metals. Alternative extraction techniques may be required.

Some cutting tools cannot cut new ultra-high-strength steel.

- It is highly recommended that the firefighter department review the abilities of their cutting equipment against ultra-high strength steel prior to encountering these materials in the field.

Paragraph 15

**7.4. Advertencia**

● Evite el contacto con el cableado y los componentes de alta tensión. SIEMPRE asuma que el sistema HV está energizado.

**NUNCA corte el cableado naranja de alta tensión ni penetre los componentes de alta tensión con herramientas.**

● Los procedimientos de apagado del sistema HV están diseñados para desactivar el sistema HV del vehículo, no para descargar la batería HV.

**LA BATERÍA HV PERMANECERÁ CON ENERGÍA.**

● Si no se puede acceder al sistema de 12 V del vehículo y no se puede desactivar, los sistemas de protección de los ocupantes, como las bolsas de aire o los pretensores, pueden permanecer activos, incluso si el sistema HV está apagado

**7.5. Nota**

VEHÍCULOS HÍBRIDOS Y ELÉCTRICOS

El cableado azul y amarillo de voltaje medio/intermedio se trata igual que el cableado naranja de alto voltaje (HV). Todas las referencias a las prácticas de alta tensión también se aplican a los sistemas de tensión media/ intermedia.

7.4 Warning

- Avoid contact with high-voltage wiring and components. Always assume the HV system is energized.

**Never cut the orange high-voltage wiring or penetrate high-voltage components with tools.**

- The shutdown procedures of the HV system are designed to deactivate the HV system of the vehicle, not to discharge the HV battery.

**The HV battery will remain with energy.**

- If the vehicle's 12 V system is not accessible and cannot be deactivated, the occupant protection systems, such as the airbags or pretensioners, may remain active even if the HV system is turned off.

7.5 Note

Hybrid-electric vehicles

The blue and yellow medium/intermediate voltage wiring is treated the same as the orange high voltage (HV) wiring. All references to HV practices also apply to medium/intermediate voltage systems.

| |
|---|
| Transposition |
| Modulation |
| Expansion |
| Explicitation |
| Literal Translation |
| Reduction |

**Investigación y Desarrollo de la Tecnología de Extinción de Incendios en Baterías de Litio**

Paragraph 1

**Abstract**

By summarizing the previous experimental studies on fire extinguishing of lithium battery, it was found that the lithium battery fire extinguishing exhibits some essential characteristics, such as long duration, high temperature, large water consumption and great difficulty in extinction. The applicability of fire extinguishing agent for power lithium batteries was analysed in this work. Through the acupuncture experiment, the different efficiencies of fire extinguishing agents were compared. It is expected to provide some useful references for future safety design and prevention of such lithium batteries.

## 1. Introduction

In recent years, the demand for new energy sources is increasing with the increasingly serious environmental problem, and the new energy vehicles represented by electric vehicles gets more attention. By the end of 2015, the total annual production of new energy vehicles are nearly 380000, and the number of new energy vehicles shows explosive growth trend. It is expected that production and sales of electric cars in China will reach one million in 2017.

Resumen

De acuerdo con estudios experimentales anteriores sobre la extinción de incendios en baterías de litio, se encontraron algunas características esenciales como su larga duración, las altas temperaturas que se desprenden de estos sucesos, el alto consumo de agua y la gran dificultad para extinguir estos sucesos. La aplicabilidad de los agentes extintores de incendios en baterías de litio fue analizada en este trabajo, a través del experimento de acupuntura se compararon las diferentes eficiencias de los agentes extintores de incendios; de modo que se pretende proveer referencias útiles para el futuro diseño de seguridad y mantenimiento preventivo de las baterías de litio.

## 6. Introducción.

En los últimos años hubo un aumento en la demanda de nuevas fuentes de energía, con esto se incrementaron los problemas ambientales, así como la mayor atención de vehículos de energía nueva, como lo son los vehículos eléctricos. Para finales del año 2015, el total de la producción anual de vehículos de energía nueva fue de aproximadamente 380 000, número que demuestra una tendencia a la alza de manera muy rápida. Se estima que en China la producción y venta de autos eléctricos alcance un millón para el 2017.

Paragraph 2

China is now in a critical stage of the development of new energy automotive industry and thus the security of new energy vehicles becomes more sensitive. Safety accidents of new energy vehicles have their special internal reasons, because the battery serves as a high energy carrier. The thermal runaway occurs at low temperature, and it is not easy to eliminate such accidents. Many influential fire accidents have caused numerous economic loss, fatalities and severe social influence. Thermal self-ignition, fire and explosion phenomenon of electric vehicle battery make the safety of lithium-ion battery become the focus of attention. Questions about the safety and reliability of power battery of electric vehicles bring new problems and challenges for fire fighting and emergency rescue. Recently, the scholars in State Key Laboratory of Fire Science carried out fire extinguishing experiments on the technology of lithium battery fire prevention and control, but the research is still in the initial stage [1].

China está en una etapa crítica del desarrollo de la industria automovilística de nuevas energías, por lo tanto, la seguridad de estos vehículos se vuelve más sensible.

Los accidentes de seguridad en vehículos de energía nueva deben ser manejados con extrema cautela, pues la batería de litio que forma parte de su estructura actúa como un gran portador de energía.

En estos casos, la fuga térmica ocurre a baja temperatura y eliminar estos accidentes no es fácil, es por esto que, los fenómenos de autoignición térmica, incendio y explosión de la batería del vehículo eléctrico hacen que la seguridad de las baterías de iones de litio se convierta en el centro de atención. Así, las preguntas sobre seguridad y fiabilidad de la batería de litio de los vehículos eléctricos presentan nuevos problemas y desafíos para la lucha contra incendios y rescates de emergencias. Recientemente, los académicos de State Key Laboratory of Fire Science llevaron a cabo experimentos relacionados con la extinción de incendios sobre la tecnología de prevención y control de incendios en baterías de litio, pero la investigación aún se encuentra en la fase inicial.

Paragraph 3

This study utlizes 18650# lithium-ion batteris to examine the efficiency of pure water, 5% F-500 solution and 5% self-made solution (anionic nonionic surfactants) on lithium battery fires. In addition, the water mist extinguishing system is applied to extinguish lithium battery fires, which provides an alternative method for such fires. This work reveals some fundamental insight into studying the technology of extinguishing large-scale lithium battery fires.

## 2. Characteristics of fire extinguishing for power lithium battery

Although the cause of electric vehicle fire is complex, one of the main reasons is the spontaneous ignition caused by power lithium battery. In the study of fire accidents of power lithium battery, NFPA [2] has carried out the lithium battery fire experiment.

### *2.1. Fast burning and long duration*

The power lithium battery causes a series of effects because of various incentives leading to thermal runaway. Once the heat accumulation of lithium battery is out of control, the battery would burn immediately.

Este estudio utiliza baterías de iones de litio #18650 para examinar la eficiencia de agua pura, al 5 % de solución F-5000 y al 5 % de solución creada (anicónico, niónico y surfactantes) en incendios de baterías de litio. Además, el sistema de extinción por agua nebulizada fue aplicada para extinguir los incendios de baterías de litio, proporcionando un método alternativo para estos incendios. Este trabajo revela una percepción fundamental sobre el estudio de la tecnología de extinción de incendios de batería de litio a gran escala.

## 7. Características de la extinción de incendios para la batería de energía de litio.

Aunque la causa de incendio en vehículos eléctricos es complicada, una de las razones principales es la ignición espontánea causada por la batería de litio. En el estudio de accidentes de incendio por baterías de litio, la Asociación Nacional de Protección contra el Fuego (NFPA) ha llevado a cabo el experimento sobre incendios causados por baterías de litio.

7.1. Quemado rápido y larga duración

La batería de litio causa una serie de efectos debido a que varios incentivos llevan a una fuga termológica. Una vez que la acumulación de calor de una batería de litio esta fuera de control, la batería se quema inmediatamente.

Paragraph 4

Figure 1 shows the lithium batteries fire extinguishing process carried out by NFPA. It only took a few seconds for the battery to transform to intense combustion, whereas the suppression process had lasted about 27 minutes [2].

**2.2.** ***High temperature***

During the fire tests, NFPA used thermocouple to measure the temperature and found that the maximum temperature outside the battery is in the range of 283 to 1090 degrees, and the maximum temperature inside the battery is between 572 and 1121 degrees. The peak heat flux at a distance of 5 feet from the VFT device is 2.2kW/ $m^2$ , and the value ranges from1.5 kW/ $m^2$ to 2.1kW/ $m^2$ when the distance is15, 20 and 25 feet individually. The maximum temperature and heat flux measured during the tests mostly occurred after the burner was terminated. It indicated that the battery fire was still very hot at that time. Therefore, the flame temperature is high enough to ignite other combustibles once the vehicle's power lithium battery burns.

La figura 1 muestra el proceso de extinción de un incendio de una batería de litio llevado a cabo por la Asociación Nacional de Protección contra el Fuego. En este caso a la batería solo le tomó unos segundos transformase en una combustión intensa, mientras que el proceso de supresión duró unos 27 minutos [2].

### 7.2. Temperatura alta

Durante las pruebas de incendio, la NFPA utilizó un termopar para medir la temperatura y para encontrar la temperatura máxima fuera de la batería en un rango entre 283 y 1090 grados, se determinó que la temperatura máxima dentro de la batería se encontraba entre 572 y 1121 grados. Se debe tomar en cuenta que el flujo de calor máximo a una distancia de 5 pies del dispositivo VFT es de 2.2kW/ $m^2$ , y el valor oscila entre 1.5kW/ $m^2$ a 2.1kW/ $m^2$ cuando la distancia es de 15, 20 y 25 pies respectivamente. La temperatura máxima y el flujo de calor medido durante las pruebas ocurrieron después de que el incendio fue controlado, esto indica que la batería aún estaba muy caliente; por lo tanto, la temperatura de la flama es lo suficientemente caliente para encender otros combustibles una vez que la batería de litio del vehículo se quema.

Paragraph 5

***2.3 Large water consumption***

During the fire extinguishing tests, NFPA used water to put out the power lithium battery fire. In order to avoid the reignition, the fire extinguishing continued for a long time and the water consumption was larger than others. Although the increased amount of water extinguished the fire more thoroughly, it endangered the battery at thermal runaway temperature.

***2.4 Enhanced difficulty in extinguishing***

The combustion reaction of power lithium battery generally occurs inside the battery. Water cannot get access to the "fire", which is an important problem for fire fight. For the power battery pack, shell material of battery pack prevent fire extinguishing agent from acting on electrical core directly. So fire fighting is more difficult [3].

7.3. Gran consumo de agua

Durante las pruebas para extinguir el fuego, la NFPA utilizó agua para controlar y apagar el incendio y evitar que la batería de litio reiniciara el fuego; además la extinción del fuego tardó mucho tiempo y el consumo de agua fue mayor que en otros eventos similares pero con materiales diferentes, el exceso de agua puso en peligro la batería por un flujo térmico de temperatura.

7.4. Mayor dificultad para extinguir

La reacción de la combustión de las baterías de litio generalmente ocurre dentro de la batería, por esta razón el agua no puede acceder al incendio, pues la carcasa de la batería previene que el agente de extinción de incendios actúe directamente en el núcleo eléctrico; por lo tanto, se convierte en un tema importante que se debe tomar en cuenta a la hora de extinguir un evento de este tipo.

Paragraph 6

During tests, the total time spent on fighting fires exceeds the fire fighters' oxygen supply time and it poses a greater challenge to the personal security of fire fighters. Therefore, there is no effective method for the firefighting of power lithium batteries, which belongs to the worldwide problem.

**7.5. Complexity of power lithium battery's fire extinguishing**

A power battery is an energy storage unit whose fire is transformed from its electrical and chemical energy. When the electric and chemical energy is not consumed completely, the heat is in the sustained release stage. After the thermal runaway's expansion stage, the effectiveness of the fire suppression is very effective. This is the origin of the saying "why power fires can not be extinguished"., the development of the battery fire is very swift and violent especially for the ternary polymer lithium battery, and it releases oxygen itself. Consequently, it can hardly be extinguished after the fire spread.

Durante las pruebas, el tiempo total dedicado para luchar contra incendios excede el tiempo del suministro de oxígeno de los bomberos y presenta un gran desafío para la seguridad personal de los bomberos; de modo que se evidenció que no hay un método efectivo para luchar contra incendios provocados por las baterías de litio.

2.5. La complejidad para extinguir incendios en baterías de litio

Una batería es una unidad de energía de almacenamiento cuyo fuego se transforma a partir de su energía eléctrica y química, cuando estas no se consumen completamente el calor se encuentra en una fase de liberación sostenida. Después de la etapa de expansión del flujo térmico, la supresión del fuego se vuelve muy eficaz. Este es el origen del dicho “por qué los incendios de energía no se pueden extinguir”. El desarrollo de los incendios por baterías es muy veloz y violento, especialmente por la batería ternaria de polímero de litio que libera oxígeno por sí sola. Por consiguiente, es muy difícil de extinguir después de que el fuego se haya propagado.

Paragraph 7

Employing some specific methods can inhibit the occurrence and spread of fire. In addition to fire extinguishing at an open fire stage, the control of thermal runaway stage is also very important, such as the use of flame retardant materials, the addition of flame retardants in electrolyte. It is more important to develop the early warning technology. Study of the power battery fire on intelligent fire detection and flame retardant mechanism has been a breakthrough. However, there is rare effective breakthrough in the basic research about the technology of clean fire prevention and control, and its development has encountered considerable difficulties.

3. Research on fire extinguishing of lithium battery

At present the research on fire experiments of power lithium battery is highly concerned. The United States and the countries in Europe concerned about the fire safety of lithium batteries in the earlier times [4,5], such as the National Fire Protection Association (NFPA), the Federal Aviation Administration (FAA), and the Civil Aviation Authority (CAA).

El empleo de algunos métodos específicos puede impedir que ocurra y se propague el incendio. Adicionalmente, para extinguir un incendio abierto, el control de la fase de la fuga térmica también es muy importante, así como el uso de materiales ignífugos, principalmente en electrolitos. Por lo tanto, es más importante desarrollar la tecnología de alerta rápida, gracias a esto la detección inteligente de incendios y de mecanismos ignífugos han sido un avance en relación con las baterías. Sin embargo, hay un avance extraño y eficiente en la investigación básica sobre la tecnología de prevención y control de incendios, su desarrollo se ha enfrentado con dificultades considerables.

Actualmente, las investigaciones sobre incendios en baterías de litio es muy preocupante, anteriormente en Estados Unidos y países europeos se preocupaban [4,5] por la seguridad contra incendios en baterías de litio, entidades como la Asociación Nacional de Protección contra el Fuego (NFPA), la Administración Federal de Aviación (FAA), y la Dirección General de Aviación Civil (CAA).

Paragraph 8

Recently, the scholars in the United States FM Global, the National Fire Protection Association (NFPA) and State Key Laboratory of Fire Science carried out fire extinguishing experiments on the technology of lithium battery fire's prevention and control, but the fire model was different [1].

### 3.1. Study on fire extinguishing of lithium batteries abroad

FAA has carried out the screening experiments of effective fire extinguishing agent fighting lithium battery fires, and evaluated their effectiveness through the fire simulation experiment and the experiment on cooling effect of fire extinguishing agents [6]. The experiment on cooling effect of fire extinguishing agent compared Halon1211 fire extinguishing agent with water based extinguishing agent such as water, AF-31, AF-21, A-B-D. It also compared gas fire extinguishing agent such as FM-200, FE-36, Halotron I with powder extinguishing agent and new fire extinguishing agent such as Purple-K and Novec1230.

Recientemente, los académicos de FM Global de Estados Unidos, la Asociación Nacional de Protección contra el Fuego (NFPA) y State Key Laboratory of Fire Science llevaron a cabo experimentos de extinción de incendios en relación con la tecnología de prevención y control de incendios en baterías de litio, pero el modelo de incendio es diferente [1].

3.1. Estudio sobre la extinción de incendios de baterías de litio en el extranjero

La FAA ha llevado a cabo experimentos de prueba de un agente extintor eficaz contra los incendios de baterías de litio, se realizó una simulación de incendio, tomando como punto de partida experimentos basados en el enfriamiento de los agentes extintores. Este se comparó el agente extintor de incendios Halon1211 con agentes de extinción acuosos, así como el agua, AF-31, AF-21, A-B-D. También se compararon agentes extintores de incendios de gas, como el FM-200, FE-36, Halotron I con un agente extintor en polvo y un nuevo agente extintor de fuego como el Purple-K y el Novec1230.

Paragraph 9

The results showed that the water based extinguishing agent has good cooling effect. With the increase of extinguishing agent's dosage, the cooling effect is more significant. And reducing the sprinkling capacity also has remarkable effects on the cooling effect. But non-water based extinguishing agent's cooling effect is not obvious. With the increase of extinguishing agent's dosage, the cooling capacity has little changes. Water based fire extinguishing agent's cooling ability was prioritized as AF-31, AF-21, A-B-D and Novec 1230.

Based on the experimental research on the fire extinguishing agent's cooling effect, FAA carried out the fire experiment of lithium battery. The experiment used a 18650# lithium-ion battery (battery capacity is 2600mAh, SOC is 50%). First, the heater of tube furnace was turned on, and then the heater of hexane was opened when the first battery's temperature was heated to 100℃.

Los resultados mostraron que el agente extintor a base de agua posee un buen efecto más significativo en relación con el enfriamiento. Al reducir la capacidad de aspersión también se pueden obtener efectos notables en el proceso de enfriamiento; sin embargo, el efecto de enfriamiento de los agentes extintores no acuosos no es evidente, pues con el incremento de la dosis del agente extintor, la capacidad de enfriamiento tiene pequeños cambios. La capacidad de enfriamiento del agente extintor a base de agua se priorizó como AF-31, AF-21, A-B-D y Novec 1230.

Con base en la investigación experimental sobre el efecto refrigerante del agente extintor de incendios, la FAA llevó a cabo el experimento de incendio en baterías de litio, en este se usó una batería de iones de litio #18650 (la capacidad de la batería es de 2600mAh, SOC es de 50%). Primero se encendió el calentador del horno tubular, luego se abrió el calentador de hexano cuando la temperatura de la primera batería se calentó a 100 grados Celsius.

Paragraph 10

After the first battery was out of control, the fire extinguishing agents were sprayed. When the fire extinguishing agents is liquid at ambient temperature and pressure, such as water, AF-31, AF-21, A-B-D and Novec1230, they were sprinkled by a 500ml hand-held bottle. Other fire extinguishing agents, such as Halon1211, Halotron, I, FM-200, FE-36, CO2 and Purple-K, were sprayed by a hand-held bottle. After the fire was over, the heater was closed and data was recorded for about 20 minutes. The results showed that all thermal runaway of lithium battery occurred and spread in the absence of fire extinguishing agents, and only 500ml liquid fire extinguishing agents can effectively inhibit the spread of lithium-ion battery fire. Non-liquid fire extinguishing agents had no effect on lithium-ion battery.

Una vez que la primera batería estuvo fuera de control, se rociaron los agentes extintores de incendios.

Cuando los agentes extintores de incendios son líquidos a temperatura y presión ambiente, como el agua, AF-31, AF-21, A-B-D and el Novec1230, estos fueron rociados por una botella de 500ml. Otros agentes extintores de incendios, como el Halon1211, Halotron, I, FM-200, FE-36, CO2 y el Purple-K fueron rociados con una botella. Después de que el incendio se apagara, el calentador se cerró, los datos fueron grabados por 20 minutos. Los resultados mostraron que todas las fugas térmicas de las baterías de litio ocurrieron y se propagaron en la ausencia de agentes extintores de incendios, y solo 500 ml de un agente extintor de incendios puede impedir eficazmente la propagación de un incendio de una batería de iones de litio. Además se concluyó que los agentes extintores no acuosos de incendios no hacen efecto en baterías de iones de litio.

Paragraph 11

Through the research of this project, FAA found that the experimental results of fire extinguishing agents' cooling effect are similar to the experimental results of lithium battery fire extinguishing. It further testified that the cooling ability of fire extinguishing agents is the key factor to prevent the spread of lithium battery fire. Water based fire extinguishing agents had the best effect on the suppression of lithium battery fires, while gas extinguishing agents and dry powder extinguishing agents are ineffective in suppressing lithium battery fires.

3.2. The study on fire extinguishing of lithium battery in China

In order to reduce the risk of lithium battery fires, Wuhan Institute of China Classification Society [7] carried out the research on the effectiveness of extinguishing agent of fighting power lithium battery fire.

A lo largo de la investigación de este proyecto, la FAA encontró que los resultados experimentales del efecto de enfriamiento de los agentes extintores de incendios son similares a los resultados de los experimentos sobre la extinción de incendios en baterías de litio; asimismo se evidenció que la capacidad de enfriamiento de los agentes extintores de incendios es el factor clave para prevenir la propagación de incendios de baterías de litio. Los agentes extintores a base de agua tuvieron un mejor efecto en la supresión de los incendios en baterías de litio, mientras que los agentes extintores de gas y polvo seco no son efectivos al suprimir los incendios en baterías de litio.

3.2. Estudio sobre la extinción de incendios en baterías de litio en China.

Para reducir el riesgo de incendios por baterías de litio, el Wuhan Institute of China Classification Society llevó a cabo una investigación sobre la eficacia de agentes extintores en la lucha contra incendios en baterías de litio.

Paragraph 12

They evaluated its effectiveness from three aspects such as the fire extinguishing time, the recrudescence rate and smoke effect synthetically.The experiment found that the carbon dioxide's extinguishing effect is poor and the resurgence of fire occurred. powder extinguishing agent has little effect on the lithium battery, and explosion occurred even during the experiment. The best effect on extinguishing lithium battery fires is heptafluoropropane.

University of Science and Technology of China [8] carried out the research on the effectiveness of dry powder, carbon dioxide and heptafluoropropane of extinguishing lithium battery fires. It was found that heptafluoropropane has good effect, but also the resurgence of fire occurred.

Tianjin fire station of Ministry of public security [3] conducted the experiment of extinguishing lithium battery fires with the powder, carbon dioxide and AFFF fire extinguishing agent and water mist technology.

Los investigadores analizaron la eficacia del dióxido de carbono, polvo seco y heptafluoropropano, que impiden los incendios en baterías de litio; asimismo evaluaron su eficacia desde tres aspectos, como el tiempo de extinción del incendio, la tasa de resurgimiento y el efecto del humo sintético. Al respecto el experimento mostró que el efecto extintor del dióxido de carbono fue débil y se produjo un resurgimiento del incendio. El agente en polvo seco presentó un pequeño efecto en la batería de litio, y se presentó una explosión durante el experimento, entre todos estos agentes extintores el que tuvo un mejor efecto extinguiendo el incendio de la batería de litio fue el heptafluoropropano.

En la misma línea la Universidad de Ciencia y Tecnología de China llevó a cabo una investigación sobre la eficacia del polvo seco, dióxido de carbono y heptafluoropropano en la extinción de incendios en baterías de litio. Se descubrió que el efecto del heptafluoropropano es bueno, pero también se produjo un resurgimiento del incendio. Taijin Fire Station of Ministry of Public Security realizó un experimento sobre la extinción de incendios en baterías de litio utilizando el polvo, el dióxido de carbono y con el agente extintor de incendios AFFF y la tecnología de agua nebulizada.

Paragraph 13

The results showed that the carbon dioxide, dry powder, 3% AFFF can extinguish the open fire of 18650# lithium-ion batteries. Due to the thermal runaway of lithium-ion batteries, it continued to release heat, combustible gas and oxygen. It can not extinguish the fire completely. All of them appeared resurgence phenomenon. With the fire extinguishing agent’s cooling ability increasing, the time of appearing resurgence prolonged. For completely extinguishing 18650# lithium-ion battery fires, it needs to improve the fire extinguishing agent's ability of cooling and absorbing heat. Water mist fire extinguishing technology can not inhibit the 18650# lithium-ion battery fires effectively. Some studies showed that [4,5] water mist containing surface active agent is an efficient and environmental fire extinguishing technology. The utility of lithium battery fire needs further study.

Los resultados demostraron que el dióxido de carbono, el polvo seco y el 3 % de AFFF pueden extinguir el incendio de una batería de iones de litio #18650. Debido a una fuga térmica, la batería de litio siguió liberando calor, gas combustible y oxígeno; sin embargo, con ninguno de estos agentes se puede extinguir completamente el incendio.

En todos los casos mencionados anteriormente se presentó el fenómeno de resurgimiento, pero se debe tomar en cuenta que con el incremento de la capacidad de enfriamiento de los agentes extintores de incendios, se prolonga el tiempo de aparición de un resurgimiento. Para extinguir completamente el incendio de baterías de iones de litio #18650 se necesita mejorar la capacidad de enfriamiento y de absorción de calor de los agentes extintores de incendios. En estos casos la tecnología de aspersión de agua no puede inhibir con eficacia los incendios de la batería de iones de litio #18650. Algunos estudios mostraron que el agua nebulizada con un agente superficial activo es una tecnología de extinción de incendios eficaz y amigable con el ambiente. Se concluye que la extinción de los incendios en las baterías de litio requiere más estudios.

Paragraph 14

3.3. Application of F-500 micro capsule technology and water mist containing additives system in the lithium battery fire extinguishing

There are few studies on the micro capsule technology of explosive hydrocarbons in the literature, and the results of existing research are concentrated mainly in developed countries. The existing advanced technology is F-500 micro capsule's material technology, which is a new high efficiency fire extinguishing, explosion prevention and environmental technology developed by the American dangerous goods Control Arts Inc (HCT). In 2009, Bosch tested the extinguishing effect of water, foam, powder and F-500 on lithium battery fires. The tests found that F-500 is the first choice of lithium battery fire extinguishing agent.

In April 2013, German motor vehicle inspection association (DEKRA) selected three kinds of fire extinguishing agent, and studied the extinguishing effect on power lithium battery fire of electric vehicle [9].

3.3. Aplicación de la tecnología de microcápsulas F-500 y del sistema de agua nebulizada con aditivos en la extinción de incendios de baterías de litio.

Existen pocos estudios en la literatura sobre la tecnología de microcápsulas de hidrocarburos explosivos y los resultados de las investigaciones existentes se concentran principalmente en países desarrollados. La tecnología avanzada existente es la tecnología de materiales de las microcápsulas F-500, que es una nueva tecnología altamente eficaz para la extinción de incendios, prevención de explosiones y protectora del medio ambiente desarrollada por American Dangerous Goods Control Arts Inc (HCT). En 2009, Bosch probó el efecto extintor de agua, espuma, polvo y F-500 en incendios de baterías de litio. Las pruebas revelaron que el F-500 es la primera opción como agente extintor de incendios en baterías de litio.

En abril de 2013, la German Motor Vehicle Inspection Association (DEKRA) seleccionó tres tipos de agentes extintores de incendios e investigó el efecto de extinción de los incendios en baterías de litio de vehículos eléctricos.

Paragraph 15

According to the structure of electric vehicle's lithium battery, DEKRA used n-heptane to ignite lithium battery and set up fire model. They compared F-500 fire extinguishing agent's effect with water and powder fire extinguishing agent's effect on extinguishing lithium battery fire. Firefighters began to fight fire after n-heptane combustion's time at about 20min. Through simulation experiments, DEKRA found that water can successfully extinguish the lithium battery fire of electric vehicles. But there are many other problems, such as large water consumption and long extinguishing time. F-500 fire extinguishing agent can improve the efficiency of extinguishing lithium battery fires. The extinguishing time of extinguishing agent containing 1% F-500 is only fourteen seconds. The water consumption is greatly reduced. As a kind of micro cellular agent, F-500 can effectively inhibit class D (metal) fire in which no explosion exists.

De acuerdo con la estructura de la batería de litio del vehículo, DEKRA utilizó n-heptano para encender la batería de litio y crear un modelo de incendio. Se compararon los efectos del agente extintor F-500 con el agua y el del agente extintor en polvo en relación con la extinción de incendios en baterías de litio. Los bomberos comenzaron a luchar contra el incendio por alrededor de 20 minutos después de la combustión de n-heptano. En este experimento de simulación DEKRA descubrió que el agua puede extinguir con éxito el incendio en batería de litio de vehículos eléctricos. Sin embargo, hay muchos otros problemas, como el gran consumo de agua y el largo tiempo de extinción. Se demostró que el agente extintor F-500 puede mejorar la eficacia de la extinción de incendios en baterías de litio. El tiempo de extinción de este agente con tan solo un 1 % de F-500 es de solo catorce segundos, de esta manera el consumo de agua se redujo considerablemente; así, el F-500, como un tipo de agente microcelular, puede inhibir eficazmente un incendio clase D (metal) en el que no exista una explosión.

### 5.1.3 Glossary.

The glossary is a chart the researcher mainly uses to become familiar with the vocabulary presented in both source texts. In this case, the target word, the grammatical category, and the definitions were the main aspects analyzed for each single word collected during the translation process.

| ***English Glossary*** | | | |
|---|---|---|---|
| ***Word*** | ***Target Word*** | ***Grammatical Category*** | ***Definition*** |
| Runaway | Descontrolado | Noun | The act of running away out of control |
| Self-ignition | Autoignición | Verb | To become ignited without flame or spark (as under high compression) |
| Automotive | Automotor | Adjective | Of, relating to, or concerned with self-propelled vehicles or machines |
| Hazards | Riesgo | Verb | To offer or present at a risk |
| Standpoint | Punto de vista | Noun | A position from which objects or principles are viewed and according to which they are compared and judged |
| Suppression | Supresión | Noun | An act or instance of suppressing**:** the state of being suppressed |
| Intercalated | Intercaladas | Verb | To insert or position between or among existing elements or layers |
| Flux | Cambio constante | Noun | A continuous moving on or passing by |

| | | | |
|---|---|---|---|
| Recrudescence | Recrudecimiento | Noun | A new outbreak after a period of abatement or inactivity |
| Droplets | Gotitas | Noun | A tiny drop (as of a liquid) |
| Prodded | Pinchado | Verb | To poke or stir as if with a prod |
| Extrusion | Extrusión | Noun | The act or process of extruding<br>*Also,* a form or product produced by this process |
| Thermocouples | Termopares | Noun | A device for measuring temperature in which a pair of wires of dissimilar metals (such as copper and iron) are joined and the free ends of the wires are connected to an instrument (such as a voltmeter) that measures the difference in potential created at the junction of the two metals |
| Hissing | Silvar | Verb | To make a sharp sibilant sound |
| Spurt | Escupir | Noun | To make a spurt |

| | | | |
|---|---|---|---|
| Nozzle | Pulverizador | Noun | A part in a rocket engine that accelerates the exhaust gases from the combustion chamber to a high velocity |
| Feasibility | Factibilidad | Adjective | Capable of being done or carried out |
| Phenomenon | Fenómeno | Noun | A fact or event of scientific interest susceptible to scientific description and explanation |
| Acupuncture | Acupuntura | Noun | An originally Chinese practice of inserting fine needles through the skin at specific points specially to cure disease or relieve pain (as in surgery) |
| Standardized | Estandarizado | Adjective | Brought into conformity with a standard**:** done or produced in a standard, consistent way |
| Additives | Aditivo | Adjective | Characterized by, being, or producing effects (such as drug responses or gene products) that when the causative factors act together are the sum of their individual effects |
| Degradation | Degradación | Noun | Decline to a low, destitute,<br>or demoralized state |
| Inhibiting | Impedir | Verb | To prohibit from doing something |

| | | | |
|---|---|---|---|
| Salvage | Salvar | Verb | To rescue or save especially from wreckage or ruin |
| Recreational | Recreativo | Adjective | Of, relating to, or characteristic of recreation |

***Table 3. Glossary of the most relevant terms found in the document from Spanish into English***
***Source: Researcher's creation***

| ***Glosario en español*** | | | |
|---|---|---|---|
| ***Palabra*** | ***Traducción*** | ***Categoría Gramatical*** | ***Definición*** |
| Prolifera | Proliferates | Verbo | Reproducirse en formas similares |
| Consenso | Consensus | Sustantivo | Acuerdo producido por consentimiento entre los miembros de un grupo o entre varios grupos |
| Sumergidos | Submerged | Adjetivo | Que está metido debajo del agua o de otro liquid |
| Carrocería | Bodywork | Sustantivo | Parte de los vehículos automóviles o ferroviarios que, asentada sobre el bastidor, reviste el motor y otros elementos, y cuyo interior se acomodan los pasajeros o la carga |
| Hacer palanca | Lever | Verbo | Apoyar sobre un punto una palanca para levanter, hacer deslizarse o hacer girar un objeto |
| Radiadores | Radiators | Sustantivo | Aparato metálico con gran desarrollo superficial, por cuyo interior circula un fluido caliente que transmite calor al medio circundante |
| Apuntalamiento | Shoring | Sustantivo | Acción y efecto de apuntalar |

| | | | |
|---|---|---|---|
| Bastidor | Chassis | Sustantivo | Armazón metalico que soporta la carrocería de un automóvil |
| Manipulación | Handling | Verbo | Operar con las manos o con cualquier instrumento |
| Electrólisis | Electrolysis | Sustantivo | Descomposición en iones de una sustancia de disolución mediante la corriente eléctrica |
| Cortocircuito | Short circuit | Sustantivo | Circuito que se produce, generalemnte de manera accidental por contacto entre los conductors de polos opuestos y suele ocasionar una descarga |
| Aislante | Ribbon | Adjetivo | Que aísla |
| Refrigerante | Cooling | Adjetivo | Que refrigera |
| Cáusticos | Caustic | Adjetivo | Dicho de una cosa: Que quema y destruye los tejidos animales |
| Ingestión | Ingestion | Verbo | Acción de ingerir |
| Implicaciones | Implications | Sustantivo | Acción y efecto de implicar o implicarse |
| Divulgando | Reporting | Verbo | Publicar, extender, poner al alcance del público algo |
| Disolventes | Solvents | Adjetivo | Que se disuelve |
| Compresion | Contraction | Sustantivo | Acción y efecto de comprimir |
| Proyección | Launch(ing) | Sustantivo | Resonancia o alcance de un hecho o de las cualidades de una persona |
| Inhabilitar | Disqualify | Verbo | Declarar a alguien inhábil o incapaz de obtener o ejercer cargos públicos, o de ejercitar derechos civiles o politicos |
| Ocupante | Occupying | Adjetivo | Que ocupa |
| Enfáticamente | Emphatically | Adverbio | Con énfasis |

| | | | |
|---|---|---|---|
| Alcalino | Alkaline | Adjetivo | Propio de las sustancias, elementos o soluciones alcalinas |
| Corrosivo | Corrosive | Adjetivo | Que correo o tiene la propiedad de corroer |

***Table 4. Glossary of the most relevant terms found in the document from English into Spanish***
***Source: Researcher's creation***

# Chapter VI

# Conclusions and Recommendations

## 6.1 Purpose of the Conclusion

The purpose of the conclusions is reasonably straightforward; they are important because they focus on disclosing and explaining the final results and the outcome of the stated and implemented objectives as a guide to achieving the desired goal of this research project. In addition, they present the significance and the conclusions related to the specific objectives during the realization of the distinct task that corresponds to the research project, the restatement of the research question to check if it remains the same after the realization of the research project or if changes were made along the way, and finally some recommendation of the researcher to future students that might be useful for the realization to the same or a similar research project.

## 6.2 Conclusions

Once the research project has been completed, the following conclusions about the objectives presented in the first chapter will be drawn. These objectives are related to the researcher's experience during the translation process of the documents provided by the institution, how the different translation techniques were applied by the researcher in order to obtain the desired result of the target text, as well as for the evaluation of the impact of the use of these techniques and how was their impact during the translation process of the two translated documents. Finally, the relevance of the realization of a glossary, which the researcher mainly used to gather information about the vocabulary presented in both documents. Refer to the following points for further information on this matter.

**6.2.1** To translate the documents "Programa para bomberos dentro del proyecto "avanzando con un enfoque regional para movilidad eléctrica en América Latina" from Spanish into English, "Research and Development of Fire Extinguishing Technology for Power Lithium Batteries from English into Spanish, and "Best Practices for Emergency Response to Incidents Involving Electric Vehicles Battery Hazards: A Report on Full-Scale Testing Results" from English to Spanish for the Academia Nacional de Bomberos.

In order to properly translate the documents, the researcher prioritized multiple prior readings and simultaneous work with the glossary in order to become familiar with the content of the document as well as to know the meaning of those unknown words that were presented not only, in the English document, but also in the Spanish document, because although Spanish is the native language of the researcher, some words were either too technical to understand at first. Furthermore, it is important to consider that it is important to know the meaning of the words and understand how those words affect the context of the document.

In addition, the use of the Text Analysis method implemented by Newmark was another key tool for gathering information that helped the researcher to get a deeper look at these documents that provide a different or more complex point of view on the context in order to convert the information as accurately as possible because it will be delivered to the institution that requires these documents to be translated in the best way possible. Another aspect that was also crucial was consulting the bibliographies of the documents in order to check further information related to electric vehicles and firefighting procedures in order to have a deeper understanding of these topics, which will facilitate the translation process of what is presented in the document with additional knowledge to complement what is already presented in the source text.

### **6.2.2** To apply various translation techniques to the documents in order to achieve natural and accurate target texts.

Various translation techniques such as transposition, modulation, expansion or amplification, explication, literal translation, and reduction or omission were very useful and crucial for the researcher. The use of these translation techniques guided the researcher not only, in the process of translating the documents, but also in the process of reading and understanding because it also helped the researcher to understand the content of the document and to have a previous point of view on how to implement these techniques in the translation in order to keep it as natural and accurate to the original document as possible. Furthermore, by considering this aspect, the researcher was able to get more attached to the overall idea that the author of the documents intended to provide because the content of these documents was not something that people who are not related to or do not have knowledge related to firefighting might know, therefore by taking advantage of all the useful tools at hand the task becomes easier and more manageable before and during the translation process.

### **6.2.3** To evaluate the effect of the translation techniques applied to the documents.

As mentioned before, implementing translation techniques was a significant element during the translation process. However, transpositions, modulations, omissions, and amplifications were the most common to maintain a clearer idea of the final document for the English-to-Spanish and Spanish-to-English translations. In this research project, the technicality of the original documents was noticeable, so there were occasions when translation techniques were more present in each paragraph. In the case of the translations presented in this research project, the presence of the most translation procedures was in the translation from English to Spanish rather than the translation from Spanish to English due to the nature of the Spanish language, which is more technical and requires to be more precise in order to be understood.

Suppose you compare the color coding for each translation. In that case, it is evident that translation procedures were necessary to convey the message in the target text when translating from English to Spanish. On the other hand, when translating from Spanish to English, the use of translation procedures in the target text is still present but is not as noticeable as in the other translation. Nevertheless, it is not a matter of not using or overusing translation techniques; each language has its structure and meaning, and these techniques are the ones that help and guide the translator to get the desired translation.

#### **6.2.4** To create a glossary with the most relevant terminology found in both texts.

The realization of the glossary during the translation process was really useful for the researcher because it provided a source of learning and understanding that was essential to maintain the translation efficiency for both documents. In addition, getting to know more words and their meanings led the researcher to create confidence in the final version of my translation.

### 6.3 Restatement of the Research Question

As mentioned in the very first chapter of this research project, the following research question was used as a reference throughout the realization of the research project: What is the effect of the procedures and methods used to translate the documents *Programa para bomberos dentro del proyecto avanzando con un enfoque regional para movilidad eléctrica en América Latina* from Spanish into English, *Research, and Development of Fire Extinguishing Technology for Power Lithium Batteries*, and *Best Practices for Emergency Response to Incidents Involving Electric Vehicles Battery Hazards: A Report on Full-Scale Testing Results* from English into Spanish for the Academia Nacional de Bomberos? According to the final product of this research project, it was determined that the research question could remain the same as initially stated since the main objectives presented at the beginning of this research project were accomplished. No unexpected changes interfered with the realization of the research project.

## 6.4 Recommendations

After completing this research project, the researcher considered that some important aspects are recommended to benefit future students. The first recommendation of the researcher is to prioritize finding an institution that is interested in helping the student with the documents to be translated because it is crucial to have the documents as soon as possible in order to take advantage of the time to translate them to get the best results without feeling pressured with the other tasks that start to add up when it comes to completing the chapters and other aspects that need to be completed on time as well.

In addition to this, it is important to find not only, an institution that provides the document, but also one that is willing to assist in case the student needs something because if the institution is not fully aware of the student's inquiries, they will not only, affect the service provided by the student, but also they will interfere with the student's journey and time that might affect with the realization of the investigation project. Therefore, it is important to consider these aspects regarding the institution, and when the institution is found, maintain good communication with the institution in case anything is needed.

Another recommendation is to read and understand the documents before starting the translation part, as this will facilitate the translation process because you will get to know the content and the topic presented in the documents even before you start interacting with them. Of course, you will encounter this information during the translation process. However, you should have a preliminary look at what the documents present. In that case, it will give you an initial point of view or preparation before the translation, which is technically an extra step that will only benefit your research project.

In addition, it is important to remember the procedures and aspects that Newmark presents to get to know them and how they influence the translation process and learn how to apply them as much as possible. For instance, the variety of translation procedures and methods that can be used during the translation process can be beneficial if the translator wants to maintain naturalness and accuracy when translating from one language to another, which is known to be the main purpose and priority of all current and future translators in the world.

Finally, the researcher considers that the most important recommendation of all is to be responsible and committed to the research project, as well as to be well organized with the time given for each task to be completed and presented because it may seem that there is enough time left to complete the chapters or the translation. However, there is always the possibility of encountering some situations or circumstances where a minimal change in the course path could delay the process.

The researcher hopes that future students will consider these recommendations, as one never knows if they will be useful in completing this research project at this important stage of their careers and for future projects or jobs where these strategies can still be applied.

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# Annexes.



Gmail **Fabrizio Calvo Chavarria <fabriziocalvochava14@gmail.com>**

## Carta de agradecimiento estudiante Fabrizio Calvo Chavarría. Universidad Internacional de las Américas.

**RONNY LA TOUCHE ARGUELLO** <rlatouche@bomberos.go.cr> 13 de noviembre de 2023, 15:06
CC: fabriziocalvochava14@gmail.com

**Benemérito Cuerpo de Bomberos de Costa Rica**
**Academia Nacional de Bomberos**

**CBCR-040664-2023-ANB-00889**

**Lunes 13 de Noviembre de 2023**

Señor,

Lic. Leslie Elizondo Mora
**Universidad Internacional de las Américas**

**Referencia:** Carta de agradecimiento estudiante Fabrizio Calvo Chavarría. Universidad Internacional de las Américas.

Estimado Señor,

Es un honor dirigirnos a usted en calidad de director de carrera, para expresar nuestra más sincera gratitud por la colaboración invaluable que hemos recibido en el marco del *"Programa para Bomberos: Avanzando con un enfoque regional para la movilidad eléctrica en América Latina."*

Nos complace informarle que hemos recibido los documentos traducidos con gran precisión y profesionalismo por parte del Sr. Fabrizio Calvo Chavarría, quien está actualmente cursando el Bachillerato en inglés con énfasis en Traducción en la Universidad Internacional de las Américas.

Dichos documentos, que abarcan temas cruciales como "Research and Development of Fire Extinguishing Technology for Power Lithium Batteries" y "Best Practices for Emergency Response to Incidents Involving Electric Vehicles Battery Hazards: A Report on Full-Scale Testing Results", han sido entregados con éxito.

La dedicación y habilidades de traducción del Sr. Calvo Chavarría han sido evidentes en el alto estándar de los documentos que ahora tenemos a nuestra disposición. Estos materiales serán de inmenso valor para la Academia Nacional de Bomberos del Benemérito Cuerpo de Bomberos de Costa Rica, contribuyendo significativamente a nuestro compromiso continuo con la excelencia en la formación y preparación de nuestros bomberos.

Queremos expresar nuestra completa satisfacción con el servicio proporcionado por la Universidad Internacional de las Américas y, en particular, con el desempeño excepcional del Sr. Fabrizio Calvo Chavarría, su contribución ha sido esencial para el éxito de nuestro programa.

Le agradecemos sinceramente por su continua colaboración y esperamos seguir fortaleciendo esta fructífera relación en futuras iniciativas.

Cualquier consulta que se presente, con gusto será atendida.

Atentamente,

RONNY LA TOUCHE ARGUELLO
**Academia Nacional de Bomberos**

cc: CARLOS ANDR BACA REYES; CINDY GABRIELA QUESADA DIAZ; Fabrizio Calvo Chavarría

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La SUSCRITA, Margarita Pérez Roig, Profesora de la Carrera de Enseñanza del Inglés e Inglés de la Universidad Internacional de las Américas, en mi condición de Lectora del TRABAJO FINAL DE GRADUACIÓN titulado: "***TRANSLATION AND ANALYSIS OF SOME DOCUMENTS FROM ENGLISH INTO SPANISH AND VICE VERSA***", elaborado por el estudiante **Fabrizio Calvo Chavarría**, cédula 117880766, para optar por el título de Bachillerato en Inglés, CONSIDERA que dicho trabajo reúne los requisitos exigidos por la universidad, por lo tanto, doy la aprobación para ser sometido a la defensa pública y evaluación por parte del Tribunal Examinador asignado para tal efecto.

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Día: __10___, Mes: __Enero___, Año: _2024_

# Programa para bomberos

Dentro del proyecto “Avanzando con un enfoque regional para movilidad eléctrica en América Latina”

Material de referencia – Junio 2022

Financiado por la Unión Europea

# 1. Introducción

A medida que prolifera el uso de energía alternativa, el servicio de bomberos de Santiago de Cali ha identificado una serie de áreas de preocupación con respecto a la mitigación de riesgos y la respuesta a emergencias. Esto incluye vehículos eléctricos e híbridos que presentan peligros nuevos e inesperados para los bomberos y otros respondedores de emergencias.

Hoy en día es común ver vehículos eléctricos en todo tipo de vías. El número de vehículos de este tipo, incluidos los híbridos, está en constante aumento. En términos estadísticos, esto significa que hay mayores probabilidades de que, en caso de ocurrir, un accidente involucre a un vehículo eléctrico.

Así, es relevante acceder a información sobre el manejo de situaciones de riesgo y emergencias alrededor de esta tecnología con el propósito de crear capacidades de atención.

Este material de referencia recoge las MEJORES PRÁCTICAS que están divulgando fabricantes y otros actores relevantes sobre la seguridad en movilidad eléctrica. El documento tiene la intención de ser una referencia para los primeros en la escena, en este caso para BOMBEROS, por lo cual NO es permitido su uso comercial.

## 2. Tipo de vehículo de combustible alternativo

Se pueden encontrar múltiples definiciones del término vehículo eléctrico en la literatura común, y en los códigos y estándares de consenso. Los siguientes son los que se han tomado para este material de referencia:

### a. Vehículo híbrido-eléctrico (HEV)

Un vehículo eléctrico híbrido (HEV) utiliza dos fuentes de energía: un motor de combustión interna convencional (ICE) y una combinación de motor eléctrico/batería. En contraste a un vehículo híbrido enchufable, no brinda la capacidad de conexión a una fuente externa para cargar las baterías. Sin embargo, las baterías se cargan mediante el motor de combustión interna o un sistema de frenado regenerativo.

### b. Vehículo eléctrico híbrido enchufable (PHEV)

Un vehículo eléctrico híbrido enchufable puede recargar sus baterías mediante el uso de una conexión a una fuente de energía eléctrica externa como un enchufe de pared. Un PHEV comparte las características de un vehículo eléctrico híbrido (un motor eléctrico y un motor de combustión interna) y un vehículo totalmente eléctrico (la capacidad de conectarlo a una estación de carga).

### c. Vehículo eléctrico (EV)

Un vehículo eléctrico (EV) utiliza solo un motor o motores eléctricos para la propulsión y debe conectarse a una estación de carga para poder recargar la batería que transmite la energía al motor.

### d. Vehículos eléctricos especiales (NEV)

Una subclase especial de un EV es un vehículo eléctrico NEV, vehículo Eléctrico para usos ESPECIALES. Estos son vehículos eléctricos que no están destinados ni diseñados para viajes de larga distancia o velocidades de carretera. Un NEV es un vehículo de baja velocidad de cuatro ruedas que funciona con batería y normalmente se recarga en circuitos eléctricos normales.

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## 3. Iconos de advertencia e identificadores

Icono Advertencia Batería iones de Litio Icono Advertencia



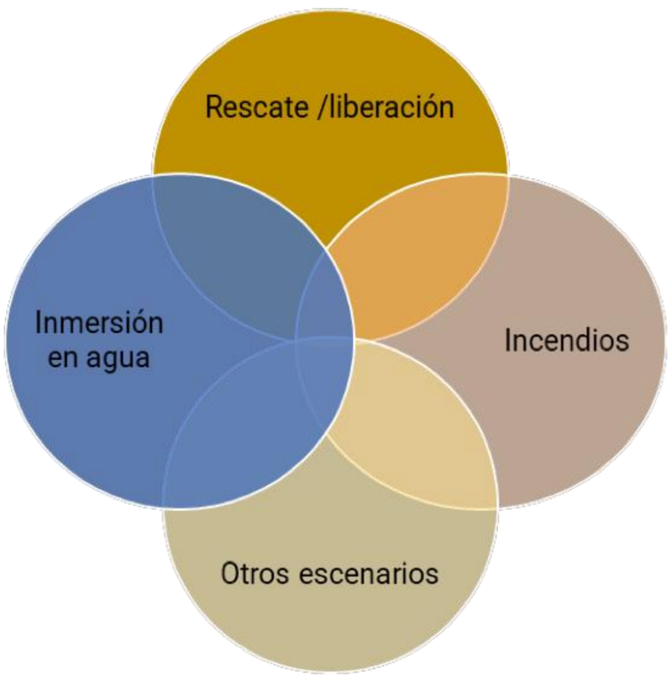

4

## 4. Conjunto de mejores prácticas para la respuesta de emergencia

Cada incidente de emergencia al que responde un departamento de bomberos es único. A pesar de las diferencias, sin embargo, hay características comunes que permiten al personal del servicio de bomberos comprender mejor las tareas que deben realizar y prepararse para sus funciones. Esta sección proporciona una revisión de los elementos comunes de mayor interés para los bomberos cuando manejan emergencias que involucran EV y HEV.

Los principales escenarios de emergencia que podría esperar el servicio de bomberos que responda a una emergencia que involucre un EV o HEV se ilustran en la siguiente figura. Escenarios de emergencia clave para EV y HEV.

Esta figura considera las cuatro posibilidades básicas de: (1) Extricación/Rescate; (2) Fuego; (3) Inmersión en agua; y (4) Otros Escenarios.



# 5. Respuesta general

Este material de referencia se orienta a dar una “Respuesta general”. Presenta una respuesta inicial, así como una guía para escenarios que no son específicos de ningún vehículo en particular (incendio, sumersión, derrames, etc.).

La seguridad de los bomberos y cualquier otro personal de primera respuesta de emergencias depende de la comprensión y el manejo adecuado de estas orientaciones a través de la capacitación y preparación adecuadas.

Tenga en cuenta que este material de referencia es genérico y se aplica a la mayoría de los vehículos, pero siempre existe la posibilidad de contradicción entre la orientación genérica y las instrucciones específicas del vehículo proporcionadas por el fabricante. En tal caso, siga siempre las instrucciones específicas del fabricante del vehículo.

## a. Datos específicos del vehículo

Esta información está organizada alfabéticamente por fabricante y luego por modelo de vehículo para cada etiqueta de fabricante.

Cada entrada de vehículo se presenta en un formato de dos páginas con información crítica para ayudar con la identificación, inmovilización, inhabilitación y extracción. Consulte la siguiente página para obtener una descripción del diseño.

Todos los procedimientos de desactivación primarios, así como la mayoría de los procedimientos alternativos, están diseñados para desactivar tanto el sistema eléctrico de combustible o de alto voltaje como el SRS (bolsas de aire, etc.). La realización parcial de cualquiera de los procedimientos no garantizará que ambos sistemas se apaguen.

NOTA: Siempre que sea posible, se indican las ubicaciones de componentes como el

HEV

2008-14 CHEVROLET

HYBRID

CHEVROLET TAHOE

## INFORMACION DEL VEHICULO

**INMOVILIZAR VEHICULO**

1. Bloque las ruedas.
2. Ponga el freno de mano.
3. coloque el vehiculo en PARKING- PARQUEO.

**DESHABILITAR VEHÍCULO**

Determine si el vehículo está ENCENDIDO.

- El vehículo está ENCENDIDO si la aguja del tacómetro apunta a PARADA AUTOMÁTICA.
- El vehículo está APAGADO si la aguja apunta a APAGADO.

PROCEDIMIENTO PRIMARIO

1. Si está ENCENDIDO, apague el encendido del vehículo (columna de dirección, llave). Quitar llave.
2. Desconecte el cable positivo (+) de la batería de 12 V (compartimento del motor, lado del conductor). La batería de 12 V tiene terminales de liberación rápida tipo palanca.
3. Asegúrese de que el terminal no pueda hacer contacto con el poste de la batería.

PROCEDIMIENTO ALTERNATIVO
(si no se puede acceder a la llave de contacto)

1. Desconecte el cable positivo (+) de la batería de 12 V (compartimento del motor, lado del conductor).
2. Corte los tres 12V positivos expuestos cables identificados por el amarillo Primero Etiquetas de respondedor.

DESCONEXIÓN MANUAL DE ALTA TENSIÓN

Si está accesible, puede minimizar el potencial de flujo de corriente de alto voltaje quitando la palanca de desconexión manual de la batería de alto voltaje. Está ubicado debajo del asiento trasero del lado del pasajero, segunda fila.

Corte 3 cables expuestos (procedimiento alternativo)

Desconexión manual de batería híbrida de 300 V

ADVERTENCIAS

- NUNCA corte, rompa o toque componentes o cables de alto voltaje de color naranja. Si lo hace, podría sufrir lesiones graves o la muerte.
- El sistema de alto voltaje puede permanecer encendido hasta 1 minuto después de apagar el vehículo.
- El sistema SRS (bolsas de aire, etc.) puede permanecer encendido hasta 1 minuto después de desactivarlo.
- La falta de ruido del motor no significa que el vehículo está APAGADO. El movimiento silencioso o la capacidad de inicio instantáneo existen hasta que el vehículo se apaga por completo.

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encendido, la batería de 12 V, el freno de mano y el selector de marchas. Sin embargo, siempre es posible que estos componentes se encuentren en otros lugares debido a actualizaciones del modelo del fabricante o modificaciones del mercado secundario.

## b. Información de

## liberación

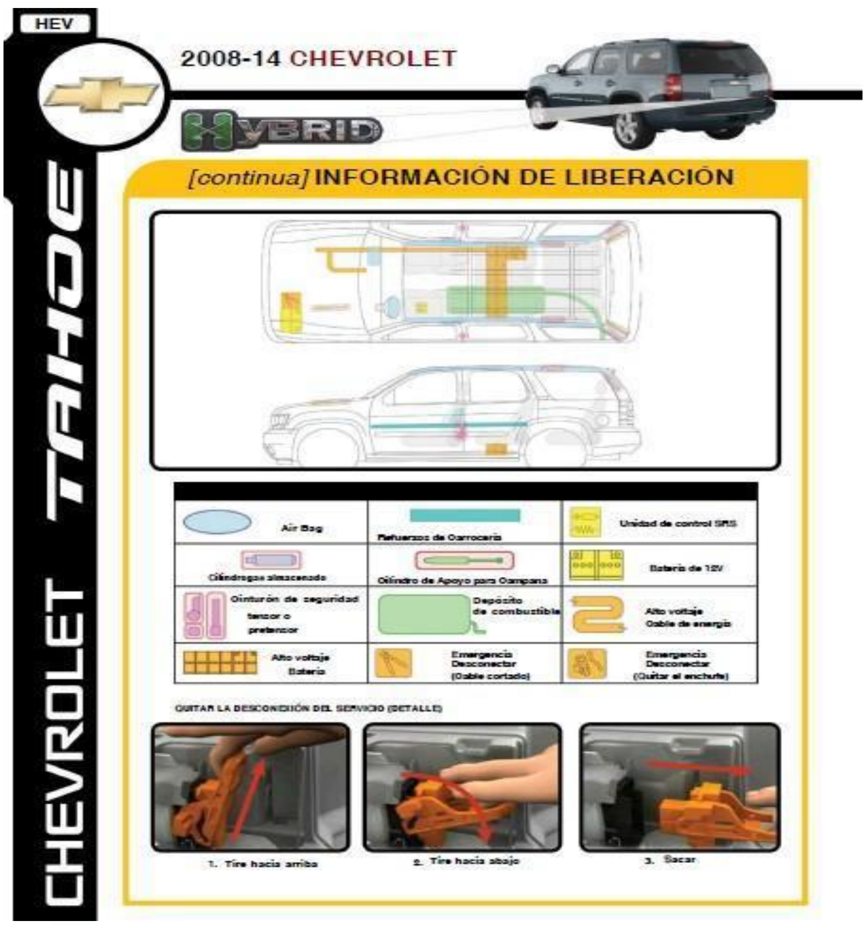
Los fabricantes de automóviles colorearon voluntariamente el cableado para estos sistemas de alto voltaje de color naranja brillante para una identificación fácil y consistente.

En ciertos modelos recientes, han aparecido cables codificados en color azul y amarillo que también presentan un peligro de descarga peligrosa, a pesar de no ser considerados específicamente como de alto voltaje.

Además, el cableado de alto voltaje en los diseños de vehículos a menudo está protegido en canales de conductos protectores, lo que dificulta su localización visual.

En términos de liberación del vehículo, quizás la diferencia más significativa entre un vehículo convencional y un EV o HEV es el sistema eléctrico de alto voltaje.

Los EV y HEV generalmente incluyen baterías de alto voltaje, y la presencia de componentes de alto voltaje crea un posible peligro de electrocución (entre 36 y 600 voltios de electricidad) para el personal de emergencia, especialmente antes de que se den cuenta de que el vehículo es un modelo híbrido.

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Si bien es comprensible que el alto voltaje en los vehículos eléctricos e híbridos genere preocupaciones entre los bomberos que exigen un mayor grado de precaución, también genera ciertos conceptos erróneos que merecen ser abordados.

Por ejemplo, la electrocución no es un peligro real por simplemente tocar el exterior de un EV o HEV chocado. Esto no debería ser diferente a un vehículo de motor convencional, ya que el sistema de alto está completamente aislado del chasis/carrocería del vehículo. Sin embargo, la única excepción obvia para un peligro de electrocución exterior, y que se aplicaría a cualquier vehículo, es una situación de choque que involucre una fuente de energía eléctrica exterior, como cuando las líneas eléctricas caídas se colocan sobre el vehículo chocado.

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# 6. Procedimientos genéricos de respuesta inicial para vehículos híbridos – eléctricos

Evaluación / escena 360

**IDENTIFICAR-INMOVILIZAR -DESHABILITAR**

## a. Identificar el vehículo

SIEMPRE ASUMA QUE EL VEHÍCULO ES DE ALGÚN TIPO HÍBRIDO, ELÉCTRICO O DE COMBUSTIBLE ALTERNATIVO HASTA QUE SE DEMUESTRE LO CONTRARIO.

- Busque distintivos logos externos que indiquen un vehículo de combustible alternativo.
- La identificación puede estar oculta en un choque o incendio, por lo que los métodos de identificación alternativos pueden necesitar ser utilizado.

- Determine la marca, el modelo y el año del vehículo para acceder a un vehículo más específico información que se encuentra en esta guía.
- Es posible que algunos modelos híbridos y eléctricos no tengan distintivos externos para identificar ellos, pero todavía tendrán etiquetas de advertencia de

- alto voltaje y otros secundarios indicadores como el distintivo “Cero emisiones”

## b. Inmovilizar

TODOS LOS VEHÍCULOS DEBEN SER INMOVILIZADOS ANTES DE TRABAJAR ALREDEDOR DE ELLOS.

LOS VEHÍCULOS HÍBRIDOS Y ELÉCTRICOS PUEDEN PARECER APAGADOS INCLUSO CUANDO NO LO ESTÁN, DEBIDO A LA POTENCIAL FALTA DE RUIDO DEL MOTOR.

- Acérquese al vehículo desde un ángulo de 45° para mantenerse fuera del eje de PROYECCIÓN y:

1. **BLOQUEE LLANTAS**
2. **COLOQUE FRENO DE MANO/ EMERGENCIA**
3. **COLOQUE VEHICULO EN PARKING/PARQUEO**



## c. Deshabilitar

**MÉTODO DE APAGADO PRIMARIO** (para la mayoría de los vehículos)

1. Apague el encendido del vehículo (si está encendido).

2. Desconecte la batería de 12V (según instrucciones del vehículo). ALGUNOS VEHÍCULOS UTILIZAN LLAVE DE PROXIMIDAD.

SI SE PUEDE LOCALIZAR LA LLAVE, QUITARLA Y ALEJARLA AL MENOS 16 PIES (5 METROS) DEL VEHÍCULO.

SI NO LO PUEDE LOCALIZAR RÁPIDAMENTE, PROCEDA A INHABILITAR EL VEHÍCULO.

UNA VEZ APAGADO EL VEHÍCULO Y DESCONECTADA LA BATERÍA DE 12V, SE DESACTIVA EL SISTEMA DE LLAVE DE PROXIMIDAD.

**MÉTODO DE APAGADO ALTERNO** (si no puede acceder al encendido)

- Consulte la página específica del vehículo para obtener más información.

**NOTA:** La mayoría de los vehículos híbridos y eléctricos están equipados con sistemas de seguridad que están diseñados para apagar automáticamente el vehículo en caso de

un choque.

Por lo tanto, en la mayoría de los incidentes de colisión, el vehículo ya debería estar APAGADO. Verifique el estado del vehículo, para que no reinicie inadvertidamente un vehículo que ya se apagó.

**NOTA:** Todos los procedimientos de desactivación principal, así como la mayoría de los procedimientos alternativos, están diseñados para desactivar el sistema de combustible

y/o de alto voltaje del vehículo y el SRS (bolsas de aire, etc.).

La realización parcial de cualquiera de los procedimientos no garantizará que ambos sistemas se apaguen.

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# 7. Procedimientos y consideraciones generales para la respuesta a incidentes en vehículos híbridos / eléctricos

Siempre siga y haga referencia a todos los Procedimientos propios al realizar la respuesta y la liberación en un accidente de vehicular.

## 7.1. Accidentes

Siga los procedimientos de respuesta inicial:

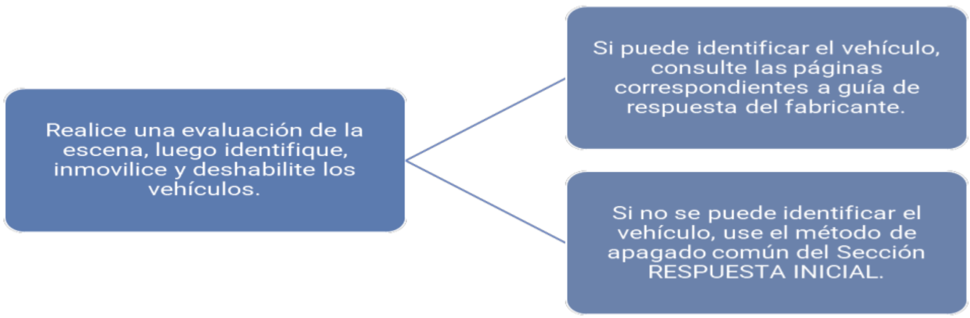
## 7.2. Liberación

Inmovilice y deshabilite el vehículo antes de iniciar las operaciones de extracción.

**SIEMPRE que sea posible estabilice el vehículo antes de comenzar la liberación**

(ver ESTABILIZACIÓN). Antes de cortar o hacer palanca, verifique visualmente para determinar la ubicación de:

- **SRS** y Sistemas de Protección de Ocupantes.
- ○




**HV** Componentes y cableado de alta tensión.
**Líneas de combustible** gaseoso y cilindros/tanques.

11

● El cableado y los componentes HV se enrutan principalmente a lo largo de la parte inferior del vehículo desde el HV batería al compartimiento debajo del capó [motor] y, por lo tanto, NO se encuentran en los puntos de corte de extracción típicos.

● Las ubicaciones de las baterías y los componentes HV pueden impedir técnicas avanzadas como la tunelización troncal y extracción a través del suelo.

## 7.3. Estabilización

● Utilice soportes estándar y métodos de estabilización, los mismos que se utilizan en los vehículos convencionales.
● NO coloque el apuntalamiento en un lugar que atrape o pueda enredar cables de alto voltaje o líneas de combustible gaseoso entre el apuntalamiento y el bastidor del vehículo o puntos estructurales. Verifique visualmente antes de colocar el apuntalamiento

**SIEMPRE estabilice el vehículo antes de comenzar la extracción.**
**ACEROS DE ULTRA ALTA RESISTENCIA [UHSS]**

● Resistencia/bajo peso los metales se están utilizando mucho en los diseños de vehículos más nuevos

● Las herramientas de corte hidráulicas que no están diseñadas para aceros de ultra alta resistencia puede resultar inadecuadas.

**Es posible que herramientas como las sierras alternativas no puedan cortar estos metales. Puede que se requieran técnicas de extracción alternativas.**

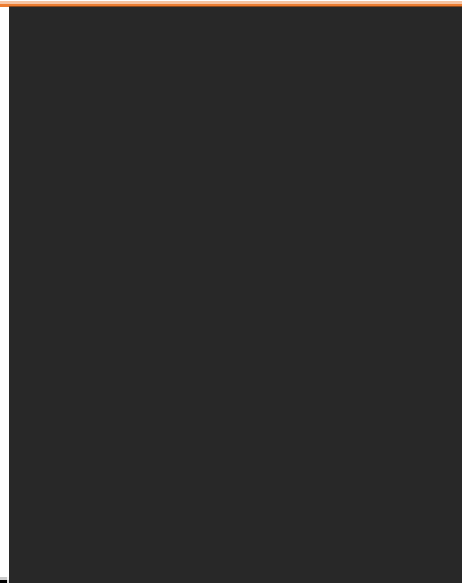
**Algunas herramientas de corte NO PUEDEN CORTAR aceros nuevos de ultra alta resistencia.**

● Se recomienda enfáticamente que los departamentos de BOMBEROS revisen las capacidades de sus equipos de corte frente a los aceros de ultra alta resistencia antes de encontrar estos materiales en el campo.

## 7.4. Advertencia

● Evite el contacto con el cableado y los componentes de alta tensión. SIEMPRE asuma que el sistema HV está energizado.

**NUNCA corte el cableado naranja de alta tensión ni penetre los componentes de alta tensión con herramientas.**



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MOVILIDAD ELÉCTRICA LATINOAMÉRICA Y EL CARIBE

ONU programa para el medio ambiente 50 1972-2022

● Los procedimientos de apagado del sistema HV están diseñados para desactivar el sistema HV del vehículo, no para descargar la batería HV.

**LA BATERÍA HV PERMANECERÁ CON ENERGÍA.**

● Si no se puede acceder al sistema de 12 V del vehículo y no se puede desactivar, los sistemas de protección de los ocupantes, como las bolsas de aire o los pretensores, pueden permanecer activos, incluso si el sistema HV está apagado

## 7.5. Nota

VEHÍCULOS HÍBRIDOS Y ELÉCTRICOS
El cableado azul y amarillo de voltaje medio/intermedio se trata igual que el cableado naranja de alto voltaje (HV). Todas las referencias a las prácticas de alta tensión también se aplican a los sistemas de tensión media/ intermedia.

BATERÍAS DE ALTO VOLTAJE (HV) DAÑADAS

- ● Si están dañadas, las baterías HV pueden emitir gases nocivos y/o inflamables.
- ● Si detecta olores inusuales o Si experimenta irritación en los ojos, la nariz, la garganta o la piel, póngase el equipo de protección personal completo con SCBA.

● Si detecta fugas de fluidos, chispas, humo o ruidos burbujeantes provenientes de la batería HV, ventile el vehículo abriendo las ventanas y el baúl para evitar la acumulación de vapores.

Las chispas, el humo o los ruidos burbujeantes provenientes de la batería HV son signos de que la batería se está sobrecalentando, lo que podría provocar un incendio retardado.

El contenido de las baterías HV debe considerarse corrosivo, tóxico y/o inflamable. Consulte **PELIGROS DE DERRAME/FUGA** si el contenido de la batería está expuesto o tiene fugas.

**Evite el contacto con una batería HV dañada; puede existir un riesgo de descarga eléctrica significativo.**

MANUALES DE SERVICIO DESCONEXIONES
● La mayoría de los vehículos híbridos y eléctricos Si experimenta irritación en los ojos, la nariz, la garganta o la piel, póngase el equipo de protección personal completo con SCBA.

● Consulte las páginas específicas del vehículo o guías de respuesta del fabricante antes de usar una desconexión manual o de servicio.
● Cualquier fabricante recomienda equipos de corte eléctrico aislado cuando se usan

[redacted]



desconexiones de servicio.

- ● La mayoría de los departamentos no poseen o llevan regularmente.
- ● Tenga en cuenta que quitar una desconexión del servicio desactivará el sistema HV, pero en la mayoría de los vehículos, las SRS (bolsas de aire) permanecerán activas hasta que se desactive el sistema de 12 V CC. Quitar una desconexión manual no descarga la batería HV.

## 7.6. Post-incidente

Todos los vehículos híbridos y eléctricos deben transportarse en una plataforma.

Si esto no es posible, asegúrese de remolcarlo con las ruedas motrices levantadas del suelo [varía según el modelo].

## EL REMOLQUE CON LAS RUEDAS MOTRICES EN EL SUELO REPRESENTA UN RIESGO DE INCENDIO EN EL SISTEMA ELÉCTRICO

- Si el daño a la batería es observado o sospechado, notificar el distribuidor o fabricante representante.

Es posible que tengan procedimientos para desenergizar una batería.

- Debido a la posibilidad de que se produzca un incendio retardado, no guarde un vehículo gravemente dañado que contenga una batería de iones de litio HV dentro al menos de 50 pies (15 metros) de una estructura u otro vehículo. Es posible que sea necesario aumentar la distancia, dependiendo del tamaño del vehículo.

- Después de un incendio o accidente, comuníquese con el personal de servicio de la flota o con el fabricante para obtener ayuda en la remoción y el almacenamiento del vehículo.

## NOTIFIQUE A LOS OPERADORES DE REMOLQUE /GRUAS QUE RETIRAN EL VEHÍCULO QUE DEBE SER EN PLATAFORMA, O SIN TENER QUE RODAR SUS LLANTAS, EL PERSONAL DEBE ESTAR CAPACITADO PARA INSPECCIONARLO Y PROPORCIONAR RECOMENDACIONES PARA EL PARQUEO FINAL.

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# 8. Procedimientos generales para extinción de incendios en vehículos de combustible alternativo

Todo el personal debe usar y usar equipo de protección personal completo y SCBA según

se requiera en todos los incendios de vehículos.

•

## 8.1. General

***Vehículos híbridos y eléctricos***

Use equipo y tácticas de extinción de incendios de vehículos estándar de acuerdo con los *Procedimiento y Guías Operacionales del departamento de Bomberos*.

Los vehículos híbridos y eléctricos no requieren equipos especiales para la supresión/extinción de incendios.

La dificultad para extinguir un incendio en una batería HV depende de varios factores:

- ● Tamaño y ubicación de la batería.
- ● Alcance del fuego dentro de la batería.
- ● Acceso y capacidad del agente extintor para ser aplicado a la caja de montaje de la batería.

  Posibles aberturas en la caja de la batería que permiten colocar el agente extintor directamente sobre las celdas en llamas.

## 8.2. Agentes de extinción

Use agua u otros agentes estándar para incendios de vehículos.
El uso de agua no presenta un peligro eléctrico para el personal de extinción de incendios.

## Use equipo de protección personal completo y SCBA

●

Si una batería HV se incendia, requerirá un volumen grande y sostenido de agua.

**Las pruebas han indicado que podría requerir más de 2600 galones, según el tamaño y la ubicación de la batería. Asegúrese de establecer un suministro sostenido de agua a través de un hidrante o una fuente de agua estática.**

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## 8.3. Advertencias

Si usa agua para extinguir/suprimir una batería HV, use una gran cantidad de agua. Usar solo una pequeña cantidad podría permitir la liberación de gases tóxicos peligrosos.

Si una batería HV de iones de litio [Li-Ion] está involucrada en un incendio, existe la posibilidad de que se vuelva a encender después de la extinción. Si está disponible, use imágenes térmicas para monitorear la batería. No almacene un vehículo que contenga una batería HV de iones de litio dañada o quemada dentro o dentro de los 50 pies [15m] de una estructura u otro vehículo hasta que la batería se pueda descargar.

El reencendido del fuego en un paquete de baterías HV suele ir acompañado de sonidos de "silbido" o "estallido", seguidos por la liberación de gases de humo blanco y/o arcos eléctricos/ chispas que se reavivan con llamas/fuegos visibles. El reencendido puede ocurrir en cualquier momento desde varias horas al día o más después de la extinción.

## 8.4. Nota:

Debido a que las baterías HV están en estuches protectores, es muy difícil que algún agente extintor llegue directamente a las celdas en llamas. La aplicación de grandes volúmenes de agua puede enfriar la batería HV lo suficiente como para evitar la propagación del fuego a las celdas adyacentes. Aplicación continua de agua sobre un área localizada de la batería durante un período prolongado de tiempo antes de pasar a otra sección de la batería proporciona una extinción más rápida. Continúe aplicando agua incluso después de que la llama visible ya no esté presente para enfriar adecuadamente HV batería y prevenir/reducir el riesgo de reencendido.

Anticipar tiempos de extinción de incendios más prolongados una vez que la batería HV esté involucrada debido a la dificultad de acceder al material en llamas dentro de la caja de la batería. Pruebas ha demostrado que puede llevar una hora o más dependiendo del tamaño y la ubicación de la batería, así como de la extensión del incendio.

## 8.5. Táctica

NO perfore a ciegas el capó con herramientas como una barra Halligan para acceder. Esta táctica podría penetrar los componentes HV en el compartimiento del motor, creando un grave riesgo de descarga eléctrica.

NUNCA perfore, corte, haga palanca ni desmonte ninguna estructura del vehículo en un esfuerzo por introducir agua directamente en la batería. Puede entrar en contacto con un componente HV y correr el riesgo de sufrir lesiones.



**ATAQUE OFENSIVO:** Recomendado donde hay exposiciones presentes o la batería HV no está involucrada.

**ATAQUE DEFENSIVO:** Recomendado si la batería HV está involucrada, no hay exposiciones presentes y hay un suministro de agua limitado disponible. Debido a la dificultad de alcanzar las celdas en llamas dentro de la batería con el agente extintor, el comandante del incidente puede optar por dejar que se queme solo. Cualquier individuo sin SCBA debe permanecer contra el viento del fuego y evitar la inhalación, debido a los compuestos tóxicos en el humo. Si no se aplica agua directamente, la batería HV podría tardar 90 minutos o más en autoextinguirse.

## 8.6. Incendios en estaciones de carga

Localice la fuente de alimentación para la carga estación y apagarla.

● Hasta que se corte la energía a la estación de carga, trate el fuego como lo haría con un fuego eléctrico energizado.

● Si un vehículo está conectado a la estación de carga, debe desconectarse tan pronto como sea seguro hacerlo. Si es posible, apague primero la estación de carga.

### 8.7. Revisión y recuperación

- ● Inmovilizar e inutilizar el vehículo si aún no se ha hecho.
- ● Nunca desconecte ni entre en contacto con ningún componente o cableado de alto voltaje expuesto.

● Intente ponerse en contacto con un distribuidor o representante del fabricante lo antes posible para obtener ayuda con la disposición del vehículo posterior al incidente y la des energización de la batería HV si es necesario.
● Nunca rompa ni extraiga la batería HV. Si lo hace, puede provocar quemaduras eléctricas graves, descargas eléctricas y/o electrocución.
● No almacene un vehículo con una batería de iones de litio dañada o quemada dentro de una estructura u otro vehículo o dentro de una distancia de 50 pies (15 metros) hasta que se pueda descargar la batería.

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## 9. Procedimientos generales para la inmersión en agua de vehículos híbridos, eléctricos

### 9.1. General

● Los vehículos híbridos, eléctricos están diseñados para ser seguros en el agua, incluso cuando están completamente sumergidos.

○

El sistema HV está aislado del chasis y está diseñado para que no presente peligro de descarga al tocar la carrocería del vehículo.

○
○ El sistema está equipado con detectores de fallas de cortocircuito diseñados para apagar el sistema HV en caso de un cortocircuito.

## 9.2. Prácticas de respuesta

Evite el contacto con componentes HV, cableado o desconexiones de servicio en un vehículo sumergido.

- Siga las prácticas y los procedimientos estándar propios para el acceso de los pacientes y la retirada del vehículo del agua.

- Puede ser necesario esperar hasta que el vehículo esté seguro en tierra y sin agua para realizar o completar los procedimientos de desactivación.

## 9.3. Microburbujas

- Las microburbujas son una reacción burbujeante o burbujeante que proviene de una batería HV sumergida
- NO indica peligro de descarga eléctrica. Este proceso es interno a la caja de la batería y NO energiza el agua circundante.

- Las microburbujas son el resultado de la electrólisis, donde la corriente pasa entre los terminales positivo y negativo dentro de la batería y rompe las moléculas de agua en gases de hidrógeno y oxígeno.

Cuando cesan las microburbujas, la batería de alto voltaje se ha descargado.

## 9.4. Advertencia

Este proceso produce gas de hidrógeno y oxígeno inflamables, que pueden ser potencialmente explosivos en espacios confinados. Puede ser necesario ventilar el compartimiento de pasajeros para reducir la acumulación de gas.

El sistema está diseñado para no energizar el agua circundante.

## ¡Nunca retire una desconexión de servicio sumergida!

La inmersión parcial en agua, como durante una inundación, puede provocar un cortocircuito en los componentes internos y un posible incendio.

## 9.5. Ejemplos de recomendaciones específicas del fabricante

Algunos fabricantes pueden tener una guía específica del modelo para vehículos sumergidos. Consulte la guía de respuesta del vehículo adecuada que se encuentra más adelante en este documento para conocer los procedimientos de manejo y apagado.

**FORD/MERCURY (**Escape, Fusion, Mariner, Milan Hybrids): Ford recomienda que un vehículo sumergido no se saque del agua hasta que la batería HV esté completamente descargada (cuando las microburbujas se hayan detenido por completo).

**MITSUBISHI (Mitsubishi i):** Después de sacar el vehículo del agua, enjuague la batería HV mediante el siguiente procedimiento: Retire la tapa de servicio (debajo del asiento del conductor delantero) mientras usa EPP aislante (guantes de resistencia mínima de 400 V) y vierta al menos 8 galones (30 litros) de agua no salina en el orificio de la tapa de servicio.

# 10. Procedimientos generales por peligros en derrame/fuga

Las baterías de alto voltaje (HV), ya sean de hidruro metálico de níquel (NiMH) o de iones de litio (Li-Ion), se consideran esencialmente baterías de celda seca y, si se dañan o rompen, la fuga de electrolito debe ser mínima.

## 10.1. General

Siga los Procedimientos de su departamentales para fluidos automotrices comunes. Los vehículos híbridos y eléctricos pueden contener muchos de los mismos fluidos automotrices
comunes que los vehículos convencionales.

- Asegure el área y mantenga al personal que no sea de emergencia fuera de la zona de peligro.
- Use equipo de protección personal respiratorio y estructural apropiado para combatir incendios cuando trabaje cerca de contenido filtrado de una batería de vehículo híbrido o eléctrico.

- Cuando sea posible, intente contener el electrolito fugado y evitar su introducción en el medio ambiente.

**Los humos de las celdas rotas de las baterías de iones de litio suelen ser irritantes o tóxicos.**

**Use SCBA y EPP apropiado.**

## 10.2. Nota

Algunas baterías HV están refrigeradas por líquido. Si una batería de este tipo está dañada, puede haber fugas de refrigerante. El refrigerante es similar al que se encuentra en los radiadores de vehículos convencionales y no debe confundirse con el electrolito de la batería (aunque es posible la contaminación cruzada con el electrolito si el daño es extenso).

## 10.3. Advertencias

**SOBRE FUGAS DE ELECTROLITO EN LA BATERÍA DE ALTO VOLTAJE (HV)**

● Debido a la dificultad para determinar la composición de una batería HV específica, el electrolito de todas las baterías HV debe considerarse potencialmente corrosivo, tóxico y/o inflamable.



● Si se daña, la batería HV puede emitir vapores nocivos o inflamables. Use equipo de protección personal completo y SCBA y evite el contacto directo con la batería, ya que también puede presentar un riesgo de descarga eléctrica.

● Si detecta olores inusuales o experimenta irritación en los ojos, la nariz, la garganta o la piel, póngase el EPP completo con SCBA y retire inmediatamente a los ocupantes y al personal de respuesta del vehículo, si es posible.

● Si tales vapores están presentes, no es posible retirar inmediatamente a los pacientes y, si hay equipo disponible, instale una ventilación de presión positiva (PPV) o un eyector de humo para alejar los vapores del interior del vehículo. Si es posible, suministre oxígeno al (los) paciente(s) mediante un respirador sin reinhalación como mínimo, para reducir la posibilidad de inhalación de gases peligrosos.

Cualquier fuga de líquido y deséchelo de acuerdo con los procedimientos de disposición final del departamento BOMBEROS.

Póngase en contacto con el distribuidor o fabricante local para obtener orientación sobre el manejo y eliminación de cualquier electrolito derramado.

**Considere todos los electrolitos de la batería cáusticos o corrosivos, especialmente hidruro metálico de níquel (NiMH). Use EPP apropiado.**

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# 11. Procedimientos generales para primeros auxilios para peligros específicos

**NOTA:** Las prácticas a continuación no pretenden reemplazar directivas médicas locales, protocolos o procedimientos operacionales.

## 11.1. General

- Siga los protocolos médicos locales y los PROCEDIMIENTOS de primeros auxilios para cualquier lesión por quemadura, eléctrica o de otro tipo.

## 11.2. Respuesta a la exposición a electrolitos de la batería

- La exposición al electrolito de la batería HV es improbable excepto en un choque severo.

- Use EPP apropiado si se espera exposición a electrolitos. SCBA es altamente recomendado debido a la posibilidad de vapores severamente irritantes.

- El PPE para manipular electrolitos o una batería dañada que pueda tener fugas incluye:

○
○ Delantal o prenda superior apta para disolventes orgánicos (goma, tyvek, etc.).

Guantes aptos para disolventes orgánicos (caucho, látex, nitrilo, etc.).

○ Botas aptas para disolventes orgánicos (goma, etc.).
○ La manipulación de una batería HV dañada es muy desaconsejable. Sin embargo, si la manipulación es absolutamente necesaria, se debe usar EPP eléctrico HV.

## 11.3. Advertencias

● La manipulación de una batería HV dañada solo debe realizarse cuando sea absolutamente necesario, ya que presenta un peligro potencial significativo.
● El electrolito de la batería de NiMH es un alcalino cáustico (pH 13,5) que daña los tejidos humanos. Para evitar lesiones al entrar en contacto con el electrolito, use el EPP adecuado.

## 11.4. Nota

Cualquier ropa o equipo de protección personal que pueda haber estado en contacto con electrolitos debe descontaminarse o desecharse adecuadamente.





## 11.5. Contacto con la piel

- ● Quítese la ropa contaminada.
- ● Enjuague la piel con agua durante 20 minutos.
- ● Busque atención médica inmediata.

## 11.6. Contacto con los ojos

● Enjuague inmediatamente con agua durante 15 a 20 minutos. Asegure un lavado adecuado separando los párpados con los dedos.
● Busque atención médica inmediata.

## 11.7. En caso de ingestión

● Permita que el paciente beba grandes cantidades de agua para diluir el electrolito (nunca le dé agua a una persona inconsciente).

- ● No induzca el vómito.

- ● Si el vómito ocurre espontáneamente, mantenga la cabeza del paciente hacia abajo y hacia adelante para reducir el riesgo de asfixia. Si inconsciente, mantenga la cabeza del paciente hacia un lado y tenga lista la succión.

- ● Busque atención médica inmediata.
- ● Contacte a centro asistencial para el tratamiento de control de intoxicaciones.

## 11.8. Inhalación de vapor electrolítico

● Si hay fugas de electrolito y queda expuesto al aire, se pueden liberar vapores •

electrolíticos. Incluso en una situación que no sea de incendio, los vapores electrolíticos

pueden ser tóxicos o al menos irritantes.

- ● Si se inhalan los vapores, trasládese inmediatamente al aire libre.
- ● Si se espera exposición por inhalación, administre oxígeno y transporte al paciente •

a un centro médico apropiado.

## 11.9. Inhalación en situaciones de extinción de incendios

- ● Los gases tóxicos se desprenden como subproductos de la combustión.
- ● Todo el personal de respuesta debe usar el EPP adecuado para combatir incendios,

● incluido SCBA.

En caso de inhalación de humo, administre oxígeno y transporte al paciente a un centro

A medida que los diseños de los vehículos se alejan cada vez más de los motores de gasolina convencionales, los vehículos de combustible alternativo se vuelven más frecuentes en las carreteras, particularmente en el transporte masivo y los servicios de entrega de última milla.

médico adecuado.

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Antes de que los investigadores de incendios puedan determinar correctamente el origen y la causa de los incendios de vehículos de combustible alternativo, deben comprender cómo se diseñan y alimentan estos vehículos. Aunque cada vehículo es diferente, como ocurre con los vehículos de combustible convencional, hay muchos elementos comunes que pueden fundamentar la comprensión del investigador de los principios básicos de cómo funcionan los vehículos de combustible alternativo, cómo convierten el combustible alternativo en energía

y las implicaciones importantes de estos combustibles alternativos para la investigación de incendios.

Estas Buenas prácticas comparten los conceptos básicos para los vehículos que funcionan con combustible alternativo,

**ADVERTENCIA IMPORTANTE DE SEGURIDAD:** Una investigación de incendio que involucre un vehículo de combustible alternativo NO DEBE continuar a menos que el vehículo se haya hecho seguro de acuerdo con las instrucciones del fabricante para esa marca/modelo/año de vehículo específico.

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https://www.nfpa.org/EV

https://www.nfpa.org/News-and-Research/Resources/Fire-Protection- Research-Foundation

https://www.toyota.com/espanol/hybrid/ https://www.nfpa.org/-/media/Files/Training/AFV/EV-Fire-QR-info-card.ashx

## REFERENCIA

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## Favor imprimir y diligenciar datos entregar el primer dia del curso

Avanzando con un enfoque regional para movilidad eléctrica en América Latina

Curso Entrenamiento Operaciones en Incidentes en Vehiculos Hibridos y electricos FICHA DE INSCRIPCIÓN

**CIUDAD** DE ORIGEN INSTITUCIÓN QUE REPRESENTA

NOMBRES Y APELLIDOS GENERO Masculino

**CORREO PERSONAL [e-mail] CARGO ACTUAL** :

fotografia

Femenino

Otro

**CORREO LABORAL [e-mail] DOCUMENTO DE IDENTIDAD:**

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| DIRECCIÓN DE DOMICILIO: | DIRECCIÓN LABORAL: |

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| **ESCOLARIDAD APROBADA**<br><br>PRIMARIA SECUNDARIAUNIVERSIDAD<br>Título: ______________________________________ | **ACTIVIDAD DOCENTE**<br><br>NO SÍ CUANTO TIEMPO? ____________________ |
| **EXPERIENCIA DE TRABAJO EN EL CAMPO DE PRIMERA RESPUESTA** | |

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|---|
| RESCATE VEHICULAR INSTRUCTOR BOMBEROS SISTEMA COMANDO INCIDENTES PRIMEROS AUXILIOS B.L.S.<br><br>OTRO, cuál |
| **Nombre:**<br><br>**ESCRIBA CLARAMENTE SU NOMBRE COMO USTED DESEE QUE FIGURE EN EL CERTIFICADO DE APROBACIÓN. POR FAVOR FIRME E INDIQUE LA FECHA.**<br><br>**Fecha:** |

Rev. Abril-2022

Documentación Inicial del Participante

**CUESTIONARIO**

## Favor imprimir y resolver cuestionario entregar el primer dia del curso

**Avanzando con un enfoque regional para movilidad eléctrica en América Latina**
Curso "Manejo Incidentes en Vehículos Híbridos y Eléctricos"

**Cuestionario - Trabajo Previo**

Previo al Curso Taller Entrenamiento Operaciones en Incidentes en Vehiculos Híbridos y eléctricos, cada participante deberá leer el Material de Referencia adjunto, responder el siguiente cuestionario y entregarlo al Coordinador del proceso al inicio del proceso de inscripción del Curso.

1. **1- Cuáles son los identificadores por tipo de vehículo de combustible alternativo, revisados en material entregado.**

   VEHÍCULO HÍBRIDO-ELÉCTRICO
   VEHÍCULO ELÉCTRICO HÍBRIDO ENCHUFABLE

   VEHICULO ELECTRICO VEHICULO ESPECIAL

2. **2- Las actividades genéricas a la respuesta inicial para vehículos de combustible alternativo son: evaluación / escena 360, identifique el paso que falta y escríbalo**

   IDENTIFICAR ________________________ DESHABILITAR

3. **3- Al realizar actividades de respuesta se DEBE acérquese al vehículo desde un ángulo de ____________________ para mantenerse fuera del EJE de proyección.**

| | | | |
|---|---|---|---|
| | | | |

Evaluación Trabajo Previo- 1

**4- ¿En TODA intervención en vehículos DEBEN ser inmovilizados antes de trabajar alrededor de ellos?**

Falso

VERDADERO

5. **5- De acuerdo a pruebas realizadas han indicado que podría requerir más de ____________ galones, según el tamaño y la ubicación de la batería.**
6. 6- **Las microburbujas son una reacción burbujeante que proviene de una batería HV __________________________________________________.**
7. **7- Debido a la dificultad para determinar la composición de una batería HV específica, el electrolito de todas las baterías HV ¿se DEBEN considerarse potencialmente corrosivo, tóxico y/o inflamable?**

Falso

VERDADERO

8- **El electrolito de la batería de NIMH es un alcalino cáustico [PH 13,5] que daña los tejidos humanos. para evitar lesiones al entrar en contacto con el electrolito, se DEBE utilizar un ______________ adecuado.**

**Apellido y Nombre _____________________________**

Evaluación Trabajo Previo- 2

# Best Practices for
# Emergency Response to Incidents Involving Electric Vehicles Battery Hazards: A Report on Full-Scale Testing Results

Final Report

Prepared by:

R. Thomas Long Jr., P.E., CFEI Andrew F. Blum, P.E., CFEI Thomas J. Bress, Ph.D., P.E., CRE Benjamin R.T. Cotts, Ph.D.

Exponent, Inc.
17000 Science Drive, Suite 200 Bowie, MD 20715



THE FIRE PROTECTION RESEARCH FOUNDATION ONE BATTERYMARCH PARK QUINCY, MASSACHUSETTS, U.S.A. 02169-7471 E-MAIL: Foundation@NFPA.org WEB: www.nfpa.org/Foundation

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## FOREWORD

Fires involving cars, trucks and other highway vehicles are a common concern for emergency responders. Fire Service personnel are accustomed to responding to conventional vehicle fires, and generally receive training on the hazards associated with vehicle subsystems (e.g., air bag initiators, seat belt pre-tensioners, etc). For vehicle fires, and in particular fires involving electric drive vehicles, a key question for emergency responders is: "what is different with electric drive vehicles and what tactical adjustments are required?"

The overall goal of this project is to conduct a research program to develop the technical basis for best practices for emergency response procedures for electric drive vehicle battery incidents, with consideration for certain details including: suppression methods and agents; personal protective equipment (PPE); and clean-up/overhaul operations. A key component of this project goal is to conduct full-scale testing of large format Li-ion batteries used in these

vehicles. This report summarizes these tests, and includes discussion on the key findings relating to best practices for emergency response procedures for electric drive vehicle battery incidents.

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The content, opinions and conclusions contained in this report are solely those of the authors.

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## PROJECT SPONSORS

Alliance of Automobile Manufacturers

U.S. Department of Energy (Idaho National Laboratory)

U.S. Department of Transportation (National Highway Traffic Safety Administration)

## PROJECT TECHNICAL PANEL

David Anderson, DOE, Department of Energy
David Bryson, NHTSA, National Highway Transportation and Safety Administration
Chris Dubay, NFPA, National Fire Protection Association
James Francfort, Idaho National Laboratory
Andrew Klock, NFPA, National Fire Protection Association
Steve Pegram, IAFC, International Association of Fire Chiefs
Anthony Putorti, NIST, National Institute of Standards and Technology
Scott Schmidt, Alliance of Automobile Manufacturers (Alliance)
Robert Strassburger, Alliance of Automobile Manufacturers (Alliance)
Ken Willette, NFPA, National Fire Protection Association

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## EMERGENCY RESPONDER ADVISORY PANEL

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Maria Bianchi, AAA, American Ambulance Association
Jim Carroll, NAFTD, CT Fire Academy
Laura Cathcart, NAEMT, State of Maryland
Frank Cheatham, NASEMSO, National Association of EMS Officials
Gregg Cleveland, NFPA Fire Service Section, La Crosse Fire Dept, La Crosse WI Don Cooper, NFPA 1670 TC Chair, Ohio State Fire Marshal's Office
John Cunningham, NAFTD, Nova Scotia Firefighter's School
Karen Deppa, NASFM
Rich Duffy, Alexandria VA
Gregory Frederick, Metro Chiefs, Louisville Fire & Rescue., Louisville, KY
Bill Giorgis, Michigan Towing Association, Mike's Wrecker Service, Saginaw, MI
Victoria Lee, IAFC
Stéphan Lepouriel, Major - Civil Security and Crisis Management, France Terry McDonnell, New York State Police, Albany, NY
Ron McGraw, IAFF, Washington DC
Larry McKenna, USFA, Emmitsburg MD
Jim Narva, NASFM, National Association of State Fire Marshals
Steve Pegram, IAFC & ISFSI, Goshen Township Fire & EMS, Goshen OH
Al Rosamond, NVFC, Hixon TN
Tony Sanfilippo, IFMA, Michigan Bureau of Fire Services

## BATTERY TECHNOLOGY ADVISORY PANEL

Domenico Gabrielli, Ford Motor Company Robert Galyen, Chair - SAE EV Battery Committee Mark Gielow, Mercedes Benz

Oliver Gross, Chrysler Group
Christopher Michelbacher, Idaho National Laboratory Ron Orlando, General Motors Corp
Doug Sato, Toyota Motor Sales USA
Mark Saxonberg, Toyota Motor Sales USA
Keith Schultz, General Motors Corporation
Dan Selke, Mercedes Benz
Mathew Shirk, Idaho National Laboratory Simon Wilkinson, Chrysler Group
Keith Wilson, SAE International
Mark Yeldham, BMW of North America



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# Best Practices for Emergency Response to Incidents involving Electric Vehicle Battery Hazards: A Report on Full-scale Testing Results

# Best Practices for Emergency Response to Incidents involving Electric Vehicle Battery Hazards

Prepared for

Fire Protection Research Foundation One Batterymarch Park
Quincy, MA 02169

Prepared by

R. Thomas Long Jr., P.E., CFEI Andrew F. Blum, P.E., CFEI Thomas J. Bress, Ph.D., P.E., CRE Benjamin R.T. Cotts, Ph.D. Exponent, Inc.

17000 Science Drive, Suite 200 Bowie, MD 20715

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# Acronyms and Abbreviations

AC alternating current
Ah Ampere hour
BEV battery electric vehicle CAN controller area network DC direct current

DOE Department of Energy
DOT Department of Transportation
EDV electric drive vehicle
EREV extended range electric vehicle
EV electric vehicle
FMVSS Federal Motor Vehicle Safety Standard
FPRF Fire Protection Research Foundation
FTIR Fourier transform infrared
gpm gallons per minute
HCl hydrogen chloride
HCN hydrogen cyanide
HEV hybrid electric vehicle
HF hydrogen fluoride
HRR heat release rate
HV hybrid vehicle
Hz Hertz
ICE internal combustion engine
IFSTA International Fire Service Training Association kHz kilohertz
kW kilowatt
kWh kilowatt hour
m meter
MFRI Maryland Fire and Rescue Institute
MJ mega joule
mph miles per hour
ms millisecond
MW megawatt
NiMH Nickel metal hydride
NFPA National Fire Protection Association
NHTSA National Highway Traffic Safety Administration NOx nitrogen oxides
OEL occupational exposure limits

PBI Polybenzimidazole
PBZ personal breathing zone
PPE personal protective equipment
PHEV plug-in hybrid electric vehicle
RESS Rechargeable Energy Storage System SAE Society of Automotive Engineers SCBA self-contained-breathing-apparatus
S Siemens
SOC state of charge
SRS supplemental restraint system
SwRI Southwest Research Institute
UL Underwriters Laboratories
V volt
VDC volts direct current
VFT vehicle fire trainer
VOC volatile organic compound
Wh Watt hour



# Limitations

At the request of the Fire Protection Research Foundation (FPRF), Exponent assessed the best practices for emergency response to electric drive vehicle (EDV) battery hazards. This report summarizes a full-scale fire testing and suppression program involving full size hybrid electric (HEV) and extended range electric vehicle (EREV) lithium ion (Li-ion) batteries installed in a vehicle fire trainer (VFT) prop. The scope of services performed during this testing program may not adequately address the needs of other users of this report, and any re-use of this report or its findings, conclusions, or recommendations presented herein are at the sole risk of the user.

The full-scale vehicle mockup test strategy, burner exposure protocol, and any recommendations made are strictly limited to the test conditions included and detailed in this report. The combined effects (including, but not limited to) of different battery types, vehicle types, collision damage, battery energy density and design, state of charge, cell chemistry, etc. are yet to be fully understood and may not be inferred from these test results alone.

The findings formulated in this review are based on observations and information available at the time of writing. The findings presented herein are made to a reasonable degree of scientific and engineering certainty. If new data becomes available or there are perceived omissions or misstatements in this report, we ask that they be brought to our attention as soon as possible so that we have the opportunity to fully address them.

# Executive Summary

This report summarizes full-scale heat release rate (HRR) and fire suppression testing of EDV large format Li-ion batteries.

In an effort to bolster preliminary guidance issued by the National Fire Protection Association (NFPA) for fire emergencies involving EDVs, full-scale fire suppression tests were conducted to collect data and evaluate any differences associated with EDV fires as compared to traditional internal combustion engine (ICE) vehicle fires. EDVs may pose new, unknown risks and variables to emergency responders. In particular, members of the emergency response community have questions regarding, (1) personal protective equipment (PPE); (2) firefighting suppression tactics; and (3) the best practices for overhaul and post-fire clean-up. Specifically, questions from the emergency response community regarding these three topics include:

1. Appropriate PPE to be used for responding to fires involving EDV batteries:
    1. Is current PPE appropriate with regard to respiratory and dermal exposure to vent gases and combustion products?
    2. Is current PPE appropriate with regard to potential electric shock hazards?
    3. What is the size of the hazard zone where full PPE, including respiratory protection, must be worn?
2. Tactics for suppression of fires involving EDV batteries:
    1. How effective is water as a suppressant for large battery fires?
    2. Are there projectile hazards?
    3. How long must suppression efforts be conducted to place the fire under control and then fully extinguish it?
    4. What level of resources will be needed to support these fire suppression efforts?
    5. Is there a need for extended suppression efforts?





f. What are the indicators for instances where the fire service should allow a large battery pack to burn rather than attempt suppression?

3. Best practices for tactics and PPE to be used during overhaul and post-fire clean-up operations.

The scope of work included, but was not limited to, the following six primary tasks:

1. A review of industry best practices for firefighting tactics for ICE and EDVs (see Section 2);

2. Identification, categorization, and prioritization of battery technologies and representative battery types for full-scale testing in conjunction with the Project Technical Panel and their advisory groups (see Section 4);
3. Identification of the key required elements of EDV emergency response PPE, tactics, and overhaul operations (see Section 2);
4. Development of full-scale fire testing program for each battery to be tested (see Section 5);
5. Full-scale fire testing per the full-scale fire testing program developed above, including one unsuppressed HRR test and six suppressed tests (see Section 6); and
6. Report of final results and summary of the best practices for emergency response to incidents involving EDV battery hazards.

In summary, this project involved full-scale HRR and fire suppression testing of EDV batteries alone (HRR test) and installed within a generic VFT prop (fire suppression tests). Fire suppression tests were conducted with and without vehicle interior finishes. All tests subjected the batteries to simulated exposure fires originating underneath the vehicle chassis. All fire suppression activities were conducted by qualified active duty firefighters.

The overriding goal of this research project was to collect data to bolster current guidance provided by NFPA through their *Electric Vehicle Emergency Field Guide*. A full listing of project observations as they relate to the current NFPA guidance is provided in Section 8 of this report.



# 1 Background 1.1 Project History

In 2009, the National Fire Protection Association (NFPA) began a partnership with the U.S. Department of Energy (DOE) and the automotive industry to develop and implement a comprehensive training program to provide safety training to emergency responders to prepare them for their role in safely handling incidents involving electric drive vehicles (EDVs). Throughout this report, the term EDV is used to describe a passenger road vehicle with an electric drive power system capable of propelling the vehicle solely by electric power or in combination with the internal combustion engine (ICE). This program had a lack of data to draw on to address the potential hazards associated with damaged EDV batteries. EDVs may pose new, unknown risks and variables to emergency responders. In particular, members of the emergency response community have questions regarding, (1) personal protective equipment (PPE); (2) firefighting suppression tactics; and (3) the best practices for overhaul and post-fire clean-up. Specifically, questions from the emergency response community include:

1. Appropriate PPE to be used for responding to fires involving EDV batteries:
    1. Is current PPE appropriate with regard to respiratory and dermal exposure to vent gases and combustion products?
    2. Is current PPE appropriate with regard to potential electric shock hazards?

   3. What is the size of the hazard zone where full PPE, including respiratory protection, must be worn?
2. Tactics for suppression of fires involving EDV batteries:
   1. How effective is water as a suppressant for large battery fires?
   2. Are there projectile hazards?
   3. How long must suppression efforts be conducted to place the fire under control and then fully extinguish it?
   4. What level of resources will be needed to support these fire suppression efforts?



5. Is there a need for extended suppression efforts?
6. What are the indicators for instances where the fire service should allow a large battery pack to burn rather than attempt suppression?

3. Best practices for tactics and PPE to be used during overhaul and post-fire clean-up operations.

## 1.2 Research Objectives and Project Scope

The overall project research objective was to develop a technical basis for the best practices for emergency response for EDV battery incident firefighting, including the necessary PPE for first fire responders, the adequacy of water as a suppression agent, and the best practices for overhaul.

The scope of work included, but was not limited to, the following six primary tasks:

1. A review of industry best practices for firefighting tactics for ICE and EDVs (see Section 2);
2. Identification, categorization, and prioritization of battery technologies and representative battery types for full-scale testing in conjunction with the Project Technical Panel and their advisory groups (see Section 4);
3. Identification of the key required elements of EDV emergency response PPE, tactics, and overhaul operations (see Section 2);
4. Development of a full-scale fire testing program for each battery to be tested (see Section 5);
5. Full-scale fire testing per the full-scale fire testing program developed above, including one unsuppressed combustion test and six suppressed tests (see Section 6); and
6. Report of final results and summary of the best practices for emergency response to incidents involving EDV battery hazards.

A more detailed description of the tasks Exponent performed to fulfill the project objectives is provided below.

## 1.2.1 Review of Industry Best Practices for Firefighting

Exponent collected, reviewed, and summarized available industry best practices for EDV battery incident firefighting as they relate to hazards, frequency, PPE, suppression tactics, suppression agents, overhaul, and clean-up. This task included a review of firefighting tactics literature, as well as technical discussions with the Maryland Fire and Rescue Institute (MFRI) in regards to industry best practices for fighting ICE and EDV fires (see Section 2).

## 1.2.2 Identification, Categorization, and Prioritization of Battery Technologies and Representative Battery Types

Exponent, in conjunction with the Project Technical Panel, identified three candidate Li-ion batteries from three different EDV manufacturers for testing. Exponent assisted in analyzing and procuring the candidate batteries. A description of each battery is provided in Section 4.

Li-ion battery technology with an approximate capacity of 5.0 DC kWh or larger if designed for a plug-in hybrid electric vehicle (PHEV) or extended range electric vehicle (EREV) and 15.0 DC kWh or larger if designed for a battery electric vehicle (BEV) was used as a benchmark for the battery selection**.**

Exponent also worked with battery and automotive manufacturers to develop protocols for safe charging and characterization of the batteries prior to testing and safe discharge and removal of the batteries after testing, where required.

## 1.2.3 Identification of Key Required Elements of PPE, Tactics, and Overhaul Operations

Exponent, in conjunction with the Project Technical Panel and MFRI, identified and summarized the key required elements of emergency response PPE, tactics, and overhaul operations based on a review of EDV fire hazards and traditional responses to vehicle and electrical fires involving energized equipment. This analysis included a review of industry references, as well as discussions with MFRI and automotive resources regarding PPE (see Section 2).



## 1.2.4 Development of Full-Scale Fire Testing Program

Exponent, in conjunction with the Project Technical Panel and their advisory groups, developed an appropriate program for full-scale fire testing, separated into two categories: (1) HRR testing of a standalone battery pack and (2) full-scale fire suppression testing of battery packs in their correct mounting location positioned inside a vehicle fire trainer prop (VFT), along with other appropriate combustible materials, including vehicle interior finishes and components. The full-scale suppression tests involved a modified VFT prop to simulate typical vehicle fuel loads and ignition and containment of the Li-ion batteries.

### 1.2.5 Full-scale Fire Testing

The full-scale fire testing involved one standalone HRR free-burn, unsuppressed fire test and suppressed fire tests of Li-ion batteries within a VFT. Instrumentation was provided to monitor fire growth and development, including, but not limited to, heat release rate, temperature, and heat flux. Gas samples and fire suppression water samples were collected for analysis of potential contaminants.

For testing that utilized the VFT, Exponent collaborated with MFRI, who provided expertise in incident command, firefighting tactics, overhaul operations, and firefighter PPE. Their training staff was utilized to identify recommended best practices for emergency response to EDV fire incidents and to facilitate the tests and suppression of the fires.

Active firefighters from MFRI performed all suppression and overhaul operations. Any hazardous events, such as projectile releases, adverse reactions to suppression agents, and electric shock were recorded.

### 1.2.6 Report and Summary of Best Practices

Exponent collected and processed the test data from the full-scale testing program in this formal research engineering report. This report provides:

1. An overview of the project work to date;
2. A summary of the full-scale test data;



3. Comparison with comments from NFPA interim guidance; and
4. Identification of future potential research.



# 2 Current State of Emergency Response to ICE and EDV Fires

## 2.1 Li-ion Overview

Li-ion battery cells are in wide consumer use today. As this technology has evolved and the energy densities have increased, the use of this technology has been applied across many consumer products, including the automotive industry. Li-ion battery cells arranged in large format Li-ion battery packs are being used to power several types of EDVs. As EDVs enter the U.S. marketplace, there is an expectation of a steep increase in the number and size of battery packs in storage and use. A recent study by NFPA's FPRF[1,2] highlights the potential hazards and uses of Li-ion battery cells and packs during the life cycle of storage and distribution. An overview of the Li-ion technology and its failure modes is also included. A brief summary of Li-ion technology is provided here.

Li-ion has become the dominant rechargeable battery chemistry for consumer electronic devices and is poised to become commonplace for industrial, transportation, and power-storage applications. This chemistry is different from previously popular rechargeable battery chemistries (e.g., nickel metal hydride, nickel cadmium, and lead acid) in a number of ways. From a technological standpoint, because of high energy density, Li-ion technology has enabled the powering of EDVs. From a safety and fire protection standpoint, a high energy density coupled with a flammable organic, rather than aqueous, electrolyte has created a number of new challenges with regard to the design of batteries containing Li-ion cells, and with regard to fire suppression.

The term Li-ion refers to an entire family of battery chemistries. It is beyond the scope of this report to describe all of the chemistries used in commercial Li-ion batteries. In addition, it should be noted that Li-ion battery chemistry is an active area of research and new materials are constantly being developed. Additional detailed information with regard to Li-ion batteries is

[1] Long RT et al. "Lithium-Ion Batteries Hazard and Use Assessment." Fire Protection Research Foundation Report, July 2011. http://www.nfpa.org/assets/files//PDF/Research/RFLithiumIonBatteriesHazard.pdf

[2] Long RT, et al. "Lithium-ion batteries hazards: What you need to know." Fire Protection Engineering Q4 2012.



available in a number of references[3,4] and a large volume of research publications and conference proceedings on the subject.

In the most basic sense, the term Li-ion battery refers to a battery where the negative electrode (anode) and positive electrode (cathode) materials serve as a host for the lithium ion (Li+). Lithium ions move from the anode to the cathode during discharge and are intercalated (inserted into voids) in the crystallographic structure of the cathode. The ions reverse direction during charging, as shown in Figure 1. Since lithium ions are intercalated into host materials during charge or discharge, there is no free lithium metal within a Li-ion cell[5,6], thus, if a cell ignites due to external flame impingement or an internal fault, metal fire suppression techniques are not appropriate for controlling the fire.

[3] *Linden's Handbook of Batteries*, 4th Edition, Thomas B. Reddy (ed), McGraw Hill, NY, 2011.
[4] *Advances in Lithium-Ion Batteries*, WA van Schalkwijk and B Scrosati (eds), Kluwer Academic/Plenum

Publishers, NY, 2002.

[5] Under certain abuse conditions, lithium metal in very small quantities can plate onto anode surfaces. However, this should not have any appreciable effect on the fire behavior of the cell.

[6] There has been some discussion about the possibility of "thermite-style" reactions occurring within cells (reaction of a metal oxide with aluminum, for example iron oxide with aluminum, the classic thermite reaction, or in the case of lithium-ion cells cobalt oxide with aluminum current collector). Even if thermodynamically favored (based on the heats of formation of the oxides), generally these types of reactions require intimate mixtures of fine powders of both species to occur. Thus, the potential for aluminum current collector to undergo a thermite-style reaction with a cathode material may be possible, but aluminum in bulk is difficult to ignite (Babrauskas V, *Ignition Handbook*, Society of Fire Protection Engineers, 2003, p. 870) and thus, the reaction may be kinetically hindered. Ignition temperatures of thermite style reactions are heavily dependent upon surface properties. Propagation of such reactions can also be heavily dependent upon mixture properties. To date, Exponent has not observed direct evidence of thermite style reactions within cells that have undergone thermal runaway reactions, nor is Exponent aware of any publically available research assessing the effect of such reactions on cell overall heat release rates. Nonetheless, even if a specific cell design is susceptible to a thermite reaction, that reaction will represent only a portion of the resulting fire, such that the use of metal fire suppression techniques will remain inappropriate.

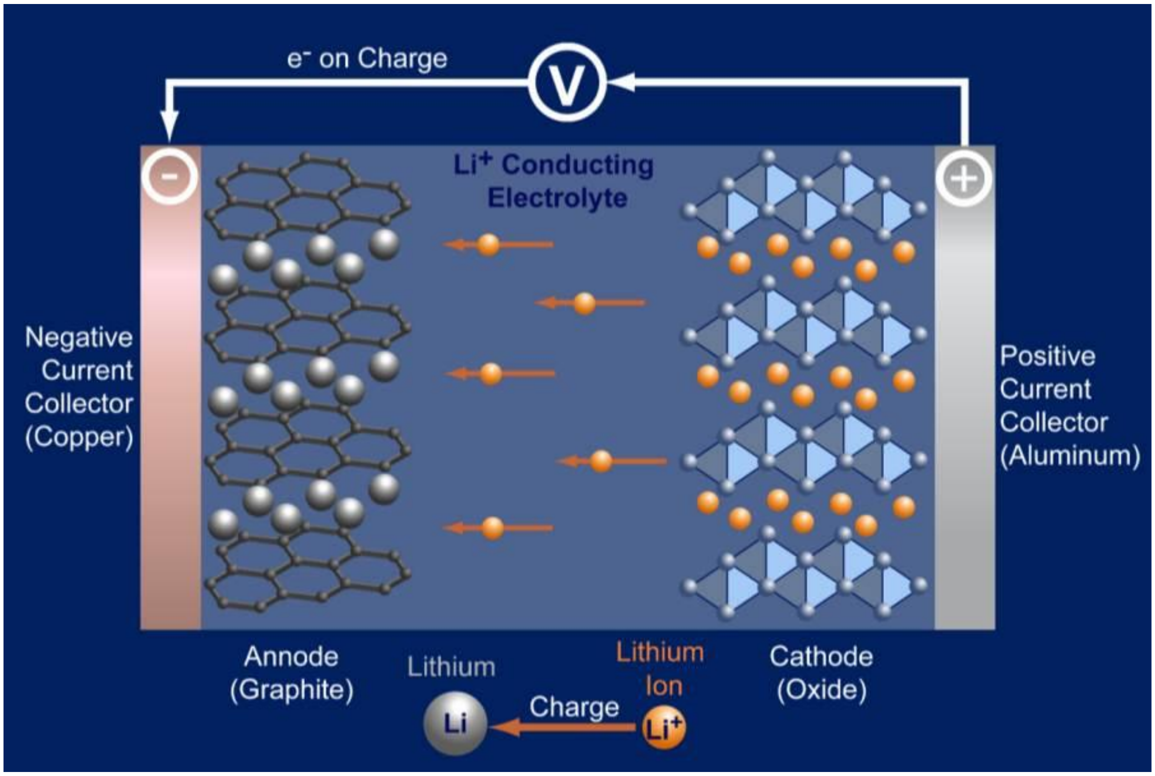


Figure 1 Li-ion cell operation, during charging lithium ions intercalate into the anode, the reverse occurs during discharge

In a Li-ion cell, alternating layers of anodes and cathodes are separated by a porous film (separator). An electrolyte composed of an organic solvent and dissolved lithium salt provides the media for Li-ion transport. A cell can be constructed by stacking alternating layers of electrodes (typical for high-rate capability prismatic cells), or by winding long strips of electrodes into a "jelly roll" configuration typical for cylindrical cells, as shown in Figure 2. Electrode stacks or rolls can be inserted into hard cases that are sealed with gaskets (most commercial cylindrical cells), as shown in Figure 3, laser-welded hard cases, as shown in Figure 4, or enclosed in foil pouches with heat-sealed seams (commonly referred to as Li-ion polymer cells[7]), as shown in Figure 5. A variety of safety mechanisms might also be included in the

[7] Note that the term "lithium polymer" has been previously used to describe lithium metal rechargeable cells that utilized a polymer-based electrolyte. The term lithium polymer is now used to describe a wide range of lithium-ion cells enclosed in soft pouches with electrolyte that may or may not be polymer based.



mechanical design of a cell, such as charge interrupt devices and positive temperature coefficient switches.[8,9]

Figure 2 Base of a cylindrical Li-ion cell showing wound structure (top); Cell being unwound revealing multiple layers: separator is white, aluminum current collector (part of cathode) appears shiny (bottom)

[8] For a more detailed discussion of Li-ion cells see: Dahn J, Ehrlich GM, "Lithium-Ion Batteries," *Linden's Handbook of Batteries*, 4th Edition, TB Reddy (ed), McGraw Hill, NY, 2011.

[9] For a review of various safety mechanisms that can be applied to Li-ion cells see: Balakrishnan PG, Ramesh R, Prem Kumar T, "Safety mechanisms in lithium-ion batteries," Journal of Power Source, 155 (2006), 401-414.

Figure 3 Example of 18650 cylindrical cells (these are the most common consumer electronics Li-ion cell form factor)

Figure 4 Example of a hard case prismatic cell

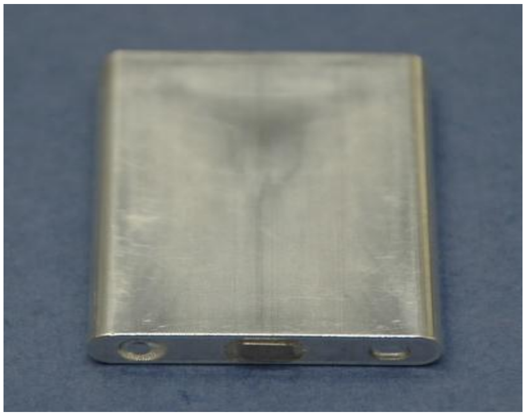

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Figure 5 Example of a soft-pouch polymer cell

A Li-ion battery is made from multiple individual cells packaged together with their associated control system and protection electronics. By connecting cells in parallel, designers increase pack capacity. By connecting cells in series, designers increase pack voltage. Thus, most battery packs will be labeled with a nominal voltage that can be used to infer the number of series elements and, along with total battery pack energy (in Watt hours [Wh]), can be used to determine the capacity (in Ampere hours [Ah]) of each series element (size of individual cells or the number of cells connected in parallel).

For large format battery packs, cells may be connected together (in series and/or in parallel) in modules. The modules may then be connected in series or in parallel to form full battery packs. Modules are used to facilitate readily changed configurations and easy replacement of faulty portions of large battery packs. Thus, large format battery pack architecture can be complex.

EDV batteries typically utilize many individual cells comprised into modules. The modules are then assembled to form a large format battery pack. Large format packs typically contain an active safeguarding system to monitor electrical current, voltage, and temperature of the cells to optimize pack performance and mitigate potential failures, including fire. Numerous standards and protocols are available for these packs, including, but not limited to:

• Underwriters Laboratories (UL) Subject 2580: Batteries for Use in Electric Vehicles;



- SAE J2464: Electric and Hybrid Electric Vehicle Rechargeable Energy Storage Systems (RESS), Safety and Abuse Testing; and
- SAE J2929: Electric and Hybrid Vehicle Propulsion Battery System Safety Standard – Lithium-based Rechargeable Cells.

It is beyond the scope of this report to discuss all potential standards and protocols; however, a summary of many testing protocols for Li-ion cells has been published previously.[10]

## 2.2 Electric Vehicle Overview

Different types of EDVs are created by unique combinations of the standard components of a hybrid and/or electric vehicle system, including the battery, electric motor, generator, mechanical transmission, and power control system. There are four primary types of EDVs:

1. Hybrid electric vehicles (HEV);
2. Plug-in hybrid electric vehicles (PHEV);
3. Extended-range electric vehicles (EREV); and
4. Battery electric vehicles (BEV).

The following summarizes the four primary types of EDVs and how they commonly function. Some variances will occur from manufacturer to manufacturer. HEVs use a small electric battery to supplement an ICE. The electric battery is recharged by the gasoline engine and regenerative braking. PHEVs are dual-fuel vehicles, where the electric motor and/or the ICE can propel the vehicle. PHEVs use a larger battery pack than HEVs and are charged directly from the power grid to supplement a smaller ICE. EREVs are propelled by electric motors only. When the propulsion battery is depleted, and ICE is used to power an electric generator that provides electricity to the drive motors. Finally, BEVs have no ICE at all and are full EVs. These vehicles must plug into the power grid to recharge.[11]

[10] UL: "Safety Issues for Lithium-Ion Batteries," 2012.
[11] http://www.tva.com/environment/technology/car_vehicles.htm



## 2.3 Current EDV Research and Other Efforts

EDVs involved in collision and fire incidents may present unique hazards associated with the high voltage system (including the battery system). These hazards can be grouped into three distinct categories: chemical, electrical, and thermal. The potential consequences can vary depending on, but not limited to, the size, configuration, and specific battery chemistry. Recently the Society of Automotive Engineers (SAE) International released J2990[12], *Hybrid and EV First and Second Responder Recommended Practice*, which describes the potential consequences associated with hazards from EDVs and suggests common procedures to help protect emergency responders, tow and/or recovery, storage, repair, and salvage personnel after an incident has occurred with an electrified vehicle. Nickel metal hydride (NiMH) and Li-ion batteries used for vehicle propulsion power are the assumed battery systems of this Recommended Practice.

Recently, full-scale fire tests have compared the fire behavior of EDVs with that of conventional ICE vehicles. In the first test series[13], researchers conducted full-scale tests of an electric battery powered EDV and a comparable ICE vehicle. In this test series, the total HRR of the burning vehicles was calculated using the mass loss rates. The peak HRR of the EDV was found to be approximately three times greater than that of the ICE vehicle; however, given that the EDV and ICE were not identical, it is unclear if the peak HRRs can be directly compared. During the EDV test, no projectiles or explosions were observed. It was noted that while the peak HRR was greater, the total energy released for the EDV was approximately 50% more than the ICE vehicle tested, but 15% less than that of a luxury ICE sedan.

In a second test series[14], researchers conducted fire tests on two vehicles. The first was an EDV and the second vehicle tested was an analogous ICE vehicle. A gas burner was used to ignite

[12] SAE International, Surface Vehicle Recommended Practice J2990 NOV2012, 11-2012, Hybrid and EV First and Second Responder Recommended Practice.

[13] Watanabe, N. et al. "Comparison of fire behaviors of an electric-battery-powered vehicle and gasoline-powered vehicle in a real-scale fire test." National Research Institute of Police Science, Japan. Presented at Second International Conference on Fires in Vehicles, September 27-28, 2012, Chicago, IL.

[14] Lecocq, A. et al. "Comparison of the Fire Consequences of an Electric Vehicle and an Internal Combustion Engine Vehicle." INERIS – National Institute of Industrial Environment and Risks, Verneuil-en-Halatte, France. Second International Conference on Fires in Vehicles, September 27-28, 2012, Chicago, IL.





the vehicles and was located on the front driver's seat. Fire development was similar for both vehicles and no projectiles were observed. The maximum HRR was similar for both vehicles, 4.2 MW for the EDV and 4.8 MW for the ICE vehicle. Gas analysis found that hydrogen fluoride (HF) was emitted in significant quantities in both the EDV and ICE vehicle tests. A distinct area of HF emission was observed during the burning of the EDV that was attributed specifically to the combustion of the EDV battery, however, these peaks were less than the initial and maximum HF peak that was possibly attributed to the air conditioning refrigerant.

Prior work conducted on EDV batteries exposed to pool fires was also reviewed.[15] In this test series, three large format 17 kWh EDV Li-ion batteries were exposed to fuel-fed pool fires in a rack located above an exposure fire. The batteries were not installed in the original host vehicle. The batteries were then extinguished with water and/or water with additives. The battery external temperatures and the total amount of water used were recorded.

The pool fire was placed directly below the battery, was fueled by 45 liters of heptane, and lasted approximately 11 minutes. When exposed to the flames, gases were observed to escape from the battery and produce visible flash fire-like flames and "short circuits" characterized by bright white flames. Water samples collected after extinguishing the batteries showed concentrations of Fluoride and Chloride. Forty (40) to 80 liters of water with various additives were used to extinguish the fire.

The National Institute for Occupational Safety and Health (NIOSH)[16] recently evaluated chemical and particulate exposures to firefighters during vehicle fire suppression training. Smoke samples from engine and cabin fires were collected and analyzed to identify the main chemicals in the smoke. Samples were also collected from the personal breathing zone (PBZ). High levels of hazardous chemicals were found in the smoke samples from the vehicle smoke, however, PBZ samples were below occupational exposure limits (OELs). Recommendations included:

[15] Egelhaaf, M., Kress, D., Wolpert, D., Lange, T. et al., "Fire Fighting of Li-Ion Traction Batteries," SAE Int. J. Alt. Power. 2(1):37-48, 2013, doi: 10.4271/2013-01-0213.

[16] Fent, K.W. et al. "Evaluation of Chemical and Particle Exposures During Vehicle Fire Suppression Training." Health Hazard Evaluation Report HETA 2008-0241-3113, NIOSH, Yellow Springs, OH, July 2010.



- Enforcement of the use of self-contained breathing apparatuses (SCBAs) during vehicle fire suppression;
- Attacking fires from upwind positions;
- Parking fire apparatus upwind of the fire;
- Donning SCBA before attacking the vehicle fire; and
- Keeping SCBA on until overhaul is complete.

## 2.4 Overview of Vehicle Fires

Highway vehicle fires are one of the common types of fires to which fire departments respond. However, the number of highway vehicle fires that occur in the United States has been on a steady downward trend since 1980, when NFPA began tracking such incidents. According to NFPA, between 1980 and 1982, there was an average of approximately 447,000 highway vehicle fires per year; between 2009 and 2011, there was an average of approximately 187,500 highway vehicle fires per year.[17] A highway vehicle is defined as a vehicle intended for highway use and is classified as either a passenger road vehicle or truck/freight road vehicle.[18]

Passenger road vehicles are vehicles designed primarily to carry people on roadways. Passenger road vehicles include cars, buses, recreational vehicles, and motorcycles, but this classification does not include pick-up trucks, which are classified as trucks. Automobiles and cars are the most common highway vehicles involved in fires. Between 2003 and 2007, over 70% of highway vehicle fires involved automobiles or cars.[19,20]

Over the past few decades, changes in automobile structural components and interior elements have made modern vehicle fires more challenging. Modern vehicles contain an increased

[17] Karter, M. *Fire Loss in the United States 2011*, NFPA Fire Analysis and Research Division, Quincy, MA, September 2012.

[18] Ahrens, M. *U.S. Vehicle Fire Trends and Patterns.* NFPA Fire Analysis and Research Division, Quincy, MA, June 2010.

[19] Ibid.

[20] More detailed information on passenger vehicle fires is available in: Long RT, et al. Passenger vehicle fires. Chapter 1, Section 21. Fire Protection Handbook, 20th Edition. National Fire Protection Association (NFPA), pp. 21-3–21-14, Quincy, MA, 2008.



amount of plastics and also present other hazards, such as compressed gas struts and absorbers that may explode under fire conditions. Modern vehicles can have components constructed from combustible metals that can react when water is applied. In addition, most vehicles now contain various supplemental restraint systems (SRS), i.e. airbags, to protect passengers during a collision and/or rollover. Airbags can deploy during the removal of crash victims, resulting in firefighter injuries if not properly handled.

Currently, the fire service is searching for ways to manage the recent and forecasted increase in the number and type of EDVs and the potential fires that may result. In addition to the hazards described above, these vehicles may present additional challenges for the fire service. Many of these vehicles have operational features with which fire service personnel are currently unfamiliar. For example, EDVs are normally silent when the vehicle is stopped. Thus an EDV can be "on" and ready to propel itself if the accelerator is depressed. Similarly, many HEVs "hibernate" when they come to a stop. These vehicles are also poised to move if the accelerator is depressed. Emergency responders can no longer assume that a vehicle is "off" when they cannot hear the engine running. However, the Department of Transportation (DOT) / National Highway Traffic Safety Administration (NHTSA) recently issued a Notice of Proposed Rulemaking for a minimum noise level to be added to EDVs, which could reduce or eliminate this issue in the future.[21]

EDVs contain high voltage batteries and electrical components that present a risk of shock or possibly electrocution to first responders if not properly handled. These are hazards not typically encountered during responses to fires in conventional ICE powered highway vehicles. Firefighters could be at risk for severe shock/injury/electrocution if they breach an energized high voltage electrical component or the high voltage battery. Firefighters may also be shocked by coming in contact with an energized high voltage component that has been compromised by fire or collision damage.

[21] US DOT/NHTSA recently issued a Notice of Proposed Rulemaking related to the Minimum Sound Requirements for Hybrid and Electric Vehicles (49 CFR 571; Docket No. NHTSA-2011-0148) based on their Draft Environmental Assessment (Docket No. NHTSA-2011-0100), dated January 2013.

## 2.5 Conventional ICE Vehicle Fires

Firefighting practices for conventional ICE vehicle fires have not changed significantly over the past 30 years, although the fire service has adapted to the new hazards presented by modern vehicles, as described previously. Vehicle fires were once treated with relative complacency. Often, firefighters would wear only portions of their PPE ensemble when fighting a vehicle fire. Firefighters rarely took measures to protect themselves from inhaling the smoke and gases emitted from burning vehicles. Increased awareness of hazards associated with modern vehicles, coupled with a more highly developed culture of safety have caused the fire service to demand the use of all safety elements in order to prevent injuries and long term chronic illnesses.

The fighting of fires in modern vehicles may place firefighters at risk of injury from projectiles. Modern vehicles are constructed with various sealed, hollow components that may become pressurized when heated. Shock-absorbing bumpers, drive shafts, and the struts used to raise hoods and hatchbacks can rupture and become projectiles during a fire. It is essential that personnel are completely outfitted in structural turn-out gear to limit the potential for injuries from projectiles.

Another factor that has affected tactics in responding to vehicle fires is the use of plastics in vehicle components. Plastic components are found in nearly every compartment of modern vehicles (i.e. engine, cabin, and cargo area) and on the exterior of vehicles. Plastics can have a higher heat release rate than the products used in the construction of older vehicles. In addition, modern vehicles may have components made of metals that can burn and react with water.

The high heat release rate characteristics of the plastics necessitate the deployment of higher flow rates than might typically have been used in years past. These higher flow rates facilitate faster suppression of the fire and provide a higher level of protection to firefighters. It was common 30 years ago for firefighters to deploy 3⁄4-inch to 1-inch booster lines to combat vehicle fires. Currently, firefighters deploy attack lines of at least 1.5 inches in diameter on vehicle fires, as recommended by the International Fire Service Training Association (IFSTA). IFSTA also recommends not relying on booster lines as they, “...do not provide the protection or rapid



cooling needed to effectively and safely fight a vehicle fire.” In addition, IFSTA encourages the deployment of a back-up line as soon as possible.[22]

The increased use of plastics and other materials, combined with a much clearer understanding of the detrimental health effects associated with vehicle fires has also resulted in changes to tactics. In the past, it was uncommon for firefighters to wear an SCBA while extinguishing a vehicle fire. A rising awareness of the vast array of volatile organic compounds (VOCs) and other gases emitted during a vehicle fire and their associated potential health effects have made the donning of SCBAs essential at every vehicle fire.[23]

## 2.6 Current Conventional ICE Vehicle Fire Tactics

In order to examine how the prevalence of EDVs should influence tactical operations at vehicle fires, it is important to look at how, in general, fires in conventional ICE vehicles are being extinguished currently. The following is a list of tasks in chronological order, typically performed at a vehicle fire. The operations described below assume there are at least four fire service personnel on scene. If fewer personnel are present, all of the tasks still must be performed by those personnel on scene.[24]

1. Upon arrival of the pumper(s), the apparatus is parked at least 50 feet from the burning vehicle, in such a position as to protect firefighters from vehicular traffic.
2. Firefighters (FF1 and FF2) and officer wear full PPE and SCBA. The pumper operator (FF3) is usually not in full PPE.
3. The officer performs a 360-degree size-up to identify hazards and determine if there are trapped occupants or injured civilians. The officer directs the firefighters throughout the extinguishment.

[22] IFSTA. Essentials of Fire Fighting. Stillwater, OK: Fire Protection Publications. 2008.

[23] Fent, K. and Evans, D. Assessing the risk to firefighters from chemical vapors and gases during vehicle fire suppression. 2010.

[24] These tactics are the basic vehicle fire operations known to MFRI.



4. The firefighters stretch an attack line (1-1/2" or 1-3/4") from the first arriving pumper. At this point, they don their SCBA (attach facemask to face and begin breathing off cylinder air), if they had not already done so.
5. The officer advises the firefighters of any observed hazards, victims, etc.
6. FF3 charges the attack line with water from the pumper's water tank.
7. FF1 opens the nozzle's bale and adjusts the stream of the nozzle. FF1 advances toward the vehicle with a wide pattern (60° fog) from uphill/upwind if possible, approaching toward one of the vehicles corners or the side of the vehicle, but not from the front or rear of the vehicle. The main priority of FF1 is to protect anyone who may be trapped in the vehicle.
8. FF2 or the officer chocks a wheel of the vehicle to prevent it from rolling as FF1 approaches the vehicle.
9. If the fire is in the passenger compartment and the window(s) have already failed, FF1 narrows the pattern to a 30° fog and directs the stream at close range into the cabin of the burning vehicle. If the windows have not failed, FF2 attempts to open the vehicle's door with the door handle. If the doors are locked, FF2 uses a forcible entry tool to smash the vehicle's window(s). FF1 can then direct the stream into the cabin.

10. If the fire is in the engine compartment, FF1 may direct the 30° fog stream up through the wheel-wells, through the grill, or under the hood from the base of the windshield. FF2 attempts to release the hood latch from the cabin of the vehicle and raise the hood. If the hood release will not work, FF2 may use a prying tool to create a gap between the hood and the fender through which the stream can be directed. Some departments utilize piercing nozzles that can be spiked though the hood to flow water into the engine compartment.
11. As fire in the engine compartment is knocked down, FF2 begins to force entry into the engine compartment by smashing/prying the hood lock/clasp or by using other tools to pry the back corners of the hood up and cut through the hood's hinges. Some departments use powered saws to cut a hole in the hood.



12. Access to a fire burning in the trunk area may be gained using methods similar to those described for forcing entry to the hood. In some instances, a firefighter may be able to drive-in the trunk lock with a forcible entry tool and pick the disabled locking mechanism with a screwdriver.
13. FF1 moves around the vehicle with the attack line to access all burning areas of the vehicle. All visible fire is extinguished.
14. FF2 accesses the compartment housing the vehicle battery and cuts or disconnects the negative (ground) cable from the battery terminal (or both cables from both terminals), to prevent a shorted electrical system from reigniting a fire. This step is repeated if the vehicle has a second battery.
15. The firefighters and officer overhaul the vehicle to ensure the fire is completely extinguished by opening areas where fire may be hidden and/or smoldering; these areas are thoroughly soaked.
16. The officer does an investigation to determine the fire's origin and cause. The officer may call for a fire investigator if the cause is undetermined, incendiary, or suspicious.

## 2.7 Current EDV Fire Tactics

Firefighters are confronted with additional hazards and challenges when dealing with EDVs. The following best practices address EDV fires.[25,26,27] The operations described below do not state how many fire service personnel will be on scene. However many are present, all of the tasks still must be performed by those personnel on scene. These tasks include:

1. Identify the vehicle;
2. Immobilize the vehicle;
3. Disable the vehicle;

[25] National Fire Protection Association. Electric Vehicle Emergency Field Guide. Quincy, MA. 2012.

[26] National Highway Traffic Safety Administration. Interim Guidance for Electric Vehicle and Hybrid-Electric Vehicles Equipped With High Voltage Batteries. Washington, D.C. 2012.

[27] SAE International, Surface Vehicle Recommended Practice J2990 NOV2012, 11-2012, Hybrid and EV First and Second Responder Recommended Practice.



4. Extrication;
5. Extinguishment; and
6. Overhaul operations.

## 2.7.1 Identify the Vehicle

Identification of a vehicle as an EDV is the first challenge firefighters face upon arriving at a vehicle fire. It must become part of every firefighter's size-up operations to determine if a burning vehicle is an EDV. In many instances, it may be readily apparent from the vehicle make/model or from exterior badges/logos. In other instances, it may not be so apparent. Damage sustained by the vehicle by either a collision/roll-over or the fire and smoke itself may make identification very difficult. During size-up of the incident, firefighters should look for warning labels on the EDV that warn of high voltage. Some labels may be less direct at communicating the fact that the vehicle in question is an EDV.

If the fire is confined to the engine compartment or trunk, a firefighter may be able to get a clear view of the instrumentation on the vehicle's dashboard. In this case, firefighters should look for words and symbols that indicate the vehicle is an EDV. If the vehicle is "on", the firefighter may be able to see dash symbols indicating charge status of the battery, or that there isn't a fuel gauge.

Whatever method is used to identify the vehicle, all personnel operating at the scene must be made aware if the vehicle on fire is an EDV.

## 2.7.2 Immobilize the Vehicle

As with conventional ICE vehicles, it is important to place chocks to the front and rear of one of the wheels to prevent the vehicle from rolling. EDVs can hibernate; although it may not be obvious that the engine is running, the vehicle may be poised to move as soon as the accelerator is depressed. EDVs should be chocked to prevent any inadvertent movement of the vehicle as soon as possible. Although a good preventative measure, chocking alone may not prevent



movement if the drive system is engaged. If possible, setting the emergency brake and placing the vehicle in park can add additional protection against inadvertent movement.

### 2.7.3 Disable the Vehicle

Determine the status of the vehicle by viewing the dash display, the position of the key in the ignition, and/or the power button to see if it has a lit indicator light. If the vehicle is "on", turn the key to the "off" position. Some new EDVs operate with a proximity key. If the proximity key is within range of the vehicle (usually less than 16 feet), the vehicle is powered "on" by a button on the dash. Turn the vehicle "off" by pressing this button. Then remove the key from the ignition and place it beyond the range of the vehicle (typically greater than 16 feet).

In addition to the high voltage battery that powers an EDV motor, there is a conventional 12-volt battery located somewhere on the vehicle. The 12-volt battery powers many of the vehicle accessories and is used to control high voltage contactors. Severing the 12-volt battery's ground cable will prevent the vehicle from powering up. Cutting the 12-volt battery in a vehicle that is "on", however, will not turn the vehicle "off", as power supplied by the DC/DC convertor may keep the contactor closed. After the vehicle has been powered down by the key/ignition button, firefighters should further disable the vehicle by severing the 12-volt battery's negative ground cable. The officer should refer to NFPA's *Electric Vehicle Emergency Field Guide* or other appropriate guides for vehicle specific information on the location of the 12-volt battery and fuses that can be pulled to disable the high voltage system.

If firefighters are unable to gain access to the area housing the 12-volt battery or fuses, they may attempt to isolate the high voltage system by removing or switching off the high voltage main disconnect (or "high voltage service disconnect"). Firefighters will need a guide, such as NFPA's *Electric Vehicle Emergency Field Guide,* in order to determine the location of the high voltage main disconnect and identify the proper method for de-energizing the system. Firefighters may not be able to complete this step until after the fire is extinguished.[28] Further detail on recommendations for high voltage system disabling can be found in SAE International Recommended Practice J2990. J2990 recommends that vehicle manufacturers provide a

[28] Delphi Corporation. Hybrid Electric Vehicles for First Responders. Troy, MI. 2012.



minimum of two methods of initiating the disconnection of the propulsion system from the high voltage sources. Utilizing more than one method increases the likelihood that the high voltage sources have been disconnected. SAE recommends the following methods of initiating the disconnection in their preferred order:

1. Automatic shutdown of the high voltage system based on the detection of a prescribed level of vehicle impact;
2. Switching the ignition switch or power button to the "off" position (assuming there is no damage to the shutdown circuits or high voltage discharge circuits;

3. Cutting or disconnecting the negative and positive 12-volt battery cables to discharge the 12-volt system while also cutting or disconnecting the DC/DC converter’s 12-volt output cable; and/or
4. Removing the manual disconnect. However, this was listed as not being a primary method for first responders to disable the vehicles high voltage circuits, as there are a variety of manual disconnect designs and locations.

Firefighters assigned the task of disabling the high voltage system via the main should consider wearing Class 0/1000v high voltage safety gloves with outer leather covers. However, a review of a selection of automotive manufacturer requirements for electrical PPE showed significant variations according a recent NFPA workshop.[29] This workshop also highlighted that there are significant differences between PPE used by the fire service and electrical professionals when handling energized electrical equipment.

It may take up to ten minutes for a high voltage system to dissipate its energy after the main has been pulled/switched off. However, it should be noted that high voltage will still be present within the battery pack and on the battery pack side of the high voltage main disconnect switch.

Should the EDV be plugged into a charging station at the time of a fire, the best practice would include isolating the electrical supply to the charging station at a safe location by trained professionals prior to any attempts at disabling the high voltage system within the vehicle.

[29] Emergency Responder Personal Protective Equipment (PPE) for Hybrid and Electric Vehicles May 1, 2012.



## 2.7.4 Extrication

Upon arrival at an incident involving the extrication of victims from an EDV, response personnel should use the steps identified above to immobilize and disable the vehicle. Due to the degree of damage to the vehicle and/or the physical aspect of the vehicle, responders may have to employ secondary methods for disabling the vehicle, as described above. The supplemental restraint systems in most vehicles will remain active if the 12-volt batteries are not disconnected.

A damaged high voltage battery may emit corrosive, toxic, and flammable fumes. If responders become aware of unusual odors and/or sense irritation of their eyes, nose, or throat, they should don PPE and SCBA. In addition, responders should use ventilation techniques to protect the occupants of the vehicle and prevent the build-up of flammable vapors in the trunk or passenger compartment.

A charged attack line should be staged in close proximity to the vehicle during extrication. Responders should constantly monitor for indications that a damaged battery may be overheating, such as sparking, smoking or making bubbling sounds.

Throughout stabilization and extrication, response personnel must avoid inadvertent contact with all high voltage cabling and high voltage components. Response personnel should never cut through any high voltage electrical component. Personnel performing the extrication should visually check for the presence of high voltage electrical cabling and components of the supplemental restraint system prior to initiating every cut or displacement (e.g. pry). The location and routing of high voltage components may prevent some advanced extrication techniques, such as trunk tunneling and gaining access through the underside or floor pan of the vehicle.

### 2.7.5 Extinguishment

Fires confined to the cabin or trunk of an EDV can be extinguished using tactics associated with conventional vehicles. EDVs contain the same polyvinyl chlorides, polyurethanes, and reactive



metals as conventional vehicles, as well as the previously discussed projectile hazards. Firefighters should be in full PPE with SCBA donned.

Firefighters must avoid contact with any orange electrical cables and components that have high voltage warning labels. If a fire has burned warning labels or rendered them otherwise illegible, firefighters should not touch any electric drive or drive system component. Firefighters should never attempt to breech a high voltage battery or its casing for any reason.

Fires in the engine compartment of an EDV may require different tactics. Many high voltage components are directly accessible from the engine compartment. Defensively applying a fog stream through existing openings in the wheel-wells and grill can be done safely to knock down the fire. Firefighters should not attempt to force entry into the engine compartment with prying tools, nor should they attempt to spike or cut the hood or fenders with a piercing nozzle, cutting tool, or prying tool. Performing any of these tasks could result in a firefighter being severely shocked or electrocuted.

It may be the case that firefighters are unable to gain access to the engine compartment. In this instance, defensive fire suppression tactics should be employed until the fire is completely extinguished.

If there are no exposures and the fire involves the high voltage battery, currently defensive tactics are recommended. Because of the potential difficulty of applying a sufficient amount of extinguishing agent to a burning high voltage battery, the incident commander may allow the vehicle to burn itself out. If the high voltage battery is involved in the fire, an offensive attack may be recommended if there are exposures (other vehicles, buildings, etc.). If the high voltage battery is not involved in the fire, an offensive attack may be mounted regardless of whether there are exposures.

### 2.7.6 Overhaul Operations

Following extinguishment, the EDV must be properly overhauled. Responders should first verify the vehicle has been properly immobilized and disabled, and take appropriate steps to



accomplish these tasks if they have not been completed. As during all phases of any response to incidents involving an EDV, responders must avoid contact with any high voltage component during the overhaul phase of the incident. Responders should never attempt to cut, breach or remove the high voltage battery or any high voltage component. Diligent thought and care should be exercised before manipulating the EDV in any way with any forcible tools.

During overhaul, firefighters will verify that the fire has been completely extinguished. Firefighters should not drive prying tools into any area that may house or cover high voltage components. Firefighters should also carefully observe the high voltage battery compartment to ensure it is not smoking, sparking, or making bubbling sounds. A thermal imaging camera may be used to assess the temperature of the battery and to assist in determining if it is producing heat.

Responders should contact a dealer/manufacturer representative to de-energize the high voltage battery (if possible) and to determine the final disposition of the vehicle. Responders should advise the company recovering the vehicle that it is an EDV, and advise them not to store the vehicle inside a structure or within 50 feet of a structure or other vehicle in accordance with current NFPA guidance. EDVs should be recovered on a flatbed truck.

## 2.8 High Voltage Battery Fires

Fires may occur in an EDV high voltage battery, or a fire may extend to the battery. Most EDV batteries currently on the road are NiMH.[30] However, the number of cars powered by Li-ion batteries is increasing. These batteries may exhibit different burning characteristics and react differently to heat exposure. There is very little literature concerning recommended tactics for EDVs in which the battery is burning. Some literature encountered during this review is contradicted by other literature, demonstrating that further testing and research, such as in this testing program, is needed.

To show the variation in reviewed literature regarding high voltage battery fires, some excerpts of the literature are quoted below.

[30] Delphi Corporation. Hybrid Electric Vehicles for First Responders. Troy, MI. 2012.

The NFPA's *Electric Vehicle Emergency Field Guide*[31] states the following:
*The use of water or other standard agents does not present an electrical hazard to*

*firefighting personnel.*
*If an HV battery catches fire, it will require a large, sustained volume of water.*

*If Li-ion HV battery is involved in fire, there is a possibility that it could reignite after extinguishment. If available use thermal imaging to monitor the battery. Do not store a vehicle containing a damaged or burned Li-ion HV battery in or within 50ft. of a structure or other vehicle until the battery can be discharged*.

The Fire Protection Research Foundation report, *Fire Fighter Safety and Emergency Response for Electric Drive and Hybrid-Electric Vehicles*[32] states:

*Dry chemical, $CO_2$, and foam are often the preferred methods for extinguishing a fire involving batteries, and water is often not the first extinguishing agent of choice.*

*Another important consideration with an EV or HEV fire is that the automatic built-in protection measures to prevent electrocution from a high voltage system may be compromised. For example, the normally open relays for the high voltage system could possibly fail in a closed position if exposed to heat and if they sustain damage. Further, short circuits to the chassis/body may become possible with the energy still contained in the high voltage battery or any of the high voltage wiring still connected to the battery.*

Delphi Corporation's, *Hybrid Electric Vehicles for First Responders*[33] states:
*Firefighting techniques for vehicles using Li-ion battery packs should be treated like any*

*electrical fire by using Class C extinguishing agent.*
*Initial attack on hybrid HEV battery pack fires: perform a fast aggressive attack.*

*Should a fire occur in the NiMH high voltage battery, attack crews should utilize a water stream or fog pattern to extinguish any fire within the trunk. The incident commander*

[31] National Fire Protection Association. Electric Vehicle Emergency Field Guide. Quincy, MA. 2012.

[32] Grant, C. Fire Fighter Safety and Emergency Response for Electric Drive and Hybrid Electric Drive Vehicles. Quincy, MA. 2010.

[33] Delphi Corporation. Hybrid Electric Vehicles for First Responders. Troy, MI. 2012.

*should make the call on whether to perform an offensive or defensive fire attack in the area around the HEV battery pack.*

The National Highway Traffic Safety Administration's publication, *Interim Guidance for Electric and Hybrid Electric Vehicles Equipped with High Voltage Batteries*[34] states:

*If the fire involves the lithium-ion battery, it will require large, sustained volumes of water for extinguishment. If there is no immediate threat to life or property, consider defensive tactics, and allow the fire to burn out.*

Based on the above, currently there is no consensus on best practices for extinguishing EDV battery pack fires. Preliminary results[35,36] indicate that water can be an effective extinguishing agent on both NiMH and Li-ion batteries; however, none of the literature reviewed indicated the level of shock/electrocution hazard from directly applying a water stream to an energized high voltage battery that has been compromised by heat and fire. Furthermore, some of the testing was conducted by applying water directly on EDV batteries that were free standing (not installed in vehicles). While these test showed that water was an effective extinguishing agent, it may be difficult to flow large volumes of water on a battery that is actually installed in/under the vehicle.

## 2.9 Summary

Current versions of various firefighting guidelines are consistent with each other regarding first responder firefighting tactics to immobilize/disable the vehicle. However, a new step for first responders has been identified when comparing tactics for conventional ICE vehicles and EDVs. This involves identifying whether or not the vehicle is an EDV. Firefighters typically will not know what type of vehicle is involved before they arrive at the scene of the incident or the type of vehicle may not be obvious once they arrive and begin their tactics. As such,

[34] National Highway Traffic Safety Administration. Interim Guidance for Electric Vehicle and Hybrid-Electric Vehicles Equipped With High Voltage Batteries. Washington, D.C. 2012.

[35] Egelhaaf , M. and Kreß, D. Fire Fighting of Li-Ion Traction Batteries, DEKRA Automobil GmbH, SAE International, 2012

[36] Delphi Corporation. Hybrid Electric Vehicles for First Responders. Troy, MI. 2012.

performing the same practices for all vehicle fires would ensure that first responders are acting safely and appropriately regardless of the type of vehicle involved in the incident.

In regards to suppression, in most instances, available literature suggests that the application of water can extinguish EDV fires, as is the case with most fires in conventional ICE vehicles. However, it may be difficult to apply a sufficient flow of water to a burning battery installed in/under a vehicle with the tools currently available to the fire service.

In most EDVs, the battery is located in the chassis, housed in a plastic or metal shell. In these cases, water may not be sufficient to achieve full extinguishment, but rather the water may serve as a medium to transfer heat and cool the battery and cell components as thermal runaway subsides and or is interrupted by the application of water.

Based on a review of the literature, the final topic that requires further research is the electrical hazard presented by burning vehicle batteries. Some of the literature[37] reviewed suggests that a burning EDV battery has the potential to discharge electrical energy to the frame and body of the vehicle. Furthermore, the application of water streams to burning EDVs at close range may also become recognized as an unacceptable practice, if it is found that the potential for high voltage shock exists.[38]

[37] Grant, C. Fire Fighter Safety and Emergency Response for Electric Drive and Hybrid Electric Drive Vehicles. Quincy, MA. 2010.

[38] Backstrom, R. et al. "Firefighter Safety and Photovoltaic Installations Research Project." Underwriters Laboratories, Northbrook, IL, November 29, 2011.



# 3 Testing Program Summary

Exponent, in conjunction with the Project Technical Panel and their advisory groups, identified three different battery assemblies for full-scale testing. The three batteries procured were different in size and vehicle installation position to simulate the varying hazards emergency responders could face in the field depending on the automobile manufacturer. A more detailed description of each battery is provided in Section 4.

The full-scale fire tests were separated into two categories: (1) free burn, unsuppressed HRR testing of a standalone battery pack and (2) full-scale suppression testing of a battery pack in its correct mounting location positioned inside a VFT, along with other appropriate combustible materials, including vehicle interior finishes.

Once the battery fire self-extinguished, as in the case of the unsuppressed fire, or extinguished, as in the suppressed fires, Exponent continued to monitor the batteries visually and through a combination of thermal imaging and thermocouple temperature measurements. This was performed to provide data on the safe handling of post-fire batteries for fire responders and those involved in overhaul and storage.

The free burn, unsuppressed HRR test was performed on one standalone battery. Data collected during this test included:

- HRR;
- Products of combustion (gas sampling);
- Temperatures;
- Heat fluxes;
- Projectile observations;
- Battery internal temperature;
- Battery internal cell voltage measurements;



- Thermal imaging;
- Still photography; and
- High definition video.

The full-scale fire suppression tests were performed in conjunction with MFRI and their firefighter training staff. Data collected included:

- Temperatures;
- Heat fluxes;
- Projectile observations;
- Suppression water sampling;
- V olume of suppression water flow;
- Nozzle voltage and current measurements;
- Chassis voltage and current measurements;
- Battery internal temperatures;
- Battery internal cell voltage measurements;
- Thermal imaging;
- Still photography;
- High definition video; and
- MFRI staff / firefighter observations.

Battery packs were tested in the configuration and arrangement as they would be located within the actual vehicle. To ignite the battery packs, an external gas burner system was used. The gas burners were located under the vehicle to simulate a moderate size gasoline pool fire underneath the battery pack.

A detailed description of these measurements, the test setups and the test protocols for each test series is provided in Section 5.





# 4 Battery Descriptions

In conjunction with NFPA's FPRF and the Project Technical Panel, Exponent procured batteries from two car manufacturers for testing, designated Battery A and Battery B.[39] Both of the batteries procured were based on a Li-ion technology are currently being used in production vehicles in the United States. Battery A is a 4.4 kWh battery that is installed under the rear cargo compartment of the vehicle. Battery B is a 16 kWh battery that is installed under the vehicle floor pan and spans nearly the length of the vehicle from the rear axle to the front axle in a T-shaped configuration. Battery A and Battery B span a wide spectrum of battery sizes and vehicle installation positions to simulate the varying hazards emergency responders could face in the field during actual EDV fire incidents.

As part of the agreement with the vehicle manufacturers who graciously donated batteries, the EDV batteries were not opened, altered, or manipulated prior to, during or after the fire tests. The designs, descriptions, and details of the batteries in the following sections were provided to Exponent by the vehicle manufacturers, as well as from publically available information sources.

### 4.1.1 Battery A

Battery A is designed for a PHEV and features a large capacity high voltage hybrid vehicle (HV) battery assembly that contains sealed Li-ion battery cells. The 4.4 kWh HV battery pack is enclosed in a metal case (see Figure 6) and is rigidly mounted in the lower portion of the rear cargo area behind the rear seat, as shown in Figure 7. The metal case is isolated from high voltage and concealed and separated from the passenger compartment by a molded plastic cover with carpeting, as shown in Figure 8. The electrolyte used in the Li-ion battery cells is a flammable organic electrolyte.

[39] Three (3) approximately 10 kWh Li-ion batteries were procured in addition to Battery A and Battery B from a third manufacturer. However, once procured, the battery packs were found to have significant anomalies and damaged cells, which presented significant safety hazards associated with handling and charging the battery packs. Therefore, these batteries were not included in the test program.

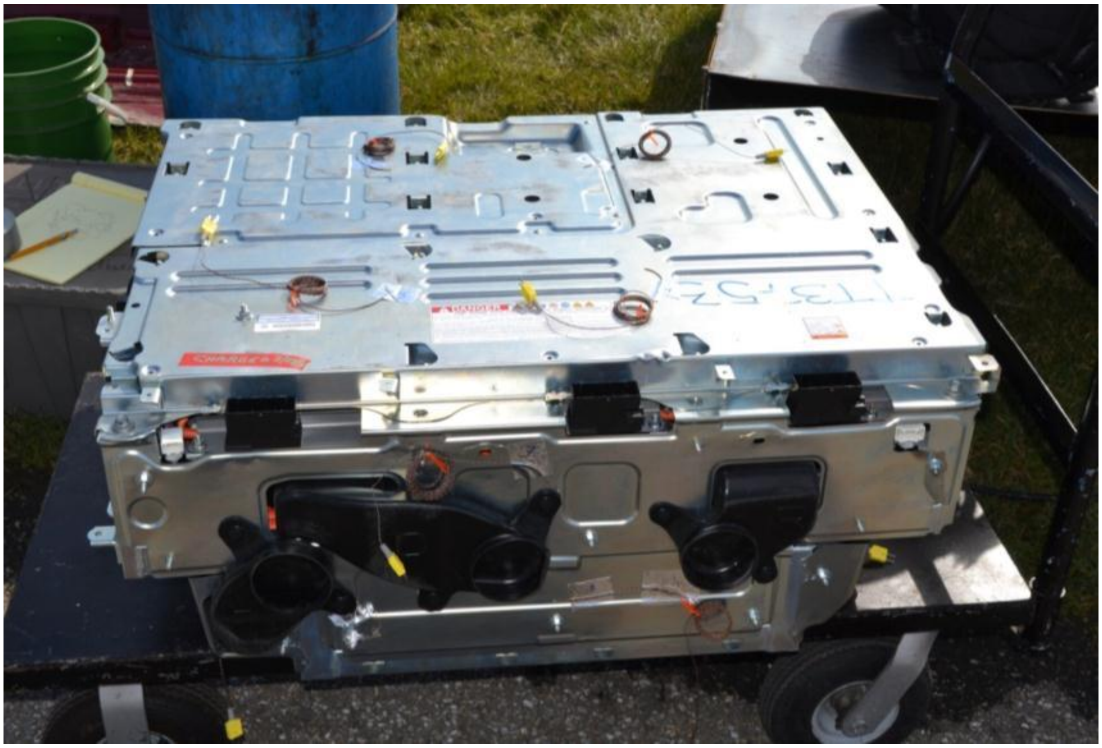

Figure 6 Battery A

Figure 7 Battery A cargo area over the battery compartment

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Figure 8 Battery A compartment in cargo area with carpet and molded plastic cover removed

### 4.1.2 Battery B

Battery B is designed for an EREV and features a battery assembly that contains sealed Li-ion battery cells. The 16 kWh battery pack sits on top of a steel plate and is enclosed in a fiberglass case, as shown in Figure 9. The T-shaped battery spans nearly the length of the vehicle from the rear axle to the front axle and is rigidly mounted underneath the vehicle floor pan, as shown in Figure 10. A vehicle passenger compartment floor pan separates the battery assembly from the passenger compartment. The electrolyte used in the Li-ion battery cells is a flammable organic electrolyte.

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Rear

Forward

Figure 9 Battery B

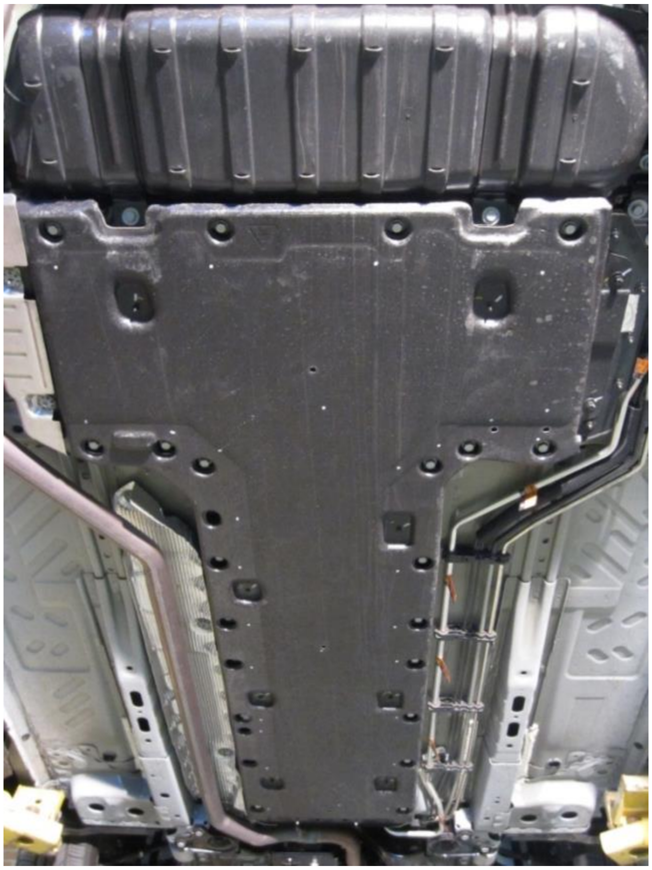

Figure 10 Battery B installed in vehicle 1205174.000 F0F0 0613 RTL3

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# 5 Test Setup

The full-scale fire tests were separated into two categories: (1) HRR testing and (2) full-scale fire suppression testing. The test setup for each phase of the project is described herein.

The overall intent of the testing is to provide a repeatable scientific experiment that evaluates water-based suppression of an EDV fire. The data generated will then be used to answer many of the questions first responders have regarding EDV fires. In addition, the data will facilitate any necessary revision to the NFPA training materials for first responders regarding how to safely and efficiently extinguish EDV fires while highlighting how these fires are different from those involving traditional ICE vehicles. The following are key assumptions related to the testing:

- The EDV batteries were tested at a 100% SOC.
- The suppression tests were conducted in a modified VFT capable of housing the different manufacturer battery packs.

## 5.1 HRR Testing

The full-scale HRR testing was performed at Southwest Research Institute (SwRI) in San Antonio, Texas.[40] The objective of the HRR testing was to determine the amount of energy released from the battery alone when it was ignited by an external ignition source. The secondary objective of the testing was to verify the battery could be induced into thermal runaway with the external ignition source (propane fueled burners positioned beneath the battery) for use during the full-scale fire suppression tests and to collect data as to the indications that the battery was experiencing thermal runaway. Due to a limited number of batteries available for the project, only one standalone battery pack was designated for HRR testing from the Battery B sample set. Data collected during this test included:

- HRR;

[40] SwRI is one of the oldest and largest independent, nonprofit, applied research and development organizations in the United States. The Fire Technology Department is one of the world's largest organizations dedicated to fire research and testing.



- Products of combustion (gas sampling);
- Temperatures;
- Heat fluxes;
- Projectile observations;
- Battery internal temperature;
- Battery internal cell voltage measurements;
- Thermal imaging;
- Still photography; and
- High definition video.

SwRI was responsible for providing the facility for the fire test and performing the following analyses:

- HRR measurements using oxygen calorimetry;
- Products of combustion by collecting gas samples and analyzing the gas using

Fourier transform infrared spectroscopy (FTIR);

- Temperature measurements using thermocouples;
- Heat flux measurements using heat flux gauges;
- Test observations;
- Still photography; and
- High definition video recording.

The full SwRI report detailing these measurements is provided in Appendix A.

Exponent was responsible for the following:

- Test observations;

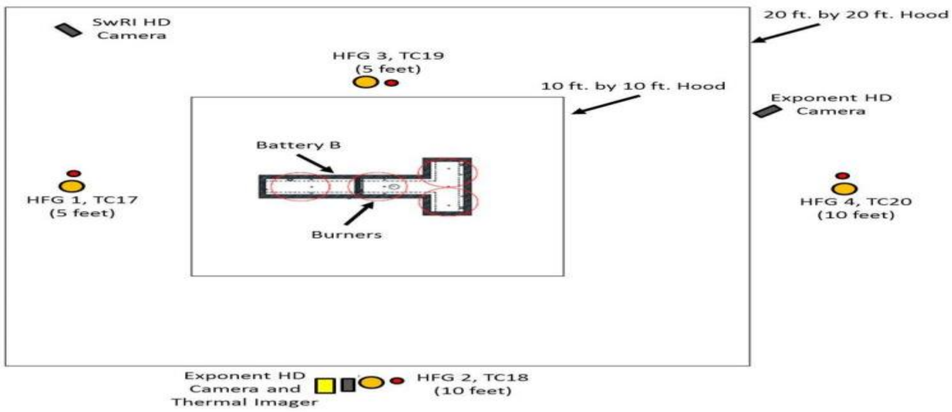
- Still photography; 

- High definition video recording;
- Providing and controlling the external burner assembly;
- Internal battery cell voltage and temperature measurements through direct communication with the battery; and
- Thermal images of the battery during and after the test.

### 5.1.1 Battery Positioning

Battery B was centered under a 20 foot by 20 foot hood supported by five stainless steel legs, as shown in Figure 11 and Figure 12. The leg supports held the battery in place, twenty inches above the ground to provide a viewing angle to the bottom of the battery during testing.

Figure 11 Battery B configuration and burner locations for HRR testing




(4 burners total)

Figure 12 Layout and arrangement of the HRR testing perimeter instrumentation

### 5.1.2 Burner Description

As part of the agreement with the vehicle manufacturers, the EDV batteries were not to be opened, altered, or manipulated internally prior to, during, or after testing. This included ignition of the batteries during testing. As such, an external ignition source was chosen. Fires occurring from some type of internal cell fault are therefore outside the scope of this project. Given that EDVs are still a small percentage of the marketplace, a collision involving an EDV and an ICE vehicle was considered a possible scenario. Based on a review of NFPA data on vehicle fire risk[41], flammable or combustible liquids or gases were the first item ignited in 31% of U.S. highway vehicle fires, resulting in 70% of civilian deaths, 58% of civilian injuries, and 31% of the direct property damage. As such, a pool fire scenario under the EDV was selected

[41] Ahrens, M. "U.S. Vehicle Fire Trends and Patterns." National Fire Protection Association, Quincy, MA; June 2010.



as the likely ignition scenario where the batteries become near fully involved and "burning on their own."

While previous tests were successful in burning the batteries with a pool fire exposure, a pool fire ignition source is not easily "throttled" or "turned off." As such, four propane-fueled gas burners were utilized as the external ignition source in this test series to induce the batteries into thermal runaway. Propane fueled burners were chosen to allow for definitive control of the exposure and repeatability, as well as to allow for turning off the exposure once the battery was in thermal runaway so that the “battery only” scenario fire could be evaluated.

The burner assembly comprised three main sections: fuel supply, fuel control, and burners, as shown in Figure 13 and Figure 14 and listed in Table 1. Propane gas was supplied from two 100-gallon (400 lb.) capacity cylinders and regulated to a working pressure of up to 35 psi. The gas cylinders were connected to the fuel control section via 9/16-inch hoses, which fed into a 1- inch stainless steel pipe section, a 1-inch manual shutoff valve and a 1-inch electric-powered solenoid valve (ASCO Model HV285926002), respectively.

Table 1 Burner Assembly Components

Burner Assembly Component

Fuel Supply:
100 gallon (400 lb.) propane cylinders 9/16-inch diameter hoses
1-inch diameter stainless steel piping

Fuel Control:
1-inch manual shutoff valve 1-inch solenoid valve 1-inch mass flow controller DAQ

Burners:
1/4-inch manual burner isolation valve

Second stage regulator and 1/4-inch stainless steel braided hose

19-inch diameter burners

Figure 13 / Figure 14 Number 1

2 3 4 8

5 6

7



Downstream of the solenoid valve, a mass flow controller (Bronkhorst M+W Model D6383, with ±2% accuracy) was instrumented to allow for measurement and control of the LP-gas mass supply rate. The solenoid valve and the mass flow controller were controlled by a data acquisition system (DAQ), which is discussed in Section 5.1.7. All sections of pipe between the manual shutoff valve, solenoid valve and mass flow controller were 1-inch and constructed of stainless steel.

From the outlet of the mass flow controller, LP-gas continued via 1-inch stainless steel piping to a four-outlet manifold, allowing for simultaneous operation of up to four (4) burners. From each of the manifold outlets, a 1⁄4-inch manual isolation valve and a second stage regulator are instrumented, respectively. A 1⁄4-inch flexible stainless steel braided hose 40 feet in length was used to connect the outlet of the second stage regulator to a circular, 19-inch diameter gas burner containing eighty-eight (88) 0.30-inch diameter nozzles. Exponent utilized four burners positioned under the span of the T-shaped battery to provide an even heat source to the entire battery pack, as shown in Figure 15 and Figure 16. The burners were placed six inches under the battery, as measured from the top of the nozzle tip to the bottom of the battery frame to allow for optimal flame development from the burners.



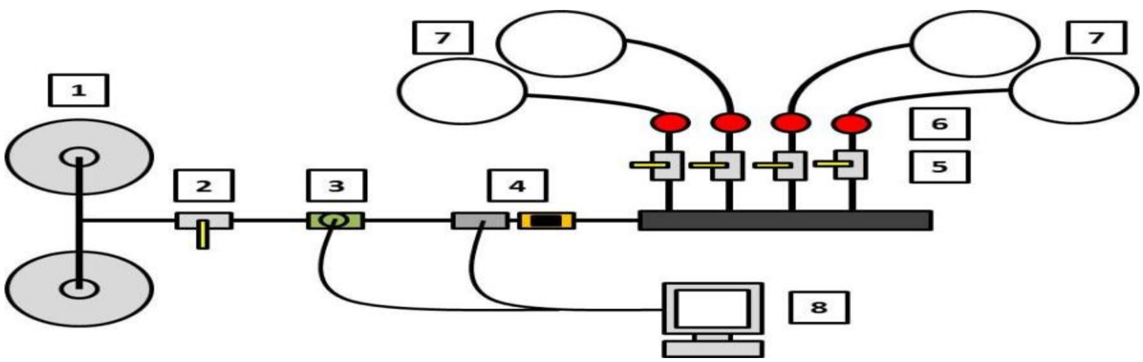



Figure 13 Layout of burner assembly

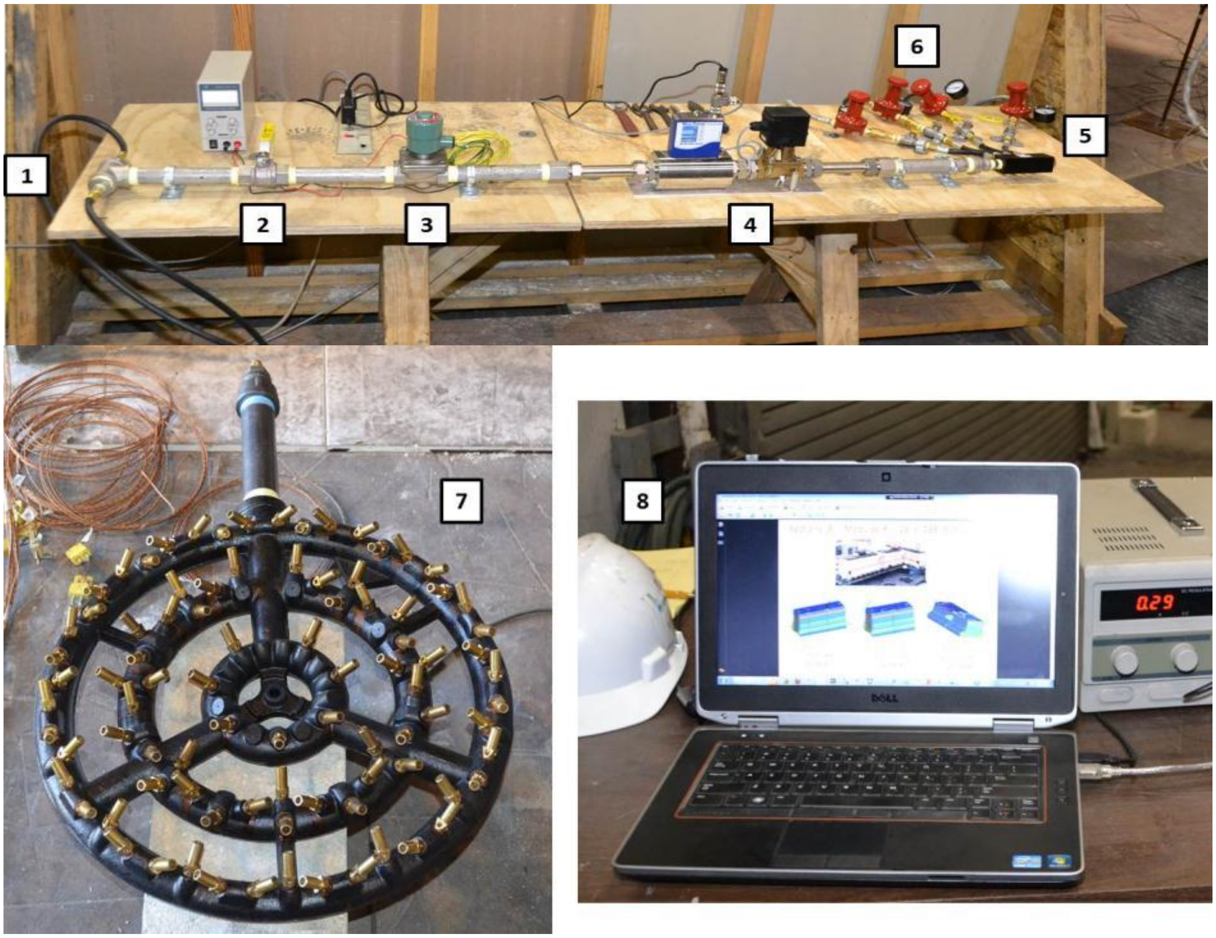



Figure 14 Burner assembly (top); single burner (bottom left); and DAQ (bottom right)

Figure 15 T-shaped burner arrangement comprised of four burners

Figure 16 Four burners positioned under Battery B

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### 5.1.3 HRR Measurements

The HRR was measured during the test by SwRI using oxygen consumption calorimetry. This requires the measurement of gas concentrations, namely oxygen ($O_2$), carbon dioxide ($CO_2$), and carbon monoxide (CO) in the exhaust duct and the volumetric flow of these gases. The products of combustion and entrained air were collected in a hood and extracted through a duct by an exhaust fan. A sample of the gas was drawn from the exhaust duct through a sample line by a pump and analyzed for $O_2$, $CO_2$, and CO concentrations. The gas temperature and differential pressure across a bi-directional probe were also measured to determine the mass flow rate of the exhaust gases. In addition, smoke production and smoke temperature measurements were taken throughout the duration of the test.

### 5.1.4 Products of Combustion Gas Sampling

Product of combustion gas sampling was performed by SwRI using FTIR spectroscopy to analyze the byproducts of the battery fire. SwRI performed these measurements by positioning a smaller 10-foot by 10-foot steel truncated cone hood above the battery pack, as shown in Figure 17. The hood was positioned in this manner to concentrate the products of combustion for FTIR sampling. The top of the hood was open to allow the products to temporarily collect within the smaller hood but ultimately escape into the large hood setup for HRR measurements. A gas sampling tube with nine (9) 1-mm holes was located across the top of the smaller hood and was connected to a heated sample line. A pump drew the gases through the 1-mm holes and heated sample line and filled Tedlar grab bags at five minute intervals during testing.



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20 ft. by 20 ft. Hood

Battery

Burners

Figure 17 SwRI hood and test arrangement

### 5.1.5 Temperature and Heat Flux Measurements

The temperature and heat flux measurements were performed by SwRI using a total of twenty Type K thermocouples (TCs) and four Schmidt-Boelter HFGs, as shown in Figure 12 and Figure 18. The location and measurement description of the TCs and HFGs are listed in Table 2 and Table 3.



Table 2 Summary of TC Locations

**TC Measurement**

1. 1 Battery exterior
2. 2 Battery exterior
3. 3 Battery exterior

4. 4 Battery exterior
5. 5 Battery exterior
6. 6 Battery exterior
7. 7 Battery exterior
8. 8 Battery exterior
9. 9 Battery exterior
10. 10 Battery exterior

Table 3 Summary of HFG Locations

**TC Measurement**

11 Battery exterior
12 Battery exterior
13 Battery interior
14 Battery interior
15 Battery interior
16 Flame temperature 17 Air temperature (5 ft) 18 Air temperature (10 ft) 19 Air temperature (5 ft) 20 Air temperature (10 ft)

**Thermocouple Measurement**

3 Heat Flux (5 ft) 4 Heat Flux (10 ft)

**Heat Flux Gauge**

1 2

**Measurement**

Heat Flux (5 ft) Heat Flux (10 ft)

TCs 1 through 12 were fixed to the exterior surface of the battery using Omega Bond CC High Temperature Bonding cement. The cement was located over the TC bead and was allowed to dry for at least 24 hours prior to testing. TCs 13 through 15 were located inside three vents on the battery, as shown in Figure 19. The TCs were placed through the vent opening to measure the internal air temperature within the battery casing. The vent hole was covered with the appropriate self-adhesive covers provided by the manufacturer. TC 16 was positioned 1-inch under the bottom steel plate of the battery pack, just above the burners to measure the approximate flame temperature. TCs 17 through 20 were positioned around the perimeter of the battery pack to measure the air temperature at five and ten foot standoff distances. HFGs 1 through 4 were also positioned at the same five and ten foot standoff distances and were capable of measuring a radiant heat flux between 0 and 50 $kW/m^2$.

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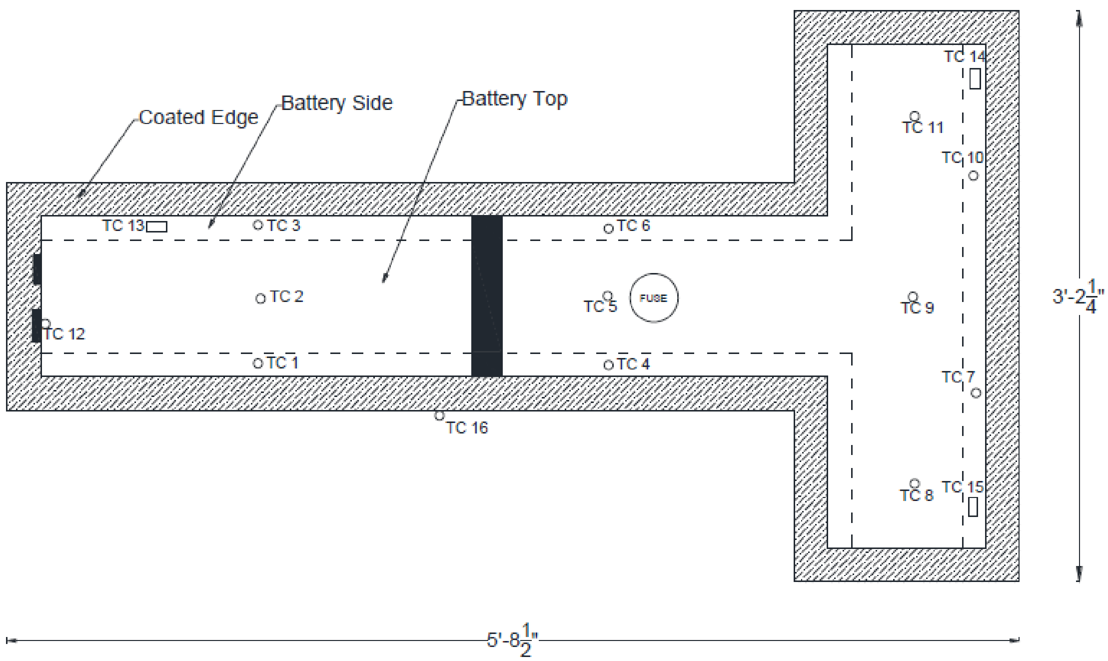


Figure 18 TC locations around Battery B during HRR testing (see Figure 12 for TC and HFG positions around the perimeter of the battery pack)

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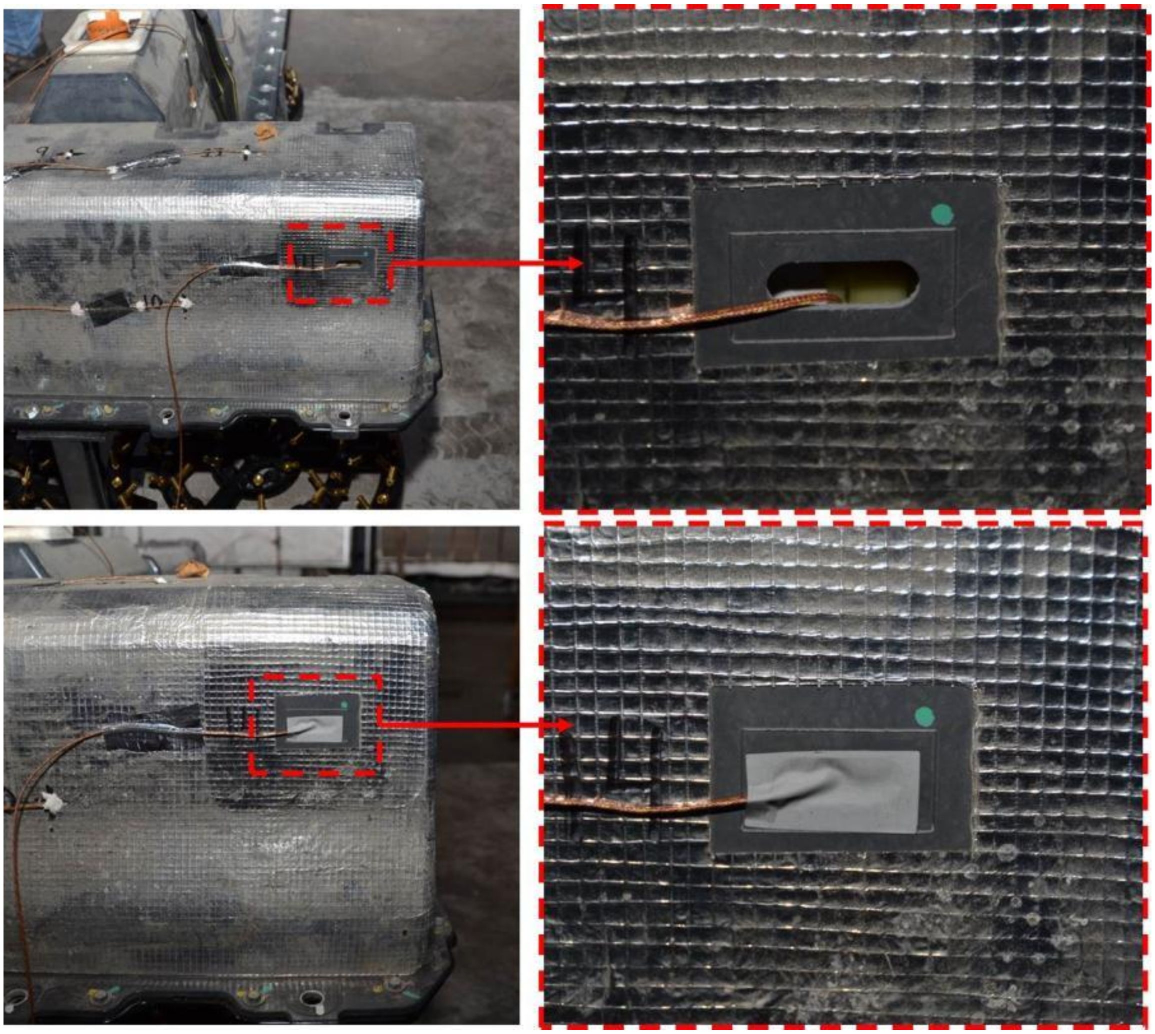

Figure 19 Installation of typical TCs inside Battery B

### 5.1.6 Internal Battery Sensor Measurements

During the fire test, Exponent collected internal battery temperatures and individual cell voltages from the battery's own sensors, including 96 cell voltages and nine temperature sensors as possible. To collect this data, Exponent communicated directly with the battery through its own CAN bus protocol utilizing a custom Lab VIEW software program. This allowed Exponent to retrieve internal battery temperatures and cell voltages as the battery was being exposed to an external heat source. The CAN bus protocol is a serial bus standard that allows automotive components to communicate with each other. The custom Lab VIEW code used the National Instruments (NI) XNET protocol in combination with the NI 9862 CAN bus module and a 7-port NI CAN breakout box, which allowed Exponent to send and receive individual data

TC14

TC14

frames to and from the battery. The NI 9862 is a single-port high-speed CAN bus module and the 7-port NI CAN breakout box provided a means to power the CAN port and to set the termination resistance. The NI 9862 bus module and CAN breakout box are shown in Figure 20. The NI 9862 was connected to the breakout box using an NI CAN high-speed cable. The breakout box was in turn connected to the battery using a custom interface cable provided by the manufacturer. In addition, the manufacturer provided the necessary binary codes to Exponent to use in its custom Lab VIEW program so that communication could occur. This cable connected directly to the battery, as shown in Figure 21. To protect these connection points and the cables, a calcium silicate board assembly was installed just below the connection points to shield the area from direct flame impingement by the burners below. In addition, Kaowool insulation ceramic fiber blankets were wrapped around these connection points and cables to insulate them from heat, as shown in Figure 22.

The custom Lab VIEW program was part of the same DAQ system that was used to control the burner assembly discussed previously in Section 5.1.2. The DAQ will be discussed in more detail in Section 5.1.7.



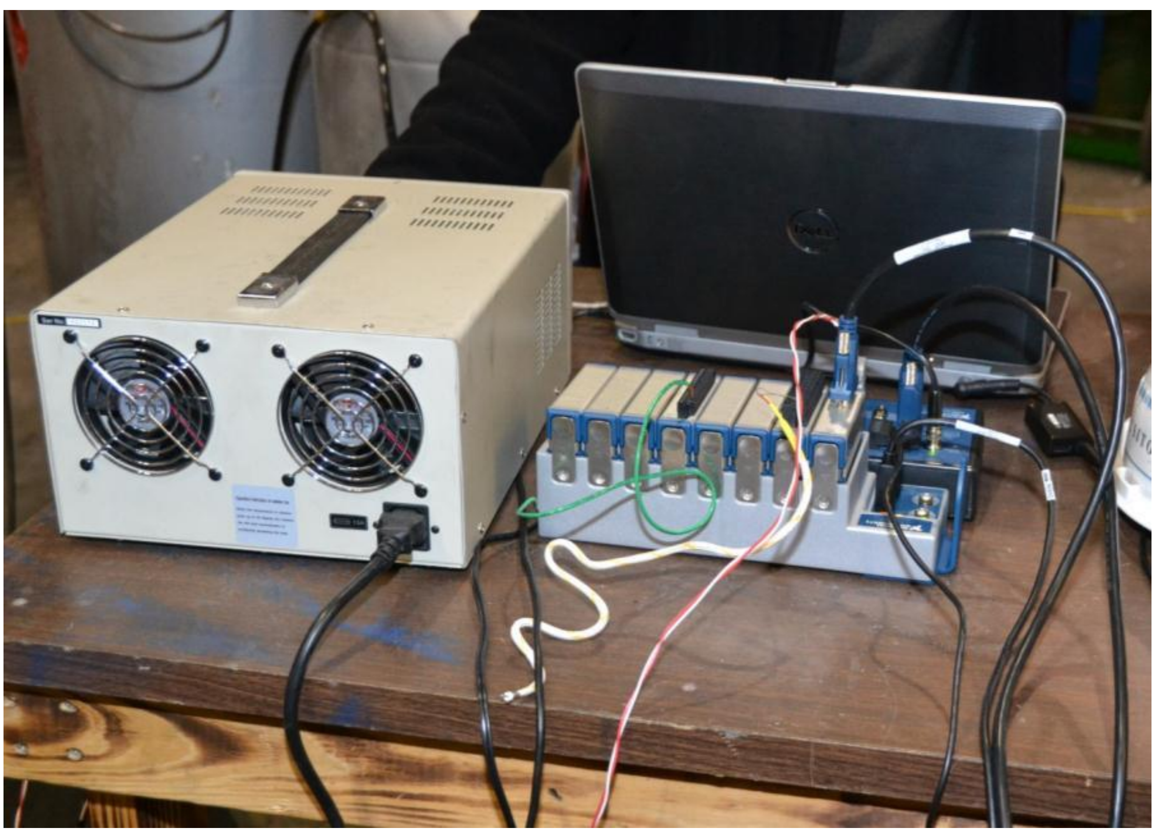

Figure 20 NI 9862 CAN bus module and 7-port NI CAN breakout box

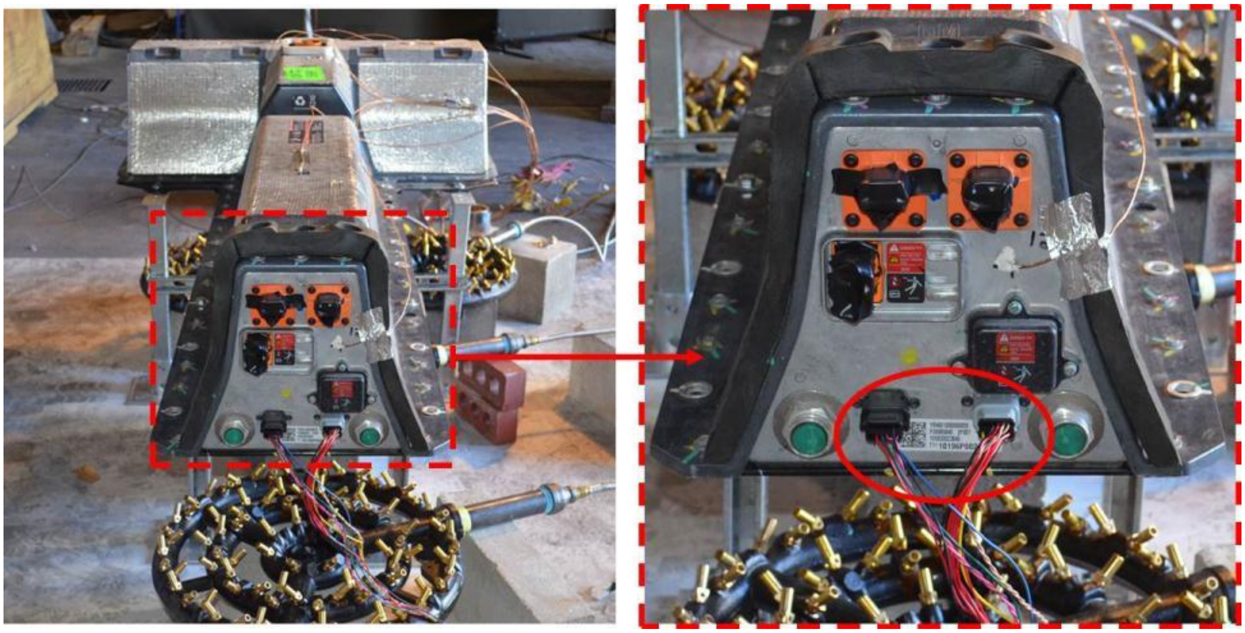

Figure 21 Location of the connection points to the internal battery sensors (circled right)



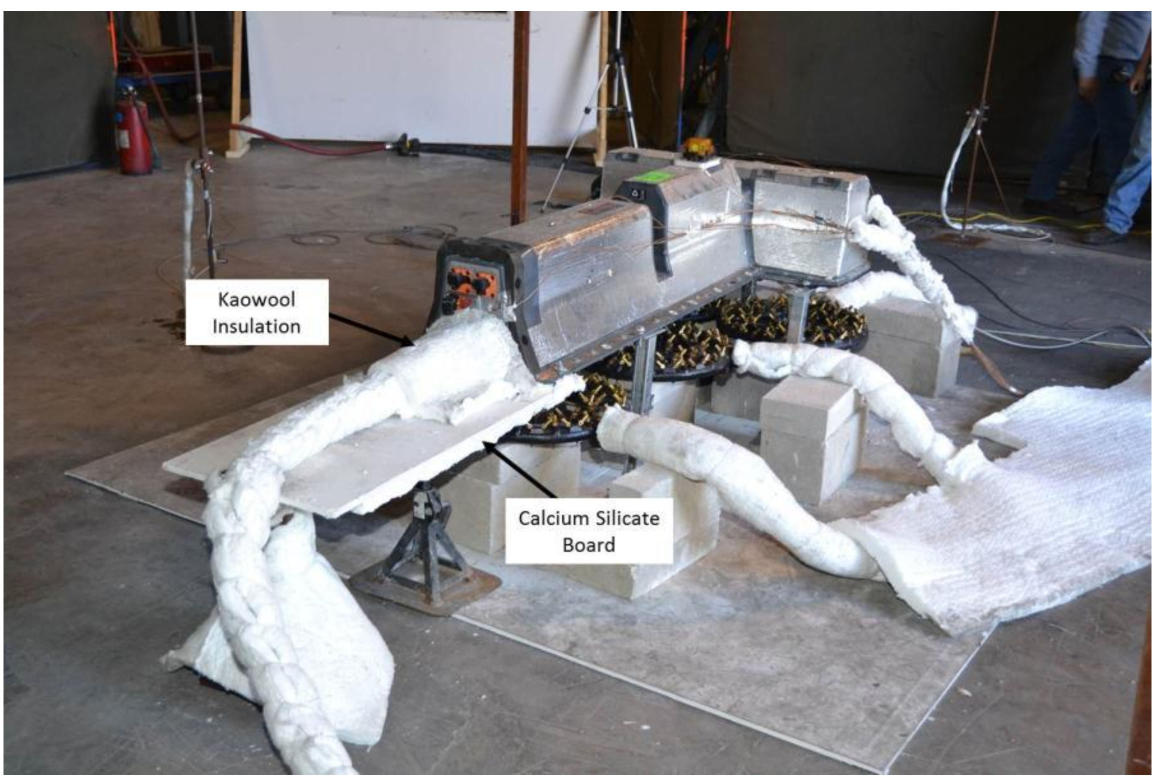

Figure 22 Protection scheme for the connection points and cables

### 5.1.7 DAQ System

The data acquisition was performed by a custom Lab VIEW code. The code performed three simultaneous tasks during the HRR testing:

- CAN bus communication with internal battery cell voltage and temperature sensors;
- Digital output to the relay module to control the burner; and
- Serial input and output to the mass flow meter.

These tasks were performed by a modular data acquisition system, a NI cDAQ 9178, which is an eight-slot USB-based data acquisition chassis. To communicate with the battery, the DAQ requested data at one-second intervals. However, communication with the battery through the CAN bus was asynchronous, meaning data is transmitted intermittently rather than in a steady stream. Communication with the battery consisted of broadcasting a request for a particular piece of information and then waiting for a response. Requests for all voltages and temperatures were made at a rate of one per second, however not all of the data would be received during that



same second due to the asynchronous nature of the CAN bus. To circumvent this issue, each data frame received from the battery included identification bytes and a timestamp, so the data that was received could be properly identified and synchronized.

To communicate with the burner controls, a ±60 VDC, 750 mA NI 9485 8-channel switching relay module and a serial cable was connected to the cDAQ 9178 chassis. The relay module was used to switch the burners on and off during the test. The serial cable was used to communicate with the mass flow controller during the test.

The remainder of the data collected during the HRR tests, such as $O_2$, $CO_2$, and CO concentrations for oxygen calorimetry, TC, and HFG measurements performed by SwRI were also recorded at one-second intervals.

### 5.1.8 Thermal Imaging, Still Photography and High Definition Video

Thermal imaging, still photography, and high definition video were also recorded during the HRR testing by SwRI and Exponent. The thermal imager is a Fluke TI32 infrared camera with a temperature measurement range up to 1112°F. Infrared images were captured at 1-minute intervals during the test and after test completion to monitor the battery post fire. Still photography was captured using a Nikon D3100 digital camera. Representative images of the test were captured as possible during the test. High definition video was captured using a Canon Vixia HFS10 high definition camcorder. Three camcorders were used during testing (one by

SwRI and two by Exponent) to ensure all angles of the battery were captured. The positioning of the high definition camcorders and thermal imager during testing is shown in Figure 12.

## 5.2 Full-scale Fire Suppression Testing

The full-scale suppression testing was performed at MFRI in College Park, Maryland.[42] The objective of the suppression testing was to evaluate the following when dealing with an EDV battery fire:

[42] MFRI is Maryland's comprehensive fire and emergency response training and education agency. MFRI plans, researches, develops, and delivers quality programs to enhance the ability of emergency services providers to protect life, the environment, and property.



- Tactics and procedures for first responders;
- PPE of first responders;
- Adequacy and amount of water as a sole suppression agent; and
- Procedures for overhaul and post-fire clean-up.

Six tests were conducted; three for Battery A and three for Battery B. For each battery type, two of the tests were performed with only the battery pack positioned inside the VFT as they would be positioned in the host vehicle and one test was performed with typical interior finishes/upholstery (i.e., car seats, carpeting, dashboard, etc.). The additional interior finishes were installed within the VFT to simulate a fuel load more typical of a vehicle fire. Data collected during this test included:

- Temperatures;
- Heat fluxes;
- Projectile observations;
- Suppression water sampling;
- V olume of suppression water flow;
- Nozzle voltage and current measurements;
- Chassis voltage and current measurements;
- Battery internal temperatures;
- Battery internal cell voltage measurements;
- Thermal imaging;
- Still photography;
- High definition video; and

- MFRI staff / firefighter observations.



MFRI was responsible for providing the facility for the fire testing, the gear and equipment required for suppression efforts, all PPE and SCBA required for the firefighters, as well as the personnel to perform the fire suppression activities. Exponent was responsible for providing and controlling the external burner assembly used to ignite the battery pack and for providing all other instrumentation relating to data collection, still photography, and video recording.

### 5.2.1 VFT and Battery Positioning

In lieu of procuring fully intact production vehicles for the full-scale suppression tests due to the extreme costs, Exponent, in conjunction with an outside contractor, Tactical Incident Systems[43], designed and manufactured a VFT that could be outfitted with the two different battery assemblies. This allowed for multiple tests of different battery sizes, dimensions, and installation locations all while using the same VFT.

The VFT was constructed to resemble a modern EDV both in size and design, as shown in Figure 23 and Figure 24. It stands approximately 57 inches tall, 70 inches wide, and 15 feet long. The VFT was designed to open in the back, similar to a hatchback, to allow for the installation of the batteries as well as to facilitate firefighter access. The batteries were placed on top of a 1⁄4-inch steel plate simulating the floor pan of the vehicle. The floor pan had two holes cut out to allow the burners, positioned below the VFT, direct access to the bottom of the battery assemblies, as shown as the shaded areas in Figure 23. Each of the battery assemblies weighed over 400 pounds, as such, two carriages, one for each battery type, were constructed for the battery assemblies to sit inside the VFT. The carriages were placed inside the VFT and rolled into position, either in the cargo compartment for Battery A or the middle of the VFT for Battery B, as shown in Figure 25 through Figure 27. The carriages rolled on wheels in two (2) 3-inch wide welded channels installed on top of the steel floor pan. The passenger compartment was framed of 2-inch by 2-inch by 1⁄4-inch welded steel tube. The exterior of the VFT was formed of 1⁄4-inch steel plates and was painted black. The frame was supported by four “peg legs” hidden behind fixed steel tire assemblies. The fixed tires were not operational and were for aesthetic purposes only. Two (2) 8-inch by 4-inch by 1⁄4-inch steel tubes were installed

[43] Tactical Incident Systems, 9130 Flint Overland Park, Kansas 66214



under the floor pan such that the VFT could be moved with a forklift. Drawings of the VFT and the battery carriages are provided in Appendix B.

Figure 23 VFT design drawing

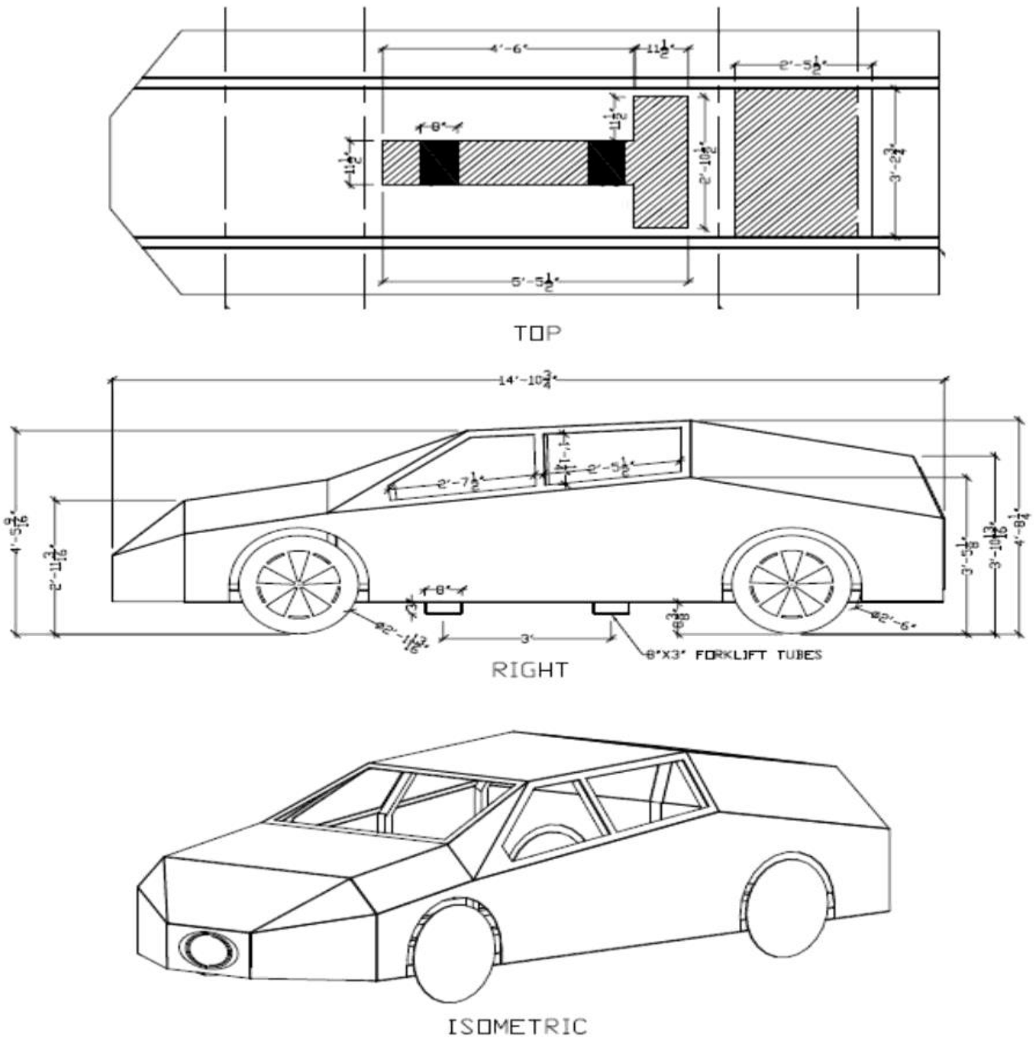


Figure 24 VFT: Side profile (top); rear profile with hatchback open (bottom left); and front profile with hood open (bottom right) 1205174.000 F0F0 0613 RTL3

Figure 25 Carriage installed inside the VFT positioned above the four burners located in the rear test position

Figure 26 Battery A positioned on the carriage above the burners and inside the VFT


Figure 27 Battery B positioned on the carriage above the burners inside the VFT; burners located in the center test position

The VFT was placed on a concrete burn pad at MFRI, as shown in Figure 28. The burners slid under the VFT and into position depending on the battery type and had direct access to the bottom of the batteries through the holes cut out in the VFT floor pan. For Battery A, the four burners were centered six inches under the rectangular battery, as shown in Figure 25 and Figure 26. For the first two tests, Tests A1 and A2, the battery was installed alone within the VFT, as shown previously in Figure 26. For test A3, typical interior finishes/upholstery, including car seats, a dashboard, and a carpet layer above the battery (used to separate the battery from the cargo compartment) were also installed within the VFT, as shown in Figure 29 through Figure 33. The car interiors were procured from vehicles that were of a similar size as the VFT. These additional vehicle interior finishes were installed to better simulate the fuel load of a typical vehicle.

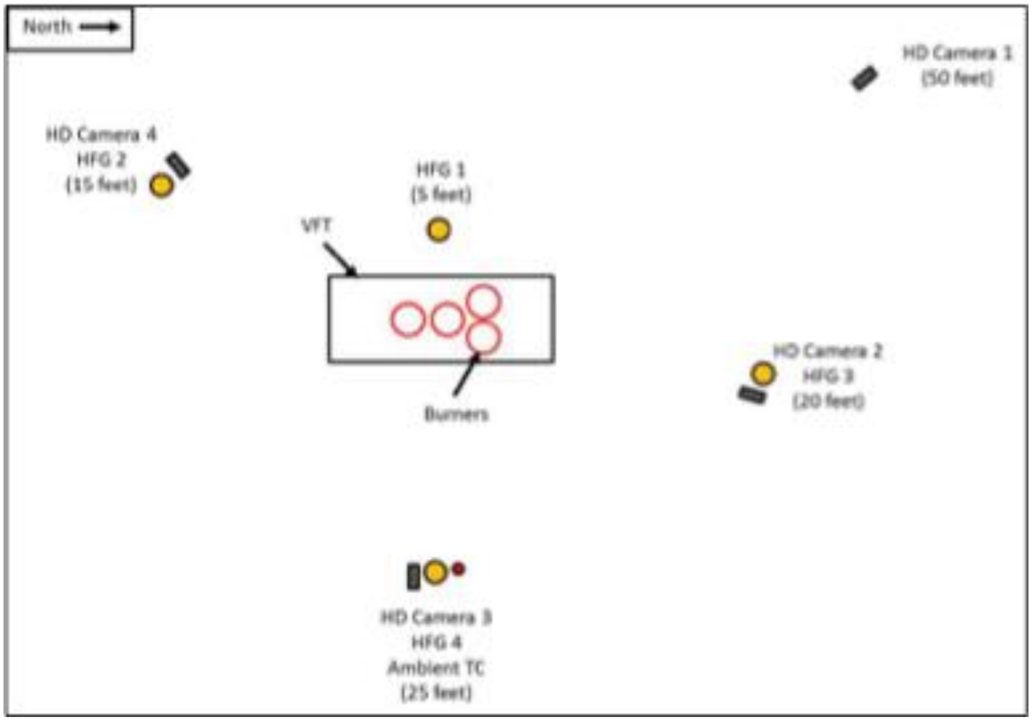


Figure 28 Layout and arrangement of the suppression testing perimeter instrumentation

Figure 29 Overall view of the VFT with interior finishes for Test A3

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Figure 30 Dashboard and front seats installed inside the VFT for Test A3

Figure 31 Front seats installed inside the VFT for Test A3



61

Figure 32 Back seats installed inside the VFT for Test A3

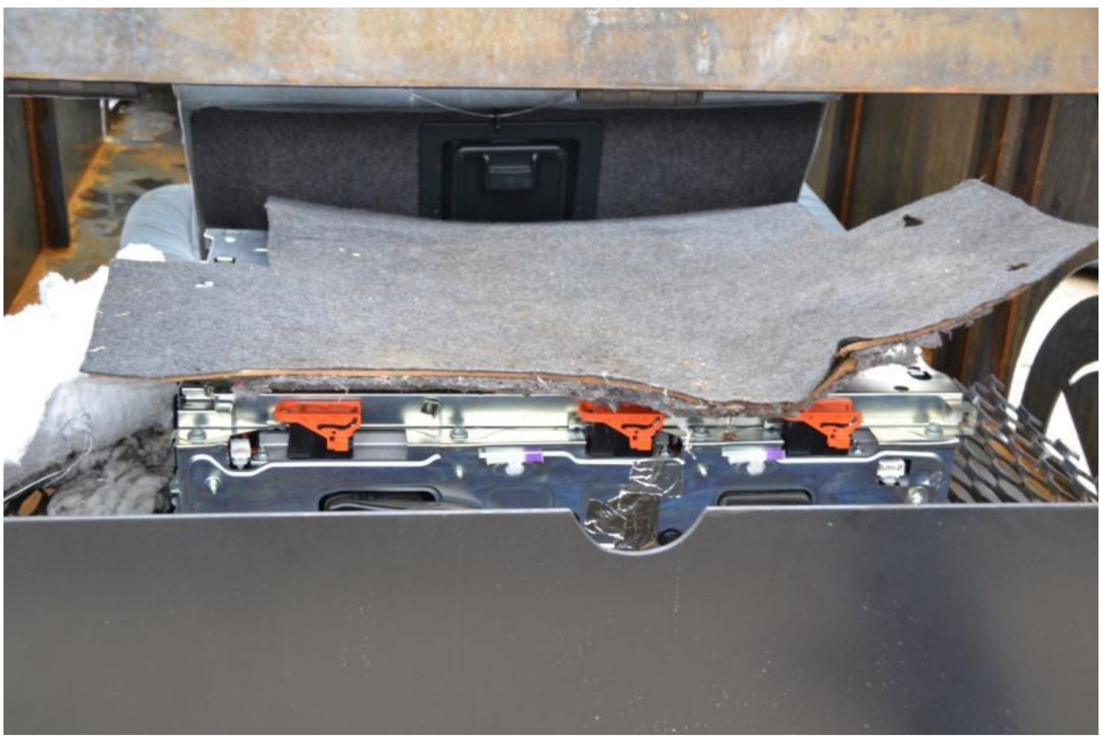

Figure 33 Carpet installed on top of the battery for Test A3

For Battery B, the four burners were positioned under the span of the T-shaped battery to provide a uniform heat source to the entire battery pack, as described in Section 5.1.2 for the HRR test. Inside its production vehicle, a steel floor pan is positioned on top of the battery, separating it from the passenger compartment. As such, the vehicle manufacturer that donated Battery B also donated a steel floor pan from an actual vehicle to be placed above the battery during testing. This configuration provided a more realistic vehicle fire scenario, as shown in Figure 34 and Figure 35. For the first two tests, Tests B1 and B2, the battery and the steel floor pan were installed within the VFT. For Test B3, typical interior finishes/upholstery, including car seats, a dashboard, and carpeting were added to the VFT along with the battery and steel floor pan, as shown in Figure 36 through Figure 40. The car interiors were procured from vehicles of a similar size to the VFT. These additional vehicle interior finishes were installed to better simulate the typical fuel load expected in a vehicle fire.




Figure 34 View of Battery B inside the VFT without the floor pan (top) and with the floor pan (bottom); the blue tank at the rear of the battery is the empty gasoline tank for the production vehicle, which blocks direct access to the rear of the battery

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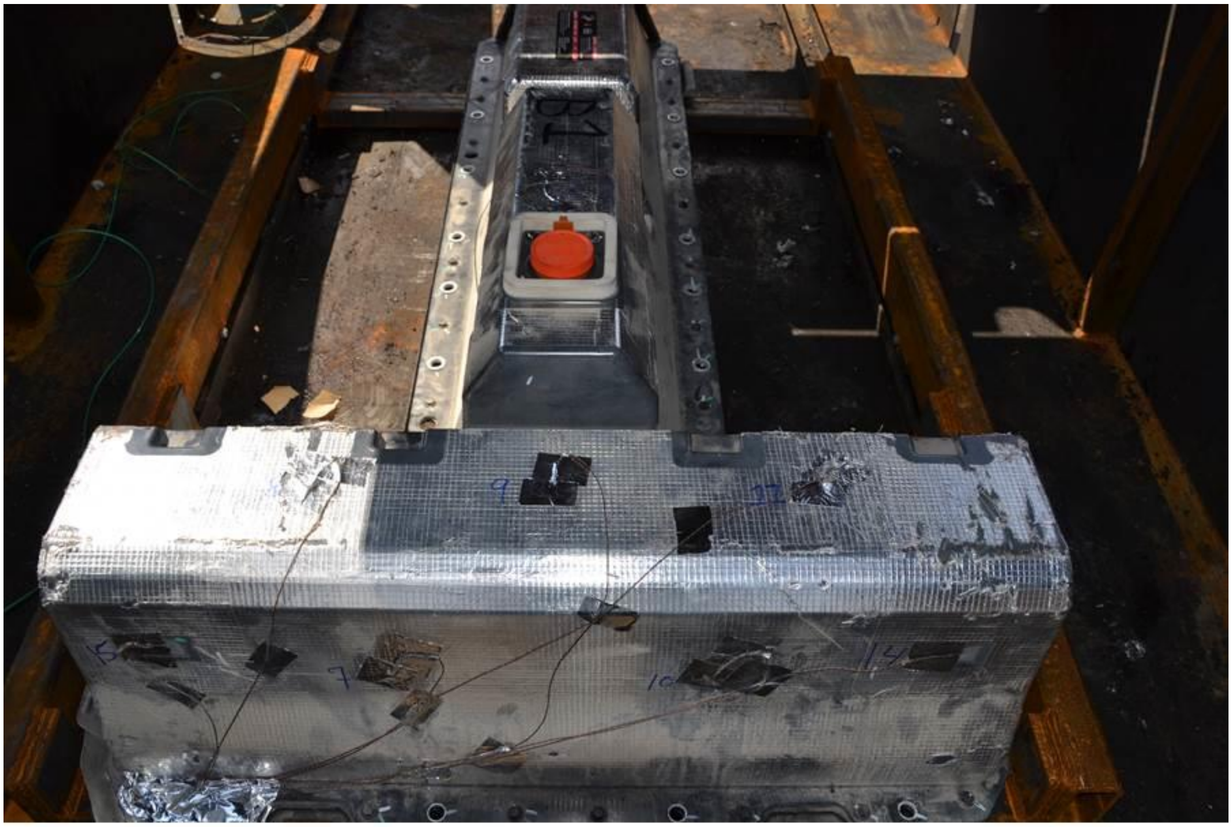

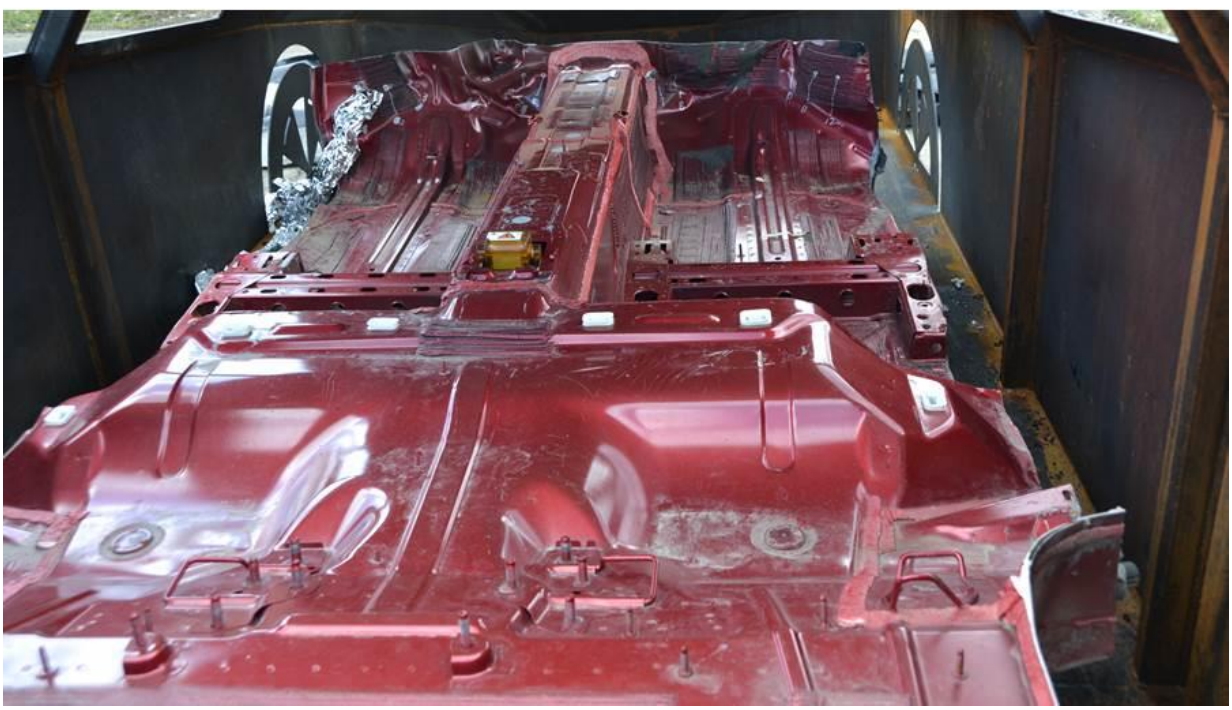

Figure 35 Top view of Battery B inside the VFT without the floor pan (top) and with the floor pan (bottom); the yellow fuse in the middle of the red floor pan is the only hole within the pan that allows for access to the battery



Figure 36 Overall view of the VFT with interior finishes for Test B3

Figure 37 Dashboard, front seats, and carpet installed inside the VFT for Test B3

Figure 38 Front seats and carpet installed inside the VFT for Test B3

Figure 39 Back seats installed inside the VFT for Test B3

Figure 40 Back seats and carpet installed inside the VFT for Test B3

### 5.2.2 Burner Description

The components, design, and function of the burner assembly utilized during the full-scale fire suppression testing were the same as those used during the HRR test, as described previously in Section 5.1.2. The only difference between the two setups, Battery A and Battery B, was the positioning of the burners under the VFT, as described in the previous section.

### 5.2.3 Electrical Measurements during Fire Suppression

One of the objectives of this test series was to evaluate the potential electric shock hazards associated with fighting EDV fires. Literature was reviewed on the subject of electric shocks and the physiological response to touch potentials, as well as the impedance of the human body.[44,45,46,47] In addition, literature was reviewed to investigate methodologies of fire

[44] Backstrom, R. and Dini, D.A., "Firefighter Safety and Photovoltaic Installations Research Project" November, 29, 2011.

[45] NFPA 15, 2007 edition, Chapter 6.

suppression of electrical fires[44,48,49,50,51,52,53], as well as literature discussing previously-used testing methodologies for measuring voltage and current through a water stream and the effect of PPE.[44,48,54] These previous studies provided guidance as to how to best measure and collect electrical data during the test to (1) protect the firefighters suppressing the fires and (2) provide useful data to the firefighting community in regards to potential electrical hazards during suppression of an EDV fire.

Electrical measurements were recorded to investigate the possibility of electric shock by a firefighter while suppressing an EDV fire. While both voltage and current measurements were recorded, the parameter important for characterizing the potential shock hazard is current. While simultaneous voltage measurements can provide an indication as to the presence of a shock hazard, the effects of voltage on different individuals can vary substantially. Conversely, the current magnitude can be directly related to physiological effects ranging from a slight tingling sensation to cardiac arrest and probable death.[55]

Another important parameter is the conductivity of water used for the suppression of the fire. Electrical conductivity is a measure of the ability of a material to conduct (or allow the flow) of electricity and is measured in units of Siemens per meter (S/m). Good conductors, such as copper, have a very high conductivity ($5.96 \times 10^7$ S/m), whereas poor conductors (or insulators),

46. [46] OSHA Construction eTool, “How Electrical current Affects the Human Body”,

    http://www.osha.gov/SLTC/etools/construction/electrical_incidents/eleccurrent.html

47. [47] Olsen, G. R., Schneider, J.B., Tell, R. A., “Radio Frequency Burns in the Power System Workplace” IEEE Transactions on Power Dleivery, Vol. 26, No. 1, January, 2011.
48. [48] Bolander, G.G., Jughes, J. T., Toomey, T. A., Carhart, H.W., and J.T. Leonard. “Use of Seawater for Fighting Electrical Fires” Navy Technology Center for Safety and Survivability, Chemistry Division. May 25, 1989.
49. [49] “Electrical Conductivity of Extinguishing Agents”, Factory Mutual Handbook of Industrial Loss Protection,
50. [50] Thorns, J., “Feuerwehreinsatz an Hochvoltfarzeugen,: Aubau, Funktion und Einsatzhinweise” BrandSchutz, Zeitschrift fuer das gesamte Fuerwehrwesen, fuer Rettungsdienst und Umweltschutz. (English translation: Firefighting on High Voltage Vehicles: Structure, Function, and Application notes), March 2011
51. [51] Electric Vehicle Safety Training Online Blog, 08/14/2012
52. [52] Firehouse World, online firefighter blog, http://www.firehouse.com/forums/t20745/
53. [53] conEdison 2010 Sustainability Report downloaded from: http://www.conedison.com/ehs/2010annualreport/print- template.asp
54. [54] Sprague, C.S. and C.F. Harding. “Electrical Conductivity of Fire Streams” Research series no. 53. Engineering Experiment Station, Purdue University Lafayette, Indiana, January 1936
55. [55] OSHA http://www.osha.gov/SLTC/etools/construction/electrical_incidents/eleccurrent.html.

such as glass, have a very low conductivity (approximately 1 x $10^{-11}$ S/m or less). The conductivity of water is typically much lower than good conductors and is, therefore, often measured in units of microSiemens per centimeter (μS/cm). The conductivity of water is, however, highly dependent on the amount of other material (minerals, salts, etc.) dissolved in the water. For example, deionized water is a poor conductor (0.055 μS/cm), while seawater (with a high salt content) is a much better conductor (58,000 μS/cm). In order for a firefighter to experience an electrical shock during fire suppression efforts, the firefighter must either make physical contact with something held at an elevated voltage potential (thereby providing a path for the electricity to ground) or the electricity must pass through the water stream back to the firefighter in order to complete the circuit. The conductivity (or ability of the water to conduct electricity) will, therefore, play a role in determining the potential shock hazard. A sample of water was collected from the suppression water source used for the tests and its conductivity was tested by Microbac Laboratories, Inc.[56] The conductivity of the water used during the suppression tests was found to be 190 μS/cm, which is a very low conductivity. The full Microbac Laboratories report is provided in Appendix C.

Previous tests[57] have characterized the shock hazard of alternating current (AC) electricity at a variety of voltage levels, nozzle patterns, and distances, as well as water conductivities. In these tests, a metal screen or plate was intentionally energized to a specified voltage and then the voltage and/or current level was measured as a function of distance from the energized source. The effect of water conductivity was also assessed in these tests, with water ranging from well water (185 μS/cm) to seawater (58,000 μS/cm). Finally, these previous tests performed measurements where the nozzle was connected through a short circuit to ground (no additional resistance) or, optionally, through a 500 Ohm resistor to simulate the resistance of an average person to the flow of electricity (under wet conditions).

Following a similar methodology to previous studies, the electrical measurements performed in Exponent's full-scale fire suppression tests were conducted by measuring both the voltage and current at the nozzle. In addition, the voltage and current at the body of the chassis in which the

[56] Microbac Laboratories, Inc. 2101 Van Deman Street . Baltimore, MD 21224 [57] Sprague and Harding, 1936; Bolander 1989



battery was placed were also measured. For the electrical measurements at the nozzle, 14 AWG stranded copper wire was securely soldered to a hose clamp and affixed to the nozzle's exterior housing, as shown in Figure 41. Continuity tests confirmed that the front of the nozzle from which water was expelled was electrically connected to the discharge portion of the nozzle. The wire was then routed back to the DAQ system utilized to collect the voltage and current measurements, as shown in Figure 42. Similarly, at the chassis, a separate 14 AWG stranded copper wire was securely connected to the body of the chassis and run along the ground to the

DAQ system, where it was connected to the measurement circuit shown in Figure 42. Inside the chassis, additional metallic components, such as the sliding chassis and the VFT body components were also connected using a 14 AWG stranded copper wire to the same measurement wire such that all conductive items, including the sliding chassis and the VFT body components, were electrically connected. Due to the high temperatures expected inside the VFT, the internal wires were protected using aluminum foil and Kaowool. Though in most tests the wire insulation nearest the most intense portion of the fire was found to be degraded in post-test assessment, continuity after each test was confirmed to verify all conducting objects in the chassis remained electrically connected throughout the test.

Figure 41 14 AWG stranded copper wire soldered to a hose clamp and affixed to the nozzle's exterior housing





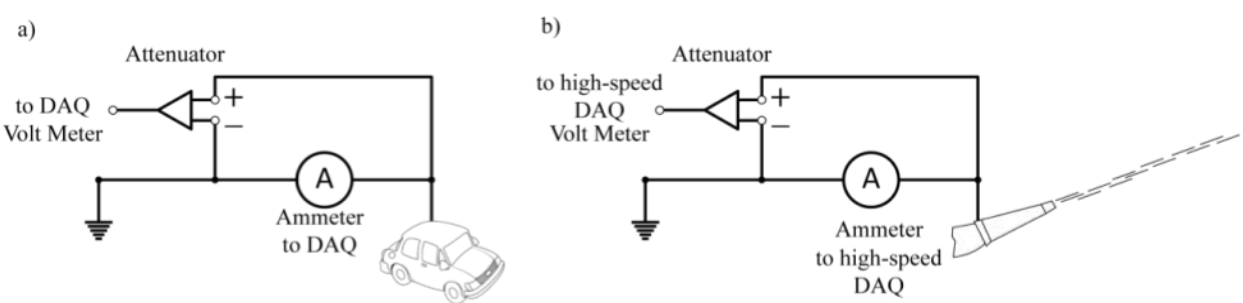


Figure 42 Simplified circuit diagram for the electrical measurements

Due to the likely transient nature of the electrical connection from the EDV battery to the nozzle through the water stream, a high-sampling-rate of 2 kilohertz (kHz) was performed to identify any brief electrical connection of the EDV battery voltage to the nozzle. This allowed for the detection of any electrical activity at the nozzle such that the hazard could be relayed to the firefighters as quickly as possible and data could be collected and subsequently analyzed regarding the potential electrical hazards involved with suppressing an EDV fire. For the chassis measurements, the transitory nature of voltage/current flow was not expected; therefore, measurements were recorded at one-second intervals, or 1 Hertz (Hz). These measurements were collected for as long as fire suppression activities were being performed.

In both measurement cases, the maximum voltage level of the battery was approximately 400 VDC, while the maximum input voltage of the DAQ was limited to ± 10 V. In order to ensure that the full voltage range was covered, a voltage attenuator was incorporated into the voltage measurement circuit, as shown in Figure 42. In addition, due to the long wires necessary in connecting the nozzle and chassis to the DAQ system, external sources of noise were present. The most prevalent noise was from power lines at 60 Hz and their harmonics. The 1 Hz sampling used for the chassis measurements was too low to be affected by the power-line noise, however, the nozzle measurements sampled at 2 kHz were significantly affected by not only the 60 Hz fundamental frequency of the power-line, but also the first 15 harmonics (120 Hz, 180 Hz,... 960 Hz). Post-test analysis confirmed that the noise from these power-line sources was seen in the voltage measurements. As such, a comb-filter comprising each of these frequencies was applied to the recorded data to mitigate these effects.



Current measurements for both the nozzle and chassis were performed through the use of Hall-effect probes. The magnitude of current conducted to ground through either the nozzle or from the chassis were expected to be relatively low, therefore a relatively high-gain setting (100 mV/A) was selected for both probes. While this selection is more likely to detect relatively low current levels on the respective wires, the higher gain also contributes to relatively higher noise levels, which were addressed by post-test filtering and processing of the data, including background noise subtraction and averaging.

The four measurements described here, the high-speed 2 kHz sampling rate current and voltage measurements of the nozzle and the 1 Hz sampling measurements of the chassis current and voltage were performed using the DAQ described in Section 5.2.7.

### 5.2.4 Water Sampling

Contaminated water runoff created by suppression of an EDV fire is an environmental concern, as well as a concern to first responders in regards to their PPE. To evaluate this potential hazard, Exponent collected water samples after each test to analyze what, if any, potentially harmful byproducts may be present in the water. Approximately one pint of water was collected in a sealed glass jar after each test. The water was collected off the ground approximately two feet in front of the VFT after suppression efforts had ceased by one of the firefighters, as shown in Figure 43. This collection method was utilized, as opposed to collecting water from directly underneath the battery through a collection pan or trough, to better sample from a location that first responders would be performing activities, possibly standing in the water, during and immediately after suppression activities. The chemical analysis of the water samples was performed by Analyze, Inc.[58]

Once received by Analyze, Inc., the test samples were filtered of any particulates (debris) prior to analysis. Each sample was analyzed for pH using a Fisher Scientific Accumet Excel XL15 pH meter and screened for cations and anions using a Dionex ICS-2000 Ion Chromatograph. In addition, elemental analysis was performed to survey the amount of organic and inorganic

[58] Analyze, Inc. 318 South Bracken Lane, Chandler, Arizona, 85224.



carbon present in the samples. The full water sampling report from Analyze, Inc. detailing the measurement techniques is provided in Appendix D.

Figure 43 Water sample collection during test A1 just in front of the VFT

### 5.2.5 Temperature and Heat Flux Measurements

The temperature and heat flux measurements were performed using sixteen 0.10-inch diameter Type K TCs and four Schmidt-Boelter HFGs, as shown in Figure 28. The location and measurement description of the TCs and HFGs are provided in Table 4 and Table 5. These measurements were collected for at least one hour after testing or until external battery temperatures had dropped to near ambient levels, whichever was first.

During Battery A tests, TCs 1 through 12 were fixed to the exterior surface of the batteries using Omega Bond CC High Temperature Bonding cement, as shown in Figure 44. The cement was located over the TC bead and allowed to dry prior to testing. An ambient TC was placed 25 feet east of the VFT, as shown in Figure 28.


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During Battery B tests, TCs 1 through 15 were installed in the same locations around the exterior of the battery and within the interior of the battery through the vent holes, as described in Section 5.1.5 and as shown in Figure 45.

During all six of the Battery A and B tests, HFGs 1 through 4 were positioned at 5, 15, 20, and 25 foot standoff distances from the VFT. The HFGs were capable of measuring a radiant heat flux between 0 and 50 $kW/m^2$.

Table 4 Summary of TC Locations

**Thermocouple**

**Measurement**

**Thermocouple**

9
10
11
12

13
14
15
16

**Measurement**

Battery exterior Battery exterior Battery exterior Battery exterior Battery interior (B only) Battery interior (B only) Battery interior (B only) Ambient temperature

1. 1 Battery exterior
2. 2 Battery exterior
3. 3 Battery exterior
4. 4 Battery exterior
5. 5 Battery exterior
6. 6 Battery exterior
7. 7 Battery exterior
8. 8 Battery exterior

Table 5 Summary of HFG Locations

**Heat Flux Gauge**

1 2

**Measurement**

Heat Flux (5 ft) Heat Flux (15 ft)

**Thermocouple**

3 4

**Measurement**

Heat Flux (20 ft) Heat Flux (25 ft))

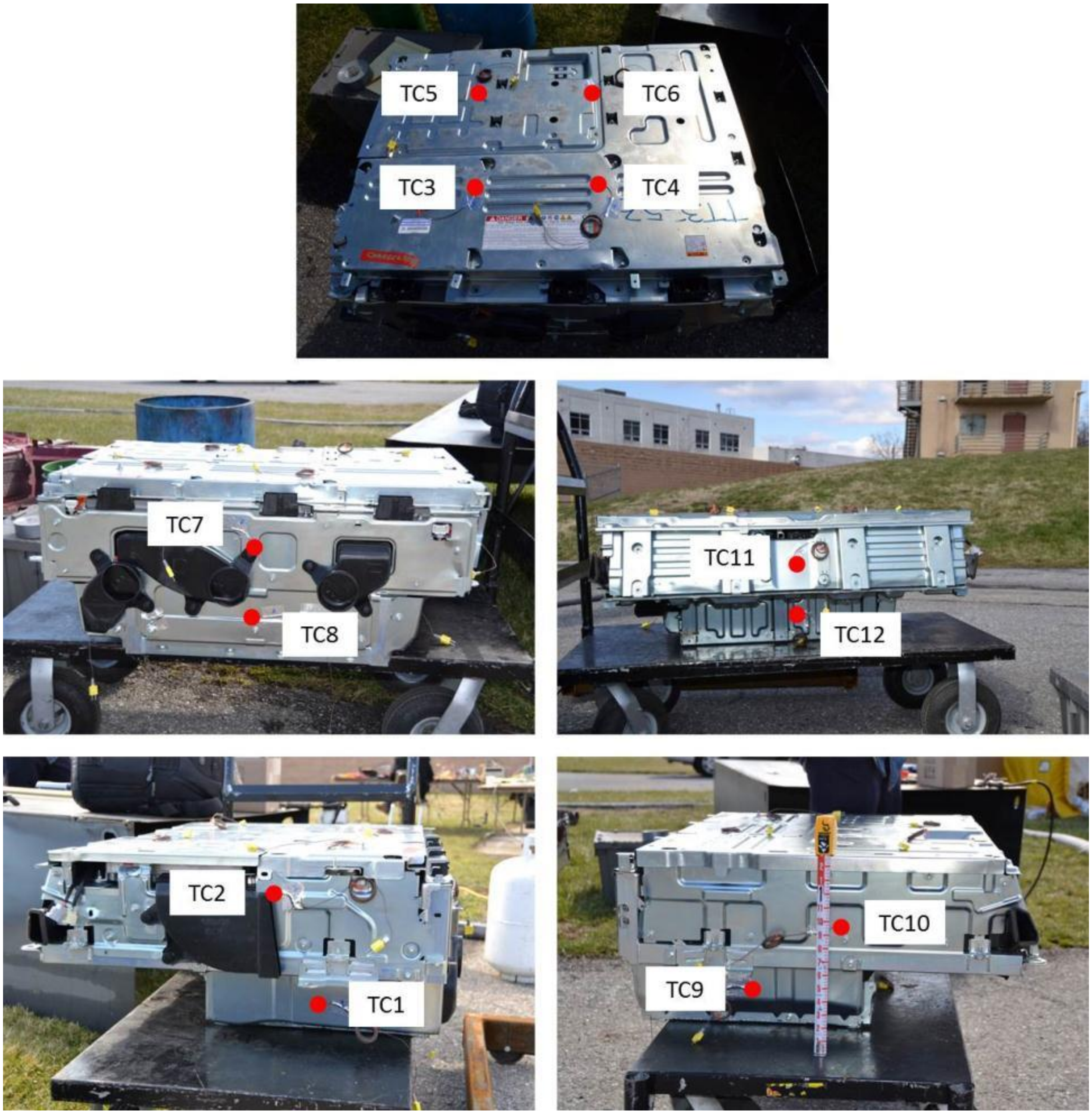


Figure 44 TC locations (red circles) on battery exterior for Battery A tests

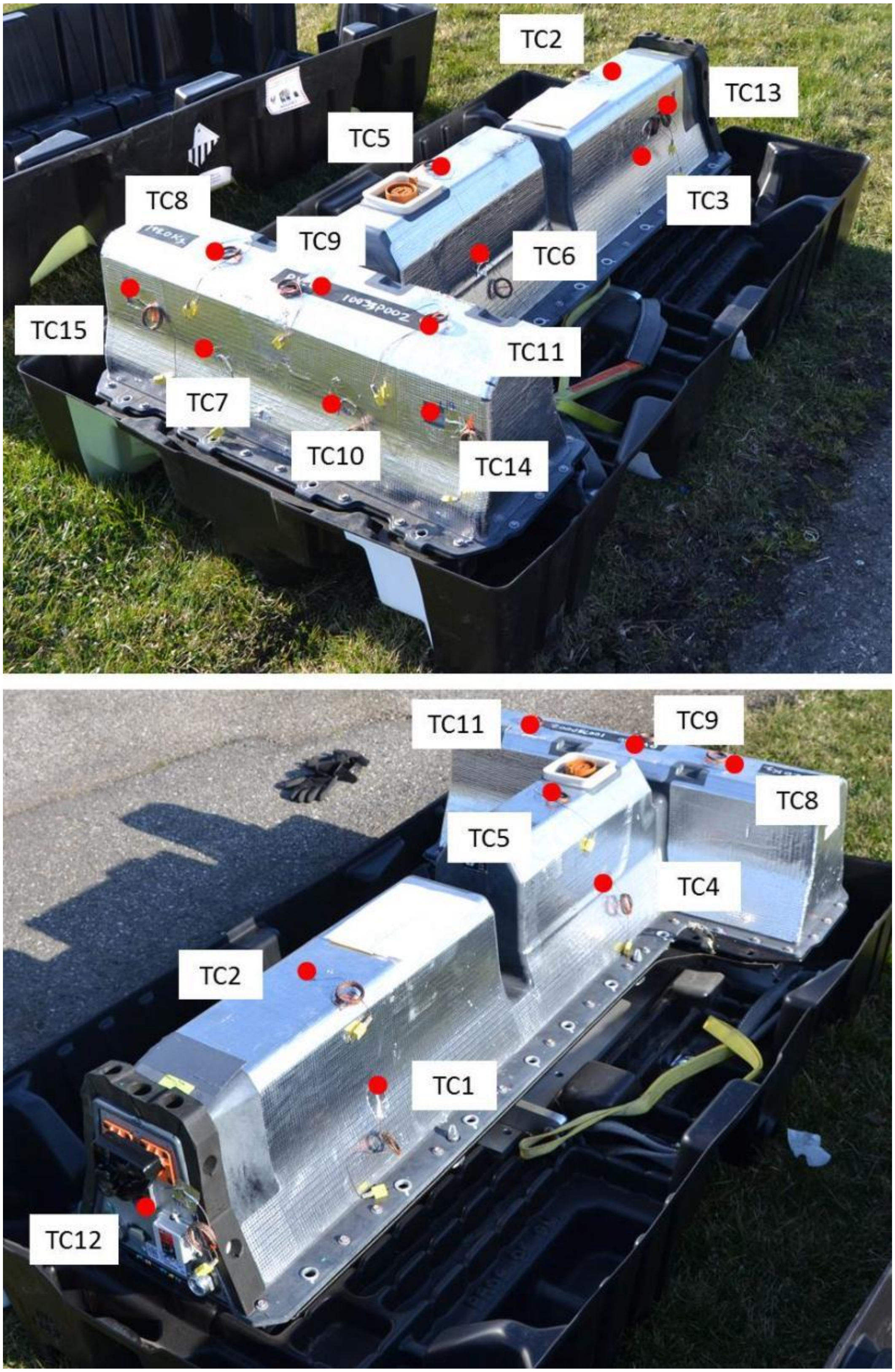


Figure 45 TC locations (red circles) on battery exterior/interior for Battery B tests

### 5.2.6 Internal Battery Sensor Measurements

During the Battery B tests, Exponent collected internal battery temperatures and individual cell voltages from the battery's own sensors. Exponent was not provided with the necessary supporting information to communicate with the A series batteries. These measurements were collected for as long as the connection between the battery and the DAQ system would allow (i.e., that is until fire exposure conditions compromised the communication paths). To collect this data, Exponent communicated directly with the battery using the same software programs, cables, equipment, sensors, and connection points to the battery described in Section 5.1.6. Prior to the suppression tests however, the battery was installed within the VFT, which required a slightly modified protection scheme for the battery's connection points. To protect these connection points, a modified calcium silicate board structure was erected around the front end of the battery once it was positioned within the VFT, as shown in Figure 46 and Figure 47. This structure shielded the connection area from direct flame impingement by the burners below, as well as any flames licking around the bottom edge and sides of the battery. In addition, Kaowool was inserted into the structure to insulate the connection points further and wrapped around the cables running to the battery from the DAQ system.

Figure 46 Connection points to Battery B once installed inside the VFT (before protection)

Figure 47 Protection scheme for the connection points and cables running to Battery B



### 5.2.7 DAQ System

Data acquisition was performed by a custom Lab VIEW code. The code performed five simultaneous tasks during the suppression testing:

- Analog input at a rate of 1 Hz for the TCs, HFGs, and chassis electrical measurements;
- Analog input at a rate of 2 kHz for the nozzle electrical measurements;
- CAN bus communication with individual internal battery cell voltage and temperature sensors;
- Digital output to the relay module to control the burner; and
- Serial input and output to the mass flow controller.

The temperature measurements consisted of up to sixteen Type K TCs and four calibrated Schmidt-Boelter HFGs. The TCs were monitored by an NI 9213 16-channel, 24-bit resolution TC module with built-in cold-junction compensation, as shown in Figure 48. The HFGs were monitored by an NI 9207 8-channel current/8-channel voltage module and a 24-bit resolution module with 50/60 Hz noise rejection. The TCs and HFGs were monitored continuously at a sampling rate of 1 Hz, or once per second.

The electrical measurements were performed at two different sampling rates by two data acquisition modules. The chassis voltage and current were monitored at a sampling rate of 1 Hz by the NI 9213 module described above. The nozzle voltage and current were continuously sampled at a rate of 2000 Hz by an NI 9239 module, a high-speed 4-channel analog input module with 24 bits of resolution, channel-to-channel isolation and anti-aliasing circuitry.

CAN bus communication and burner control were performed using the same software programs, cables, equipment, and connection points to the battery described in Section 5.1.7.

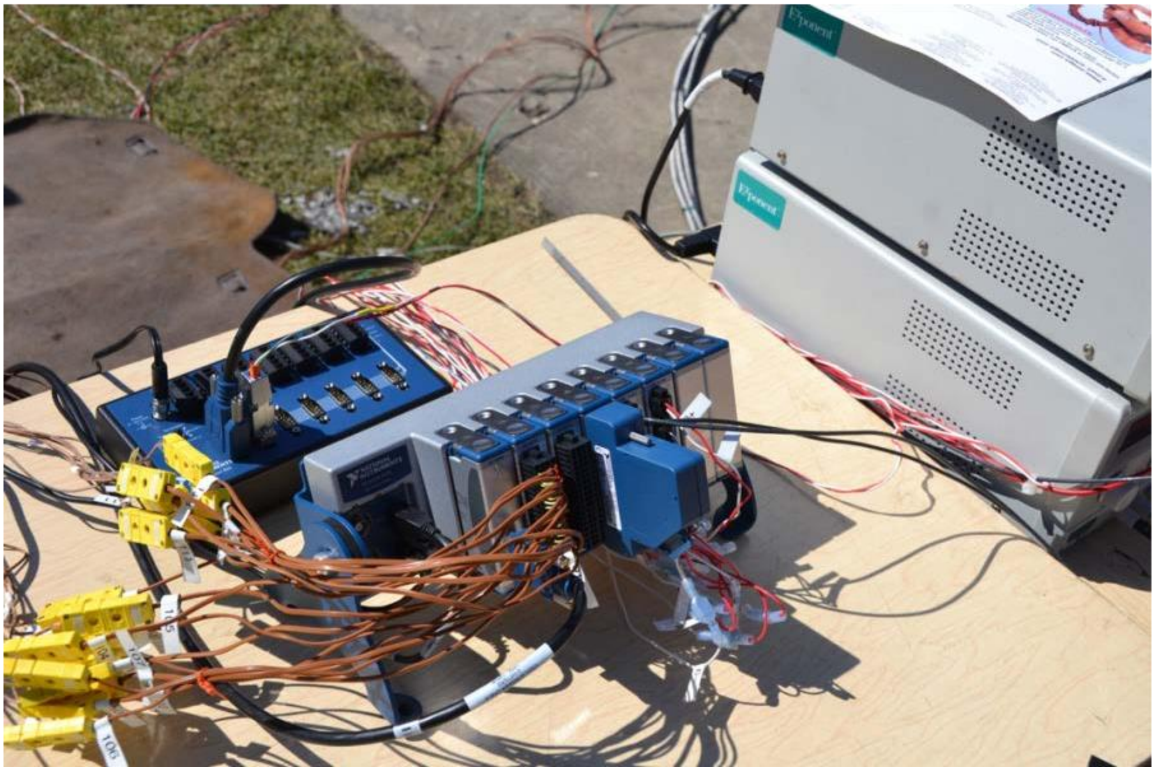

Figure 48 NI 9213 TC module and NI 9207 voltage module (for HFGs) plugged into the NI cDAQ 9178 data acquisition chassis

## 5.2.8 Thermal Imaging, Still Photography and High Definition Video

Still photography and high definition video was recorded during the suppression testing by Exponent using the same cameras as described in Section 5.1.8. Images of the tests were captured as the situation warranted and/or important events occurred. Four high definition camcorders were used during testing to ensure all angles of the VFT and battery were recorded. The positioning of the high definition camcorders during testing is shown in Figure 28.

Due to the position of the batteries within the VFT, it was not possible to take thermal images that could provide meaningful data during the suppression tests given that direct access was obstructed by the VFT or floor pan components. However, thermal images were recorded after test completion to supplement the TCs in monitoring the battery post fire. The thermal imager used during the suppression tests was the same as described in Section 5.1.8.



## 5.2.9 Suppression Activities

Suppression activities were handled by MFRI. No guidance was given to the firefighters regarding what they could and could not do tactically to suppress the fires. They were instructed to fight the fire as they would normally approach a vehicle fire with an offensive attack. Any tactics or modifications to those tactics during the fire tests were at the sole discretion of the MFRI staff and based on their many years of firefighting and training experience. The suppression team was restricted from using any forcible tools to access the VFT or the battery for safety reasons.

However, due to the setup of the tests, there were two limitations regarding how MFRI could attack the fires: (1) they were not able to fight the fire from the east side of the VFT, as the instrumentation wires and cables in that area posed a tripping hazard and (2) they were not able to fight the fire from underneath the VFT (i.e. shooting water up to the undercarriage of the batteries) due to the presence of the four propane burners.

These two limitations did not greatly affect MFRI's tactics, as the VFT was designed to provide ample access to the interior of the VFT. Each VFT window was open to air, mimicking a more involved vehicle fire, where all of the windows would be broken prior to fire department arrival or by first responders once on scene, as shown in Figure 49. In addition, the top section of the back hatch was left open to provide better access to the batteries during the test. The MFRI firefighters stated that they would normally attempt to open the back hatch or trunk as one of their first actions if this were a real fire scenario. As such, for safety reasons, as a means to limit the touching, moving, and manipulating of the VFT as the firefighters are standing within a few feet of a potentially fully involved battery, the top portion of the back hatch was kept open from the beginning of the test. Ultimately, having the hatch open also greatly aided in the video recording and still photography captured during the tests.

All tests were conducted with a defacto incident commander and assistant and two active firefighters; one on the nozzle and one on the hose. This is equivalent to one company, as defined by NFPA 1710, *Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career*



*Fire Departments*, 2010 edition. All staff outside of the suppression team was kept behind a 50-foot perimeter around the VFT. A 1.75-inch diameter hose line fed by a private hydrant was used to supply the Elkhart Brass - Chief nozzle (model no. 4000-10, variable fog 30 degree, 60 degree, and 90 degree), which discharged approximately 125 gallons of water per minute (gpm) at 75 psi. The water usage was tracked by Exponent staff (time of application estimates) during the tests so that an estimate of the total water used for suppression could be determined. Final data was cross checked with video recording for accuracy. In addition, interviews with the firefighters after the tests were conducted to, among other things, gain insight into:

- What they saw;
- How they attacked the fire;
- How the fire differed from a conventional vehicle fire;
- What they may have learned from the test regarding tactics; and
- General observations.

The two firefighter suppression team donned full SCBA and firefighting turnout gear prior to the beginning of the test and only removed their SCBAs if they needed to swap out a cylinder or once the fire was deemed “out.” The turnout gear consisted of:

- Polybenzimidazole (PBI) coat (Globe G-Extreme or Lion Apparel Janesville);
- PBI pants (Morning Pride);
- Polycarbonate helmet (Morning Pride Ben Franklin II or MSA 660);
- Kangaroo skin (Honeywell) or leather (Shelby) gloves;
- PBI (Firecraft) or lanzing (PAC II) hood; and
- Leather boots (Warren Pro or HAIX).

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# Research and Development of Fire Extinguishing Technology for Power Lithium Batteries

Wei-tao LUO[a], Shun-bing ZHU[a,b,*], Jun-hui GONG[a,b], Zheng ZHOU[a]

[a]Jiangsu Key Laboratory of Hazardous Chemicals Safety and control,
[b]College of Safety Science and Engineering,Nanjing Tech University,Nanjing 210009,China

**Abstract**

By summarizing the previous experimental studies on fire extinguishing of lithium battery, it was found that the lithium battery fire extinguishing exhibits some essential characteristics,such as long duration, high temperature, large water consumption and great difficulty in extinction. The applicability of fire extinguishing agent for power lithium batteries was analysed in this work. Through the acupuncture experiment, the different efficiencies of fire extinguishing agents were compared. It is expected to provide some useful references for future safety design and prevention of such lithium batteries.


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Key words: lithium batteries, fire, fire extinguishing agent

## 1. Introduction

In recent years, the demand for new energy sources is increasing with the increasingly serious environmental problem, and the new energy vehicles represented by electric vehicles gets more attention. By the end of 2015, the total annual production of new energy vehicles are nearly 380000, and the number of new energy vehicles shows explosive growth trend. It is expected that production and sales of electric cars in China will reach one million in 2017. China is now in a critical stage of the development of new energy automotive industry and thus the security of new energy vehicles becomes more sensitive. Safety accidents of new energy vehicles have their special internal reasons, because the battery serves as a high energy carrier. The thermal runaway occurs at low temperature, and it is not easy to eliminate such accidents. Many influential fire accidents have caused numerous economic loss, fatalities and severe social influence.Thermal self-ignition, fire and explosion phenomenon of electric vehicle battery make the safety of lithium-ion battery become the focus of attention. Questions about the safety and reliability of power battery of electric vehicles bring new problems and challenges for fire fighting and emergency rescue. Recently, the scholars in State Key Laboratory of Fire Science carried out fire extinguishing experiments on the technology of lithium battery fire prevention and control, but the research is still in the initial stage [1].

This study utlizes 18650# lithium-ion batteris to examine the efficiency of pure water, 5% F-500 solution and 5% self-made solution (anionic nonionic surfactants) on lithium battery fires. In addition, the water mist extinguishing system is applied to extinguish lithium battery fires, which provides an alternative method for such fires. This work reveals some fundamental insight into studying the technology of extinguishing large-scale lithium battery fires.

## 2. Characteristics of fire extinguishing for power lithium battery

Although the cause of electric vehicle fire is complex, one of the main reasons is the spontaneous ignition caused by power lithium battery. In the study of fire accidents of power lithium battery, NFPA [2] has carried out the lithium battery fire

* Corresponding author. Tel.: +86-189-5183-7818; fax: +86-189-5183-7818.
E-mail address: 2934399475@qq.com

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experiment.

*2.1. Fast burning and long duration*

The power lithium battery causes a series of effects because of various incentives leading to thermal runaway. Once the heat accumulation of lithium battery is out of control, the battery would burn immediately.Figure 1 shows the lithium batteries fire extinguishing process carried out by NFPA. It only took a few seconds for the battery to transform to intense combustion, whereas the suppression process had lasted about 27 minutes [2].

*2.2. High temperature*

During the fire tests, NFPA used thermocouple to measure the temperature and found that the maximum temperature outside the battery is in the range of 283 to 1090 degrees, and the maximum temperature inside the battery is between 572 and 1121 degrees. The peak heat flux at a distance of 5 feet from the VFT device is 2.2kW/$m^2$, and the value ranges from1.5 kW/$m^2$ to 2.1kW/$m^2$ when the distance is15, 20 and 25 feet individually. The maximum temperature and heat flux measured during the tests mostly occurred after the burner was terminated. It indicated that the battery fire was still very hot at that time. Therefore, the flame temperature is high enough to ignite other combustibles once the vehicle's power lithium battery burns.

*2.3. Large water consumption*

During the fire extinguishing tests, NFPA used water to put out the power lithium battery fire. In order to avoid the reignition, the fire extinguishing continued for a long time and the water consumption was larger than others. Although the increased amount of water extinguished the fire more thoroughly, it endangered the battery at thermal runaway temperature.

*2.4. Enhanced difficulty in extinguishing*

The combustion reaction of power lithium battery generally occurs inside the battery. Water can not get access to the "fire", which is an important problem for fire fight. For the power battery pack, shell material of battery pack prevent fire extinguishing agent from acting on electrical core directly. So fire fighting is more difficult [3]. During tests, the total time spent on fighting fires exceeds the fire fighters' oxygen supply time and it poses a greater challenge to the personal security of fire fighters. Therefore, there is no effective method for the fire fighting of power lithium batteries, which belongs to the worldwide problem.


Figure 1 test: propane burner ignition (upper left); combustion(upper right); ignition off (left); the fire extinguishing started (right); fire again and inhibition again (lower left); the fire extinguishing completed (lower right)

### *2.5. Complexity of power lithium battery's fire extinguishing*

A power battery is an energy storage unit whose fire is transformed from its electrical and chemical energy. When the electric and chemical energy is not consumed completely, the heat is in the sustained release stage. After the thermal runaway's expansion stage, the effectiveness of the fire suppression is very effective. This is the origin of the saying "why power fires can not be extinguished"., the development of the battery fire is very swift and violent especially for the ternary polymer lithium battery, and it releases oxygen itself. Consequently, it can hardly be extinguished after the fire spread.

Employing some specific methods can inhibit the occurrence and spread of fire. In addition to fire extinguishing at an open fire stage, the control of thermal runaway stage is also very important, such as the use of flame retardant materials, the addition of flame retardants in electrolyte. It is more important to develop the early warning technology. Study of the power battery fire on intelligent fire detection and flame retardant mechanism has been a breakthrough. However, there is rare effective breakthrough in the basic research about the technology of clean fire prevention and control, and its development has encountered considerable difficulties.

## 3. Research on fire extinguishing of lithium battery

At present the research on fire experiments of power lithium battery is highly concerned. The United States and the countries in Europe concerned about the fire safety of lithium batteries in the earlier times [4,5], such as the National Fire Protection Association (NFPA), the Federal Aviation Administration (FAA), and the Civil Aviation Authority (CAA). Recently, the scholars in the United States FM Global, the National Fire Protection Association (NFPA) and State Key Laboratory of Fire Science carried out fire extinguishing experiments on the technology of lithium battery fire's prevention and control, but the fire model was different [1].

### *3.1. Study on fire extinguishing of lithium batteries abroad*

FAA has carried out the screening experiments of effective fire extinguishing agent fighting lithium battery fires, and evaluated their effectiveness through the fire simulation experiment and the experiment on cooling effect of fire extinguishing agents [6]. The experiment on cooling effect of fire extinguishing agent compared Halon1211 fire extinguishing agent with water based extinguishing agent such as water, AF-31, AF-21, A-B-D. It also compared gas fire extinguishing agent such as FM-200, FE-36, Halotron I with powder extinguishing agent and new fire extinguishing agent such as Purple-K and Novec1230. The results showed that the water based extinguishing agent has good cooling effect. With the increase of extinguishing agent's dosage, the cooling effect is more significant. And reducing the sprinkling capacity also has remarkable effects on the cooling effect. But non-water based extinguishing agent's cooling effect is not obvious. With the increase of extinguishing agent's dosage, the cooling capacity has little changes. Water based fire extinguishing agent's cooling ability was prioritized as AF-31, AF-21, A-B-D and Novec 1230.

Based on the experimental research on the fire extinguishing agent's cooling effect, FAA carried out the fire experiment of lithium battery. The experiment used a 18650# lithium-ion battery (battery capacity is 2600mAh, SOC is 50%). First, the heater of tube furnace was turned on, and then the heater of hexane was opened when the first battery's temperature was heated to 100℃. After the first battery was out of control, the fire extinguishing agents were sprayed. When the fire extinguishing agents is liquid at ambient temperature and pressure, such as water, AF-31, AF-21, A-B-D and Novec1230, they were sprinkled by a 500ml hand-held bottle. Other fire extinguishing agents, such as Halon1211, Halotron. I, FM-200, FE-36, $CO_2$

and Purple-K, were sprayed by a hand-held bottle. After the fire was over, the heater was closed and data was recorded for about 20 minutes.The results showed that all thermal runaway of lithium battery occurred and spread in the absence of fire extinguishing agents, and only 500ml liquid fire extinguishing agents can effectively inhibit the spread of lithium-ion battery fire. Non-liquid fire extinguishing agents had no effect on lithium-ion battery.

Through the research of this project, FAA found that the experimental results of fire extinguishing agents' cooling effect are similar to the experimental results of lithium battery fire extinguishing. It further testified that the cooling ability of fire extinguishing agents is the key factor to prevent the spread of lithium battery fire. Water based fire extinguishing agents had the best effect on the suppression of lithium battery fires, while gas extinguishing agents and dry powder extinguishing agents are ineffective in suppressing lithium battery fires.

### *3.2. The study on fire extinguishing of lithium battery in China*

In order to reduce the risk of lithium battery fires, Wuhan Institute of China Classification Society [7] carried out the research on the effectiveness of extinguishing agent of fighting power lithium battery fire. They analyzed the effectiveness of carbon dioxide, dry powder and heptafluoropropane which inhibit lithium battery fire. They evaluated its effectiveness from three aspects such as the fire extinguishing time, the recrudescence rate and smoke effect synthetically.The experiment found that the carbon dioxide's extinguishing effect is poor and the resurgence of fire occurred. Dry powder extinguishing agent has little effect on the lithium battery, and explosion occurred even during the experiment. The best effect on extinguishing lithium battery fires is heptafluoropropane.

University of Science and Technology of China [8] carried out the research on the effectiveness of dry powder, carbon dioxide and heptafluoropropane of extinguishing lithium battery fires. It was found that heptafluoropropane has good effect, but also the resurgence of fire occurred.

Tianjin fire station of Ministry of public security [3] conducted the experiment of extinguishing lithium battery fires with the powder, carbon dioxide and AFFF fire extinguishing agent and water mist technology. The results showed that the carbon dioxide, dry powder, 3% AFFF can extinguish the open fire of 18650# lithium-ion batteries. Due to the thermal runaway of lithium-ion batteries, it continued to release heat, combustible gas and oxygen. It can not extinguish the fire completely. All of them appeared resurgence phenomenon. With the fire extinguishing agent's cooling ability increasing, the time of appearing resurgence prolonged. For completely extinguishing 18650# lithium-ion battery fires, it needs to improve the fire extinguishing agent's ability of cooling and absorbing heat. Water mist fire extinguishing technology can not inhibit the 18650# lithium-ion battery fires effectively. Some studies showed that [4,5] water mist containing surface active agent is an efficient and environmental fire extinguishing technology. The utility of lithium battery fire needs further study.

### *3.3. Application of F-500 micro capsule technology and water mist containing additives system in the lithium battery fire extinguishing*

There are few studies on the micro capsule technology of explosive hydrocarbons in the literature, and the results of existing research are concentrated mainly in developed countries. The existing advanced technology is F-500 micro capsule's material technology, which is a new high efficiency fire extinguishing, explosion prevention and environmental technology developed by the American dangerous goods Control Arts Inc (HCT). In 2009, Bosch tested the extinguishing effect of water, foam, powder and F-500 on lithium battery fires. The tests found that F-500 is the first choice of lithium battery fire extinguishing agent.

In April 2013, German motor vehicle inspection association (DEKRA) selected three kinds of fire extinguishing agent, and studied the extinguishing effect on power lithium battery fire of electric vehicle [9]. According to the structure of electric vehicle's lithium battery, DEKRA used n-heptane to ignite lithium battery and set up fire model. They compared F-500 fire extinguishing agent's effect with water and powder fire extinguishing agent's effect on extinguishing lithium battery fire. Firefighters began to fight fire after n-heptane combustion's time at about 20min. Through simulation experiments, DEKRA found that water can successfully extinguish the lithium battery fire of electric vehicles. But there are many other problems, such as large water consumption and long extinguishing time. F-500 fire extinguishing agent can improve the efficiency of extinguishing lithium battery fires. The extinguishing time of extinguishing agent containing 1% F-500 is only fourteen seconds. The water consumption is greatly reduced. As a kind of micro cellular agent, F-500 can effectively inhibit class D (metal) fire in which no explosion exists. When the water is applied to class D (metal) fire, high temperature can make water into hydrogen and oxygen. The after-combustion and explosion will occur easily. Powder extinguishing agent can not cool the fire, and the fire will happen again. F-500 can reduce the surface tension of water. The formation of smaller droplets can make them penetrate into the internal of lithium battery. They quickly extinguished the fire and the fire will not happen again. F-500 forms a layer of protective film on the surface of the water forming a spherical micro capsule "chemical cocoon". The fuel elements of combustion were wrapped up in the micro capsule inhibiting combustion.The fast cooling ability of F-500 can quickly extinguish the fires and prevent the fire occurring again. These characteristics make F-500 not only apply to metal magnesium, metal titanium and other class D fire, but also apply to lithium battery fires.

Figure 2 comparison of pre

## 4. Experiment of lithium battery fire extinguishing

### *4.1. Experimental samples*

The experimental sample is a commercial iron phosphate lithium-ion battery. The total capacity of the battery is 80A·h. It is connected in series by four 20A·h cells, and the weight of each battery is 2375±3g.

### *4.2. Experimental method*

In order to simulate the daily common state of charge, the pre-cycle of battery was carried out between 3–4.5V before the tests. Circulation ratio was 0.2 C.When it was in a desired state of charge (50%SOC), the battery was prodded. Acupuncture experiment was carried out in a special acupuncture extrusion stage. Acupuncture equipped with thermocouples installed in the puncture fixture. The diameter of steel needle was 5mm and it penetrated into the single battery of 50% SOC at a rate of 30mm/s. The thermocouples were attached to the surface of the battery and measured the variation and distribution of temperature. Tests were conducted in two groups. One group was used to observe the phenomenon of lithium battery fire, and the other group was used to perform extinguishing fire tests when thermal runaway of lithium battery occurred. The extinguishing effect of pure water was compared with that of 5% F-500 solution and 5% self-made solution (anionic nonionic surfactants) to evaluate the fire extinguishing technology of water mist containing additives. Anionic nonionic surfactant combines many advantages of anionic and nonionic surfactants. It shows excellent characteristics such as good water solubility, high temperature resistance, easy degradation and high efficient foaming ability.

### *4.3. Experimental phenomena and results*

SOC of the battery has a great influence on the results of the acupuncture experiment. The SOC is controlled at 50% to repeat tests. After the battery was prodded, a little amount of liquid was sprayed immediately to produce a lot of white smoke. The surface temperature of the battery increased rapidly. It reached a high temperature of 813.7℃ at 29s as shown in Fig. 3. After the occurrence of thermal runaway, the fire behavior of lithium batteries was roughly divided into the following five stages: (1) The expansion of the battery took place after the acupuncture. Gas and internal material were sprayed from the small hole. The battery was seriously deformed and a large amount of smoke could be observed. (2) At 14s, the battery emitted a hissing explosion and spurt a large amount of white aerosol which is probably made up of electrolyte droplet. The white aerosol was ignited instantaneously and emitted a strong jet flame. (3) The battery entered a steady combustion state and lasted about 15s. (4) At 29s, the battery flame was enhanced. (5) After a period of time, the flame went out gradually and ended at 1637s.

According to Fig. 4, it is found that 5% F-500 solution and 5% self-made solution have significant extinguishing effect on lithium battery fire in the tests. Compared to that of pure water, the extinguishing time of them are shortened by more than half. The two solutions can reduce the temperature of the lithium battery rapidly and extinguish the flame quickly. There is little difference between the extinguishing times of the two solutions. The self-made solution is slightly better than the F-500 solution. Pure water is very unstable in the early stage of flame suppression. The stability of flame suppression effect of both solutions is much better than that of pure water. Compared to spraying pure water, spraying 5% self-made solution and F-500 solution weakens the combustion intensity of lithium battery flame obviously. After spraying for 4s, it could inhibit the combustion of lithium battery very well.The experiment results infer that fuel molecules are absorbed and wrapped by solution after spraying self-made solution or F-500 solution. And thus, the combustion reaction can be terminated. Compared to the flame effect, the inert effect of F-500 solution is closed to that of self-made solution. Meanwhile, the smoke control of F-500 is slightly better than that of self-made solution after ignition and the intensity of flame after ignition is better controlled, which is obviously superior to pure water.

According to the experiment of fire extinguishing effectiveness, utilization of pure water as the extinguishing agent to extinguish the lithium battery fires has defects, such as long extinguishing time and harmful products with "black smoke". While the scenario of a certain percentage of additives is added in water, extinguishing time is greatly shortened. The fire enhancement is effectively suppressed. And a large amount of "black smoke" translates into "white smoke" at the same time. Self-made solution and F-500 solution show excellent fire extinguishing effect in the experiments. In the process of extinguishing lithium battery fires, self-made solution and F-500 solution could absorb and wrap hydrocarbon molecules quickly. Hydrocarbon molecules produced by combustion is wrapped and insulated from oxygen.The combustion could be prevented and inert. Flame intensity and combustion time are both reduced. The harmful products of combustion are reduced and the visibility in the fire is increased. Consequently, the rapid and safe extinguishing effect is reached finally.

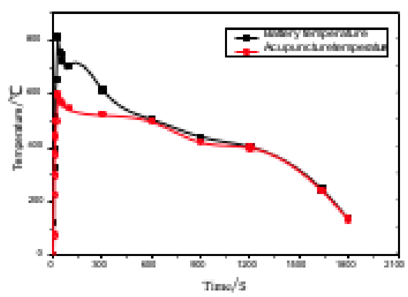


Figure 3 Surface temperature profiles of acupuncture experimental cel.

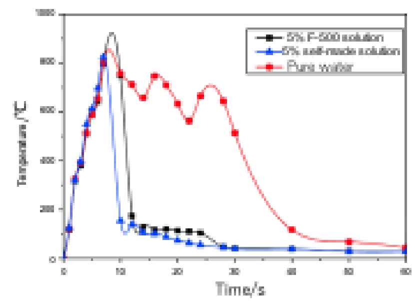


Figure 4 Comparison of the effect of fire extinguishing agents

## 5. Problems and Prospects

(1) Currently, the fire extinguishing media of lithium batteries mainly includes water, foam, dry powder, alkyl halide and carbon dioxide etc. Water mist fire extinguishing system has the characteristics such as low water consumption, cheap fire extinguishing medium, little damage to the object protected and green environmental protection. It has been concentrated in the field of fire protection in recent years. However, there are many problems in water mist fire extinguishing system. The uniformity of the water mist cannot be warranted.The liquid droplets reach the combustion surface with a certain amount of impulse. It is very difficult for water mist system to extinguish block fire. It is easy to extinguish class B (liquid) fire and it is difficult to extinguish class A (solid) fire. There is no guarantee of any water damage to objects.Water mist extinguishing system is not movable. The fire extinguishing properties are affected by droplet size, velocity distribution, impulse and geometric characteristics of nozzle. In recent years, the study on water mist extinguishing technology has been conducted extensively. But the water mist fire extinguishing system containing additives is still at the laboratory research stage. The results show that the extinguishing efficiency of water mist fire extinguishing system containing additives is obviously improved compared to the ordinary one.The study on fire extinguishing materials and fire prevention technologies for lithium batteries has become an important part in the field of fire science.

(2) The experimental studies have shown that lithium-ion batteries have high fire risk. The oxidation of lithium metal is over in a flash when the battery is heated up. The energy is the electrical energy and chemical energy contained in other substances. There are dozens of toxic and harmful substances such as five phosphorus pentafluoride, phosphine, hydrogen fluoride and hydrogen. These are the root of batteries combustion and reignition. According to the toxic and harmful gas coming from power lithium battery fire, hydrogen fluoride is regard as a model. Using the organic aggregates of surface active agent to absorb hydrogen fluoride gas is investigated. The feasibility of reducing hydrogen fluoride gas concentration is investigated. The absorption of surfactant mixtures of hydrogen fluoride is studied. Through a comprehensive analysis of the absorption performance and stability, the absorbent system with good absorption effect on hydrogen fluoride gas is screened. It reveals some fundamental insight into using the organic aggregates of surface active agent to absorb five phosphorus pentafluoride, phosphine, hydrogen and other gases.

(3) China has not yet formulated and promulgated the specifications and guidelines for emergency rescue of electric vehicles. The Chinese existing national standards for fire emergency rescue have not covered the specific contents of electric vehicles fire emergency rescue. It is very difficult for fire fighters to deal with the fire of electric vehicles. Therefore, according to the fire extinguishing experiment of power lithium battery, fundamental research on fire fighting should be combined with the emergency rescue. Furthermore, technical manual or standard specification needs to be established. To meet the needs of the fire work, normalization of the operation of fire fighters and emergency rescue should also be standardized.

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