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Alternative Fuel Vehicle Safety Summit

FINAL PROCEEDINGS BY:

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1 Batterymarch Park, Quincy, MA

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Executive Summary

These are the proceedings of the Alternative Fuels Vehicle Safety Summit held in Detroit, Michigan on 23 June 2016. This summit involved a diverse group of stakeholders focused on addressing important and useful review, validation and identification of gaps for emergency responder operational training materials on AFVs, These training materials are used by first and second emergency responders and others handling emergencies with alternative fuel vehicles, with an emphasis on gaseous fuels.

The scope of this effort includes addressing emergency activities such as: fire events, non-fire emergencies (e.g., submersion), fire investigation, crash reconstruction, tow and salvage, extrication practices, refueling and charging infrastructure, etc. The deliverables from this summit provide a summary of prioritized needs and gaps from the perspective of emergency responder stakeholders, and promotes activities to address these needs and gaps through all possible approaches. This includes working with vehicle providers to implement inherent safety design solutions through up-front innovative design.

The key summary observations from this summit address: general hazard concerns; electronic badging; fire fighting tactics; investigation; stranded energy; and other issues and trends. Of particular note, the Summit highlights the following:

- Need to address implementation of electronic badging technologies as soon as possible to enable real-time emergency event size-up and prospective data collection;
- Clarifying the tactical fire fighting approach for the venting of gaseous fuel storage vessels depending on the vessel material (i.e., metal versus composite);
- Addressing the needs of investigators to re-power damaged vehicles to harvest post event data; and
- Continuing to address the problem of stranded energy and its long time frame impact on first and second emergency responders.

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Acknowledgements

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About the Fire Protection Research Foundation
The Fire Protection Research Foundation plans, manages, and communicates research on a broad range of fire safety issues in collaboration with scientists and laboratories around the world. The Foundation is an affiliate of NFPA.

About the National Fire Protection Association (NFPA)
Founded in 1896, NFPA is a global, nonprofit organization devoted to eliminating death, injury, property and economic loss due to fire, electrical and related hazards. The association delivers information and knowledge through more than 300 consensus codes and standards, research, training, education, outreach and advocacy; and by partnering with others who share an interest in furthering the NFPA mission. All NFPA codes and standards can be viewed online for free. NFPA's membership totals more than 65,000 individuals around the world.

Keywords: Alternative fuel vehicles, LNG, CNG, LPG, lithium-ion batteries, hydrogen fuel cells, emergency responders, Electric vehicles

Table of Contents

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List of Tables

List of Figures

1) Background and Overview

The popularity of alternative fuel vehicles (AFVs) has been increasing in recent years based efforts to maximize fuel efficiency and minimize unnecessary environmental waste. There are currently millions of these vehicles on the road today, and that number continues to grow. Figure 1 illustrates the increasing usage trend of these vehicles, for the time period of 1995 through 2011. *(Source: Alternative Fuels Data Center, Energy Efficiency & Renewable Energy, U.S. Department of Energy, website: http://www.afdc.energy.gov/data/, accessed 29 July 2016)*

AFVs are those vehicles powered by other than the traditional petroleum-based internal combustion engines, and are using an alternative fuel source such as gaseous fuels (e.g., CNG, LNG, LPG), high voltage electric batteries (e.g., lithium-ion), and hydrogen fuel cells. Specifically, the Energy Policy Act of 1992 defines an alternative fuel as one of the following: Biodiesel (B100); Natural gas and liquid fuels domestically produced from natural gas; Propane (liquefied petroleum gas); Electricity; Hydrogen; Blends of 85% or more of methanol, denatured ethanol, and other alcohols with gasoline or other fuels; Methanol, denatured ethanol, and other alcohols; Coal-derived, domestically produced liquid fuels; Fuels (other than alcohol) derived from biological materials; P-Series fuels. *(Source: H.R. 776 – Energy Policy Act of 1992, Congress.Gov, website: https://www.congress.gov/bill/102nd-congress/house-bill/776/text/enr, accessed 29 July 2016)*

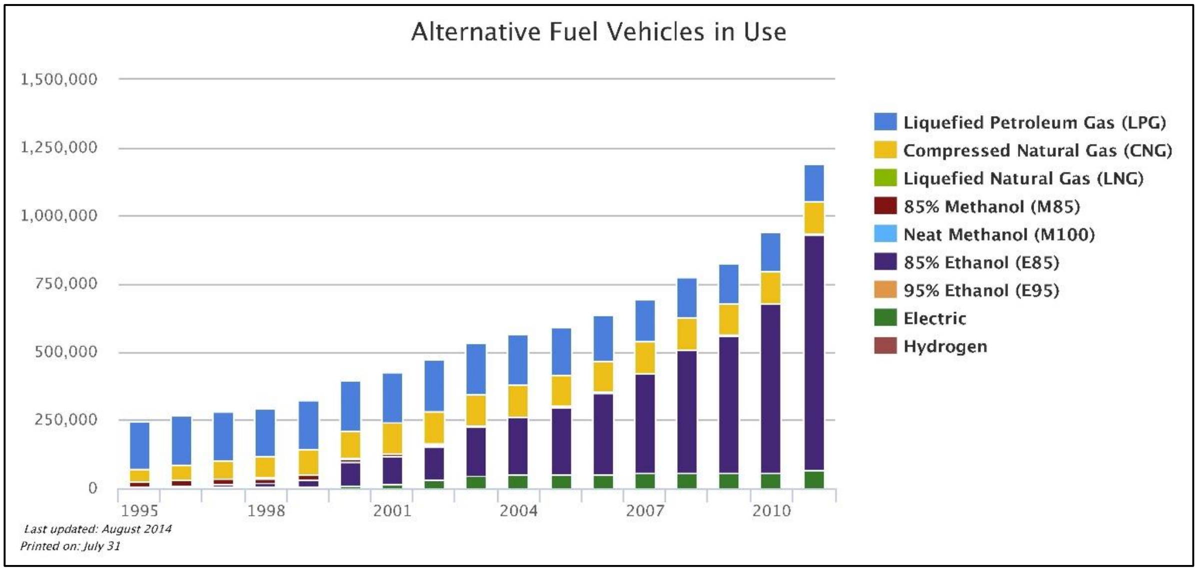

Figure 1: Alternative Fuel Vehicles in Use, 1995-2011

(Source: Alternative Fuels Data Center, Energy Efficiency & Renewable Energy, U.S. Department of Energy, website: http://www.afdc.energy.gov/data/, accessed 29 July 2016)

While much has been focused on passenger cars, this technology is also proliferating with larger fleet vehicles such as trucks and busses, which have the advantage of uniform and centralized service and maintenance. Cost efficiencies have been attractive for fleet vehicles to be utilized with fleet activities (e.g., bus networks and delivery trucks in local areas). This workshop has been focused on four-wheeled on-road generally includes traditional passenger vehicles as well as larger vehicles such as trucks and busses. However, applications other than four-wheeled on-road vehicles (e.g., motorcycles) are not totally outside the scope of consideration to the extent that similar hazard and safety concepts apply. Figure 2 summarizes the types of vehicles by weight class according to the Federal Highway Administration. *(Source: Alternative Fuels Data*

Center, Energy Efficiency & Renewable Energy, U.S. Department of Energy, website: http://www.afdc.energy.gov/data/, accessed 29 July 2016) These illustrate the types of vehicles that are the primary focus of this safety summit.

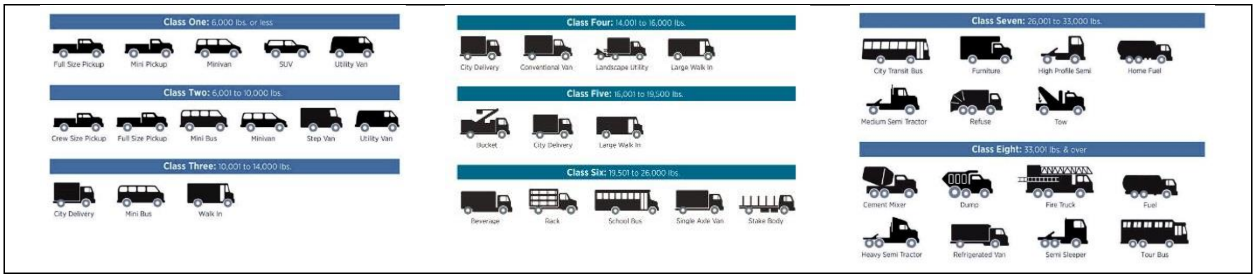

Figure 2: Types of Vehicles by Weight Class (by Federal Highway Administration)
(Source: Alternative Fuels Data Center, Energy Efficiency & Renewable Energy, U.S. Department of Energy, website: http://www.afdc.energy.gov/data/, accessed 29 July 2016)

As new fuels and power sources are introduced, so too does safety considerations associated with them. Paramount to emergency responders is a clear and rapid understanding of all the hazards they are facing, especially in during an emergency when accurate real-time information is critical.

Compared to traditional vehicles with which emergency responders are generally well familiar, the hazards associated with a particular AFV may be greater or less of a concern, but most notably they are often different and require baseline expectations beyond normal training and experience. It is not unusual nor unexpected for emergency responders to arrive at incidents that may involve AFVs (crashes, fires, entrapment, submersion, etc.). Figure 3 illustrates the types of incidents that emergency responder can expect to handle. *(Source: Grant, C., "Fire Fighter Safety and Emergency Response for Electric Drive and Hybrid Electric Drive Vehicles", Fire Protection Research Foundation, www.nfpa.org/Foundation, Quincy MA, 2010)* It is essential that emergency responders know how to best handle the hazards presented by these new vehicles.

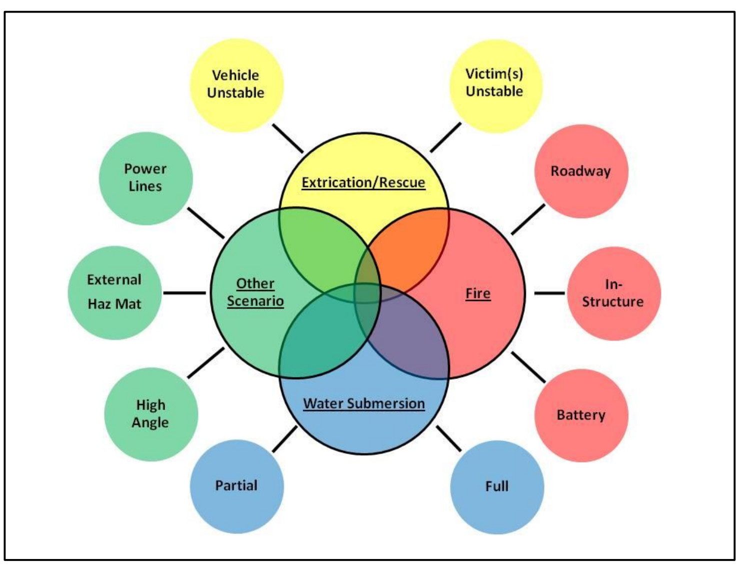

Figure 3: Key Emergency Scenarios for Emergency Responders
(Source: Grant, C., "Fire Fighter Safety and Emergency Response for Electric Drive and Hybrid Electric Drive Vehicles", Fire Protection Research Foundation, www.nfpa.org/Foundation, Quincy MA, 2010)

Emergency responders are all the professionals and organizations that respond to an emergency event. There are often two recognized tiers of first responders and second responders. The first responders are generally the organizations in charge of specific aspects of the emergency and include the fire service, emergency medical services (EMS) and law enforcement. Second responders are also critical to handling the event and include groups such as tow/salvage, medical examiner, and follow-up responders from the first tier such as investigators.

Interestingly, first responders are not always first upon an emergency event, such as when tow and salvage arrive at an emergency before any other responders. Figure 4 provides an overview of the details of emergency responders, all of whom are within the scope of this safety summit. *(Source: Grant, C., "2nd Annual Electric Vehicle Safety Standards Summit – Summary Report", Fire Protection Research Foundation, www.nfpa.org/Foundation, Quincy MA, 2011.*

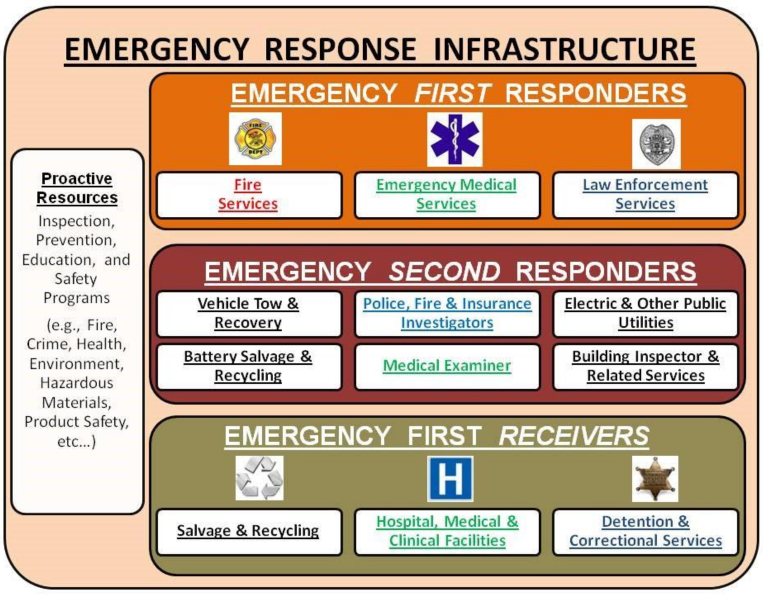

Figure 4: Emergency Responder Infrastructure

(Source: Grant, C., "2nd Annual Electric Vehicle Safety Standards Summit – Summary Report", Fire Protection Research Foundation, www.nfpa.org/Foundation, Quincy MA, 2011.)

Several directly applicable projects and workshops were completed prior to this Alternative Fuel Vehicle Safety Summit. The following are the activities, in chronological order, conducted by either the National Fire Protection Association or the Fire Protection Research Foundation:

- "Fire Fighter Safety and Emergency Response for Electric Drive and Hybrid Electric Vehicles": A background research study that assembled core principle and best practice information for emergency responders to assist in their decision making process at emergencies involving electric drive and hybrid e-vehicles. It included a one-day workshop of applicable subject matter experts to review and evaluate the topic. *(Source: Grant, C., "Fire Fighter Safety and Emergency Response for Electric Drive and Hybrid Electric Drive Vehicles", Fire Protection Research Foundation, www.nfpa.org/Foundation, Quincy MA, 2010)*

- "U.S. National Electric Vehicle Safety Standards Summit Summary Report": This was a summit held on 21-22 October 2010 in Detroit, Michigan to address safety related codes and standards issues, with a focus on the fundamental codes and standards centric areas of: vehicles, built infrastructure, and emergency responders. The intent was to develop the base elements for an action plan for the safe implementation of e-vehicles using safety standards as the primary mechanism for this action plan. *(Source: Grant, C., "U.S. National Electric Vehicle Safety Standards Summit Summary Report", Fire Protection Research Foundation, www.nfpa.org/Foundation, Quincy MA, 2010)*

- "Lithium Ion Batteries Hazard and Use Assessment": A research study to develop the technical basis for requirements in codes and standards to support the protection requirements for hazards involving lithium ion batteries. This report provides a literature review of battery technology, failure modes and events, usage, codes and standards, and a hazard assessment during the life cycle of storage and distribution. It additionally provides a research approach toward evaluating appropriate facility fire protection strategies for the bulk storage of lithium ion batteries. *(Source: Mikolajczak C., Kahn M., White K., and Long R.T., "Lithium-Ion Batteries Hazard and Use Assessment", Fire Protection Research Foundation, www.nfpa.org/Foundation, Quincy MA, July 2011)*

- "Electrical Vehicle Charging and NFPA Electrical Safety Codes and Standards": A research study that facilitated the safe integration of e-vehicles into the electrical safety infrastructure, by reviewing the technologies likely to impact electrical safety, and presenting an assessment of needed changes to codes and standards along with a roadmap for needed additional research. *(Source: Simonian, L., et al, "Electrical Vehicle Charging and NFPA Electrical Safety Codes and Standards", Fire Protection Research Foundation, www.nfpa.org/Foundation, Quincy MA, 2011)*

- "2nd Annual Electric Vehicle Safety Standards Summit – Summary Report": This was a summit held on 27-28 September 2011 in Detroit, Michigan to bring together the appropriate stakeholder groups to further refine a shared implementation plan to ensure that fire and electrical safety standards impacting e-vehicles do not serve as a barrier to their deployment. *(Source: Grant, C., "2nd Annual Electric Vehicle Safety Standards Summit – Summary Report", Fire Protection Research Foundation, www.nfpa.org/Foundation, Quincy MA, 2011)*

- "Assessment of Powered Rescue Tool Capabilities with High-Strength Alloys and Composite Materials": A research study that assessed the capabilities and existing field inventory of powered rescue tools and their ability to handle high strength steels found in e-vehicles and other new vehicles now proliferating on the highways. *(Source: Merrifield, B. and Grant, C., "Assessment of Powered Rescue Tool Capabilities with High-Strength Alloys and Composite Materials", Fire Protection Research Foundation, www.nfpa.org/Foundation, Quincy MA, 2011)*

- "Personal Protective Equipment for Hybrid and Electric Vehicles": This workshop was held on 1 May 2012 in Quincy, Massachusetts to bring together emergency responders and other stakeholders to develop guiding principles and recommended action steps to address the proper PPE for emergencies involving hybrid or e-vehicles, with a focus on minimizing the risk to emergency responders due to hazards involving electrically energized equipment. This was driven by the vehicle specific emergency response guides from automakers providing conflicting and sometimes contradictory guidance. *(Source: Grant, C., "Personal Protective Equipment for Hybrid and Electric Vehicles", Fire Protection Research Foundation, www.nfpa.org/Foundation, Quincy MA, 2012)*

- "Electric/Hybrid Vehicle Safety Training for Emergency Responders": A training materials development project focused on providing comprehensive awareness and emergency response training for fire fighters and other emergency responders to prepare them for widespread implementation of advanced electric drive vehicles, with objectives to enhance general awareness training and emergency response tactical training, as well as to establish a centralized resource for ongoing technology transfer. *(Source: Klock, A., "Electric/Hybrid Vehicle Safety Training for Emergency Responders", National Fire Protection Association, www.evsafetytraining.org, Quincy MA, 2013)*

- "Lithium Ion Batteries Hazard and Use Assessment Ph. IIB": A research study that provides results of full scale empirical fire tests of high rack storage of common lithium ion batteries, to clarify their flammability characteristics as compared to standard commodities in rack storage. This addressed various sizes of lithium ion batteries, including batteries for electronic devices such as laptops, power tools, cameras, and cell phones. *(Source: Long R.T., Sutula J., and Kahn M., "Lithium-Ion Batteries Hazard and Use Assessment Phase IIB - Flammability Characterization of Li-ion Batteries for Storage Protection", Fire Protection Research Foundation, www.nfpa.org/Foundation, Quincy MA, April 2013)*

- "Best Practices for Emergency Response to Incidents Involving Electric Vehicles Battery Hazards: A Report on Full-Scale Testing Results ": A research study involving full scale fire tests of large format lithium ion e-vehicle batteries to develop the technical basis for emergency response best practices, with consideration for certain details such as suppression methods, PPE, and clean-up/overhaul operations. *(Source: Long R.T., Blum A., Bress T., and Cotts B., "Emergency Response to Incidents Involving Electric Vehicle Battery Hazards", Fire Protection Research Foundation, www.nfpa.org/EVBatteryTests, Quincy MA, July 2013)*

- "Alternative Fuel Vehicle Safety Training Program": Training materials development project focused on providing comprehensive awareness and emergency response training for fire fighters and other emergency responders to prepare them for widespread implementation of alternative fuel vehicles, with objectives to enhance general awareness training and emergency response tactical training, as well as to establish a centralized resource for ongoing technology transfer. *(Source: Klock, A., "Alternative Fuel Vehicle Safety Training", National Fire Protection Association, www.evsafetytraining.org, Quincy MA, 2016)*

- "Hazard Assessment of Lithium Ion Battery Energy Storage Systems": This project develops a hazard assessment to address the usage of lithium ion batteries in energy storage systems (ESS), to allow for the development of safe installation requirements and appropriate emergency response tactics. *(Source: Blum A.F. and Long R.T., "Hazard Assessment of Lithium Ion Battery Energy Storage Systems", Fire Protection Research Foundation, www.nfpa.org/Foundation, Quincy MA, February 2016)*

- "Workshop on Energy Storage Systems and the Built Environment": The Research Foundation coordinated with the Fire Department of New York City (FDNY) to host a workshop on 19 November 2015 with all stakeholders to discuss the installation of electrical Energy Storage Systems (ESS) using technologies such as bulk lithium ion batteries and flow batteries, especially in residential occupancies from high-rise buildings to single- and multi-family homes. The purpose was to clarify the potential hazard, review recommended built-in fire protection measures, and inform fire fighting practices. *(Source: Gorham D.J., "Workshop on Energy Storage Systems and the Built Environment", Fire Protection Research Foundation, www.nfpa.org/Foundation, Quincy MA, March 2016)*

This summit (the "Alternative Fuel Vehicle Safety Summit") seeks to review, validate and identify gaps for the operational training materials used by first and second emergency responders and others handling emergencies with alternative fuel vehicles, with an emphasis on gaseous fuels.

To summarize, this includes addressing activities such as: fire events, non-fire emergencies (e.g., submersion), fire investigation, crash reconstruction, tow and salvage, extrication practices, refueling and charging infrastructure, etc. The deliverables from this summit provide a summary of prioritized needs and gaps from the perspective of emergency responder stakeholders, and promotes activities to address these needs and gaps through all possible approaches. This includes working with vehicle providers to implement inherent safety design solutions through up-front innovative design.

2) Agenda and Presentations

The agenda for the summit is illustrated in Table 1: Summit Agenda. Following welcoming remarks, this is structured to provide an overview of this topic area such as AFV training materials and different fuel types, followed by a dual panel discussion with stakeholders and breakout group discussions, and concluded with a plenary session addressing summary observations.

Table 1 - Summit Agenda

	Item	Time	Speaker
	Registration & Networking	0700-0800	
1)	Introduction & Welcome *(10 min)*	0800-0810	Casey Grant, FPRF
2)	Overview of NFPA Supporting Materials *(15 min)*	0810-0825	Michael Gorin, NFPA
3)	Review of AFV Training Materials *(120 min)*	0825-1000	Jason Emery, WFD
	Morning Break	1000-1015	
3)	Review of AFV Training Materials *(Continued)*	1015-1040	Jason Emery, WFD
4)	Technical Presentations		
4a)	Natural Gas (CNG / LNG) *(20 min)*	1040-1100	Dan Bowerson, NGVA
4b)	Propane (LPG) *(20 min)*	1100-1120	Mike Walters, Superior Energy Systems
4c)	Hydrogen Fuel Cells *(20 min)*	1120-1140	Will James, DOE Fuel Cell Technologies
4d)	Electric Vehicles *(20 min)*	1140-1200	Eric Rask, Argonne
	Networking Lunch *(opening)*	1200-1220	
4e)	AFV Workplace Safety *(Lunchtime Speaker, 20 min)*	1220-1240	Stephan Yborra, Yborra Assoc.
	Networking Lunch *(closing)*	1240-0100	
5)	Dual Panel Disc w/ AFV & ER Stakeholders *(60 min)*	0100-0200	AFV & ER Panelists
6)	Roundtable Breakout Group Discussions		*All Attendees*
6a)	Roundtable Assignments *(15 min)*	0200-0215	Casey Grant, FPRF
	Afternoon Break	0215-0230	
6b)	Roundtable Discussions *(75 min)*	0230-0345	*All Attendees*
7)	Breakout Group Reports *(30 min)*	0345-0415	*All Attendees*
8)	Closing Comments & Conclusion *(15 min)*	0415-0430	Casey Grant, FPRF

The baseline for this topic was established by the following seven presentations: first by Michael Gorin describing the overall AFV Training effort,, second by Jason Emery on the topic of “Review of AFV Training Materials”; third by Dan Bowerson on the topic of “Natural Gas (CNG/LNG)”; fourth by Mike Walters on the topic of “Propane (LPG)”; fifth by Will James on the topic of “Hydrogen Fuel Cells”, sixth by Eric Rask on the topic of “Electric Vehicles”; and seventh by Stephan Yborra on the topic of “AFV Workplace Safety”. These are illustrated in Annex B.

3) Discussion of Needs – Breakout Session Summary

Following introductory remarks and baseline presentations, breakout group discussions were conducted to clarify the collective consensus perspective on a series of key questions. The questions are summarized in Figure 5: Questions for Breakout Groups. For the following questions, the AFV fuel source includes EVs, fuel cells, gaseous fuels, etc., and emergency events include fire events, non-fire emergencies (e.g., submersion), fire investigation, crash reconstruction, tow and salvage, extrication practices, refueling and charging infrastructure, etc.

Roundtable Breakout Group Questions

1) **Baseline Differences:** Emergency responders deal with emergency events involving traditional ICE (internal combustion engine) vehicles on a regular basis. With this as a baseline, what makes each AFV fuel source different from this baseline? (i.e., what are the primary concerns / hazards that require additional attention? Consider each fuel and each general scenario.
2) **Specific Technical Questions for Fire:**
   Pressure Relief Design Considerations
   a) What is the basis for determining the temperature settings for pressure relief devices?
   b) What is the basis for determining the venting direction of pressure relief devices?

   ER Tactical Considerations
   c) What consideration should be given to ER water application for the design of the pressure relief device temperature setting?
   d) What tactical guidance should be provided to ERs for cooling (e.g., water application) of pressure relief devices?
   e) What are best practices for fire extinguishment?

   Storage Vessel Design Considerations
   f) What methods are being looked at to provide comprehensive real-time sensors (e.g., heat detection) for the entire storage vessel (e.g., along the full length)?
   g) What methods are being looked at to provide better storage vessel protection against fire exposure (e.g., insulation)?

   Other?
3) **Aftermarket and DIY:** How will be the problems and implications with service and other work done by non-qualified people, and how should these be addressed?
4) **Investigations:** Clarify the special challenges for investigators, and what original design considerations are important or needed?
5) **Post Event Handling:** What is the special handling guidance for post event handling (different from baseline)?
6) **High Frequency – Low Severity Events:** What special considerations are important for common events that are not high severity but raise safety questions (partially damaged vehicle with full fuel)?
7) **Research Gaps:** What research is currently needed? What is the priority for this research?
8) **Future Trends:** With continually evolving technologies and materials, what other AFV issues should be considered, now and in the future?
9) **Other issues?** Are there any other issues not addressed elsewhere? For AFV safety, are there any declarative statements on this topic that are important and should be stated?

Figure 5: Roundtable Breakout Group Questions

The breakout groups were evenly balanced with a diverse mix of attendees. They were given a neutral identifier as follows: Yellow Group; Blue Group; Green Group; and Red Group. They collectively reported back during the plenary session with the following:

1) ***<u>Baseline Differences:</u>*** *<u>Emergency responders deal with emergency events involving traditional ICE (internal combustion engine) vehicles on a regular basis. With this as a baseline, what makes each AFV fuel source different from this baseline? (i.e., what are the primary concerns / hazards that require additional attention? Consider each fuel and each general scenario.</u>*
    - Challenges of AFV hazards are different, but not necessarily more or less hazardous.
    - Full EVs have lots of similarities but are less similar to ICE vehicles than gaseous fuels.
    - Hybrid EVs have lots of variables with continuing need to be addressed.
    - Gaseous fuels are arguably less hazardous. They have greater levels of safety.
    - Lack of knowledge at an emergency is a concern. With knowledge the event is straight-forward (i.e., vehicle badging is important).
    - Consistent badging and labeling should be promoted (similar to and consistent with ICE vehicles).

2) ***<u>Specific Technical Questions for Fire:</u>***
    <u>Pressure Relief Design Considerations</u>
    a) *<u>What is the basis for determining the temperature settings for pressure relief devices?</u>*
        - Temperature thresholds are already well established for certain specific situations and fuels (e.g., based on UL132).
        - Important variables need to be considered, such as high pressures, cryogenics, vessel design, etc.
        - There is a concern between steel tanks versus composite tanks, and how best to deal with them during a fire.
        - This is very fuel dependent, among other important variables.

    b) *<u>What is the basis for determining the venting direction of pressure relief devices?</u>*
        - Venting direction is a concern.
        - Further research, training and education is important on this topic.
        - This should be directly addressed by the OEMs and others, via codes (e.g., SAE) and other impactful methods.
        - Establish a universal baseline approach, and then deviate from this as appropriate.
        - Concern for aftermarket vehicles and designs.

    <u>ER Tactical Considerations</u>
    c) *<u>What consideration should be given to ER water application for the design of the pressure relief device temperature setting?</u>*
        - More research is needed.
        - This is a major shift in fire fighting tactics, and thus is a concern and important.
        - We need SOPs and tools to address stranded energy of all fuels in the field (including for all first and second emergency responders)

    d) *<u>What tactical guidance should be provided to ERs for cooling (e.g., water application) of pressure relief devices?</u>* See responses above to 2(c).

e) *What are best practices for fire extinguishment?*
   - For extinguishing media, more research is needed along with validation of that research.
   - One size does not fit all for extinguishing media.
   - Tactics also need to be clarified, including when to “let it burn”.

Storage Vessel Design Considerations

f) *What methods are being looked at to provide comprehensive real-time sensors (e.g., heat detection) for the entire storage vessel (e.g., along the full length)?*
   - Consider RFID or similar approaches to address badging and other sensor/knowledge issues.
   - Enable on-scene telematics for emergency responders.
   - Avoid the difficulties of physical badging which are complicated, and focus on a cyber delivery of information to emergency responders on scene.
   - Collect cyber vehicle data at emergency events to populate national data collections going forward.

g) *What methods are being looked at to provide better storage vessel protection against fire exposure (e.g., insulation)?* See responses above to 2(f).

Other? See responses above to 2(f).

3) ***Aftermarket and DIY:*** *How will be the problems and implications with service and other work done by non-qualified people, and how should these be addressed?*
   - Aftermarket and DIY are a problem.
   - The use of qualified and properly credentialed personnel (e.g., service) should be promoted.
   - Clarify the need to establish oversight of aftermarket vehicle designs to assure minimal levels of safety.
   - Treat all vehicles according to the greatest possible hazard until clarified otherwise.

4) ***Investigations:*** *Clarify the special challenges for investigators, and what original design considerations are important or needed?*
   - Investigators are often re-powering damaged vehicles to harvest vehicle information.
   - Harvesting black box information in a post event needs to be considered in the original vehicle designs.

5) ***Post Event Handling:*** *What is the special handling guidance for post event handling (different from baseline)?*
   - Provide support for investigators to harvest black box information.
   - Consider other non-technical issues that support the needs of investigators, such as legal, privacy of information, etc.
   - Training and education are needed to not activate critical vehicle systems that will re-introduce a hazard.
   - Tow and salvage is important, and should be given proper attention so that a potential hazard is properly handling post event.
   - Stranded energy of fuels, and especially with electrical energy, is important and not adequately resolved.

- Establish an emergency responder information clearinghouse for real-time emergency responder information.

6) ***High Frequency – Low Severity Events:*** *What special considerations are important for common events that are not high severity but raise safety questions (partially damaged vehicle with full fuel)?*
   - Need to clarify and possibly define a "Compromised vehicle"
   - One size does not fit all.
   - Work closely with the OEMs
   - Methods are needed in the field for determining the stability and state of charge of damaged batteries, and to safely dissipate stranded energy.

7) ***Research Gaps:*** *What research is currently needed? What is the priority for this research?*
   - Clarification of fire fighting tactics is needed for various gaseous fuel tank designs, to clarify when and when not to apply water.
   - Lithium ion battery fire suppression effectiveness.
   - Ventilation of fuels in confined areas (e.g., garages).
   - SOPs and SOGs for 911 call receivers.
   - Pressure relief devices for gaseous fuels require demonstration tests as proof of concept for emergency responder tactics.
   - Numerous items covered earlier.
   - Develop technology, tools and methods that will monitor the state of health of primary hazards of AFVs.

8) ***Future Trends:*** *With continually evolving technologies and materials, what other AFV issues should be considered, now and in the future?*
   - Be aware of proposed 48V systems in vehicles, which are below the threshold of SAE hi-voltage) but arguably still a significant hazard.
   - Consider arc-flash and arc-blast.
   - Monitor and stay involved with the European based standards effort involving ECE R100 for batteries.
   - Express concerns to the ECE R100 arena that their primary criteria of one hour observations after their tests does not consider the thermal runaway concerns of emergency responders when dealing with damaged electrical batteries.
   - Address second life uses of vehicle systems and components, such as with electrical energy storage systems.
   - Consider emerging new technologies, such as low pressure absorption systems and massless batteries (with batteries built into the vehicle structure).

9) ***Other issues?*** *Are there any other issues not addressed elsewhere? For AFV safety, are there any declarative statements on this topic that are important and should be stated?*
   - Promote success stories, including the proactive positive approach of this overall effort.
   - Clarify regulations for remote fueling sites and portable charging and re-fueling, such as used for fleets.
   - Consider marine applications.
   - Continue to push for innovative solutions to the stranded electrical energy problem.

4) Summary Observations

This Alternative Fuel Vehicle Safety Summit provides and important and useful review, validation and identification of gaps for emergency responder operational training materials on AFVs, These training materials are used by first and second emergency responders and others handling emergencies with alternative fuel vehicles, with an emphasis on gaseous fuels.

The scope of this effort includes addressing emergency activities such as: fire events, non-fire emergencies (e.g., submersion), fire investigation, crash reconstruction, tow and salvage, extrication practices, refueling and charging infrastructure, etc. The deliverables from this summit provide a summary of prioritized needs and gaps from the perspective of emergency responder stakeholders, and promotes activities to address these needs and gaps through all possible approaches. This includes working with vehicle providers to implement inherent safety design solutions through up-front innovative design.

The key summary observations from this summit are the following:

1) **GENERAL HAZARD CONCERNS**
   a) **AFV Hazards:** In training materials and tactical approaches, treat all vehicles according to the greatest possible hazard until clarified otherwise. Tactics for offensive and defensive attacks need to be clarified, including when to "let it burn". The challenges of AFV hazards are different, but not necessarily more or less hazardous.
   b) **Aftermarket Vehicles**: Aftermarket and DIY vehicles continue to be a concern. Generally promote the use of qualified and properly credentialed personnel (e.g., service). Clarify the need to establish oversight of aftermarket vehicle designs to assure minimal levels of safety.
   c) **High Frequency – Low Severity Events**: Need to clarify and possibly define a "Compromised vehicle" to allow development of guidance information for emergency responders on common emergency events that are not severe. One size does not fit all, and need to work closely with the OEMs on this topic due to the implications.

2) **ELECTRONIC BADGING**
   a) **Badging**: Consider RFID or similar approaches to address badging and other sensor/knowledge issues. Avoid the difficulties of physical badging which are complicated, and focus on a cyber delivery of information to emergency responders on scene. Enable on-scene telematics for emergency responders. Work to implement this sooner rather than later, to take advantage of new vehicle-to-vehicle technologies that are now emerging in the marketplace. The lack of knowledge at an emergency is a pressing concern, since with knowledge the event becomes more straight-forward (i.e., vehicle badging is critically important).
   b) **Data Collection**: Collect cyber and electronic vehicle data at emergency events to populate national data collections going forward.
   c) **Emergency Responder Clearinghouse**: Establish an emergency responder information clearinghouse for real-time emergency responder information. (Note: the establishment of cyber-badging approaches impacts this need).
   d) **Monitoring System Status**: Continue developing technology, tools and methods that will monitor the state of health of primary hazards of AFVs. Provide this information to emergency responders at an emergency in a common, universally recognized format.

3) FIRE FIGHTING TACTICS

a) **Establishing a Baseline Fire Fighting Approach:** Establish a universal baseline approach for AFVs, and then deviate from this as appropriate. Gaseous fuels are perceived to be less hazardous, and they have greater levels of safety. Important variables need to be considered, such as high pressures, cryogenics, vessel design, etc. Temperature thresholds are already well established for certain specific situations and fuels (e.g., based on UL132).

b) **Fire Extinguishing Media**: For extinguishing media with AFVs, provide more research along with validation of that research. One size does not fit all for extinguishing media. Fresh water is the recognized baseline extinguishing media.

c) **Gaseous Fire Fighting Water Application:** Clarify when to apply water for a gaseous fuels fires depending on the vessel design. Not applying water in all cases is a major shift in the basic fire fighting tactical approach, and thus a concern and important. There is a concern between steel tanks versus composite tanks, and how best to deal with them during a fire.

d) **Gaseous Fuel Storage Venting:** Venting direction during a fire event is an on-going concern. Provide further research, training and education on this topic to optimize the best approach to a venting tank during a fire. Provide demonstration tests as proof of concept for emergency responder tactics to clarify the approach for pressure relief devices in a gaseous fuels fire.

e) **Gaseous Fuel Ventilation in Confined Areas**: Clarify the hazards of ventilation of gaseous fuels in confined areas (e.g., garages) and address in training and education materials.

4) INVESTIGATIONS

a) **Harvesting Data from Damaged Vehicles**: Address the harvesting of black box information in a post emergency event into the original vehicle design. Investigators are often re-powering damaged vehicles to harvest vehicle information, and they need support to safely harvest black box information.

b) **Non-Technical Data Issues**: Consider other non-technical issues that support the needs of investigators, such as legal, privacy of information, etc., and thus assure that harvesting vehicle data is accomplished by the appropriate professionals.

c) **Training and Education**: Provide training and education to safely re-activate critical vehicle systems in a manner that will not re-introduce un-anticipated hazards. Clarify details to maintain full control of all re-generated hazards, and establish procedures for returning a damaged vehicle to a safe condition.

5) STRANDED ENERGY

a) **Hazard of Stranded Energy**: Stranded energy of fuels, and especially with electrical energy, is important and not adequately resolved. This significantly impacts when emergency responders can declare an emergency event "safe". Tow and salvage are especially impacted, and should be given proper attention so that a potential hazard is properly handling post event.

b) **Procedures and Guidelines:** Develop needed SOPs, SOGs and related tools to address stranded energy of all fuels in the field (including for all first and second emergency responders.

6) OTHER ISSUES AND TRENDS

a) **Emerging Technologies**: Consider emerging new technologies, such as low pressure absorption systems and massless batteries (with batteries built into the vehicle structure).

b) **Marine Applications**: Consider marine applications.

c) **Promote Overall Program Success**: Promote success stories, including the proactive positive approach of this overall effort.
d) **Remote Re-fueling and Re-charging**: Clarify regulations for remote fueling sites and portable charging and re-fueling, such as used for fleets.
e) **Revised System Voltages**: Be aware of proposed 48V systems in vehicles (which are below the threshold of SAE hi-voltage) but arguably still a significant hazard.
f) **Telecommunicators**: Develop recommended guidance (via SOPs and SOGs) for 911 call receivers.
g) **Second Life Uses**: Address second life uses of vehicle systems and components, such as with electrical energy storage systems.
h) **Standardization**: Monitor and stay involved with the noteworthy European based standards effort involving ECE R100 for batteries. In doing so, express concerns to the ECE R100 arena that their primary criteria of one hour observations after their tests does not consider the thermal runaway concerns of emergency responders when dealing with damaged electrical batteries.

The key summary observations from this summit address: general hazard concerns; electronic badging; fire fighting tactics; investigation; stranded energy; and other issues and trends. Of particular note, the Summit highlights the following:

- Need to address implementation of electronic badging technologies as soon as possible to enable real-time emergency event size-up and prospective data collection;
- Clarifying the tactical fire fighting approach for the venting of gaseous fuel storage vessels depending on the vessel material (i.e., metal versus composite);
- Addressing the needs of investigators to re-power damaged vehicles to harvest post event data; and
- Continuing to address the problem of stranded energy and its long time frame impact on first and second emergency responders.

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Annex A: Summit Participants and Attendees

The Summit was facilitated by Casey Grant of the Fire Protection Research Foundation. The presenters included in Table 2: Summary of Summit Presenters, represent the individuals who made a formal presentation at the "*Alternative Fuel Vehicle Safety Summit*", held in The Westin Book Cadillac, Detroit, MI on 23 June, 2016. The available slides from these presentations are included in Annex B.

Table 2: Summary of Summit Presenters

Michael Gorin, NFPA
Jason Emery, NFPA (& Emergency Training Solutions and Waterford Fire Dept.)
Dan Bowerson, Natural Gas Vehicles for America (NGVA)
Mike Walters, Superior Energy Systems
Will James, DOE Fuel Cell Technologies
Erick Rask, Argonne National Laboratory
Stephen Yborra, Yborra & Associates

The Summit included a well-balanced cross-sectional mix of attendees. Table 3: Summary of Summit Attendees provides a full list of Summit attendees at the "*Alternative Fuel Vehicle Safety Summit*", held in The Westin Book Cadillac, Detroit, MI on 23 June, 2016.

Table 3: Summary of Summit Attendees

Daniel Bates, NY State Police
Dan Bowerson, Natural Gas Vehicles for America (NGVA)
Dave Bryson, DOT
Ron Butler, Energy Storage Safety Products International
Jim Carroll, Connecticut Fire Academy / Wallingford Fire Dept.
Victor Chevrette, Washtenaw County Hazardous Materials Response Team
Gregg Cleveland, LaCrosse (WI) Fire Dept.
Ed Conlin, NFPA
John Cunningham, Nova Scotia Firefighter's School
Jason Emery, NFPA (& Emergency Training Solutions and Waterford Fire Dept.)
Jim Francfort, DOE Idaho National Labs

Gregory Frederick, Louisville Division of Fire

Philip Gonzales, Ford Motor Company

Michael Gorin, NFPA

Gary Graham, General Motors

Casey Grant, FPRF

Will James, DOE Fuel Cell Technologies

John Jordan, Agility Fuel Systems

Dan Kimball, Ypsilanti Fire Dept.

Andrew Klock, NFPA

Todd Macintosh, General Motors

Terence McDonnell, New York State Police

Timothy Morgan, City of Warren (MI)

Larry Munson, BAE Systems

Erick Rask, Argonne

Scott Schmidt, Alliance of Automobile Manufacturers

Kenneth Smith, New York State Police

Q. Sheila Turner, FCA US LLC

Mike Walters, Superior Energy Systems

Jeff Williams, Ford Motor Company

Keith Wilson, Global Ground Vehicle Standards

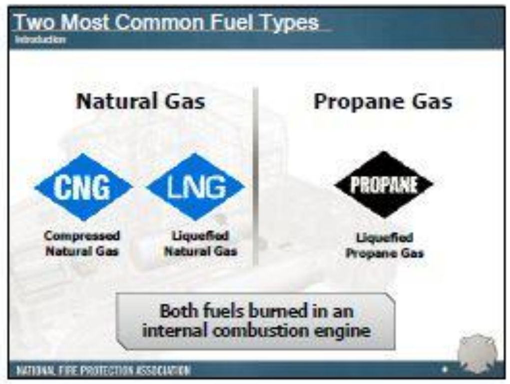
Stephen Yborra, Yborra & Associates

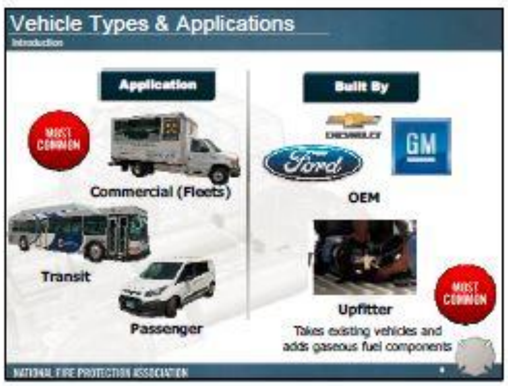
Annex B: Presentation Slides

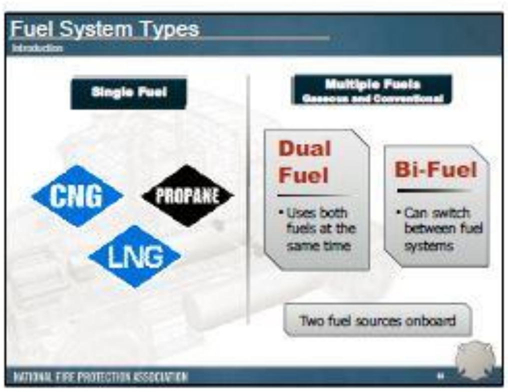
Figure 6: Slides from Michael Gorin, NFPA (page 1 of 2)

Figure 7: Slides from Michael Gorin, NFPA (page 2 of 2)

Figure 8: Slides from Jason Emery, NFPA (page 1 of 25)







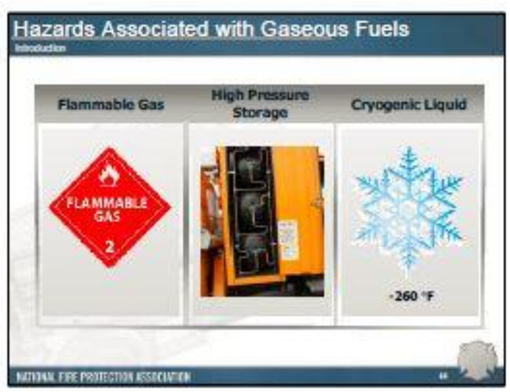


Figure 9: Slides from Jason Emery, NFPA (page 2 of 25)

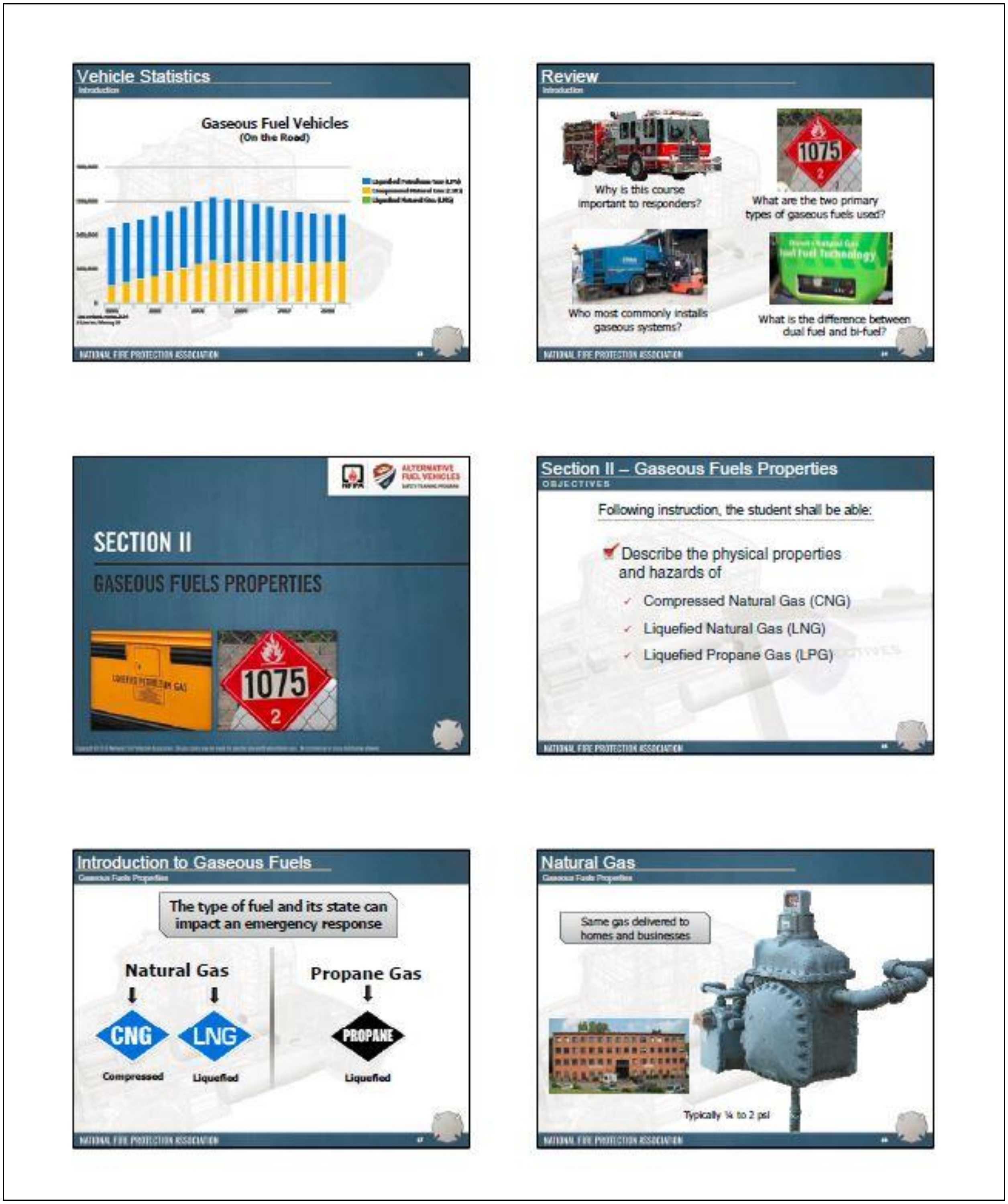


Figure 10: Slides from Jason Emery, NFPA (page 3 of 25)

Figure 11: Slides from Jason Emery, NFPA (page 4 of 25)

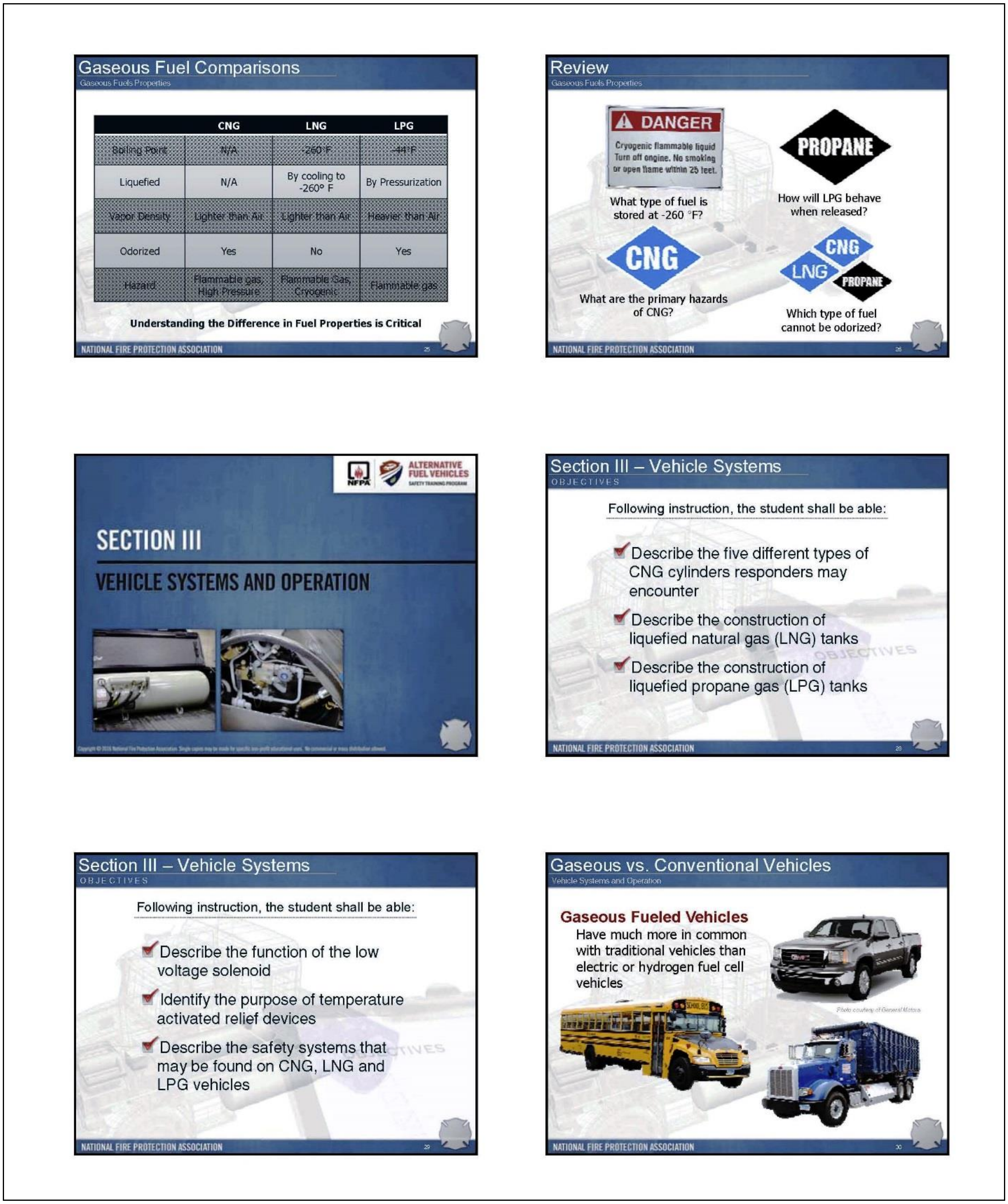
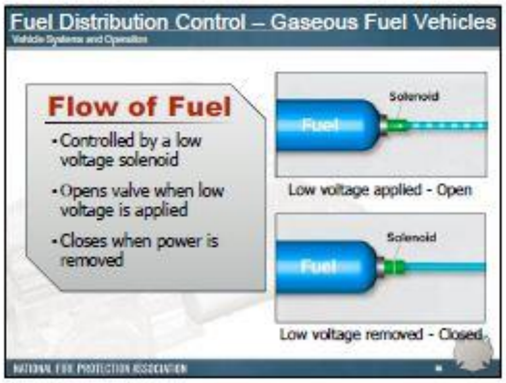


Figure 12: Slides from Jason Emery, NFPA (page 5 of 25)



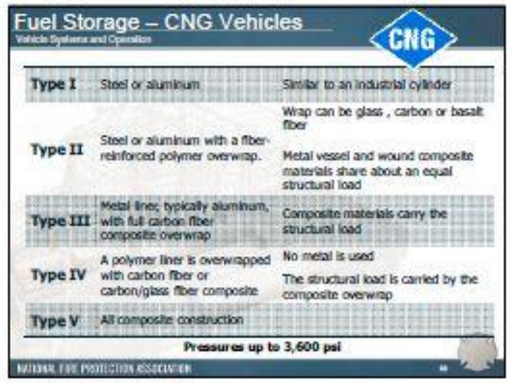
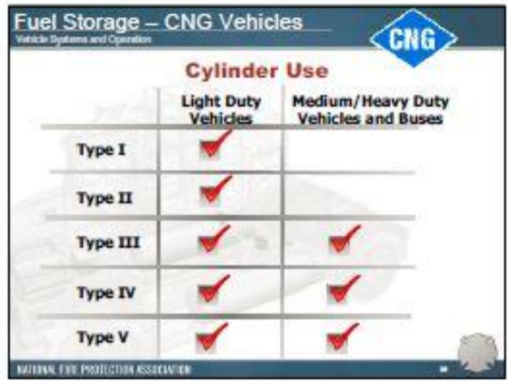
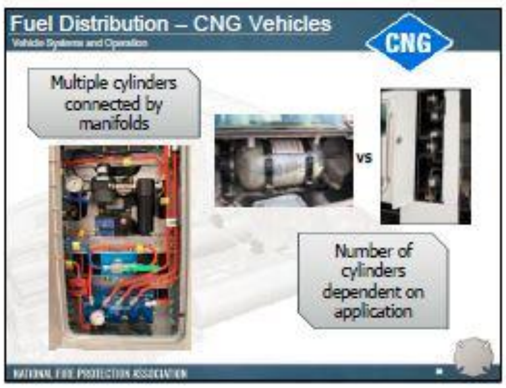
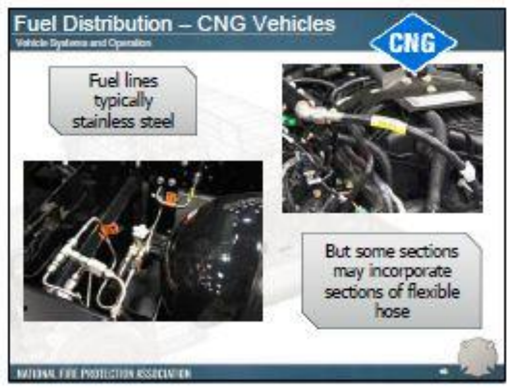
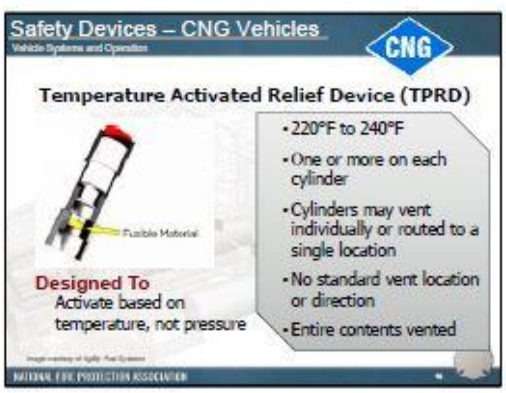


Figure 13: Slides from Jason Emery, NFPA (page 6 of 25)









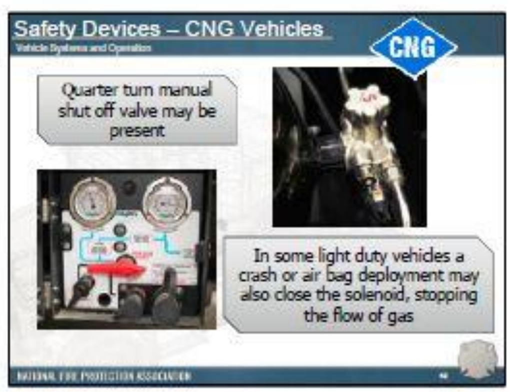


Figure 14: Slides from Jason Emery, NFPA (page 7 of 25)

Figure 15: Slides from Jason Emery, NFPA (page 8 of 25)

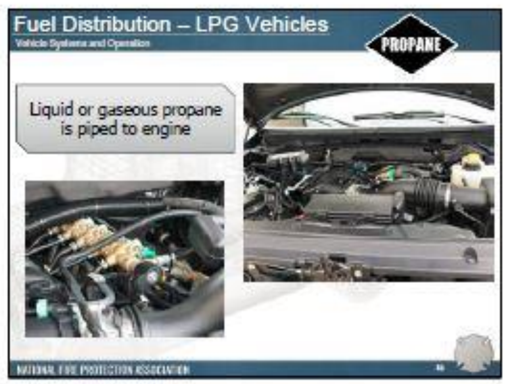
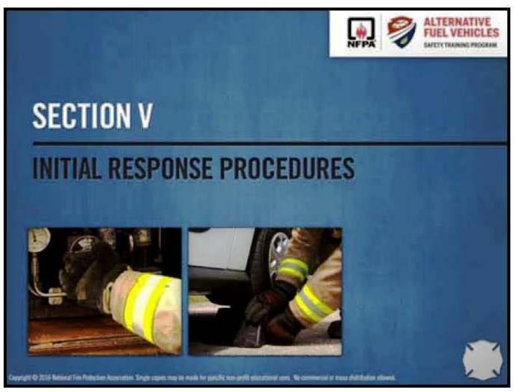


Figure 16: Slides from Jason Emery, NFPA (page 9 of 25)

Figure 17: Slides from Jason Emery, NFPA (page 10 of 25)

Figure 18: Slides from Jason Emery, NFPA (page 11 of 25)



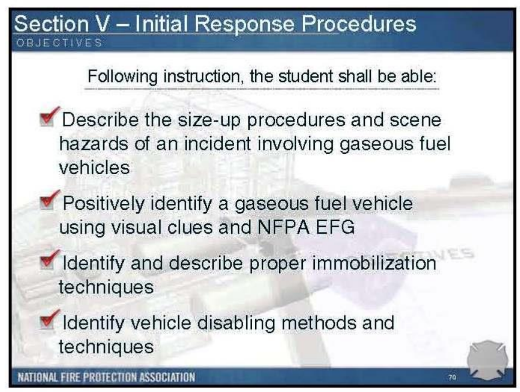


Figure 19: Slides from Jason Emery, NFPA (page 12 of 25)

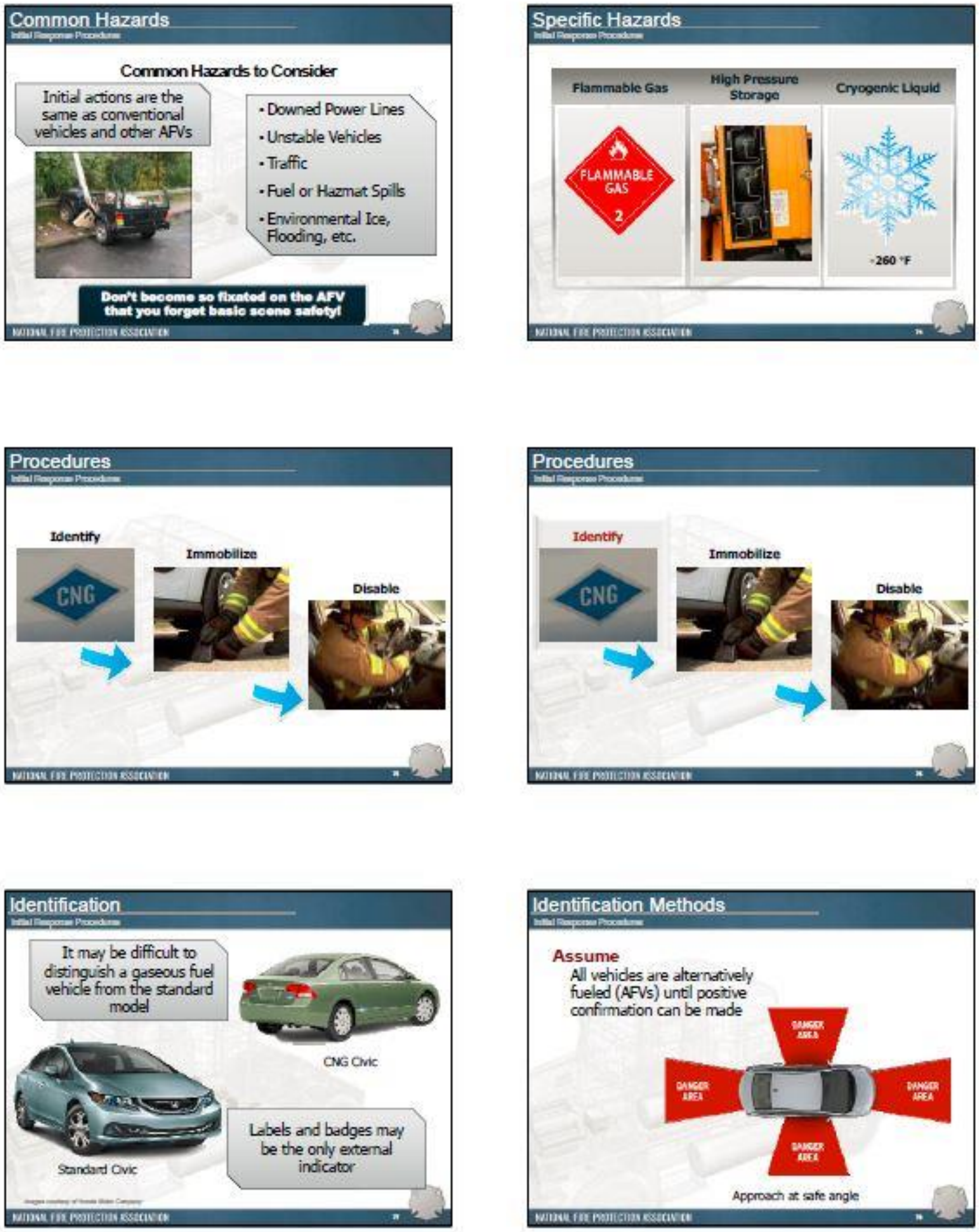


Figure 20: Slides from Jason Emery, NFPA (page 13 of 25)

Figure 21: Slides from Jason Emery, NFPA (page 14 of 25)

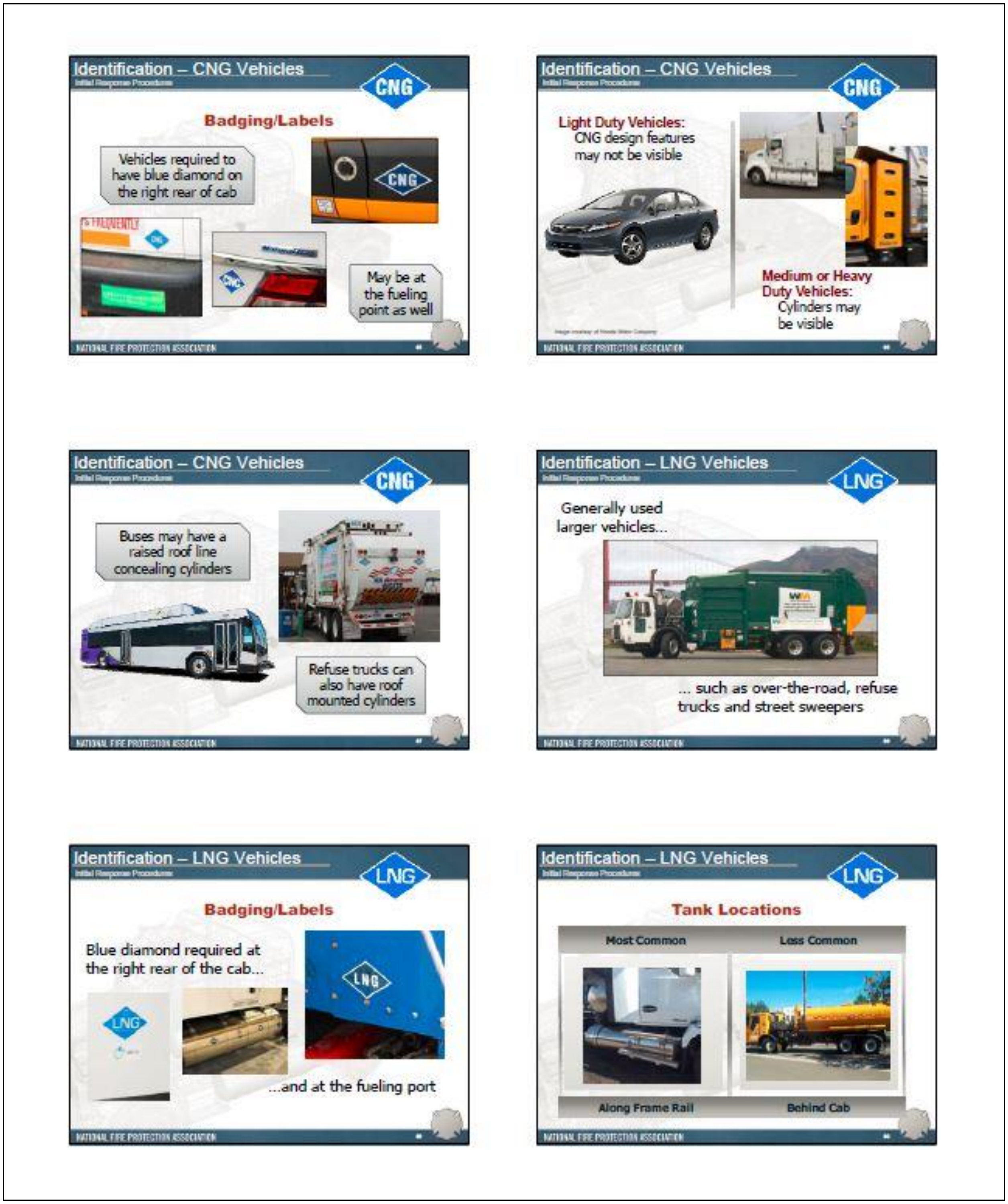


Figure 22: Slides from Jason Emery, NFPA (page 15 of 25)

Figure 23: Slides from Jason Emery, NFPA (page 16 of 25)

Figure 24: Slides from Jason Emery, NFPA (page 17 of 25)

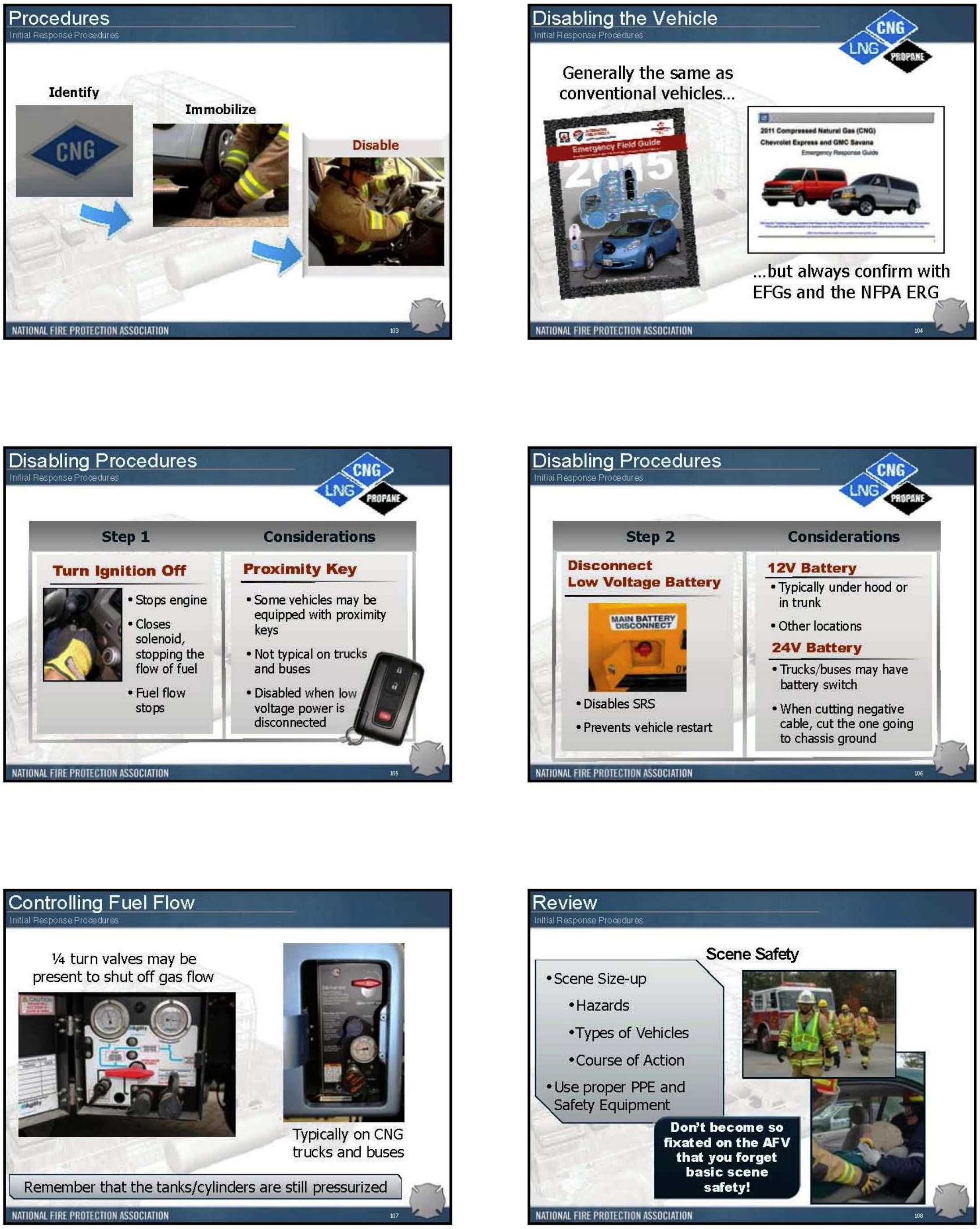
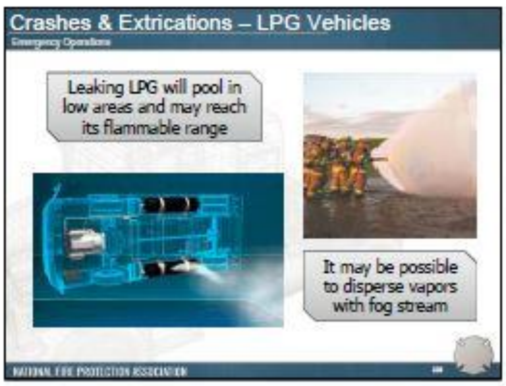


Figure 25: Slides from Jason Emery, NFPA (page 18 of 25)

Figure 26: Slides from Jason Emery, NFPA (page 19 of 25)

Figure 27: Slides from Jason Emery, NFPA (page 20 of 25)



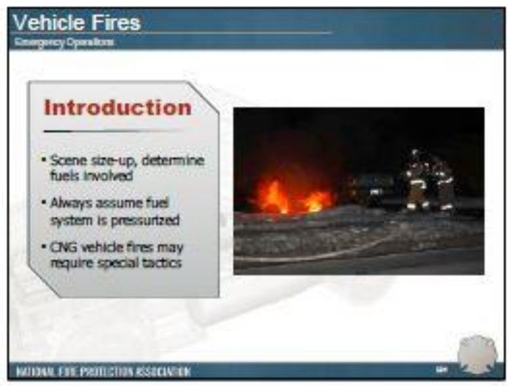
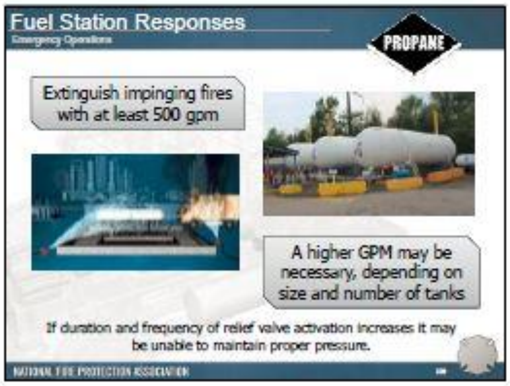
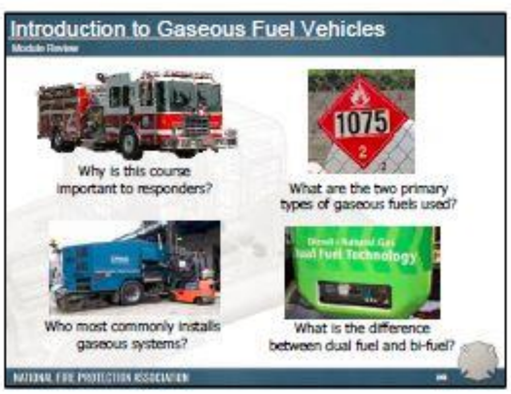


Figure 28: Slides from Jason Emery, NFPA (page 21 of 25)

Figure 29: Slides from Jason Emery, NFPA (page 22 of 25)

Figure 30: Slides from Jason Emery, NFPA (page 23 of 25)





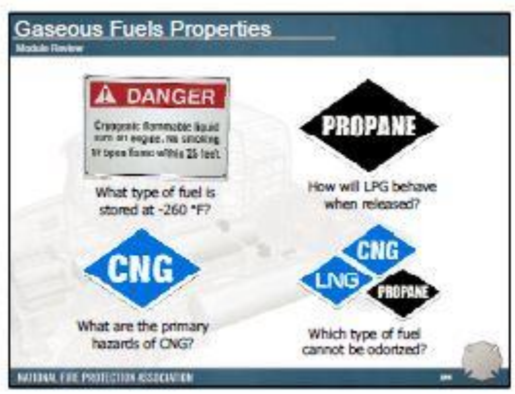
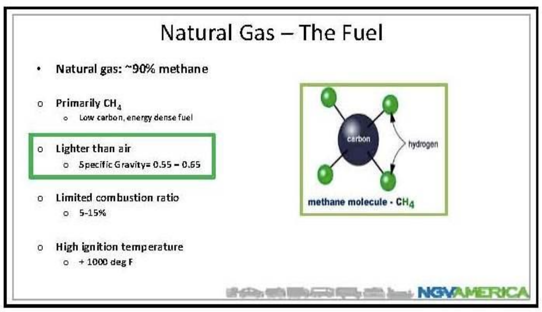


Figure 31: Slides from Jason Emery, NFPA (page 24 of 25)

Figure 32: Slides from Jason Emery, NFPA (page 25 of 25)



Fuel Properties

	CNG	LNG	Gasoline	Diesel
Physical State	Compressed Gas	Cryogenic Liquid @ -220°F	Liquid	Liquid
Vapor density vs. air	Rise	Rise (in gaseous state)	Sink	Sink
Storage Pressure	3,600 psi	Less than 220 psi	N/A	N/A
Flammable Range	5% - 15%	5% - 15%	1.2% - 7.1%	0.6% - 7.5%
Ignition Temperature	1,100°F	1,100°F	495°F	600°F

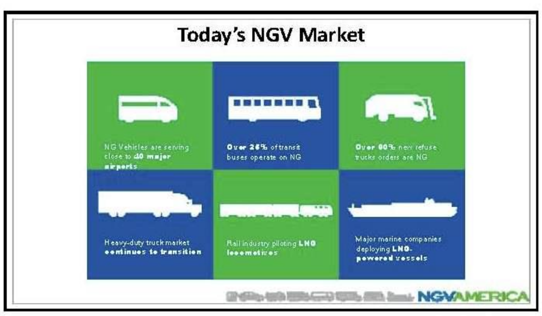
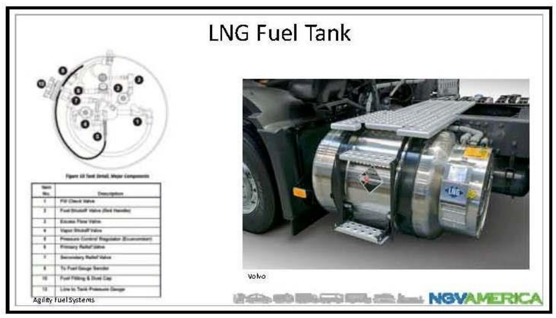
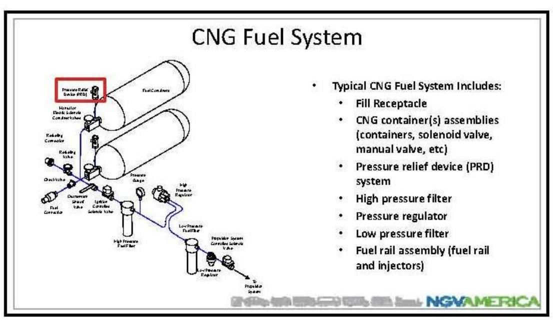


Figure 33: Slides from Dan Bowerson, NGVA (page 1 of 4)





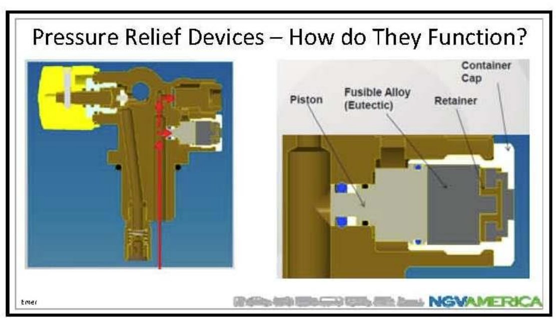
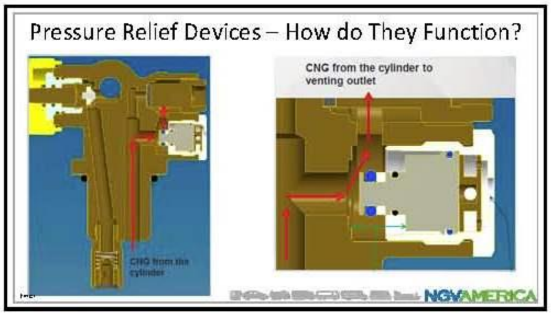


Figure 34: Slides from Dan Bowerson, NGVA (page 2 of 4)



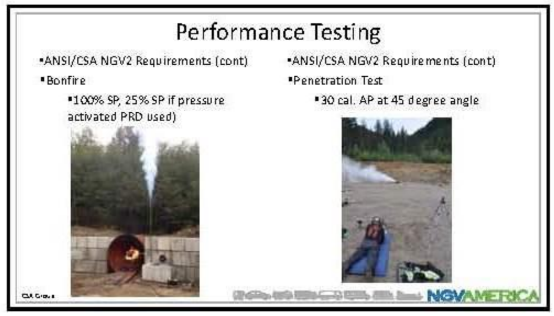


Figure 35: Slides from Dan Bowerson, NGVA (page 3 of 4)

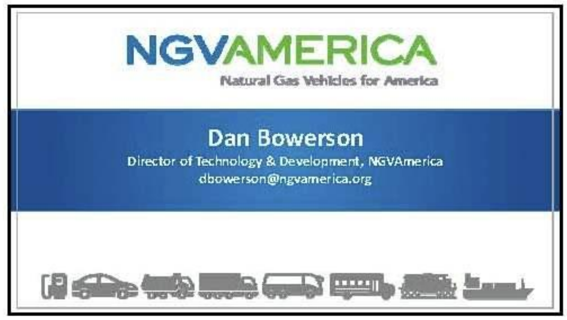


Figure 36: Slides from Dan Bowerson, NGVA (page 4 of 4)

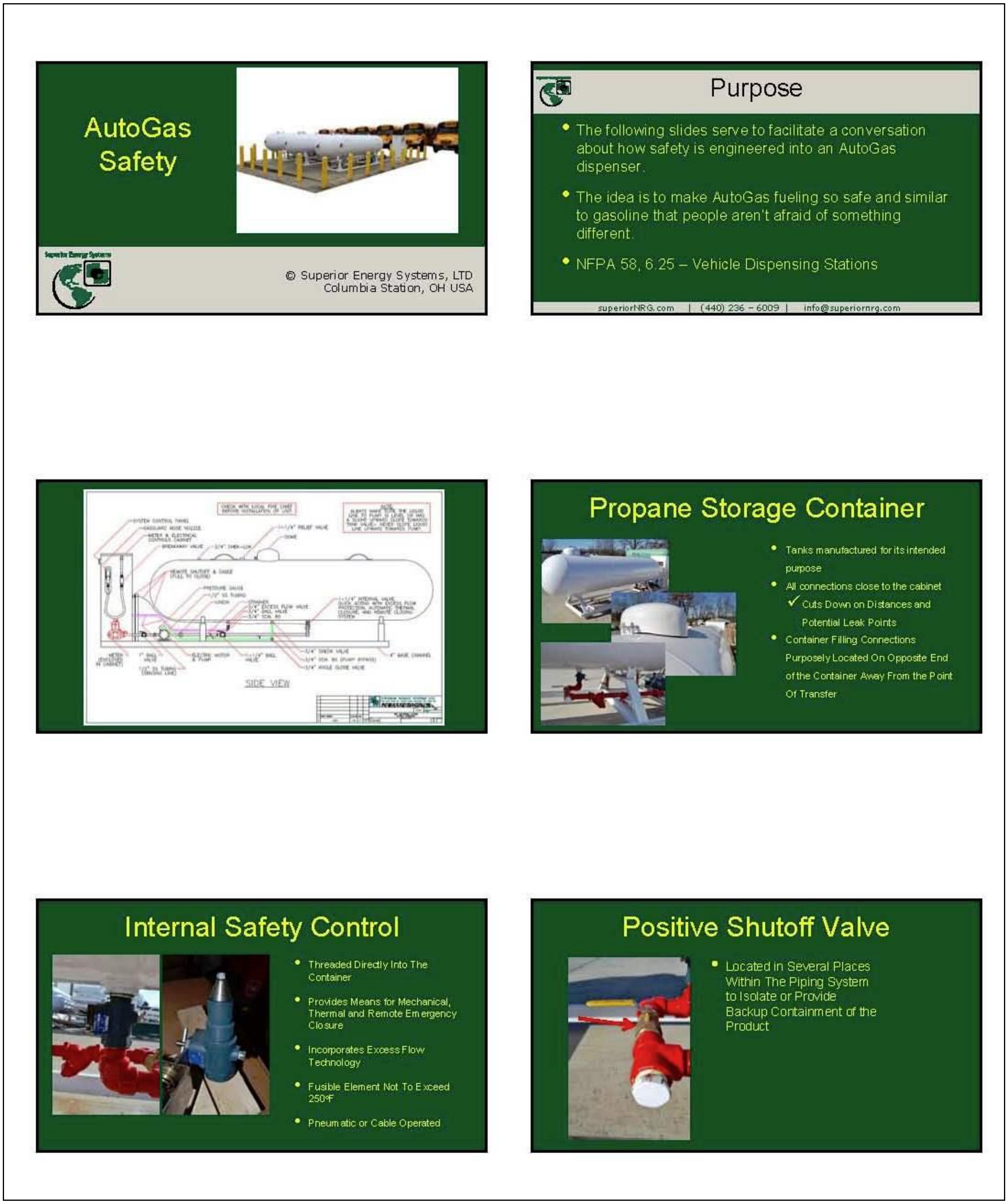


Figure 37: Slides from Mike Walters, Superior Energy Solutions (page 1 of 4)

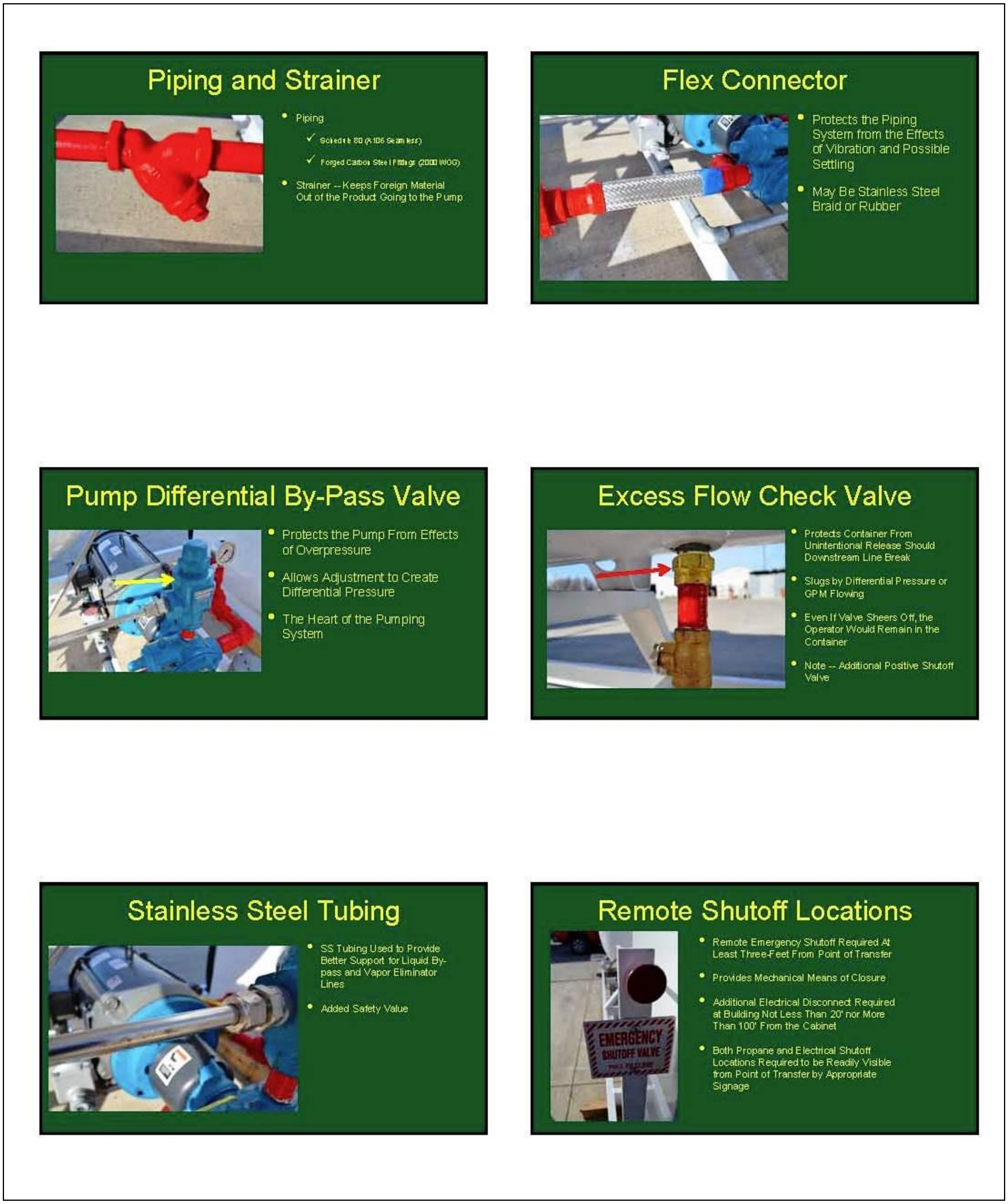
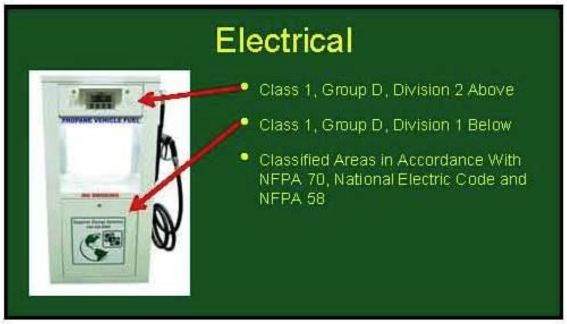


Figure 38: Slides from Mike Walters, Superior Energy Solutions (page 2 of 4)

Figure 39: Slides from Mike Walters, Superior Energy Solutions (page 3 of 4)



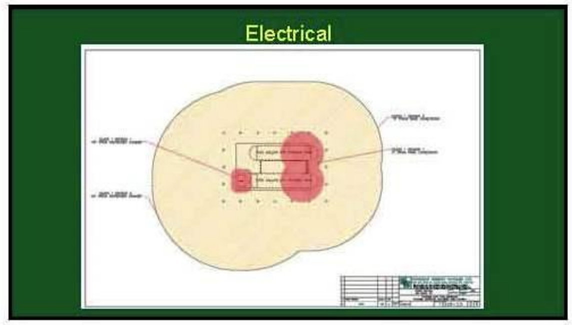
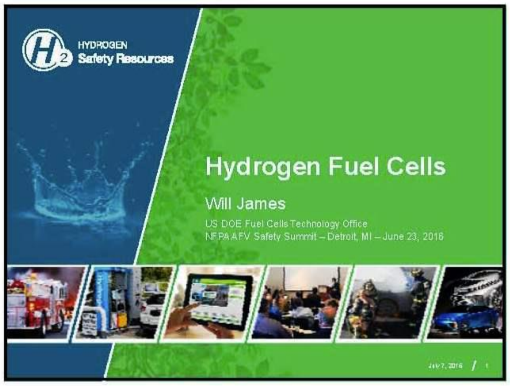
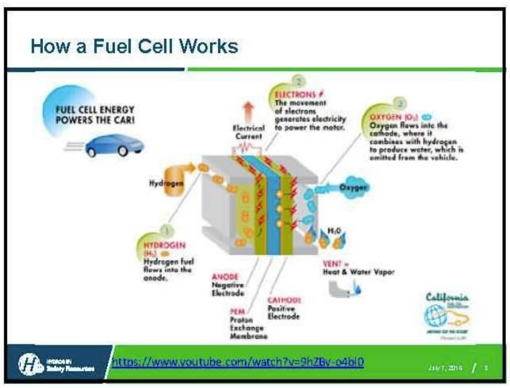
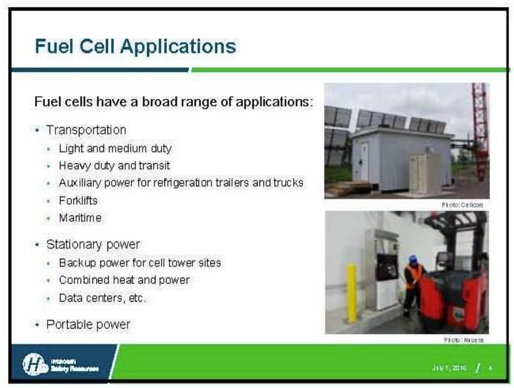


Figure 40: Slides from Mike Walters, Superior Energy Solutions (page 4 of 4)







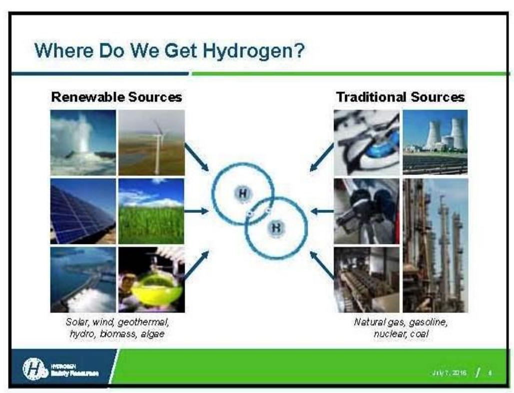


Figure 41: Slides from Will James, DOE Fuel Cell Technologies (page 1 of 5)

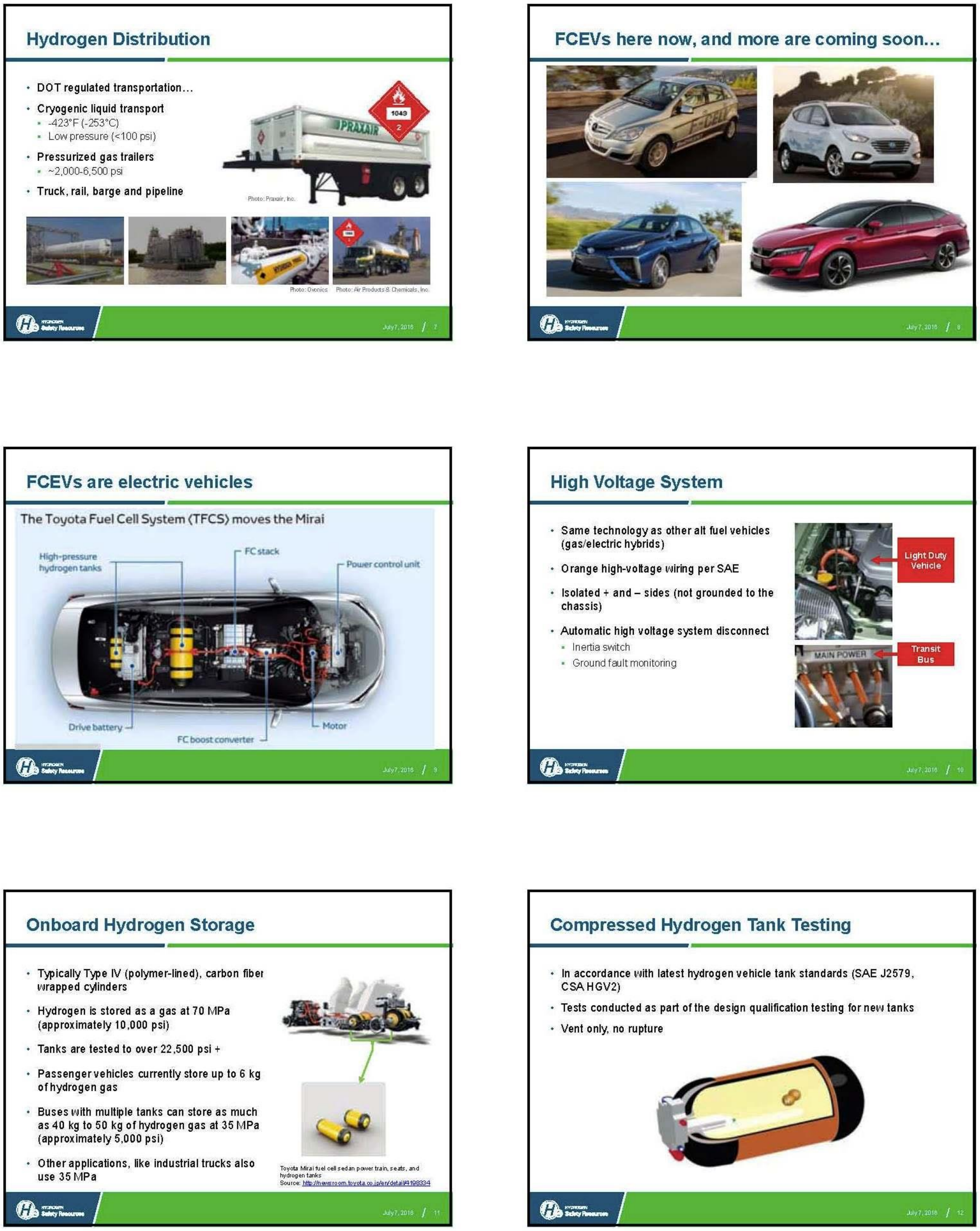
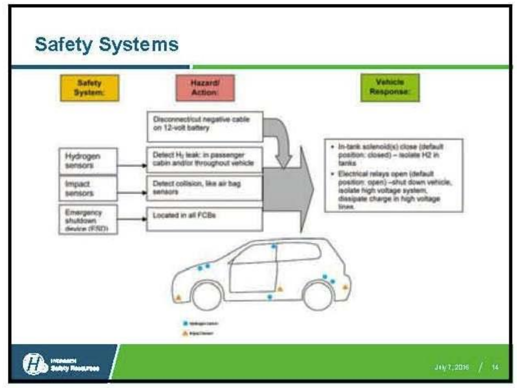
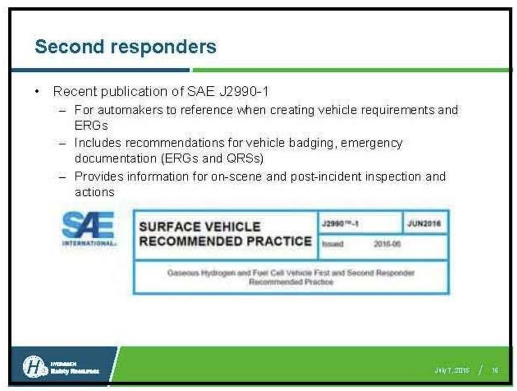


Figure 42: Slides from Will James, DOE Fuel Cell Technologies (page 2 of 5)





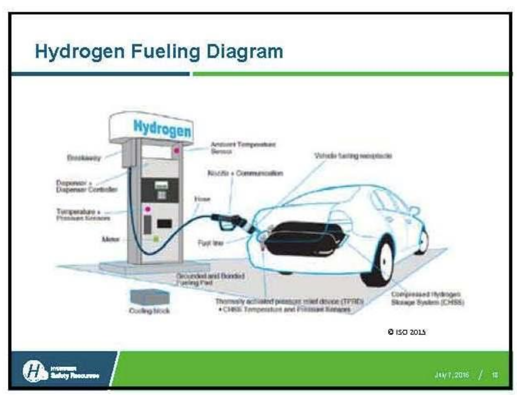
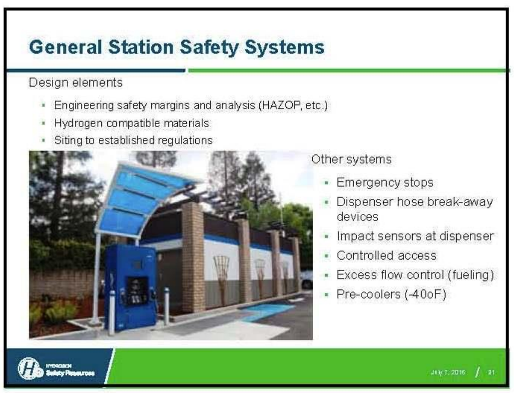
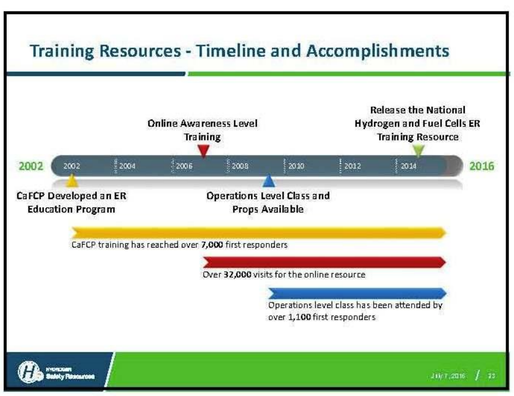


Figure 43: Slides from Will James, DOE Fuel Cell Technologies (page 3 of 5)





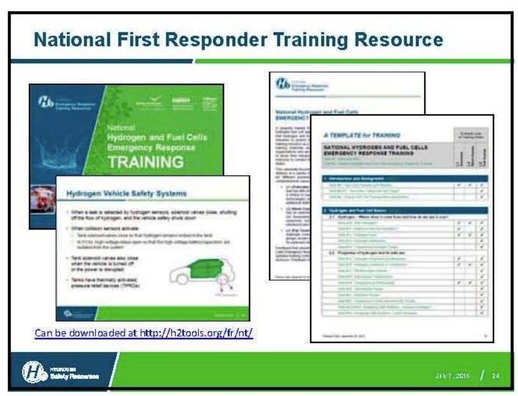


Figure 44: Slides from Will James, DOE Fuel Cell Technologies (page 4 of 5)

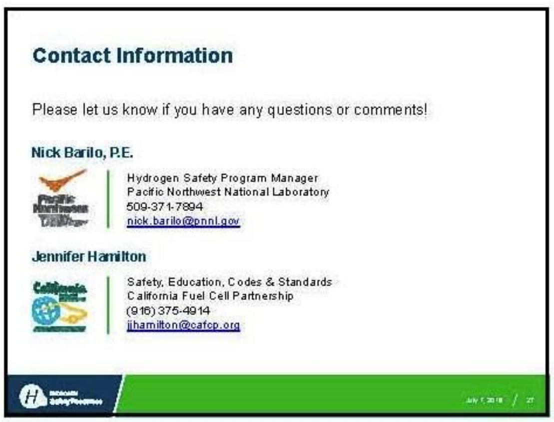
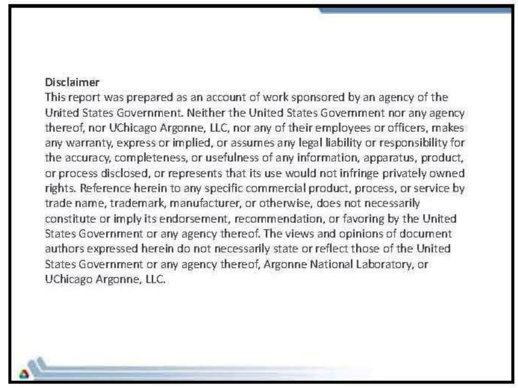
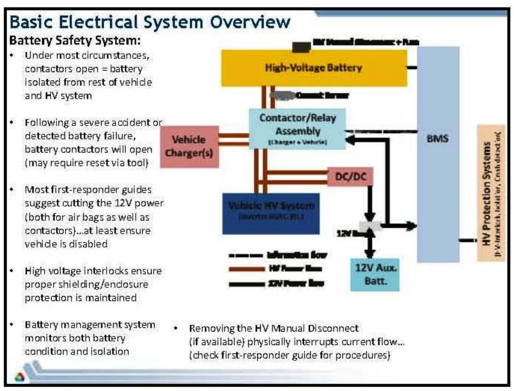
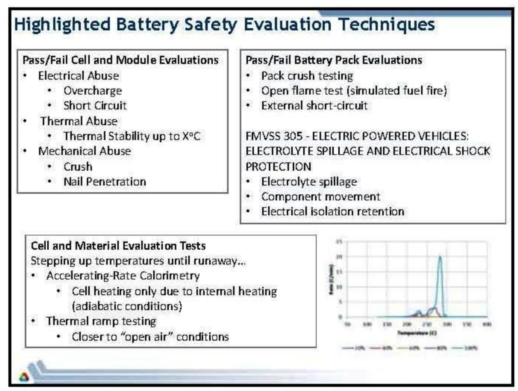
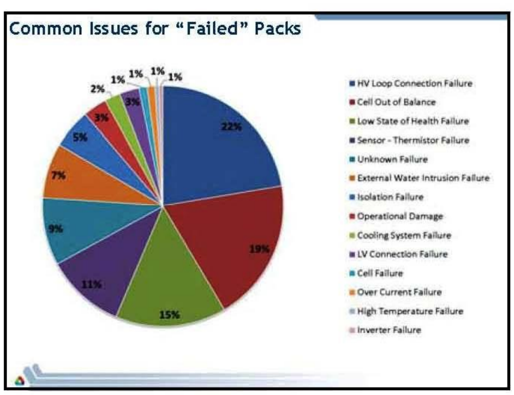


Figure 45: Slides from Will James, DOE Fuel Cell Technologies (page 5 of 5)









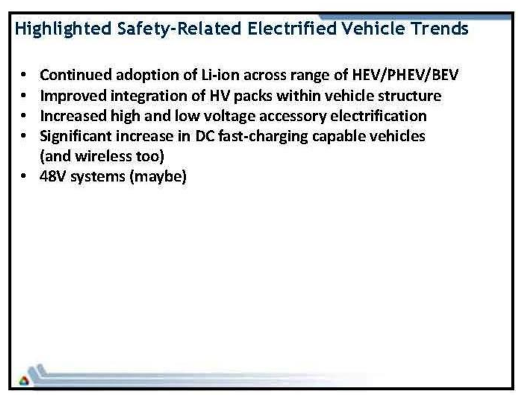


Figure 46: Slides from Eric Rask, Argonne National Laboratory (page 1 of 2)

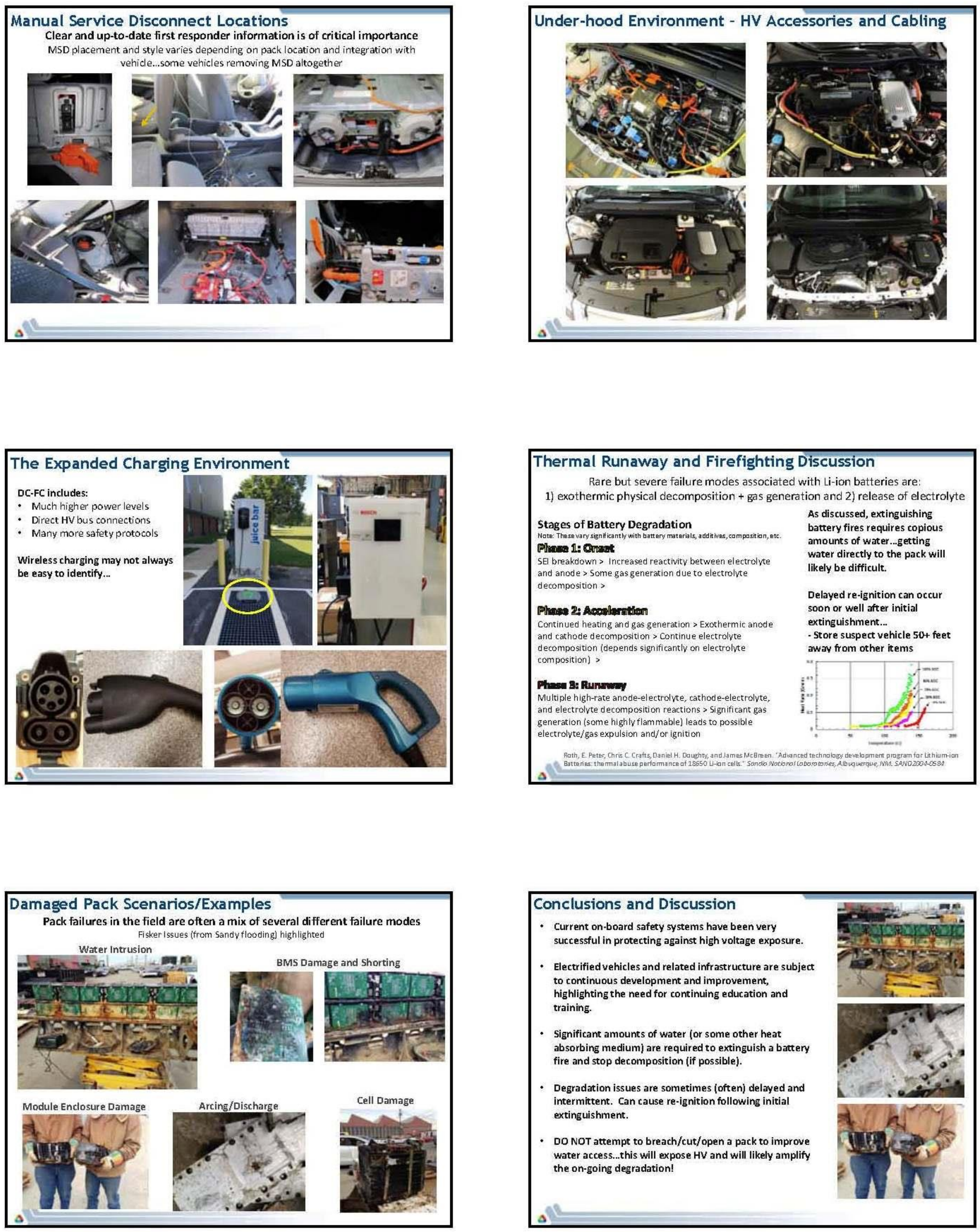


Figure 47: Slides from Eric Rask, Argonne National Laboratory (page 2 of 2)

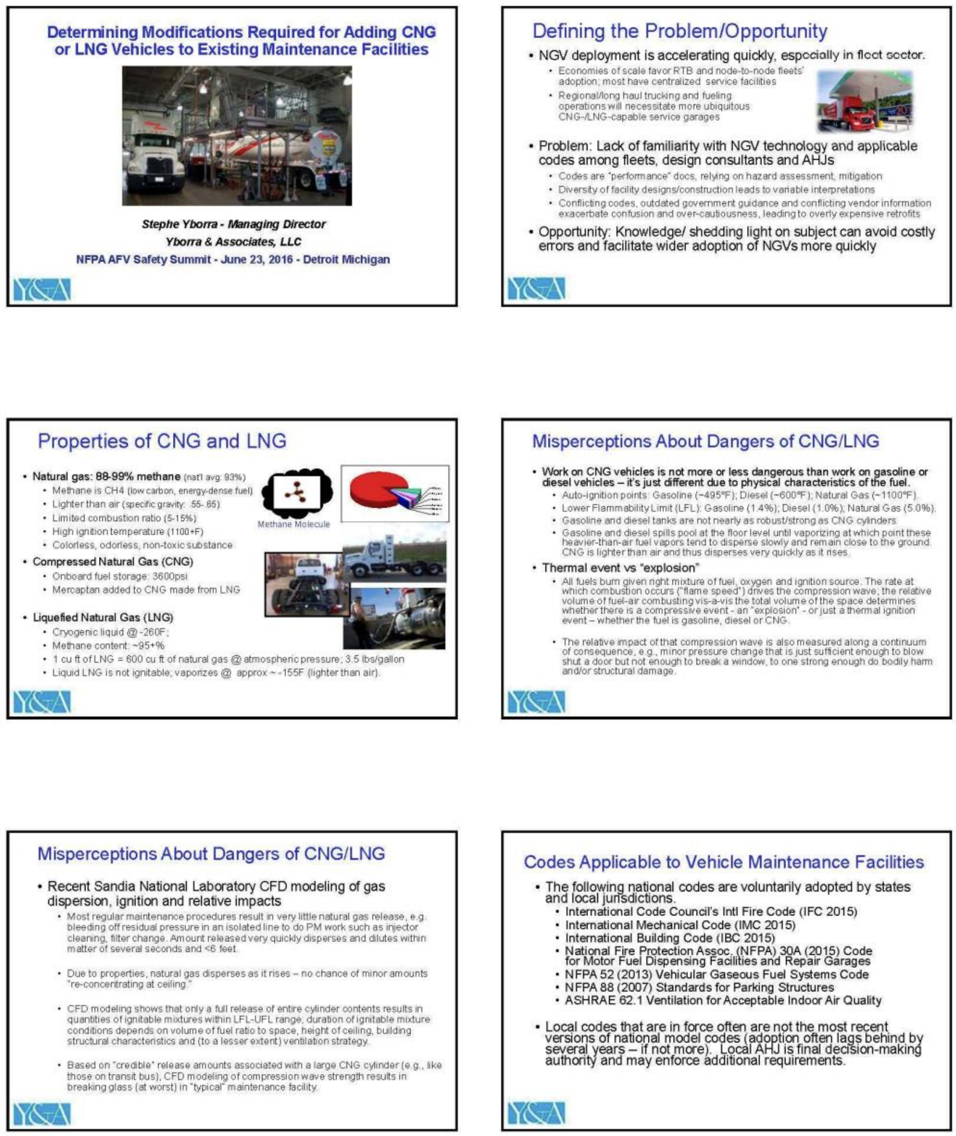


Figure 48: Slides from Stephen Yborra, Yborra & Associates (page 1 of 3)

Code Intent/Rationale/Assumptions

Most CNG- and LNG-related codes were developed in mid-late1990s based on experience of those on code committees

- Primary CNG concern: Unintended release in enclosed space.
  - Early PRD's design/selection were flawed; unintended venting
  - PRD standards were revised years ago
  - **No cylinder releases due to PRD failure in past 13 years**
- Primary LNG concerns: Venting due to pressure build-up, and liquid release due to puncture
  - Although vacuum insulated, LNG tanks still absorb energy, thus a 15psig/day gain leads to hold time of 6-7 days before venting.
  - **No record of a LNG liquid spill in a maintenance facility**

Code Intent/Rationale/Assumptions

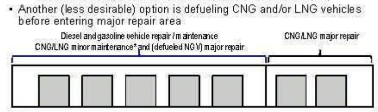
- **Codes are performance-based, not prescriptive.**
- **For each facility, perform a hazard assessment and then implement steps to eliminate or mitigate that potential hazard**
  - Engineering/modifications
  - Operational
  - Training procedures
- **While its important to investigate what others have done, don't rely on those as examples**
  - Difference in states' adoption of national model codes
  - Different non-code requirements may have played a role. e.g., now outdated 1997 FTA guidance to transit agencies

Evaluate Shop Activities, Segregate, Modify

- **IFC and NFPA 30A *exempt minor repair facilities* from code requirements specific to CNG and LNG.**
  - IFC 2211.7 exempts garages that do not work on fuel systems or do not use open flames or welding from all additional requirements
  - NFPA 30A exempts garages that do not perform:
    - Engine overhauls, painting, body & fender work, any repairs requiring draining of vehicle fuel tanks
  - NFPA 30A definition of minor repair facility maintenance:
    - Lubrication, inspection, engine tune-ups, replacement of parts, fluid changes, brake system repairs, tire rotations and similar routine maintenance work

Evaluate Shop Activities, Segregate, Modify

- **IFC and NFPA 30A *exempt minor repair facilities* from code requirements specific to CNG and LNG.**
- To avoid costly modifications, consider:
  - Segregating major repair and minor maintenance activities into separate physical areas; adding NGV-specific bay(s) for major repairs
    - If separate CNG/LNG major repair area is designated, AHJ may allow *minor maintenance* work on CNG/LNG vehicles in major repair facility (at AHJ's discretion based on fleet's implementation of clear shop rules/SOPs in manuals, etc)
  - Another (less desirable) option is defueling CNG and/or LNG vehicles before entering major repair area



Existing Code Requirements by Category
(as it relates to maintenance/repair and parking* facilities)

Modification Category	Code Reference
Ventilation Category	IMC (2012) Table 403.3; NFPA88A (2007) 5.3.2 IFC (2012) 2211.7.1, 2211.1.1, 2211.7.1.2; NFPA30A (2015) 7.5.1, 7.5.2, 7.5.3, 7.5.4, 7.4.7.2, 7.4.7.3 ASHRAE 62.1
Ventilation in Pits	IFC (2012) 2211.3; NFPA30A 7.4.5.4
Gas Detection	IFC (2012) 2211.7.2, 2211.7.2.1, 2211.7.2.2, 2211.7.2.3; NFPA30A (2015) 7.4.7, 7.4.7.1, 7.4.7.2, 7.4.7.3, 7.4.7.4
Sources of Ignition	NFPA30A (2015) 7.6.6
Electrical Classification	NFPA30A (2015) 8.2.1
Preparation of vehicles For Maintenance	IFC (2015) 2211.5
Maintenance and Decommissioning of containers	NFPA52 (2013) 6.13, 6.14

Facility Modifications to Accommodate Work on CNG and/or LNG Vehicles

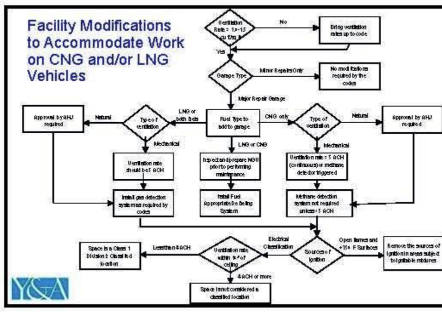


Figure 49: Slides from Stephen Yborra, Yborra & Associates (page 2 of 3)

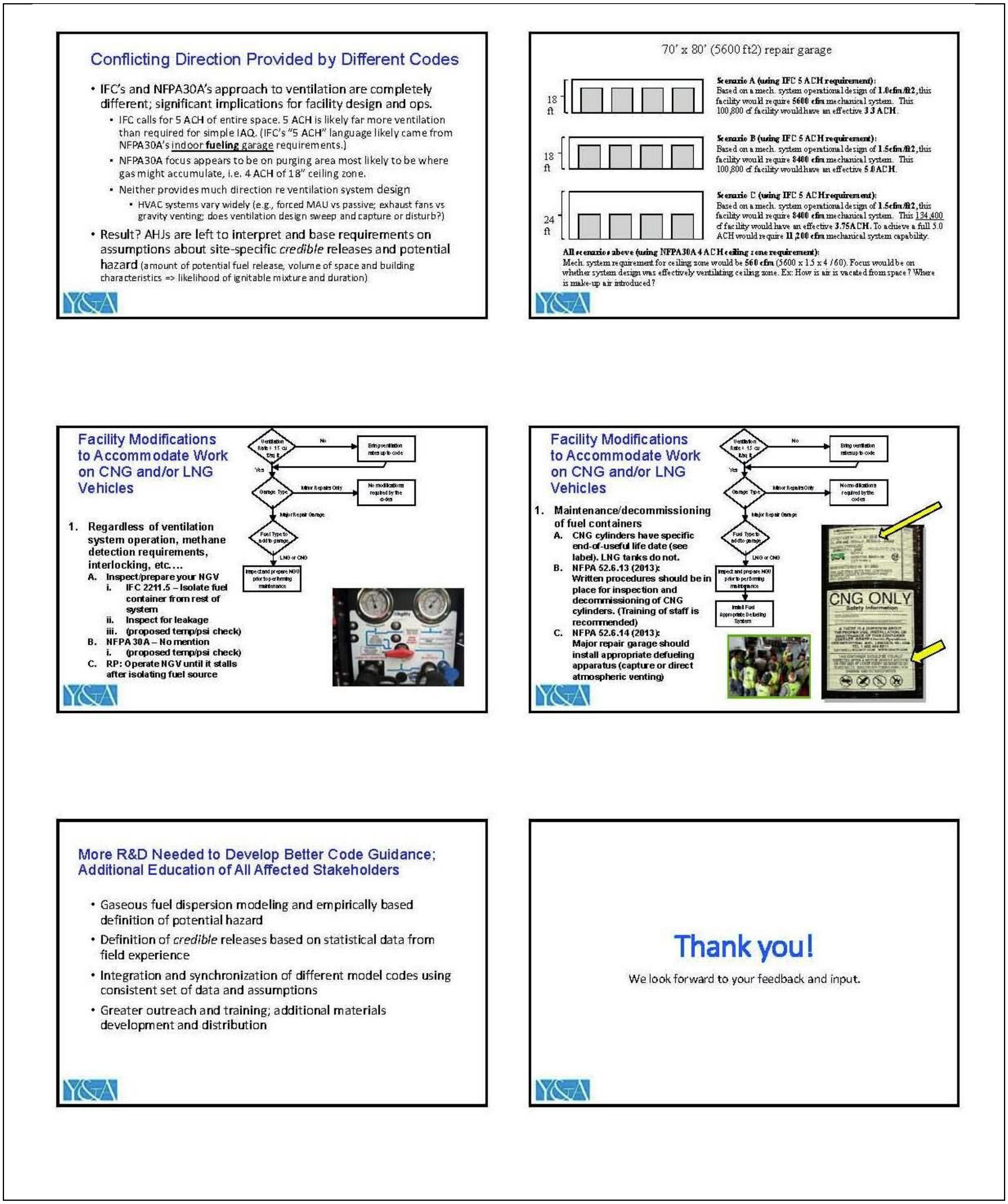


Figure 50: Slides from Stephen Yborra, Yborra & Associates (page 3 of 3)