Proceedings of the NGV Global Technical Forum

Held in Conjunction with NGV Global 2014 Conference and Exhibition

Long Beach, California, May 5th 2014

Session 1 of 2

OBJECTIVE

The Technical Forum is open to all NGV Global members. The objective is to explore technical issues in a more detailed and informal forum than normal conference sessions allow. The focus is on critical issues requiring resolution which will help to define technical objectives and priorities for NGV Global to pursue.

ATTENDANCE

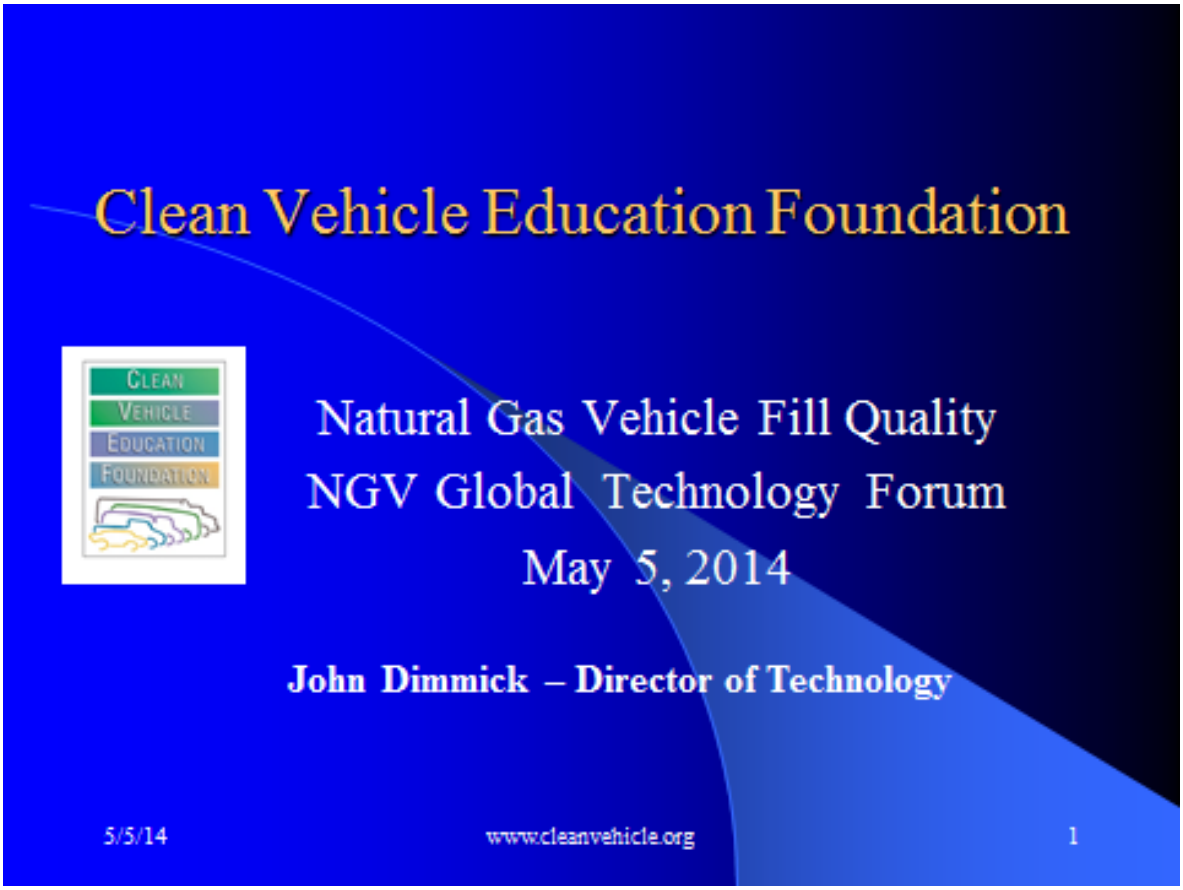
Approximately 60 people participated in the Technical Forum 2014. A partial list of Attendees was captured and is appended to these proceedings.

AGENDA

Item	Description
1. CNG Cylinder Issues	• Fill Quality: ensuring customer satisfaction to leave a refuelling station with a full tank. (John Dimmick) • End of Life Issues: Safe disposal of CNG cylinders. (Diego Goldin) • Cylinder re-inspection and re-testing techniques: Improved techniques and procedures. *(not available)* • Tank Valves: Design changes for safe removal; reliability of solenoid valves; cylinder/valve/PRD as a system. (John Dimmick)

CNG CYLINDER ISSUES

Fill Quality - John Dimmick, CVEF



Situation

NGV operators are increasingly aware that real-world range is often much less than the theoretical range. Heating due to compression in the cylinder prevents full filling in warm weather and conservative margins in lieu of precise vehicle information results in short fills even on cold days. In certain range-critical applications as much as a third of the vehicle fuel capacity is unusable.

Fast fill dispensers do not have access to accurate data about the conditions in the vehicle and must make estimates. This results in conservative under-fills in almost all cases. The lack of a standard industry test method to verify the accuracy of the dispenser in the full range of operating conditions probably adds another layer of uncertainty. Station operators may not have an adequate program of periodic verification that the dispenser stays accurate.

Factors

Why is smart fast fill not possible today?

- The maximum permissible pressure in a full cylinder is reached at a gas temperature of about 127F.
- Large capacity CNG stations with desirable utilization rates act more like buffer systems than cascade systems.
- The aftercoolers of CNG compressors are designed to deliver CNG at no more than 20F above the ambient air temperature.
- Compression heating in the cylinder can add 50 or more degrees F to the gas.
- 127F gas temperature will be reached before a full fuel charge is achieved even at moderate ambients if starting close to empty.
- A large portion of the US NGV fleet in being is concentrated in locations with very warm or hot temperatures.

More Factors

- Fill quality is not a problem for slow fill fleets such as refuse and school buses.
- For a majority of fleets it is not feasible to slow fill.
- NGV growth is concentrated in MD and HD vehicles with high fuel usage because the motivation is fuel cost savings.
- Bus systems and regional trucking must operate with a sufficient range every day. More range on cool or cold days is of little value.
- Poor fast fill quality requires NGVs to carry more fuel tanks to compensate for the unusable capacity.
- Compressor stations must deliver fuel at the maximum fill pressure on any warm day.
- Cylinders are cycled to the most severe pressure on any warm day.

More Factors

Why not just keep adding more cylinders?

- Cylinders have always been the villains in the CNG story.
  - They are too big
  - They are too expensive
  - They are too heavy
  - They don't hold enough fuel
  - They are easy to damage and expensive to replace
- There is not only the weight of the added cylinder but also of the unusable fuel in it.
- Natural gas is an economic decision and paying for extra cylinders to be partially filled increases the first cost and operating cost of NGVs with no added revenue

Big Challenge, Big Opportunity

- High-utilization highway trucking has excellent economics
  - Fast fills are essential to high utilization
  - Too-frequent fills reduce utilization
  - Combinations of captive and commercial stations
  - Most are weight-critical
  - Many are space limited
  - Regional distribution has fixed but large range requirements
  - Accurate fuel gauges for remaining range are essential
  - High fuel flow requires significant pressure in the "empty" tank
  - Wide fluctuations in fill conditions.

Remedies

- Increase service pressure to 5,000 psi
  - 40% added pressure, strength, mass, material cost
  - 22% added fuel capacity when slow filled
  - Compression heating is worse
  - Obsoletes entire filling infrastructure
  - Obsoletes vehicle and station component designs
- Communicate vehicle conditions to the station
  - Requires uniform national protocol
  - Requires addition of high-reliability vehicle sensors
  - Requires retrofit of existing dispensers
  - Does not fit national regulation practices
  - Reduces ignorance of actual compression heating but does not reduce heating
- Equip vehicle with fill control system
  - Requires addition of high-reliability vehicle sensors and power-on fueling
  - Fits well with national regulation practices
  - Does not require communication protocol
  - Requires new dispenser nozzle and uncontrolled dispensing
  - Reduces ignorance of actual compression heating but does not reduce heating

MORE REMEDIES

- Increase heat dissipation from cylinders
  - Add metals and weight
  - Add salt or other heat absorbing media and weight
  - Add a heat exchange system and weight
- Switch to evaporative coolers to reduce temperature at aftercooler outlet
  - Provides incremental but not full solution
  - Very feasible in hot arid regions
  - Limited effectiveness and seasonal complications in temperate regions
- Chill the charge gas below ambient
  - Does not require obsoleting stations, designs or vehicles
  - Adds chilling equipment to stations
  - Probably adds roughly 20%-25% to power usage at stations in hot weather
  - May improve thermal efficiency of stations
  - Station operating pressure can be reduced
  - Temperature range is appropriate for thermal storage technology
  - Can be combined with communication or on-vehicle control for true fast fill

CNG Fueling Variables

- J-T cooling, frictional heating and path dependency
- Gas composition variation, NGLs, inerts, oil moisture
- Starting fuel level and temperature in vehicle
- Starting pressure and temperature in station vessels
- Relative size of station vessels and vehicle containers
- Temperature of gas at dispenser inlet
- Dispenser is a black box
- Total vehicle container capacity
- Time required for fueling
- Thermal properties of containers
- Vehicle service pressure
- Status of vehicle container valves

Discussion:

There were several areas of opportunity raised to resolve this issue. One involved the development of a vehicle pressure management system with a smart fill valve which would deliver the optimum amount of energy into the CNG cylinder, and then shut off the supply of CNG. The vehicle is then taking control of the fill process. The vehicle could detect through its ECU, the parameters required for a consistent fill, such as type of cylinder, size and number of cylinders, initial fill condition, ambient temperature, cylinder temperature and pressure, and with a temperature compensated fuel gauge, could provide feedback to a smart control valve in the fill line. This takes much of the requirements for a consistent fill away from the station and on to the vehicle. Support for this concept was expressed by both heavy duty and light duty OEMs. A smart valve does not yet exist, but represents a control opportunity. There is also an issue on where to measure the cylinder temperature which needs development. (temperature distribution inside the cylinder)

An alternative approach is to develop better algorithms for fuel stations equipped with temperature compensation (although many stations are not so equipped). Pre-cooling of the gas being supplied to the vehicle was also discussed to reduce the increase in cylinder temperature due to compression. Metro in Spain is using pre-cooling effectively to improve the vehicle fill quality.

Key technology opportunities for NGV Global to consider:

Code of Practice for pre-cooling of CNG supply to cylinders
Lack of standard industry test method for filling cylinders
Industry working group to review opportunities for vehicle pressure management systems
Review of how to measure reliable cylinder temperatures
Development of improved algorithms for temperature compensated fuel stations
What can we learn from hydrogen experience in this area?

End of Life Issues – Diego Goldin, NGV Global

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ISSUES

- SERVICE LIFE
  - Use of cylinders manufactured under standards without life limit
    - Life of the Cylinders vs Life of the Vehicle
  - Factors affecting Service Life
    - Handling
    - Installation
    - Gas Quality/Composition
  - Periodic Inspection
- DESTRUCTION OF CONDEMNED CYLINDERS
  - Methods of destruction
  - Disposal of the cylinders

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Discussion:

The end of life disposal of the cylinders was considered a major safety issue. It is evidently not enough to puncture the cylinders, but one of the real issues is related to the verification of vehicles and cylinders prior to fill. It was noted that there are countries where control is automatically managed at the point of fill (Peru, Colombia) and where accidents due to filling of condemned cylinders is practically non-existent. In countries where control is by human intervention, the incidents occur (e.g. Argentina, Brazil). Other countries have no supervision at all, due to absence of regulations or enforcement and there incidents, sometimes very serious, are common (e.g. Pakistan). In USA, the responsibility falls under the vehicle owner, who has to seek inspection; it was mentioned that it seems not enough for vehicles that are not managed under a fleet system. It was discussed whether it would be possible to include automatic control in the vehicle OBD system.

The service life extension was also discussed, with different opinions. Some manufacturers considered totally inappropriate to extend the life of a cylinder beyond the design life, and a different opinion came from inspection agencies who stated that with appropriate calculations and testing the life could be extended for another period.

Key technology opportunities for NGV Global to consider:

Determine maximum service life for cylinders manufactured under standards with no limited life
Consider rationale and potential liabilities behind life extension
Prepare best practice document for cylinder destruction.
Industry working group to review opportunities for vehicle periodic inspection management systems

Cylinder Re-inspection and Testing Techniques - Livio Gambone, CSA

CNG Cylinder Inspection Requirements

FMVSS 304 (49 CFR Part 571)

Labeling statement: "This container should be visually inspected after a motor vehicle accident or fire and at least every 36 months or 36,000 miles, whichever comes first, for damage and deterioration."

ANSI NGV 2-2007

Any requirements for periodic re-qualification by inspection or testing during the service life shall be specified by the container designer on the basis of use under service conditions specified herein. Each container shall be visually inspected at least every 36 months, or at the time of any re-installation, for external damage and deterioration.

Prior to visual inspection, the container surface shall be exposed by the removal of protective shields and covers, unless the vehicle or container manufacturer recommends against such removal.

CNG Cylinder Inspection Requirements

ISO 11439: 2013

Annex G (Informative): Inspection and/or testing is required to be performed in accordance with the relevant regulations of the country(ies) where the cylinders are used.

Recommendations for periodic requalification by visual inspection or testing during the service life should be provided by the cylinder manufacturer on the basis of use under service conditions specified herein. Each cylinder should be visually inspected at least every 36 months, and at the time of any re-installation, for external damage and deterioration, including under the support straps. The visual inspection should be performed by a competent agency approved or recognized by the Regulatory Authority, in accordance with the manufacturer's specifications.

CNG Cylinder Inspection Procedures

CNG Cylinder Manufacturer/Vehicle OEM

Inspection procedures and criteria are specified by the cylinder manufacturer and/or the vehicle OEM and should take precedence

CGA C-6.4 (2012)

"Methods for External Visual Inspection of Natural Gas Vehicle (NGV) and Hydrogen Gas Vehicle (HGV) Fuel Containers and Their Installations"

ISO 19078: 2013

" Inspection of the cylinder installation, and requalification of high-pressure cylinders for the on-board storage of natural gas as a fuel for automotive vehicles "

Common themes: Visual inspection
Cylinder is not removed from the vehicle

Effective Inspection Techniques

Visual inspections of external cylinder surfaces are the only practical way to detect damage

- Fortunately, most kinds of damage that occur on vehicle cylinders are visually apparent, as they are caused by external effects
- Even impact damage (difficult to visually detect) should be apparent since it would be expected that there would be evidence of collateral damage to the vehicle in the immediate area of the cylinder installation
  (it is because of handling impact damage that cylinders should not be removed from a vehicle for inspection)

Hydrostatic testing exposes composite cylinders to risk of handling impact damage, offers no requalification value, but at a minimum requires that a visual inspection be performed

There is no other *practical* NDE technique for the *in-situ* inspection and requalification of composite cylinders

Inspection Enforcement/Compliance

In North America, there is currently no mechanism to force / monitor compliance with CNG cylinder inspection requirements

There is a need by the CNG industry to educate users of CNG vehicles, of the need for periodic inspections by qualified service personnel

CSA Group offers a CNG Fuel System Inspector Certification Program

Certified individuals will have demonstrated proficiency in:

- Inspecting CNG vehicle cylinders and fuel systems
- Identifying and documenting defects, and
- Safe handling of cylinders and fuel system components, enabling them to perform assigned tasks safely

http://www.csagroup.org/us/en/services/education-and-training/personnel-certification/people-search

CSA Group Inspector Certification Program

CNG Fuel System Inspector Certification Program Offers:

- Testing for fuel system inspection certification
- Formal recognition of knowledge and understanding
- Listing on the national registry of certified inspectors
- 3 year re-assessment on technical developments and industry changes

Closest thing we have to national requirements

Regulation exists in:

- Oklahoma
- West Virginia
- Utah
- Ohio: coming soon

Some insurance companies are now mandating that inspectors are certified

Extensive Training Partner Network

1. Advanced Transportation Technology / San Diego, CA
2. College of the Desert / Palm Desert, CA
3. Energy Transfer Technology / Vancouver, WA
4. AFV International / Sugar Grove, OH
5. Long Beach City College / Long Beach CA
6. Natural Gas Vehicle Institute / Las Vegas, NV
7. National Alternative Fuels Training Consortium with 29 centers in the following states:

Alabama	Massachusetts	Tennessee
Arizona	Michigan	Texas
California	Nevada	Utah
Connecticut	New Hampshire	Vermont
Florida	New Mexico	Virginia
Georgia	New York	Washington
Illinois	North Carolina	Washington, DC
Indiana	Ohio	West Virginia
Iowa	Oklahoma	Wyoming
Maine	Oregon	
Maryland	Pennsylvania	

Requalification / Life Extension of Type 1 Cylinders

Canada (CSA B51) allows Type 1 designs to be re-inspected using ultrasonic scanning (U/S), with the following benefits:

1. U/S used to extend lifespan of 15 year cylinders to 30 years
   - U/S used in factory to ensure 15 year life of metal cylinders, thus after 15 years, if cylinders do not exhibit metal loss, and can meet the original factory U/S requirements, then good for another 15 years
2. For ground storage applications using DoT transportable cylinders, U/S used to replace hydrostatic retesting every 5 years, with a 15 year period between retests
   - U/S can detect smaller defects than hydrostatic testing
   - Combined with knowledge of pressure cycle service conditions, can show using fracture mechanics that fatigue cracks cannot grow to failure within 15 years

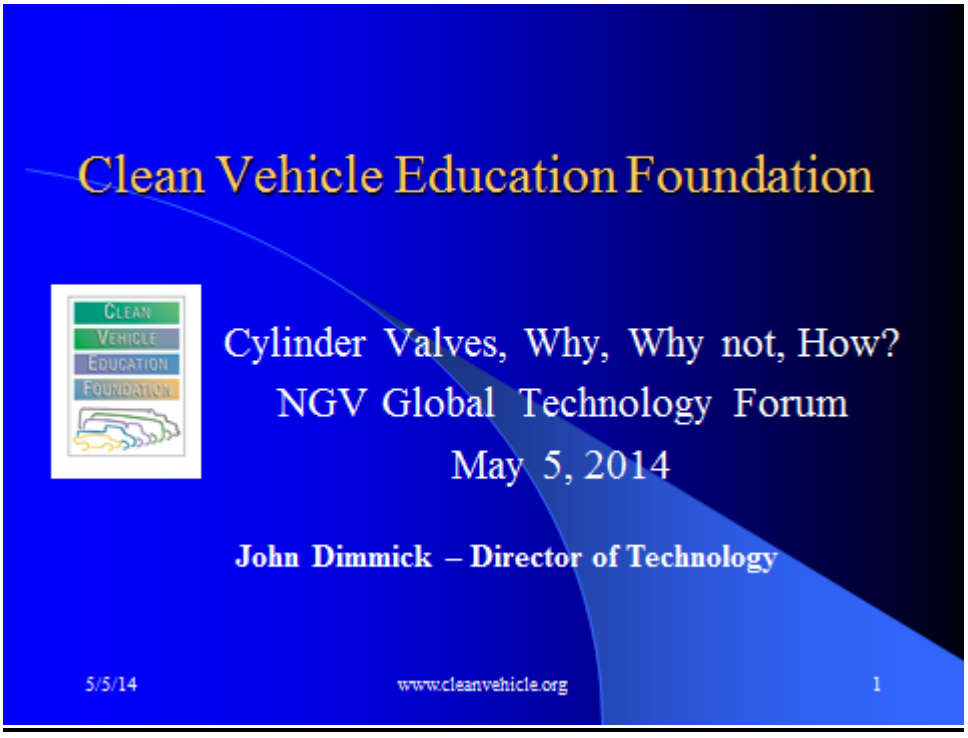
Key points for NGV Global to consider

The language of cylinder inspections needs to be addressed. Some requirements assume visual inspection takes place every three years, but visual testing can be overlooked as a routine process.

There is no benefit to hydrostatic testing for composite tanks.

Ultrasonic scanning is much more effective and can expand cylinder life with greater confidence that hydrostatic testing. Depending on cylinder design, US scanning can detect cracks.

Tank Valve Issues - John Dimmick, CVEF



Potential Root Causes

- Failure to Fully Vent Gas Through Valve in Servicing
  - Some occurred on valve removal and others because a full cylinder was treated as empty (scrap yard)
  - Seven incidents, Four Fatalities, Three serious injuries
  - Numerous reports of other occurrences without injury
  - Five involved cylinders fitted with solenoid valves
  - NFPA 52 and ANSI NGV3.1 modified to require warnings and instructions
  - Current instructions are not all adequate
  - Control by using service procedures has not eliminated the problem. A design control should be required to warn the technician that the cylinder is pressurized

Why?

- In the US and probably in many countries CNG practices were first patterned after Transportation of Dangerous Goods Regulations
- US DOT cylinders were used in early NGVs and NFPA 52 required them to be equipped in accordance with the DOT regulations
- DOT requires that flammable gas cylinders have individual valves
- **But!** US DOT requires cylinder valves to be closed during transportation
- Until 1990s cylinder valves were a convenience for maintenance and sometimes shut off after accidents
- Solenoid cylinder valves were adopted because they could be controlled by the same electrical control as electric gasoline pumps
- Solenoid valves seen as insurance in crash tests and indoors
- **But!** NHTSA requires them to stay open during crash tests

Why Not?

- Since the 1990s many HD vehicles have had interconnected live ports for PRD manifolds.
  - All interconnected cylinder valves must be closed to shut off the gas
  - There is no capability to isolate a cylinder from all piping
  - Manual and/or solenoid valves are used
  - No known adverse effects from the practice that defeats the original intent of isolating the gas into individual cylinders
- High failure rates have affected solenoid valve designs
- Valves add many uncontrolled leakage points
- Some newer manual valve designs also have unsafe failure modes
- Valves add concerns about leakage and impact damage
- Valves prevent expedited defueling after an accident or fire
- Many serious incidents and most NGV fuel system fatalities in North America would not have happened without cylinder valves.

Root Causes of Serious Incidents

- Overfill resulting from solenoid valve malfunction:
  - Four ruptures, one injury, Three designs
  - Potential with excess flow devices and manual valves
  - Typically rupture in use after fill, not during fill
  - Two cylinders had composite damage
  - Suspected dispenser inaccuracies in all four incidents
  - Three ruptures in very hot weather, one in fire.
  - NFPA 52-2013 requires detection of valve malfunction on new vehicles but replacement is not assured.
    - Existing dispenser technology does not prevent overfill
    - Extreme over-pressurization potential if dispenser fails to temperature compensate. Enough to rupture a new cylinder
    - Can cause stress rupture failure in composites
    - Can defeat PRD protection in a fire
    - Can cause rupture disc failure, a particular hazard indoors

Root Causes cont'd

- Failure to Fully Vent Gas Through Valve in Servicing
  - Some occurred on valve removal and others because a full cylinder was treated as empty (test facility and scrap yard)
  - Eight incidents, Four Fatalities, Three serious injuries
  - Numerous reports of other occurrences without injury
  - Five involved cylinders fitted with solenoid valves
  - NFPA 52 and ANSI NGV3.1 modified to require warnings and instructions
  - Current manufacturer's instructions are not all adequate
  - Control by using service procedures has not eliminated the problem. A design control should be required to warn the technician that the cylinder is pressurized
  - Some valve designs have no back-up vent capability
  - One additional fatality because the driver was turning on a closed cylinder valve when a damaged cylinder ruptured

Occurrences

- Technician at cylinder manufacturer energizes valves on an assembly returned from an OEM customer for evaluation. No gas is sensed and a valve is removed from the pressurized cylinder, propelling the valve across a busy street.
- Technician in an OEM dealership removes solenoid valve from a pressurized cylinder. The cylinder flies several hundred feet and lands in the body shop seriously injuring another employee
- Three technicians at a TC crash test facility are killed when they are mistaken about whether a cylinder has been emptied of gas.
- Technician in a manufacturer's engineering facility removes a solenoid valve under pressure and is thrown without serious injury
- Technician using factory procedures and tools is injured when a cylinder believed to have been emptied is drilled for disposal. More than 3% of the fleet's solenoid valves did not function when energized
- An experienced CNG engineer is injured after unable to obtain factory instructions for defueling a failed solenoid valve. Serious head injury.

More Occurrences

- A highly experienced technician at a major fuel system provider unscrews a manual valve from a cylinder he believes he emptied and receives a broken wrist.
- A CNG technician with more than 20 years experience unscrews a solenoid valve he knows to be defective from a cylinder he mistakenly believes is empty. The resulting shock wave is fatal. The technician did not use the factory tools and procedures but the cylinder had been removed from the original OEM NGV and installed in a converted vehicle.
- Multiple instances of a new manual valve that acts like a check valve because of a manufacturing defect. There is a recall and the valve manufacturer provides repair kits but no guidance on how to vent cylinders with failed valves.
- A woman goes upstairs to check on a noise and finds the ceiling in her bedroom damaged by half of a CNG cylinder. It is equipped with a solenoid valve and came from a recycling yard some distance away.

Other Safety Issues

- What do we tell the fireman to do with damaged cylinders with solenoid valves or EFDs?
- Would it be better if all of the fuel on a vehicle were released in a fire?
- How can we deal with a loose cylinder and valve? DOT does not permit transport until empty.
- CNG cylinders must be enclosed for protection against sunlight. First responders do not know where to locate cylinder valves even if they are accessible.
- Modeling of natural gas releases in buildings indicates that smaller releases such as even a large leak are tolerable but an unintended PRD activation is not.
- It is not clear who has the responsibility for the compatibility of valves and cylinders, valve manufacturer, cylinder manufacturer or installer.
  - There have been incidents of galvanic corrosion between the valve and cylinder
  - There is no standardization of the connection threads and sealing systems

Now What?

- Incidents occur regardless of procedures, training and tools.
- Incidents occur with both solenoid and manual valves
- Incidents occur with both malfunctioning and functioning valves
- People must be close to a valve to remove it and proximity is highly hazardous
- A robust system to prevent overfilling due to a valve failure is not available
- Questions:
  - Are there any people who are alive because CNG cylinder valves were used?
  - Does the experience with common PRDs mean that cylinder valves are unnecessary?
  - Should cylinder valve use be optional?
  - Can design changes address the servicing hazards?
  - Is there any way to force replacement of a malfunctioning valve?

Fixes?

- NFPA 52 and ANSI NGV3.1 are modified to require warnings and instructions with valve malfunction detection
- Require vehicle self diagnostics with impaired operation if failed solenoid is not replaced
- Require that dispensers sense non-functional solenoids and derate the fill
- Require a communication fill and dispenser derate
- Do not permit the installation of multiple cylinder solenoid or EFD valves
- Require that valves have an obvious and intuitive backup defuel function
- Require that valves be permanently attached to cylinders
- Require that valves produce an unmistakable visual or audible indication of pressure if unscrewed under pressure
- Do not require the installation of cylinder valves
- Do not permit the installation of cylinder valves

Key points for NGV Global to Consider:

Instructions from maintenance manuals explain procedures that do not include what happens if the cylinder is serviced under pressure, or the pre-conditions to service. Some valve designs now incorporate a slot in the thread which releases high pressure gas with an audible hiss if the valve is being removed while the cylinder is full. Perhaps a code of practice could be set up to require designs of this nature

No general agreement was expressed that solenoid tank valves are unnecessary and cause more safety issues than if they were not there. More detailed discussion is required on the design of all tank valves.

The issue of fail to open tank valves needs to be addressed with a warning system to detect when the failure occurs. The comments on this from John Dimmick are reproduced below and should be addressed –

NFPA 52-2013 says:

"**6.6.1.1** Vehicles with more than one fuel supply container, where each container is equipped with a normally closed remotely actuated shutoff valve, shall have an automatic system to detect the failure of any one of the valves."

I think that considering the potential consequences the scope of "failure" should include both mechanical and electrical failures. I'm aware of several different approaches with different levels of thoroughness.

1. The current drawn by each valve could be monitored to be within expectations.
2. An AC signal could be superimposed on the DC to verify that the inductance of the solenoid indicates that the core is in.
3. Individual pressure or temperature sensors could be installed on each tank or valve to identify if one is not seeing the same pressure or temperature changes as the other.
4. A temperature compensated fuel gauge could be checked against the MPG function in the PCM do detect that the apparent rate of fuel flow out of the containers exceeds the flow into the engine.
5 The vehicle could be started with just one valve and run for a time sufficient to to stall it if that valve is not working. It could then be run from all valves and the next start be done on the next valve in sequence.

Since 4 can probably be accomplished without any added hardware I like it but it would have to be coordinated with the engine system manufacturer. The PCM would have to be programmed with the total water volume of the vehicle tanks.

Given the mechanical failure modes of valve 1 & 2 would not be robust.

The guy who bought a 10-year old van on EBay will not be eager to replace the valve. He'll probably just fill more often. I think that consequences are needed like a de-rated limp home if the malfunction is detected and not repaired within x starts.

This problem is probably even more urgent in Europe where solenoids are required by regulation, multiple cylinders are common even in light vehicles and temperature compensation at fill may not be practiced.