

Lessons Learned from Practical Field Experience with High Pressure Gaseous Fuels



DOE – DOT
CNG – H₂ Workshop
December 10, 2009

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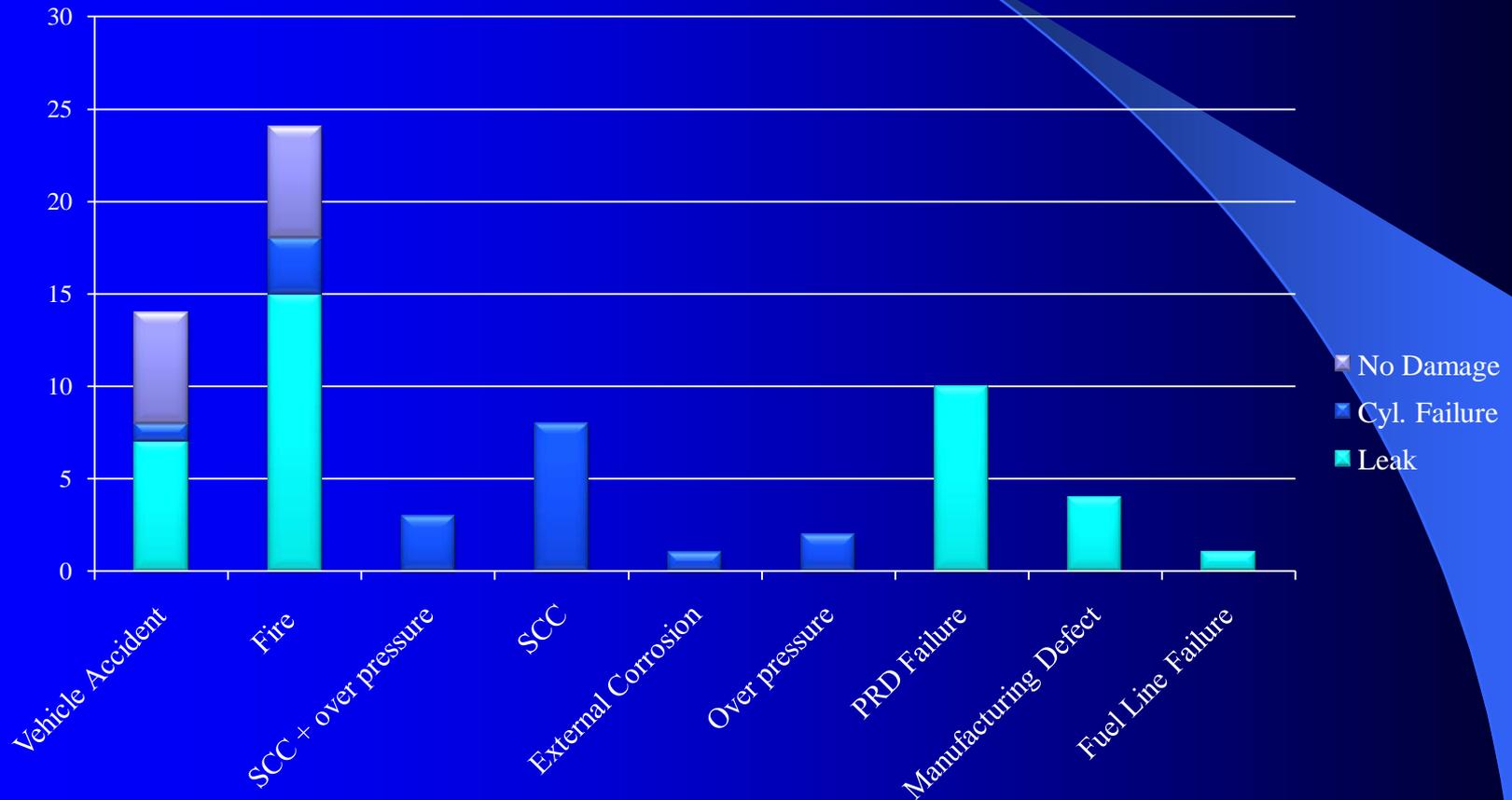
The Facts

- NGVs have been used in North America for over 30 years
- Codes and Standards (C&S) provide opportunity for safe reliable operation of NGVs
- C&S evolve with new technology and field experience
- People make mistakes, continuous training is critical for safe operations
- Cylinders have a limited life –track your cylinders!

Incidents in North America

- Since 1984 CVEF has recorded 97 incidents of which 67 involved CNG vehicles
 - 37 incidents involve either a CNG leak (15) or a release of CNG by the PRD activation (22)
 - There were 18 cylinder failures:
 - 4 Type 1 (all steel) -1 in fire where PRD failed, 1 by external corrosion and 2 by over pressurization by faulty fueling system
 - 4 Type 2 (hoop wrapped) - 1 by fire where PRD was isolated from cylinder body, 3 from a combination of SCC and over pressurization
 - 8 Type 3 (full wrap and metal liner) – SCC from acid/chemical degradation of e glass wrap
 - 2 Type 4 (full composite with plastic liner) – 1 in localized fire and 1 by physical damage

The Message — 9 Specific Categories of Incident Causes:



Type 1 Cylinder Incidents

- Type 1 cylinder failed due to extensive external corrosion, the cylinder was not visually inspected for over 10 years
- Type 1 cylinder failed due to over pressure by defective fueling system, the 2400 psi cylinder was subjected to 6000 psi



Type 2 Cylinder Incident

- Lucas Type 2 cylinder failed during fueling
- Report by CVEF indicates that there were two probable causes for the failure
 - Stress corrosion cracking of the hoop wrap by chemical attack
 - Chronic over pressure of cylinder during multiple fueling cycles
 - the safety relief valve on the station was improperly set



Type 3 Cylinder Incident

- 1996 Dodge B250 Van - four 3000 psi Comdyne Type 3 cylinders one of which ruptured after filling
- Stress corrosion cracking was evident, and led to the failure
- The van was used to haul batteries and chemicals for a yacht maintenance company
- There were no injuries or fire but the vehicle was totaled and scrapped

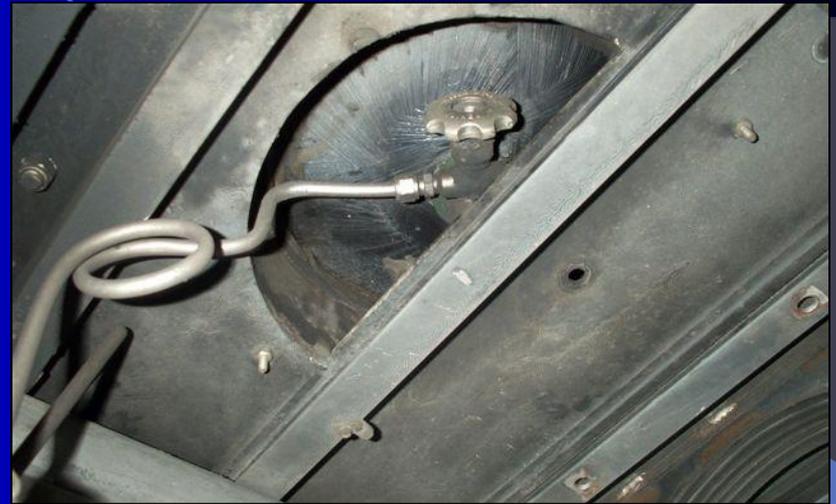


Type 4 Cylinder Incident

Physical Damage

- Two Type 4 Brunswick cylinders failed during fueling
 - The cylinders were 14 years old with one mounted horizontally under the truck and the other mounted vertically inside the truck body directly above the horizontal cylinder
 - The vertical cylinder had the valve end dome mounted on a rubber padded steel ring with the valve and piping exposed under the vehicle
 - It is believed that the horizontal cylinder failed first due to unknown road damage and when it failed the floor of the truck was forced upward with the steel ring cutting into the dome of the vertical cylinder which then failed.
 - The initial report has been completed by CVEF and additional evaluation of the cylinders will be made by NASA (White Sands)

Type 4 Cylinder Incident Physical Damage



- Typical installation in multiple vehicles of the same vintage
- No shielding of exposed cylinder under vehicle
 - PRD on vertical cylinder isolated from cylinder exposure

Type 4 Cylinder Incident Physical Damage



Type 4 Cylinder Incident

Localized Fire

- March 2007 an arsonist torched 12 vehicles in a city government holding lot. The tank in a Honda GX failed from a fire moving from the back seat area onto the center of the cylinder, while the PRD was located on one end .
- Honda recalled the GX vehicles and retrofitted the installation to protect the cylinder from a local fire and insure that the PRD would function correctly



PRD Release Physical Damage

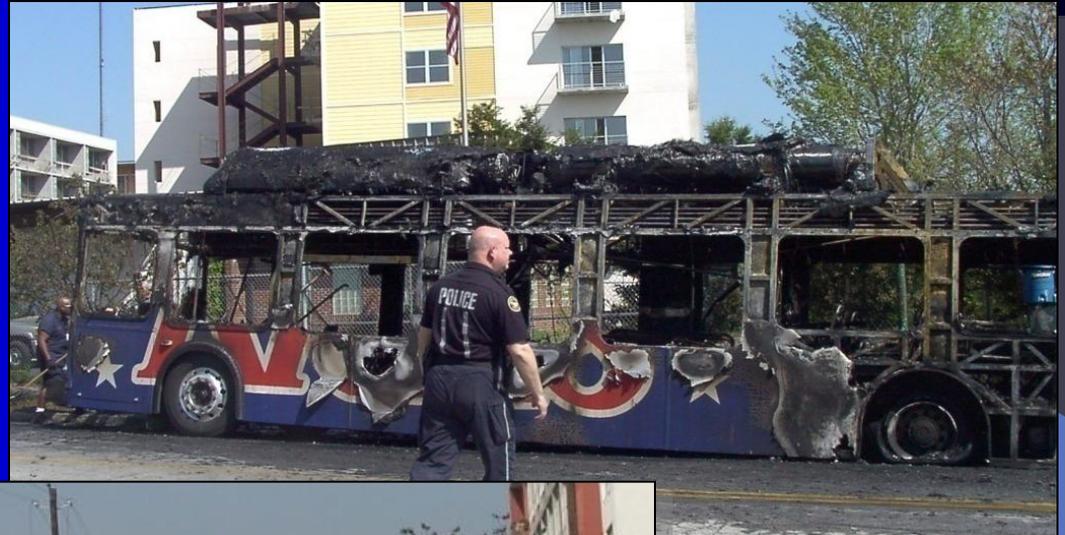
- Bus impacted a steel bridge – with no cylinders failure
- The cylinder support frame bent down and severed the PRDs.
- Gas vented from the two impacted cylinders – no fire or other vehicle damage



PRD Release

Proper Operation in Fire

- Fire originated in rear wheel due to over heated brakes
- The CNG cylinders on top of the bus vented properly through the thermally activated PRDs
- For the 24 vehicle fires in our records none were caused by the CNG fuel systems



Hydrogen PRD Release Installation Issue

"The investigation into this event showed that the relief device was a rupture disc that normally would have been built to relieve pressure to prevent catastrophic failure of the hydrogen tanks," McCullough said. "Normally, the device has a fusible bismuth plug that holds the coin-shaped disc in place until temperatures exceed 180 degrees. The device had been replaced by the hydrogen vendor several months prior, when the vendor was on-site to make repairs related to an apparent leak. The replacement relief device assembly did not have a fusible plug to support the disc." *



* http://www.powermag.com/o_and_m/Lessons-Learned-from-a-Hydrogen-Explosion_1857_p3.html

Installation Issues

- With NGV market growth and the significant saving in fuel cost, independent conversions of CNG vehicles by untrained mechanics have presented safety concerns
- While states recognized that use of conversion kits not certified by EPA or CARB was an issue, they failed to realize that EPA and CARB do not address safe installation practices
- The ASE (F1 test) certification program for technicians has been updated to cover installation as well as maintenance of CNG vehicles



Indoor Fueling Release

- Obsolete PRD design susceptible to water infiltration and freezing



Indoor Release

- Detection system not fail safe.
- Detection system known to be compromised
- Fueler ran past 3 ESD buttons exiting the facility
- Approximately 10 minutes after the gas release started, the gas inside the building ignited.
- The rooftop open flame make up air unit (right) may have been the source of ignition



Indoor Fueling Release

- The Service Building was not equipped with deflagration panels (required by NFPA 52)—the pressure of the blast blew over an inside block wall.
- The blast lifted the roof and damaged every wall of the building.



Lessons Learned—Indoor Release

1. Strong codes (NFPA 52, and the NEC) are already in place—facility was not code compliant.
2. DOT FTA recommendations for these facilities were published after installation – but no updated versions have been developed.
3. Better Maintenance and Emergency training by manufacturers and owners might have prevented this incident.

Refuse Hauler Fire



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Bad behavior:

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BY CAROLYN SACRAGASUS
Daily Press Staff Writer

PICO BLVD. — An elderly man crashed his car into an insurance office building on Thursday afternoon, leaving a gaping hole in the wall and four automobiles damaged.

No one was injured.

At 4:30 p.m., the 85-year-old driver, who hasn't been identified, was driving southbound on 14th Street approaching Pico

Boulevard. He made a right turn and struck a vehicle in the left-turn lane of eastbound Pico Boulevard. The man also hit two additional vehicles headed eastbound on Pico Boulevard.

The driver then crashed into the offices of Valdez Insurance Agency and Sanchez and Associates Notary Public, located on the north side of the 1300 block

See CRASH, page 11

1. Fire destroyed or heavily damaged 5 CNG powered garbage trucks. Approx. \$1.5M in property damage.
2. The fire was believed to have originated in one truck and spread to others from there.
3. There were no injuries.

Refuse Hauler Fire

- Vehicles were fueling.
- Staff heard a loud “metallic bang—like a hand grenade.”
- Staff immediately investigated and found the fire.



Before



After

2005. 8. 18

Refuse Hauler Fires

4 of the 5
trucks
involved
were
written off.



Refuse Hauler Fires



None of the CNG cylinders ruptured and the damage to the cylinders was surprisingly light.

Refuse Hauler Fires—Cause Undetermined

1. HP Regulator on one truck found to have failed at body.
2. PRD release could have initiated fire.
3. Ignition source could have been a static discharge from the rapidly venting gas (except fueling hose should have grounded vehicle).



Refuse Hauler Fires—PRD Vent Routing

1. PRDs not vented up, away from vehicle—responsible for the rapid inclusion of other trucks in the fire.
2. The vehicle at the center of the fire still had full CNG tanks and hydraulic reservoir.



Lessons Learned—Refuse Hauler Fire

1. Strong codes (NFPA 52) are already in place.
2. Inexperienced vehicle builder/converter did not follow current industry practice or common sense (“Reference Guide for Integration of Natural Gas Vehicle Fuel Systems” – Battelle, 2002) as they oriented the PRDs horizontally).
3. Installer personnel training might have prevented or minimized this event.
4. Not an owner maintenance or training issue.

Station Overfilling



1. OEM van 3000 psi cylinder failure.
2. Cylinder had serious degradation.
3. Evidence of overfilling at stations.

Station Overfilling--Deficiencies

- No overpressure device as required by code and best practice—2 stations.
- Overpressure devices on 3000 psig hoses tampered with at 3rd station (see right)
- High pressure solenoid valves did not provide positive shutoff (ball valves much more effective and reliable).
- Station designed to fuel both 3000 and 3600 psi vehicles—station is particularly susceptible to overfilling 3000 psi vehicles.



Lessons Learned—Vehicle Overfilling

1. Strong codes (NFPA 52) are already in place.
2. Experienced equipment suppliers-but significant code deficiencies.
3. Owner took over equipment operation with no training.
4. Maintenance personnel had very little subsequent training and a limited budget.



Recap

Lessons Learned

1. The C&S development process benefits from lessons learned and provides adequate safety but enforcement and training is lacking
2. Vehicle cylinders can be over pressurized and rupture
3. Physical or chemical abuse has led to cylinder failure
4. Cylinders have a limited life and should be tracked for ultimate destruction
5. Timely cylinder and fuel systems inspections are critical to safe operations
6. Improper installation of CNG fuel systems can lead to failures

1. The C&S development process provides adequate safety but enforcement and training is lacking

- There are no mechanisms to enforce C&S for after market installations of CNG fuel systems – few states have vehicle inspection programs and are limited in their coverage
- Authorities Having Jurisdiction (AHJs) focus on the fueling infrastructure
- CNG vehicle technicians can be ASE certified to service NGVs through a voluntary program where they receive basic C&S information
- TRAINING – TRAINING – TRAINING

2. Vehicle cylinders can be over pressurized and rupture

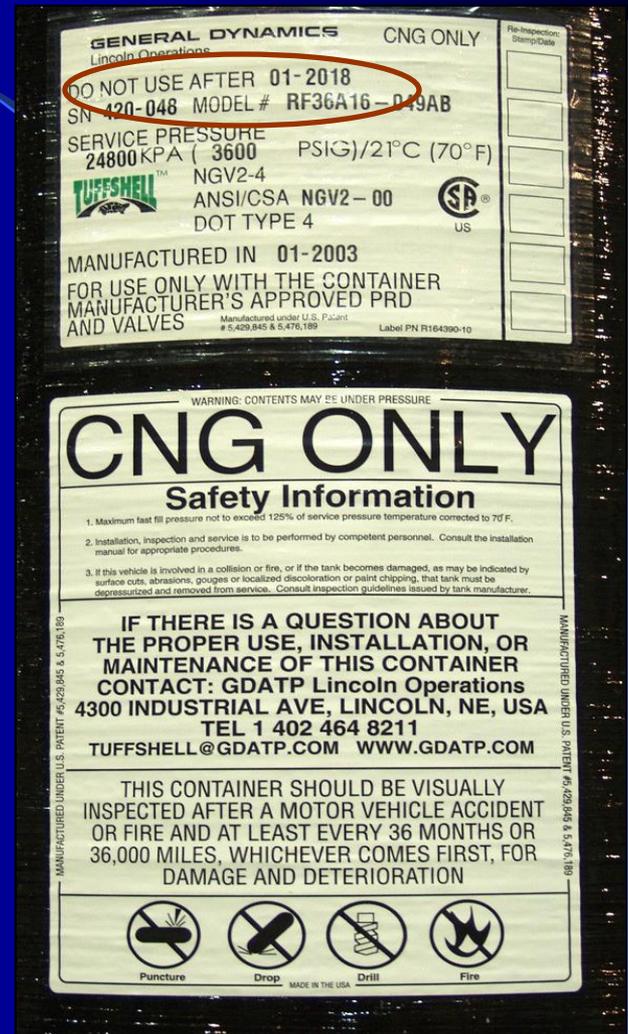
- In the US, Cylinder PRDs are only required to protect against pressure build up due to fire, not over pressure from stations
- Dispensers have two separate pressure relief valves to protect the cylinder against over pressurization
- Ongoing training of fuel station maintenance and operating personnel is critical to safety
- TRAINING – TRAINING – TRAINING

3. Physical or chemical abuse can lead to cylinder failure

- Required chemical and physical abuse tests have strengthened over the years
- Old cylinders (prior to 1996) are still in use
- Cylinders known to be susceptible to stress corrosion cracking (E glass) should be proactively removed from service – most are nearing end of life
- TRACK YOUR CYLINDERS

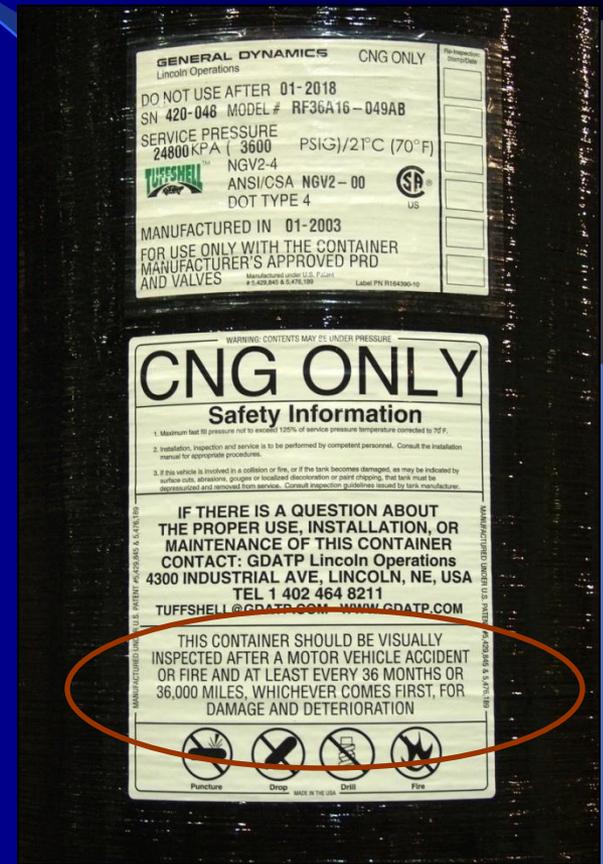
4. Cylinders have a Limited Life

- Remove cylinders at their end of life date and replace if vehicle will continue to operate
- Cylinders removed at end of life or from scrapped vehicles should be destroyed according to the manufacturers instructions
- At this time there is no mechanism to track cylinders by end of life date
- TRACK YOUR CYLINDERS
- TRAINING-TRAINING-TRAINING



5. Cylinder and fuel system inspections are critical to safe operations

- Visual inspection of CNG fuel systems is, at this time, the best method of monitoring the overall safety of NGVs
- CVEF under contract to DOE developed a “CNG Fuel System Inspector Study Guide” for the CSA administered CNG Cylinder Inspectors Certification Test
- CVEF under the same contract provided scholarship funding for training over 250 inspectors
- NFPA 52 was recently changed to require notices at each fueling dispenser about inspection of cylinders
- TRAINING-TRAINING-TRAINING



6. Improper installation of CNG fuel systems can lead to failures

- Many of the incidents can be attributed to CNG fuel system installations that do not meet applicable code
- ASE F1 Test certification of installation and maintenance technicians is a step to mitigate issues
- Conversion shop certification – industry initiated new project/collaboration with other organizations
 - NTEA collaboration on certification
- TRAINING-TRAINING-TRAINING

Best Practices and Training Materials must be Living Documents

- C. 2005 PRD Release
- Vehicle began leaking rapidly after fueling—not a full PRD release as per earlier Mirada failures
- Shook model CG-9, 999-1 rated 22 CFM, activation temperature is 217 degrees F, marked for 3600 PSIG
- **Need documented Best Practices to pass on Lessons Learned**



The Message—3 General Categories of Incidents Causes:

1. Codes and Standards

- Periodically update C&S to reflect field experience

2. Compliance Related Issues

- Tracking cylinders
- Vehicle inspections and conversion issues
- Station design and operations affect vehicle safety

3. Training on Industry Standards

- Best practices development
- Design documents to assist users to meet code requirements
- Standard operating procedures
- Training of all stakeholders

Questions

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