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Technology Assessment of Refueling-Connection Devices for CNG, LNG, and Propane

This TCRP digest provides the results of TCRP Project C-7, "Technology Assessment of Refueling-Connection Devices for CNG, LNG, and Propane," conducted by Science Applications International Corporation (SAIC).

INTRODUCTION

This digest provides an assessment of current and emerging refueling-connection-device (nozzle) technologies (both domestic and international) for fueling alternative fuel vehicles (AFVs). The nozzle technologies discussed in this digest are those used for refueling with compressed natural gas (CNG), liquefied natural gas (LNG), and liquefied petroleum gas (LPG, commonly referred to as propane). The discussion covers all types of nozzles for the listed fuels. However, the analytical work focuses on nozzles used in heavyduty applications, specifically, transit buses.

Background

CNG and LPG vehicles have been used worldwide for several decades. Countries such as Australia, Canada, Germany, Italy, the Netherlands, New Zealand, and Russia have a long history of CNG and LPG vehicle usage. Technological developments in these countries and in the United States have influenced the development of current nozzles. More recently, the use of CNG, LNG, and LPG has become more common in South American countries, such as Argentina, Brazil, and Venezuela, and in Central and Eastern European countries, such as the Czech Republic, Poland, and Slovakia. The South American and Eastern European countries have had little influence on U.S. nozzle technologies.

In the United States, the use of LPG as a transportation fuel has been popular since World War II. Although not commonly used in heavy-duty transit applications, the Chicago Transit Authority was operating more than 1,700 LPG-powered buses between 1950 and 1963. In the early 1970s, Chicago phased out the use of LPG, largely because of unfavorable economics. Today, there are more than 200,000 on-road LPG vehicles and about an equal number of off-road vehicles in the United States. However, there are only several dozen transit buses using LPG. The use of CNG and LNG for vehicular applications gained popularity in the late 1980s. By the end of 1997, about 65,000 vehicles used CNG (a six-fold increase from 1990). At the same time, approximately 1,000 LNG vehicles were in use worldwide, of which 700 were in the United States.[1] Because of this early experience, the United States has pioneered the development of nozzles used for fueling LNG vehicles.

In general, the United States is the most progressive country with respect to the development of standards and regulations for CNG and LNG vehicles, vehicle-related technologies, and emissions. However, the United States is not the leader in setting LPG standards and in developing LPG technologies. Countries such as Australia, Canada, Germany, Italy, and the Netherlands have more advanced LPG industries, which corresponds with more widespread use of LPG vehicles.

[1] Science Applications International Corporation, estimates, derived from SAIC's 1997 Natural Gas Vehicle (NGV) Survey.

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Overseas manufacturers of LPG and CNG nozzles are producing and will continue to develop nozzles that meet U.S. regulatory and market requirements. Many European countries are focusing on urban emissions, especially transit bus emissions. As a result, certain countries (e.g., Germany, Denmark, Italy, the Netherlands) may surpass the United States in the control of emissions from LPG and CNG nozzles. There is no evidence to indicate that foreign technology developers are working on LNG nozzle development. It appears that in the short term, LNG nozzle developments will continue to occur predominantly in the United States.

Scope

This digest provides a summary of nozzle legislation and technologies for CNG, LNG, and LPG. The scope of the work covers only the technology that affects the dead space volume (DSV), which can retain fuel after fueling completion, and results in the venting of that fuel to the atmosphere. The scope does not include the review of other sources of fueling-related emissions (e.g., poor connections or leaky hoses), which, in some cases, account for far greater amounts of fueling-related emissions.

Approach

The research team reviewed CNG, LNG, and LPG nozzle-related regulations. A summary of this activity is presented in the section on "Existing and Future or Proposed Regulations, Codes, and Standards" (page 5). The researchers also conducted a technical and operational review of U.S. and international nozzle technologies to determine their ability to meet current and potential future emissions limits during coupling and decoupling.

The research team contacted the manufacturers shown in Table 1, visited several nozzle manufacturers, and studied nozzle technologies at manufacturers' sites for each of the three fuels. In the United States, the team visited the plants of Moog and Sherex and met with key staff from Parker Hannifin. Internationally, visits were made to Stäubli (a European manufacturer of CNG nozzles interested in launching an LPG product line) and Brevetti Nettuno (an Italian manufacturer of LPG nozzles). The team also observed CNG and LPG fueling operations in several countries in Europe.

The discussions of U.S. and international technologies are merged because there are no major differences between U.S. and foreign products. The only relevant difference between the two is that LPG products are primarily of foreign origin and LNG products are predominantly of U.S. design and origin. Several U.S. fueling sites were visited to observe operational-, safety-, and performance-related factors. For instance, the project team visited the LNG and CNG fueling sites at Houston Metro (Texas), the LPG public fueling stations in Rockville (Maryland) and in Fairfax (Virginia), the transit LPG fueling station in Corpus Christi (Texas), and the new CNG fueling stations at GRI in Chicago (Illinois) and at Long Island Bus (New York). In addition, information obtained from observations made during past visits to CNG and LNG transit properties is incorporated in this digest. Video tapes made or obtained from other sources were viewed to assist in assessing use-related factors.

Summary

The summary findings and recommendations of this digest, by fuel, are as follows:

- **Compressed Natural** Gas--Redesigning existing CNG nozzles to reduce emissions from the decoupling operation is possible, but not recommended, because CNG nozzles already meet or exceed the requirements of the newly implemented emissions regulations. This is true for nozzles used for both light-duty vehicles (LDVs) and heavy-duty vehicles (HDVs) even in cases where the fuel is not recovered (i.e., is vented to the atmosphere). Throughout the industry, emissions from the
  CNG nozzle DSVs can be reduced by using the depressurization available on all CNG fueling systems through fuel recovery (rather than venting to the atmosphere). Several states and technical specifications require such recoveries. However, these specifications are not universally followed. The use of fuel recovery on a widespread basis would make CNG emissions from the CNG nozzle connection and disconnection processes insignificant compared to the decoupling-related losses associated with other fuels. Compared to other sources of methane (the main component of natural gas) emissions, methane losses from CNG fueling operations are insignificant (see Appendix A). More radical redesigns, which could offer near-zero emissions, should evolve through market forces.
  --Recommendation: Encourage the industry to recover natural gas from nozzle decoupling operations (rather than venting to the atmosphere).
- **Liquefied Natural** Gas-Heavy-duty LNG nozzle losses from the DSV are as low as 2.4 cm^3 of liquid. Developers of a new nozzle design claim "zero-emissions" (to be interpreted as very low rather than as 0.0 cm^3). Manufacturers of another nozzle report that efforts are under way to minimize fueling-related

TABLE 1 Nozzle manufacturers

Fuel Type/Company	Site of Manufacture †	Product
LPG		
Brevetti Nettuno, s.r.l.	Bologna, Italy	LPG Gas Erogator Gun
Krause Alternate Fuels	Winnipeg, Manitoba	Elaflex ZVG LPG Nozzle
LG Equipment	Lilli Pilli, Australia	Gasguard LPG Nozzle
Bay Bronze Industries	Winnipeg, Manitoba	Bayco Propane Nozzle
RegO/Engineered Controls	Elon College, North Carolina	Hose-End Valve (A7797)
Squibb Taylor	Houston, Texas	Hose-End Valve (AL343)
Parker Hannifin	Minneapolis, Minnesota	FS Series coupling (prototype)
CNG		
Parker Hannifin	Minneapolis, Minnesota	FM Series Refueling Nozzles
Sherex/OPW	Burlington, Ontario	200, 600, 1000 & 5000 Series
Stäubli Corp.	Duncan, South Carolina	NGV refueling connections
Hansen	Berea, Ohio	CNG Type 2 nozzles
Snap-Tite	Union City, Pennsylvania	CNG Type 2 nozzles
Erwin Weh GmbH	Illertissen, Germany	Type 1 & Type 2, & Heavy-Duty
LNG		
Parker Hannifin	Minneapolis, Minnesota	LNG Couplings
Moog	East Aurora, New York	LNG Couplings
Gibson Technical Services	Puyallup, Washington	LNG Coupling
Hiltap	Calgary, Alberta	LNG Coupling (prototype)
Whittaker Controls, Inc.	North Hollywood, California	Experimental
A. Livsey	Houston, Texas	Experimental

Source: Science Applications International Corporation, Transportation Consulting Division, September 1996.

† Some manufacturers have multiple manufacturing sites.

Note: This table represents the best information available to the researchers at the time the report was written. Other suppliers might have existed and any omissions were inadvertent.

- (DSV) losses from their nozzles. Moreover, reductions of DSV-related losses of 99 percent are achievable through nozzle depressurization and fuel recovery. This is a potentially expensive fuel recovery option, and it is unlikely that any manufacturer will voluntarily implement the fuel recovery option. However, the anticipated frequency of fueling activities at LNG transit facilities, and the potential desirability of LNG fueling in a protected environment (i.e., under a weather shelter or canopy), may cause transit facilities to request that fuel recovery be made part of their fueling systems. Such requests (market forces) may initiate the use of LNG recovery systems.
  --**Recommendation:** Develop and test the fuel recovery options for LNG and make such technologies available to the industry for use on a voluntary basis. This, along with other fuel loss-related minimization activities, could make LNG fueling a safer, cleaner, and more readily acceptable operation.
- **Liquefied Petroleum** Gas-Several manufacturers have LDV nozzles that already meet the 2-cm^3 emission requirements; other manufacturers are modifying their equipment to meet these limits. Reductions in DSV below 2 cm^3 are possible in LDV nozzles through relatively minor nozzle redesigns; heavyduty LPG vehicle nozzles are not affected by existing regulations. The DSVs of the available heavy-duty LPG nozzles are several times greater than the 2-cm^3 DSV limit allowable for LDVs. Redesigns of these nozzles could lead to major reductions in the DSV.
  --Emission reductions from the DSV of 99 percent are achievable through nozzle depressurization and fuel recovery, such as those used in CNG nozzles. It is unlikely that any manufacturer will implement this technology because of the costs associated with such changes, and because existing light-duty nozzles meet or can meet emission regulations. However, because of the anticipated frequency of fueling activities at LPG transit facilities, and the potential need for fueling in weather-protected environments, such as under canopies and in other semi-enclosed structures, transit facilities may specify the use of fuel recovery systems in their operations, particularly if they are to be performed indoors.
  --**Recommendation:** Develop and test the fuel recovery options for LPG and make such technologies available for the industry to use on a voluntary basis. This, along with other fuel loss minimization activities, such as the use of automatic fill limiting (AFL) valves, can make LPG fueling a safer, cleaner, and more readily acceptable operation.

In response to a specific project requirement, the technologies needed to meet current and proposed regulations and standards were to be identified, and recommendations presented. In this effort, the following are relevant:

- **CNG Nozzles**--CNG nozzles for LDVs meet the existing regulations. Although the existing regulations do not affect HDVs, nozzles used for these vehicles also meet and exceed the requirements of the LDV-related regulations. No new requirements are needed. However, the researchers recommend that the industry recover natural gas from nozzle decoupling operations (rather than venting to the atmosphere).
- **LNG Nozzles**--Some LNG nozzles for LDVs meet existing regulations. Although existing regulations do not affect HDVs, nozzles available for use on these vehicles almost meet the requirements of the LDV-related regulations. No new requirements are needed. However, the researchers recommend developing and testing fuel recovery options for LNG and making such technologies available to the industry for voluntary implementation.
- **LPG Nozzles**--Some LPG nozzles for LDVs meet existing regulations. Other nozzles are being redesigned specifically to meet or exceed existing regulations. While existing regulations do not affect HDVs, nozzles available for use on these vehicles do not meet the requirements of the LDV-related regulations. Simple technologies are available and voluntary efforts are being made by several manufacturers to reduce the DSV-related emissions from the heavy-duty nozzles. No new requirements are needed because the industry is making progress and because the users (e.g., the transit industry) can and may specify the use of emission-limiting technologies for their operations, particularly if they are to be performed in semi-enclosed structures. However, the researchers recommend developing and testing fuel recovery options for LPG and making such technologies available to the industry for voluntary implementation.

Appendix B contains nozzle information provided by nozzle manufacturers who responded to a survey fielded by the researchers to address issues specifically relevant to this digest. The information provided by the manufacturers includes a list of nozzle models offered, model numbers, throughput, weight, cost, relevant codes and standards, and the DSV status of each nozzle.

EXISTING AND FUTURE OR PROPOSED REGULATIONS, CODES, AND STANDARDS

This section summarizes current and proposed regulations, codes, and standards related to emissions from CNG, LNG, and LPG or propane nozzles. It

includes a review of the regulations, codes, and standards and discussions with representatives of the following:

- Environmental Protection Agency (EPA)
- California Air Resources Board (CARB)
- South Coast Air Quality Management District (SCAQMD)
- Bay Area Air Quality District
- American Trucking Association Foundation
- American National Standards Institute (ANSI)
- National Fire Protection Association
- Texas Railroad Commission
- Texas Environmental Protection Agency

In brief, only the EPA regulates emissions from nozzles during decoupling for CNG, LNG, and LPG. Its regulations cover only LDVs (defined as vehicles with a gross weight equal or under 8,500 lb) such as cars, light trucks, paratransit buses, vans, and service vehicles. ANSI has standards that apply to CNG emissions during normal operations (independent of weight class) but not to decoupling, per se. Several organizations have standards or codes affecting nozzles in the proposal or draft stage but none deal explicitly with emissions during decoupling. Some organizations specify in their codes or standards a requirement to comply with the codes or standards of other organizations. For example, the Texas Railroad Commission's CNG standards require compliance with ANSI standards. In these cases, only the primary code or standard is discussed.

Existing Regulations, Codes, and Standards

CNG and LNG

In 1994, the EPA promulgated 40 CFR 80.33, which contains the standards for emissions associated with natural gas vehicle (NGV) decoupling.[2] The standards are as follows:

- **Standard--1.2** g of natural gas (NG) per nozzle disconnect.
- **Effective Date--**January 1, 2000, for stations dispensing less than 10,000 gal of gasoline equivalent per month.
- **Applicability--LDVs** (Gross Vehicle Weight ?? 8,500 lb).

CNG Only

In 1994, ANSI published ANSI/AGA NGV-1-1994 (in Canada referenced as CGA NGV-1-M94 for the Canadian Gas Association).[3] The ANSI standard applies to CNGVs not LNGVs. It does not distinguish between LDVs and HDVs but rather among nozzle types. It does not explicitly address the issue of emissions limitations during nozzle disconnect. The following excerpts from the ANSI standard cover nozzle disconnect venting and leakage issues:

- Nozzles transferring fuel under high pressure must be fully and safely depressurized prior to being disconnected from the receptacle. This standard addresses three types of nozzles, described as follows:
  --Type 1 Nozzle. With a Type 1 nozzle, the vent valve operating mechanism is integral to the nozzle. The term "integral" means that a single operation of a lever or operating mechanism first safely vents the gas trapped between the receptacle check valve and the nozzle inlet valve and then safely disconnects the nozzle from the receptacle. This type of nozzle is primarily intended, but not restricted, to use at public fill stations.
  --Type 2 Nozzle. With a Type 2 nozzle, the vent valve operating mechanism is external to the nozzle. Venting is required prior to disconnection. This type of nozzle is primarily intended but not restricted to use in fleet vehicle applications.
  --Type 3 Nozzle. With a Type 3 nozzle, the fueling hose is automatically depressurized [typically below 340 kPa (50 psi)] at dispenser shutdown.[4] The nozzle may vent low-pressure gas between the receptacle check valve and the nozzle inlet valve coincident with disconnection. This type of nozzle is primarily intended for residential and fleet applications.

  Leakage limitations are described as follows:[5]

- An external three-way valve, nozzle or receptacle, whether coupled or uncoupled, shall not leak in excess of 200 cm^3/hour.
  --Tests shall be conducted at 34.5 kPa (5 psi), 1,030 kPa (150 psi), and 1.5 times the rated service pressure. Additionally, a 34.5 kPa test (5 psi) is required for Type 3 nozzles.
  --...The test method shall be to...apply an aerostatic pressure to the inlet of the coupled (or uncoupled) device. The external body shall then be checked for leakage using an appropriate method.

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[2] 59 FR 48472, September 21, 1994.

[3] American National Standard/Canadian Gas Association Standard for Compressed Natural Gas Vehicle (NGV) Fueling Connection Devices, ANSI/AGA NGV-1-1994 / CGA NGV-1M94, American Gas Association, Cleveland, OH, and Canadian Gas Association, Toronto, Ontario, April 1994.

[4] The actual standard section 1.3.2.c is 517 kPa or 75 psi *(Ibid.*, p. 3).

[5] *Ibid.* (p. 18, Section 2.6).

--All devices shall be checked for leakage from the time of connection through fuel flow to the time of disconnection.

- The receptacle check valve shall not leak in excess of 200 cm3/hour.

  --Tests shall be conducted at 1,030 kPa (150 psi) and 1.5 times the rated service pressure.

  --The receptacle shall be connected to a pressure vessel capable of safely accommodating the specified test pressures. The receptacle and pressure vessel shall then be pressurized. Once the pressure vessel has reached the specified test pressure, the upstream portion of the receptacle shall be quickly depressurized and the receptacle check valve checked for leakage.

Addenda NGV-1a, approved January 21, 1997 (and as of this writing unpublished), by the NGV-1 Committee of ANSI/IAS and CGA, revise the above definition. When formally adopted and published, these will likely become the official definitions for the three types of CNG nozzles. This digest will refer to the current definition; however, this will not materially affect the findings of this digest nor the classifications of the nozzles provided in this and other sections of this digest.[6]

LPG

The EPA promulgated 40 CFR 86.001-9 and 80.32, which contain standards for emissions associated with LPG decoupling, in 1994.[7] The standards are as follows:

- **Standard--0.15** g per dispensed gallon (40 CFR 86.001-9) and maximum 2.0 cm3 dead space from the face of the nozzle which seals against the vehicle receptacle O-ring (40 CFR 80.32).
- **Effective Date--40** CFR 86.001-9 is applicable for 2001 and later model years. 40 CFR 80.32, January 1, 1998, is applicable for stations dispensing more than 10,000 gal of gasoline equivalent per month; January 1, 2000, for stations dispensing less than 10,000 gal of gasoline equivalent per month.
- Applicability--Light-duty vehicles (Gross Vehicle Weight 8,500 lb).

Future or Proposed Regulations, Codes, and Standards

CNG and LNG

The EPA standards described in Section 1.1.1 apply to liquefied natural gas vehicles (LNGVs) even though the basis for the EPA standards, ANSI/AGA NGV-1, applies only to compressed natural gas vehicles (CNGVs). EPA is aware of this inconsistency. However, EPA stated that it has no intention at this time to review or revise the standards for LNGV refueling.[8]

EPA also has no plans at this time to extend the standards to HDVs.[9] The EPA rules were designed to bring NGV and LPG refueling and operating emissions in line with gasoline vehicle emissions, not diesel vehicle emissions. Thus, the regulatory relationship in the rule is between emissions from onboard refueling vapor recovery (ORVR) from light-duty gasoline vehicles (not heavy-duty diesel vehicles) and NG/LPG vehicles.

CNG Only

Revisions to the ANSI NGV-1 standard are in the final review and comment stage. None deals with emissions during decoupling, but some may state that emissions must be consistent with EPA 59 FR 48472.[10] At the time of this writing the standard was not available for public release.

LNG Only

The American Trucking Association (ATA) developed new standards (i.e., SAE J2342) for heavy-duty truck refueling for the Society of Automotive Engineers (SAE). SAE approved and adopted the standards in the winter of 1997. The standards are designed to cover general design practices but not emissions from decoupling the nozzle.[11]

All Alternative Transportation Fuels

The National Fire Protection Association (NFPA) will reorganize its standards as follows: NFPA 52 will be changed to include CNG, LNG, and LPG in one standard. NFPA 57 will be eliminated. NFPA 30a will pick up language from NFPA 52 dealing with all fuels at public fueling stations. The only substantive change will be to resolve conflicts among fuels at fueling stations under NFPA 30a. Changes will be reviewed and implemented over a 27-month period starting in mid-1996. Emissions during nozzle decoupling are not specifically addressed.[12]

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[6] To track the status of NGV-la, contact the Natural Gas Vehicle Coalition at (703)527-3022.

[7] 59 FR 48472, September 21, 1994.

[8] Personal communication between Harry Chernoff (SAIC) and John Mueller, EPA Office of Mobile Sources, Ann Arbor, MI (313)668-4275, June 4, 1996.

[9] *Ibid*

[10] Personal communication between Harry Chernoff (SAIC) and Carmen Rossi, Chairman, Joint Natural Gas Vehicle Coalition Task Group/Canadian Gas Association Subcommittee for CNGV Fueling Connection Devices, (716)827-5520, June 5, 1996.

[11] Personal communication between Gary DeMoss (SAIC) and Bill Peerenboom, Vice President, American Trucking Association's Foundation, (703) 838-1863, April 1, 1997.

[12] Personal communication between Harry Chernoff (SAIC) and Doug Horne, Chairman, NGVC Technology Committee;

EPA will be promulgating new test procedures (not new standards) for diurnal and running loss evaporative emissions for all fuels, vehicles, and weight classes. The 3-day test will be eliminated and the 2-day test will be modified. No proposals relating to nozzle decoupling are on the drawing board.[13]

Discussion

Currently, the only regulations, codes, or standards relating to emissions during decoupling of CNG, LNG, or LPG nozzles are the EPA regulations promulgated in 1994. These regulations take effect in 1998 and 2000 for LDVs only. No regulations, codes, or standards relate to emissions during decoupling for HDVs (including transit buses). No new regulations affecting nozzles are planned. However, transit organizations that operate LDVs, including paratransit vehicles with gross vehicle weight (GVW) < 8,500 lb, will need to comply with EPA regulations. ANSI standards (ANSI/AGA NGV-1) relate to emissions during pressurized operations, not emissions during or after depressurization. ATA/SAE standards covering heavy-duty trucks operating on LNG are not yet complete and are not planned to cover emissions. The two leading state agencies likely to be involved in establishing standards (the CARB and the Texas Railroad Commission) have no separate standards or plans to establish standards.

With the possible exception of the as yet unreleased ATA/SAE standards relating only to LNG, no standards or regulations exist specific to the weight class of a transit bus. EPA standards covering LDVs might be considered a likely basis for transit bus requirements, in the sense that a nozzle for a LDV could also be a nozzle for a HDV.

Discussions with the various state and federal agencies associated with air quality and the organizations associated with safety indicate that, for HDVs, a void exists in the area of standards or regulations for nozzle decoupling emissions. Whether this void implies a potentially significant emissions problem depends on many factors, including the number of CNG, LNG, and LPG vehicles on the road and the interchangeability of the most widely used nozzles.

CNG NOZZLES

The approximately 65,000 CNGVs in the United States are fueled at approximately 1,250 refueling stations. Natural Gas is readily available through the extensive gas distribution infrastructure in the United States. CNG fueling stations benefit from high-pressure gas mains (to reduce the cost of compressing gas) and mains capable of providing high capacity (so that the local gas supply system is not upset during periods of high use). The gas from the supply mains is dried to remove moisture and compressed by high-pressure compressors to pressures of 3,000 to 5,000 psi.

CNGV refueling stations fall into two distinct categories, fast fill and slow fill. Transit facilities almost exclusively use fast-fill stations, although some of their smaller service vehicles may use slow-fill facilities. At modern, fast-fill transit bus facilities, compressed gas is stored in a bank of buffer tanks, which are used to assist in meeting initial fueling demands. The compressors can also bypass the buffer tanks to fuel the vehicles directly. The compressed gas from the buffer tanks or from the compressors is channeled to the dispenser which measures and controls fuel transfer from the dispenser to the vehicle. From the dispenser, which resembles a gasoline dispenser, natural gas is delivered to the vehicle through a semiflexible, high-pressure hose, which is permanently connected to a nozzle. The open end of the nozzle is designed to fit firmly into a receptacle on the vehicle. The nozzles used for heavy duty, fast-fill fueling use a valve designed to depressurize the nozzle. In some cases, the valves are sequential dual-action devices, which, after depressurization, also decouple the nozzle from the receptacle. The depressurized gas is channeled through a thin, high-pressure hose to the low-pressure side of the system and is thus recovered. In some (unknown number) cases, the depressurized gas is vented to the atmosphere.

In general, when flow is initiated, CNG is pushed from the high-pressure (generally at 4,500 psi) buffer tanks into the onboard cylinders. As the pressure in the buffer tanks drops, the compressors automatically come on. The systems are designed to completely refuel vehicles in timeframes that are comparable (3 to 15 min) to those of gasoline- or diesel-fueled vehicles. Thus, traffic flows at facilities are similar to the flows associated with conventionally fueled vehicles. At the roughly 50 CNG transit bus facilities (essentially all of which use fast-fill dispensers), SAIC estimates that between 120 and 160 nozzles are in use. There may be an equal number of nozzles at school bus refueling stations and at other HDV refueling points.

Slow-fill stations are designed to refuel vehicles in several hours or overnight. Therefore, facilities must be designed to include nozzles at normal parking spaces. Typically, the filling is directly from the compressor output. The compressors are high-pressure compressors with capacity appropriate for the number of nozzles. Dispensers with large numbers of nozzles are at slow-fill stations, where multiple vehicles are fueled simultaneously. Thus, it is nearly impossible to estimate the total number of nozzles in service.

Chairman NFPA Technical Committee on NGVs, (404) 5844802, June 5, 1996.

[13] Personal communication between Harry Chernoff (SAIC) and John German, Program Manager, Nozzles, EPA Office of Mobile Sources, Ann Arbor, MI (313) 668-4214, June 4, 1996.

Description and Features

The nozzles feature metallic coupling devices that contain flow valves to contain and control flow. The AGA/ANSI standard, NGV-1, defines three types of nozzles. The discriminator is the method by which pressure is relieved from the device after fueling and before disconnection from the receptacle. The three types are described in the section "CNG Only" (page 5).

Most nozzles used for CNG fuel transfer are designed to fit receptacles that meet the NGV-1 standards. The NGV-1 receptacle standard defines the external size, location and design of the fastening groove, and the type of valve (see Figure 2.1). Some internal design features of the receptacles are not addressed by the standards. Operationally, however, all use pressure-actuated check valves that operate on similar principles. Only one manufacturer in the United States (with a small and declining market share) offers a nonstandard receptacle and nozzle.

Principles of Operation

Nozzles used for CNG contain the following components:

- Fastening or coupling mechanism designed to firmly and securely attach to the receptacle;
- Filler shaft (tube) that acts as the conduit for the gas and as a housing for valves and associated components (e.g., springs, O-rings);
- At least one manually activated valve;
- Housing for the above, generally covered in a colorcoded plastic sleeve that doubles as a handle; and
- Threaded inlet connector.

A generalized drawing of a CNG nozzle, including the common components as listed above, is shown in Figure 2.2. Design, safety, ergonomic, performance, and operational variations exist by type and manufacturer.

The operation of a nozzle used for CNG consists of the following steps:

1. **Coupling**--Commonly achieved by a ball-locking device inside the nozzle. Steel balls recede into the groove on the receptacle and are held in place by a retractable sleeve. At least two manufacturers use a "Jaw-lock" technology, whereby a set of radially arranged retractable jaws are locked into the recessed part of the receptacle.
2. **Valve Activation--**Either as part of, or after, the coupling process, at least one manually activated valve is opened to enable the passage of natural gas through the filler shaft.
   - In Type 1 devices, the activation is achieved by turning a serial-action lever that, among other functions, opens the valves.
   - In Type 2 and Type 3 devices, the valves are opened through the physical interaction of the nozzle with the receptacle. Most commonly, the nozzle inlet valve is recessed from its seat when the filler shaft is pushed back as the nozzle is pushed onto the receptacle.

   Nozzle inlet valve activation occurs only if the space behind the valve has been depressurized, allowing the valve to recede from its seat.

3. **Fueling--**Achieved by activating a control switch or lever on the nozzle (for Type 1), at a 3-way valve upstream from the nozzle (for Type 2), or at the dispenser (for Type 3), which provides the pressure to open the pressure-activated check valve in the receptacle. Fueling proceeds until a set pressure is reached on the vehicle or until it is manually interrupted. The fueling process is terminated at the dispenser, where a mechanically or electronically controlled valve is shut. Generally, the flow of gas stops when the pressure in the vehicle is equal to the supply pressure. The lack of flow activates a flowsensing valve and the dispenser is shut.

4. **Depressurization--Achieved** according to the nozzle design.

   - **In Types 1 and 2 Nozzles--**The hose and the nozzle remain fully pressurized until a depressurization action is initiated. In Type 1 nozzles, the nozzle depressurization action is integral to the disconnecting process (i.e., a single turn of the handle sequentially depressurizes and disconnects the nozzle). Type 2 nozzles require separate depressurization and disconnect actions by the operator. The CNG in the hose is isolated at the dispenser and at the nozzle, but it remains pressurized in both nozzle types.

     In Type 3 Nozzles--Depressurization is achieved in two stages. First, the hose and the nozzle are depressurized to inlet pressure[14] (commonly 2580 psi) at the dispenser. After disconnection of the nozzle, the gas from the nozzle and the mouth of the receptacle (now at inlet pressure) is released to the atmosphere. A check valve prevents the gas in the hose from being released.

[14] The preferred depressurization system set up for a Type 3 nozzle is to return the pressurized gas to the main gas supply (inlet) system. In practice, this gas is often vented.

Figure 2.1 Example of NGV-1 Receptacle Used in CNG Vehicles

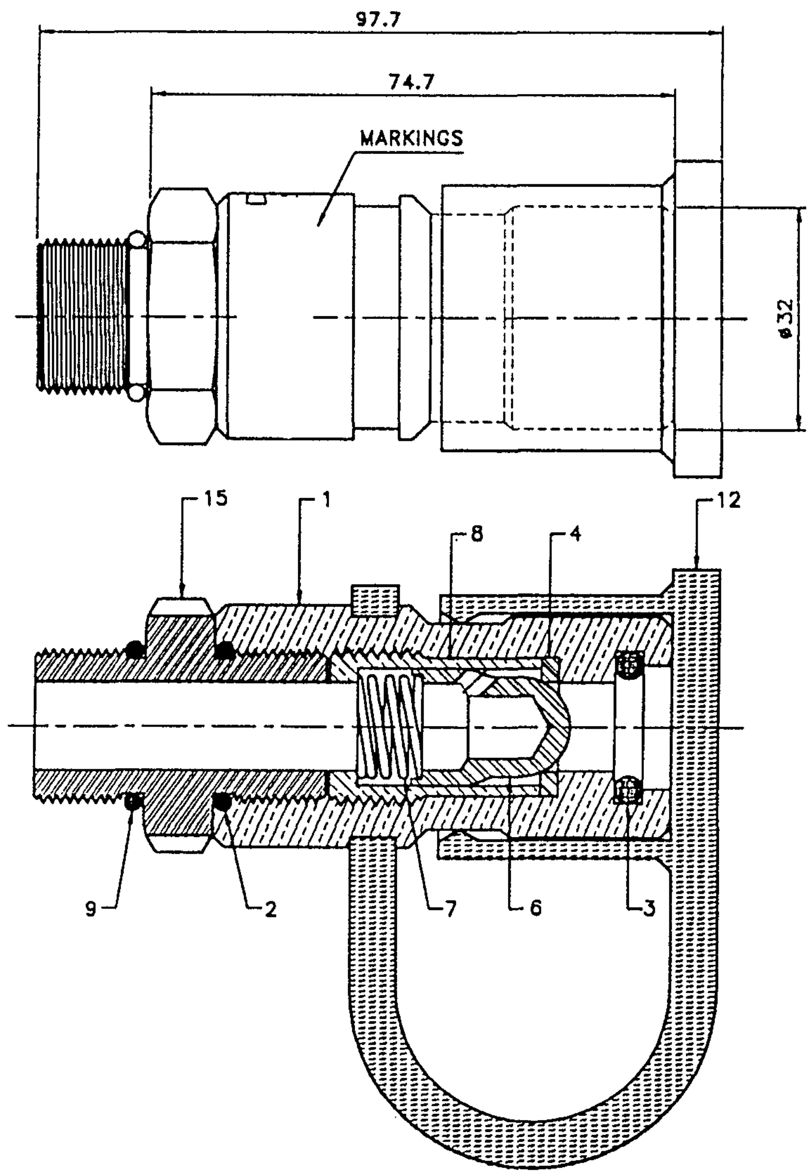
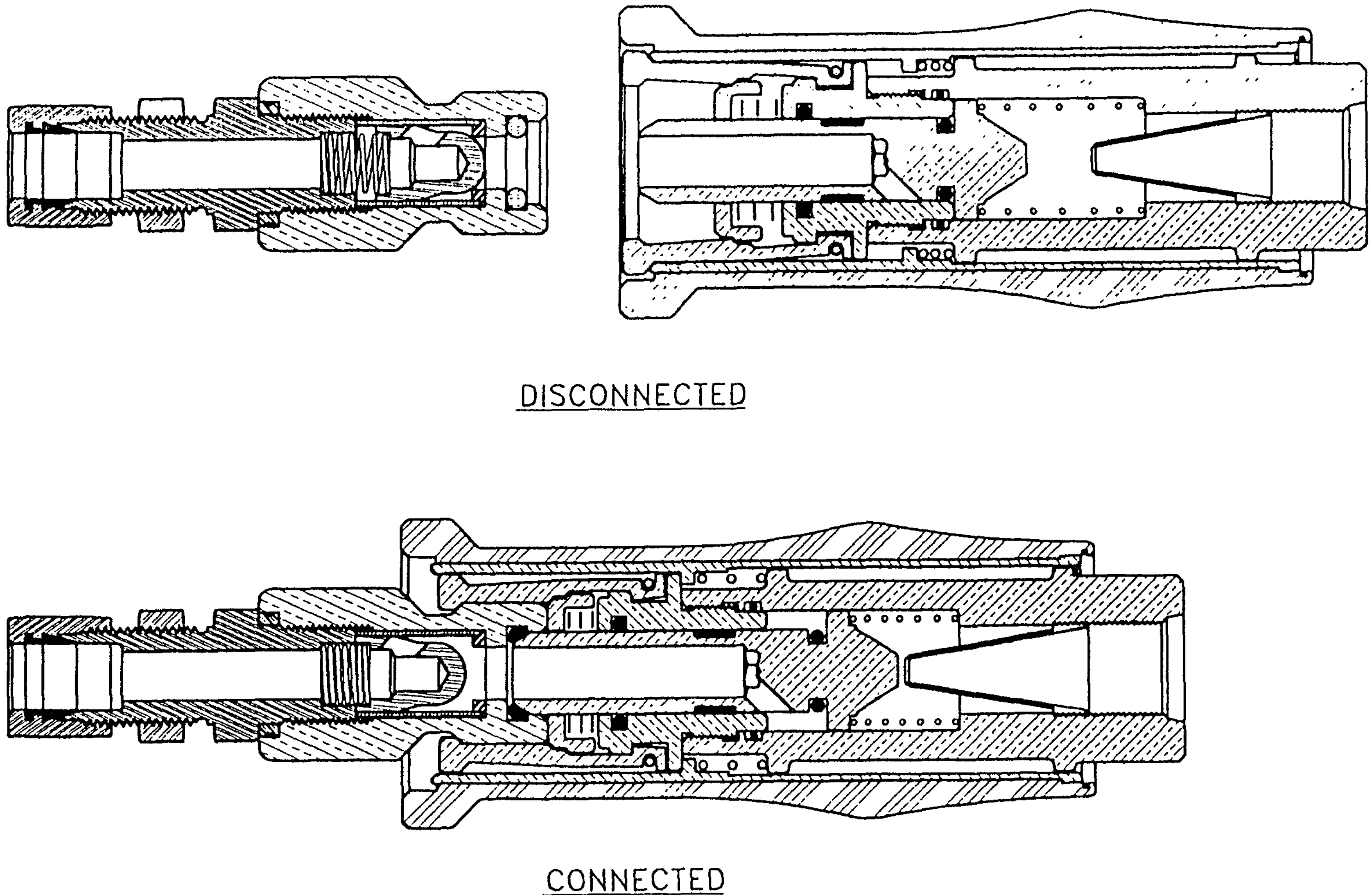


Figure 2.2 Generalized Drawing of a CNG Nozzle



5. **Decoupling--**Achieved by unlocking the retaining balls or the claws and removing the nozzle from the receptacle.

    - **Type 1 Nozzles--**On one manufacturer's product, a handle is turned to the connect position. This action removes the metal-retaining sleeve from the claws. The spring-loaded claws separate from the retaining groove on the receptacle, freeing the nozzle and allowing it to be removed. Another manufacturer's nozzle operates like a gasoline nozzle. Deactivation of the lever depressurizes the nozzle and disengages the retaining balls from the retaining groove on the receptacle, freeing the nozzle and allowing it to be removed.
    - **Type 2 and Type 3 Nozzles--**These nozzles are generally interchangeable. They have a sleevelock mechanism to lock the retaining balls or jaws into the retaining groove of the receptacle. Generally, a pull on the sleeve frees the locking mechanisms and simultaneously removes the nozzle.

Dead Space Volume (Nozzle and Receptacle)

The DSV on the nozzles varies by type and manufacturer. Generally, Type 1 nozzles have the largest DSV, followed by Type 2 and Type 3. The complex functional requirements of the Type 1 nozzle, which houses up to three valves and the mechanisms associated with opening and closing the valves and channeling of the depressurized gas, requires a larger nozzle and a longer filler shaft. Type 3 nozzles, which are generally for lighter, slow-fill, applications, are designed for fewer cycles and with smaller internal components.

The DSV is determined by the length and diameter of the filler shaft on the open side of the nozzle inlet valve. In Type 1 nozzles, additional DSV is associated with the space used by the components for integral depressurization. This space may double the DSV associated with the filler shaft. To determine the amount of gas releasable from a refueling operation, two other measurements are needed: the DSV associated with the receptacle and the pressure at which the nozzle is disconnected. The latter is of particular relevance to Type 3 nozzles.

The following DSV estimates are a combination of information supplied by manufacturers and measurements made by the authors; they show the approximate range and relative values for different types of nozzles:

- **Type 1**--1-10 cm^3, depending on manufacturer. One manufacturer markets a large, heavy-duty nozzle, that has approximately a 30-cm DSV.
- **Type 2**--1-3 cm^3, depending on the application and the manufacturer.
- **Type 3--**0.5-2.0 cm^3 when manufactured for use as a Type 3 nozzle. For Type 2 devices in Type 3 systems, the DSV is the same as for Type 2 nozzles.

At atmospheric pressure the amount of gas released to the atmosphere from the DSV is very small. Appendix A was developed to put the volume of gas released from the DSVs into perspective. However, as DSV and pressure increase, the amount of gas released to the atmosphere increases. This increased release is due to three common system design features: incomplete recovery of the residual gas, venting[15] of the nozzle only, and venting of the nozzle and the hose:

- **Incomplete Recovery of the Residual Gas—**In systems where the gas is recovered through a connection to the inlet manifold on the compressor, the high-pressure gas is released from the DSV. However, the DSV will still contain gas at the pressure of the intake manifold. Generally, this pressure is 30 to 80 psi, but can be as high as 200 to 400 psi.
- **Venting of the Nozzle Only--**In nozzles where the residual (high-pressure) gas is vented rather than recovered (at the inlet manifold of the compressor or otherwise) the amount of gas released from the nozzle may be 200 to 300 times the amount of gas resident in the DSV under atmospheric pressure.
- **Venting of the Nozzle and the Hose--**In Type 3 nozzles, which have the smallest DSV, the amount of gas released is often much more than indicated by the DSV. In Type 3 applications where the residual (highpressure) gas is vented from the nozzle and the hose, the amount of gas released from the nozzle is dwarfed by the amount of gas released from the hose.

Generally, natural gas recovery through a connection to the low-pressure side of the intake manifold (i.e., incomplete recovery of the residual gas) is recommended. This is achievable at a minor cost and system maintenance penalty. A more costly and a more complex option is to depressurize the nozzles (and, in Type 3 nozzles, including the hose) to near atmospheric pressure. Depressurization to atmospheric pressure also increases the risk of introducing air into the fuel system (a potential hazard).

Safety

All nozzles are designed to protect the user from high-pressure releases. The safety features present in all NGV-1 nozzles include the following:

- Positive connection before gas flow.

[15] Refers to atmospheric venting.

- Difficult to disconnect when pressurized.
- Difficult to connect where the nozzle inlet valve senses back pressure (back pressure can indicate that valves upstream may be leaking).
- Automatic check valve activation (nozzle inlet valve) to shut off the flow of fuel on accidental disconnection from the receptacle.

There are some operations-, weight-, and materials-related safety issues that can affect the risk from nozzle usage. In some cases, reducing the DSV may reduce some of the risks. These risk issues include the following:

- **Operations--**Nozzles depressurized through recovery to the intake manifold are not fully depressurized. There will be a slight release of some gas from disconnection. The risk is small and varies according to the amount of gas and the pressure. Decreasing the DSV can reduce or eliminate this safety issue.
- **Weight--**There is a significant difference in the nozzles' weight. Type 3 nozzles weigh only a few oz. Type 1 nozzles, designed for heavy-duty applications, may weigh up to 7 lb. These heavy nozzles require heavier hoses and present weight and flexibility issues. Some transit organizations addressed the issue by attaching the nozzle to a counterweight. Reducing the DSV may or may not reduce the weight of these devices, but it would not increase their weight.
- **Materials--**There is no discernible safety-related difference among CNG nozzles related to materials.

Performance Specifications

Manufacturer information is not necessarily related to uniform performance. The most relevant information is flow rate, measured in standard cubic feet per minute (scfm). Some manufacturers do not provide flow rate. One provides a single (maximum) flow rate for only selected nozzles in the same catalogue. Another provides detailed graphical information on flow rates at different receiver pressures (the pressure of the system being filled). Maximum flow rates of between 800 scfm for Types 2 and 3 nozzles and 5,000 scfm for Type 1 (heavy-duty applications) were noted.

Operating time differs by application. A Type 1 or 2 nozzle used for public station and fleet applications may have frequent, short cycles. This demands assured connect/disconnect performance and durability. Type 3 devices, in slow-fill applications, may have only one user per day but long operating times. Performance requirements by use category are as follows:

- **Class A Nozzle--**High-frequency use, with a cycle life of 100,000 connections and disconnections. This equates to 100 fills per day for 3 years.
- **Class B Nozzle--**Medium-frequency use, with a cycle life of 20,000 connections and disconnections. This equates to 10 fills per day for 5 years.

The extent to which each design has been proven to conform to these standards is not clear.

Operational Issues

Operations-related information is not readily available. This is primarily due to sensitivities associated with in-field performance and reliability issues. The following is provided to indicate the level of information.

Operating and Maintenance Procedures

Of the manufacturer and distributor information obtained for this digest, material from only one manufacturer provides written instructions for nozzle selection, installation, and maintenance. These instructions also provide the purchaser with warnings and safety-and operations-related information. This information is not designed for the users at the fueling station. However, information from this publication can be adopted and posted at the fueling site. Other organizations have provided only sales-related operating information.

Ergonomics

The ergonomics of nozzle use are more a function of vehicle design and the accessibility of the receptacle than of nozzle design. With the exception of Type 1 nozzles, nozzle designs are similar. Samples of Type 1 nozzles from different manufacturers are provided in Figures 2.3.A and 2.3.B. An example of a Type 2 nozzle is presented in Figure 2.4. An example of a Type 3 nozzle is presented in Figure 2.5.

One manufacturer markets a Type 1 nozzle with a gasoline nozzle design and feel (see Figure 2.3.B). This nozzle can be operated with one hand and is designed to connect and initiate fueling by squeezing a handle. The squeeze of the handle initiates several serial operations that connect, lock, and (after the lock position is engaged) open the flow valves. Disconnection is achieved through the reverse sequence of operations. These operations are transparent to the user; the user only squeezes the handle and attaches the nozzle to the receptacle. This design is not currently available for heavy-duty applications.

The only nozzle on the market designed specifically for heavy-duty applications is very heavy, weighing several pounds. Its connection to two rather inflexible hoses (supply and vent), makes it difficult to use. Some sites have adjusted for this difficulty by attaching the nozzle and hose assembly to a counterweight suspended from a pulley.

Figure 2.3.A Example of Type 1 Nozzle From Two Manufacturers

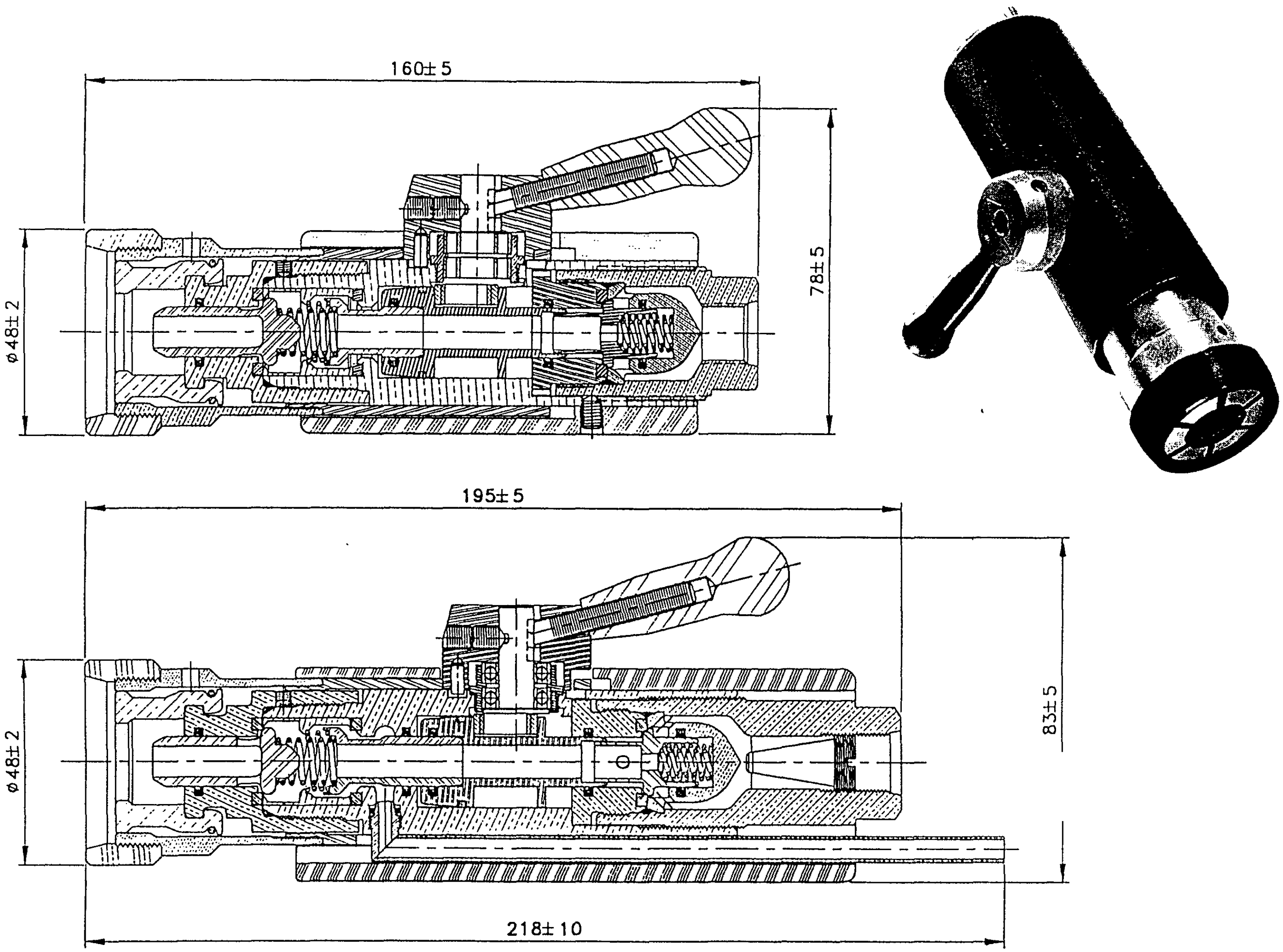
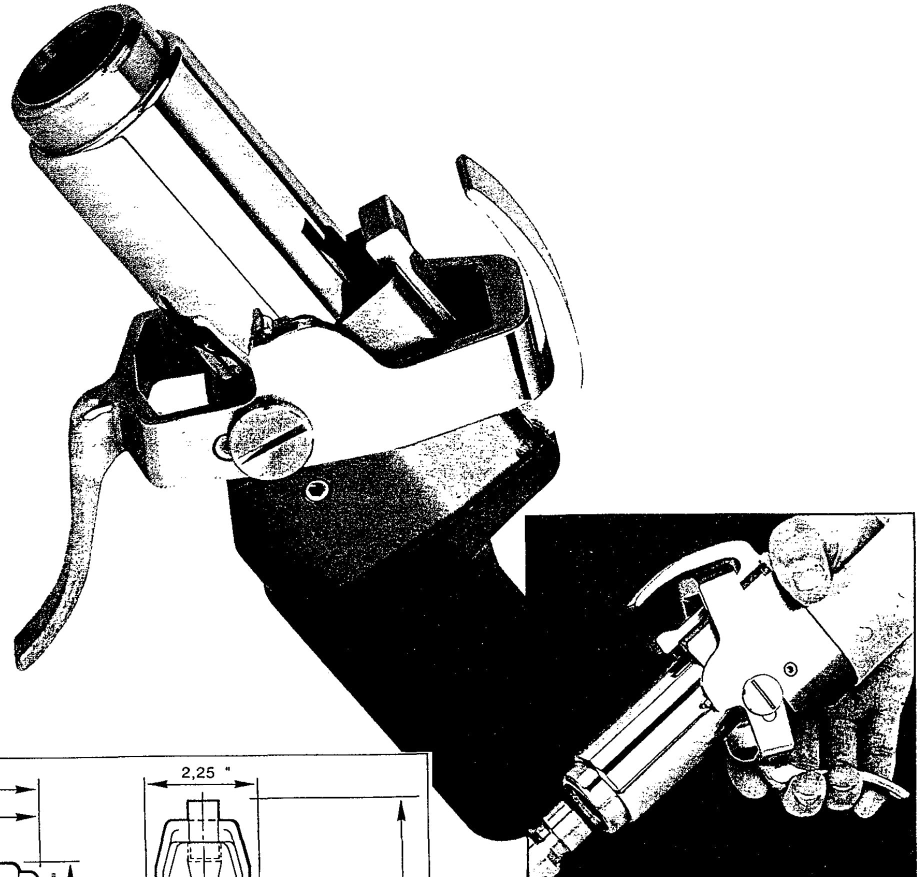


Figure 2.3.B Example of Type 1 Nozzle From Two Manufacturers



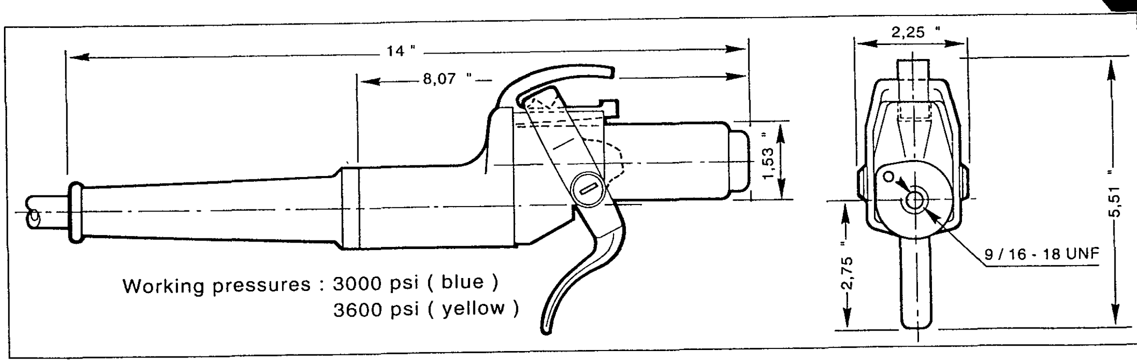


Figure 2.4 Example of a Type 2 Nozzle

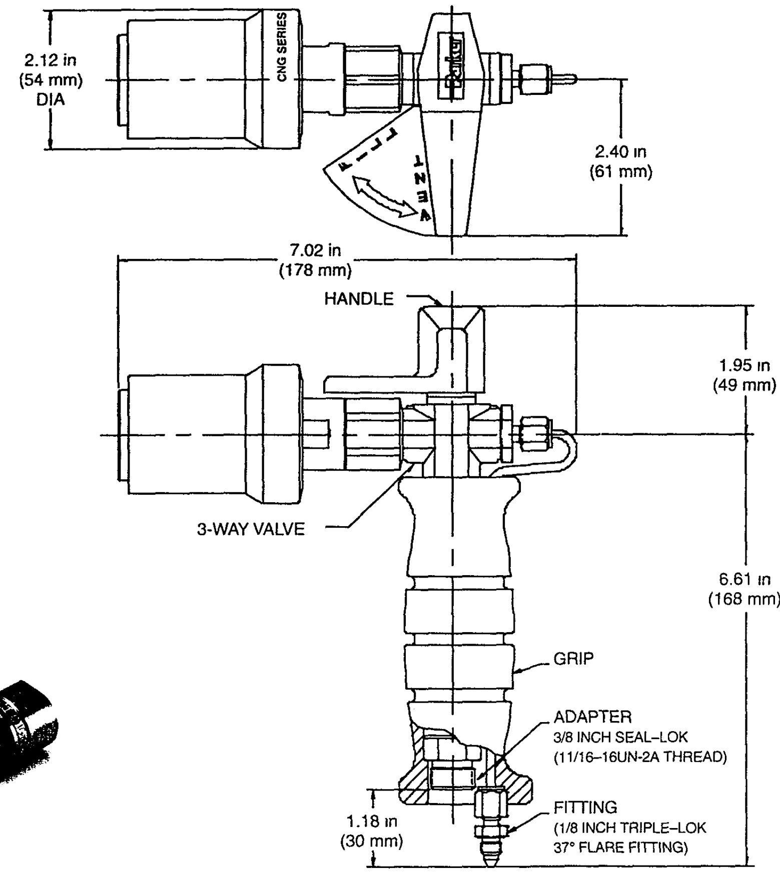
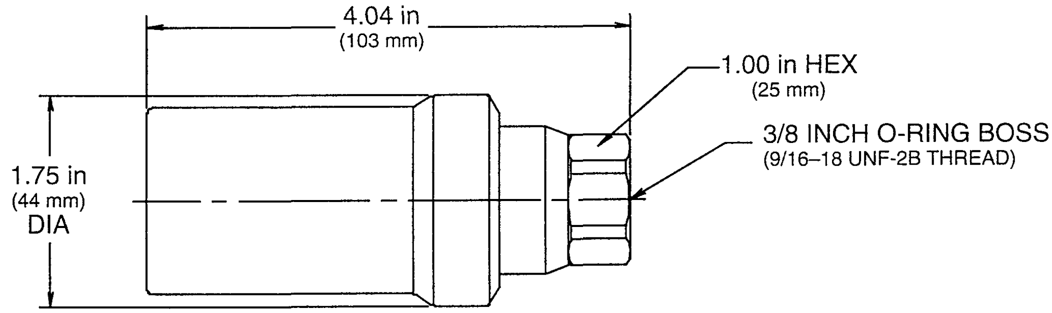
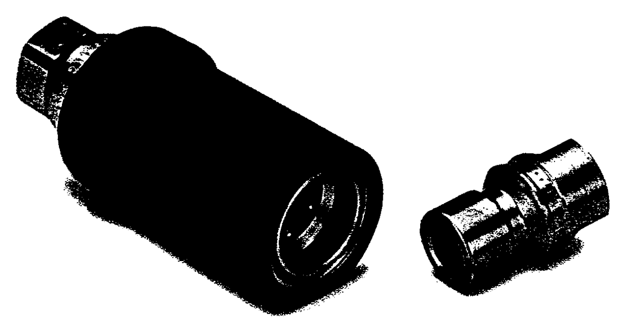


Figure 2.5 Example of a Type 3 Nozzle





Type 2 & 3 NGV1 Nozzle

Reliability

There is little comparative reliability-related information available. Therefore, comparison of reliability by type or by manufacturer is not practical, nor are such comparisons pertinent to the DSV issue. The following failure modes were noted:

- O-ring deterioration leading to slow leaks and severe leaks;
- Hose/nozzle separation leading to high-pressure leaks (manufacturers claim these leaks generally result from abuse.);
- Accumulation of foreign matter at the valves preventing a tight seal and resulting in continuous leaks;
- Poor seal because of freeze/thaw deterioration; and
- User abuse, such as driving the vehicle over the hose/nozzle assembly, resulting in the failure of the locking device, external valve failure (Type 2), internal misalignments, warping of handles, and other failures.

This list is not in order of importance or frequency of occurrence.

LNG NOZZLES

The estimated 700 LNGVs in the United States are fueled at approximately 20 refueling stations, which are located mainly in the South and Southwest.[16] LNG is delivered by truck or rail to cryogenic storage facilities near the dispensers. The refueling stations use specially designed pumps to provide flow to the dispensers. Each refueling station has at least one fuel dispenser or flow control apparatus, each with one or more LNG nozzles. There are between 50 and 100 LNG nozzles in operation in the United States; about one-half of these are at transit facilities.

There are two basic types of onboard fuel system designs that affect the fueling process. One uses a single nozzle that injects LNG into the fuel tank through a sprayer. The spraying action collapses the onboard LNG vapor, reduces the vapor pressure, and permits the liquid fuel to flow from the storage vessel into the onboard fuel tank. The second type uses a dual-hose vapor recovery/liquid delivery system. The removed vapor is either collapsed in the storage tank, vented, reliquefied, used for on-site applications (e.g., CNG vehicle fuel), or injected into the natural gas supply system. This system requires two nozzles: one for transferring LNG from storage to the fuel tank and another for vapor recovery.

[16] Science Applications International Corporation, estimates, derived from SAIC's 1997 NGV Market Survey.

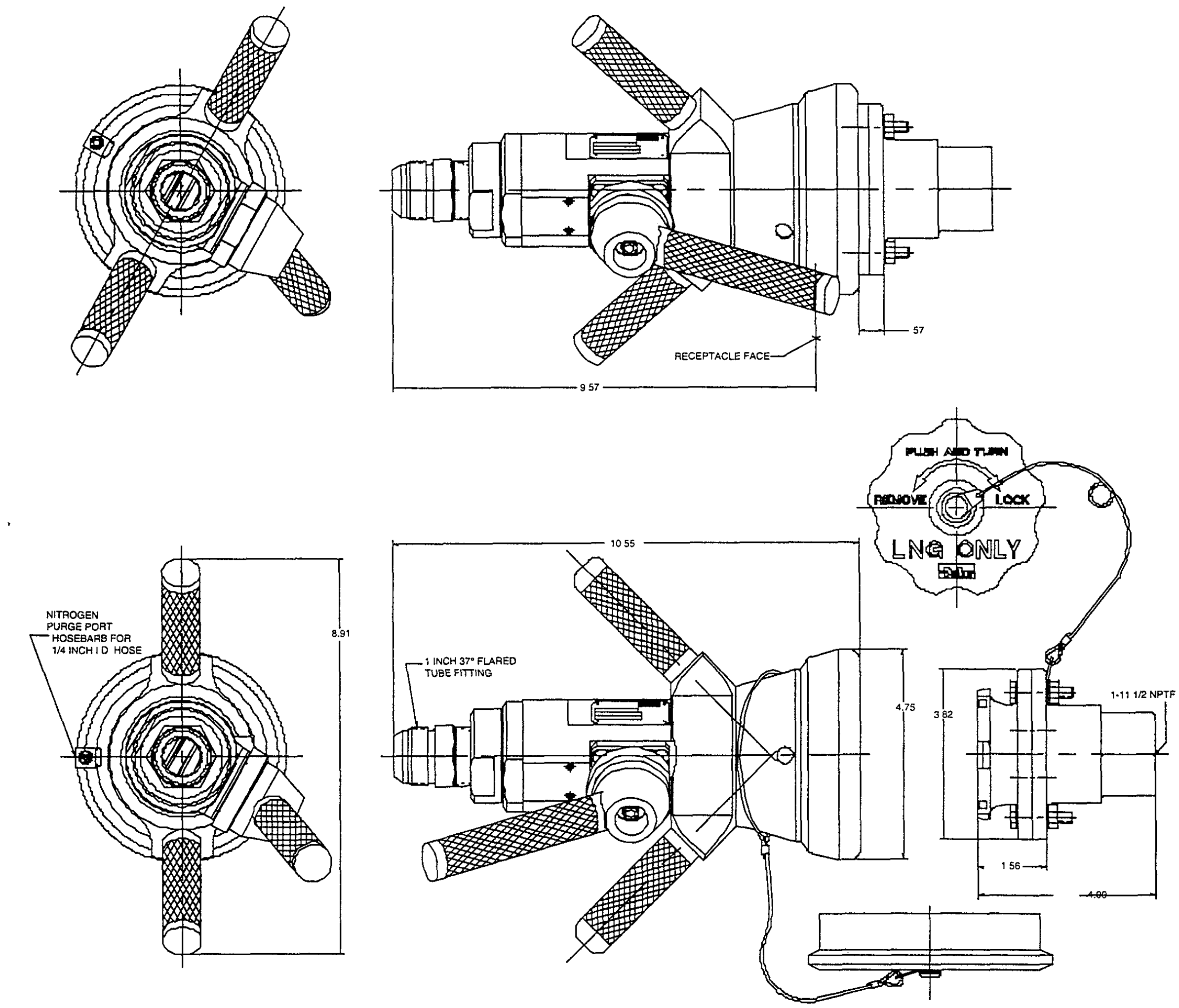
Description and Features

The nozzle used for the transfer of LNG into the vehicle is a metallic coupling device, containing at least one check valve to contain and control flow. The nozzle is attached to the end of an insulated pressure hose, which is generally attached to a dispenser. In some makeshift operations, such as on a trailer or temporary LNG storage or liquefaction facility, the hose is attached to a simple flow control assembly.

Unlike the standards for CNG nozzles, there are no American Gas Association (AGA)/ANSI standards defining size, type, function, performance, or other features of LNG nozzles or receptacles. The various nozzles, made by different manufacturers, are not directly interchangeable. The following categorization of available LNG nozzles is based on selected features, not on a standard. (For the convenience of the reader, letters are assigned to distinguish the various types of nozzle designs.)

- **Type A--**Figure 3.1 is a schematic view of a dualaction, radially connected LNG nozzle. It consists of the tube fitting, valve housing (body), valve handle, collar, collar handles, brace, and seals, bearings, and other fastening and valve activation-related components.
  The active part of the nozzle is the face valve, which is manually activated to the "open" and "close" positions. An optional nitrogen purge feature is used to reduce the accumulation of frost on the locking mechanism and face valve. The nozzle has a high flow rate to minimize fueling time. It is intended primarily for use in HDVs by trained fuellers. It is the most commonly used LNG nozzle at transit facilities.
- **Type B--**Figure 3.2 provides a view of a single-action, coaxially connected LNG nozzle. As shown, the nozzle is intended for use in non-vent systems. A variation of the design exists in a dual-line configuration for use in vent/fueling systems. It consists of a tube fitting that attaches to the LNG hose, valve housing (body), two scissor-like handles, spring-reinforced locking tongues, seals, and other fastening and valve activation-related components.
  The active part of the nozzle is the connection-activated check valve. This valve, and a similar reciprocal valve on the receptacle, are activated as part of the coupling process. This is also a high flow-rate nozzle for HDV applications by trained fuellers. It is the second most commonly used LNG nozzle at transit facilities.
- **Type C--**Figure 3.3 shows a single-action, radially attached LNG nozzle (a hybrid of the Type A and B nozzles). A radial turn of the nozzle attaches it to the receptacle and opens the valves on the nozzle and

Figure 3.1 Example of Type A: Dual-Action, Radially-Coupled LNG Nozzle



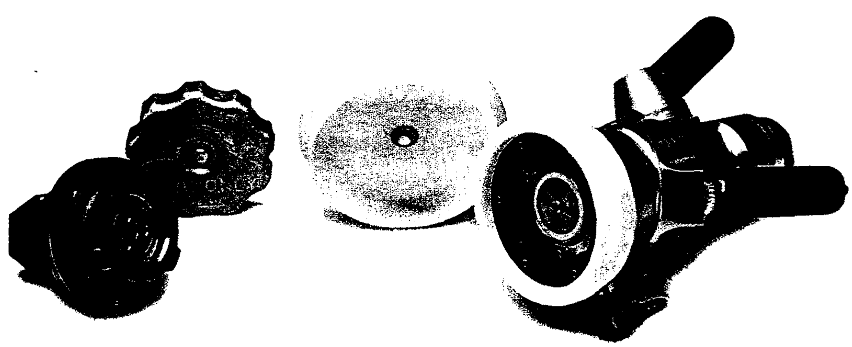
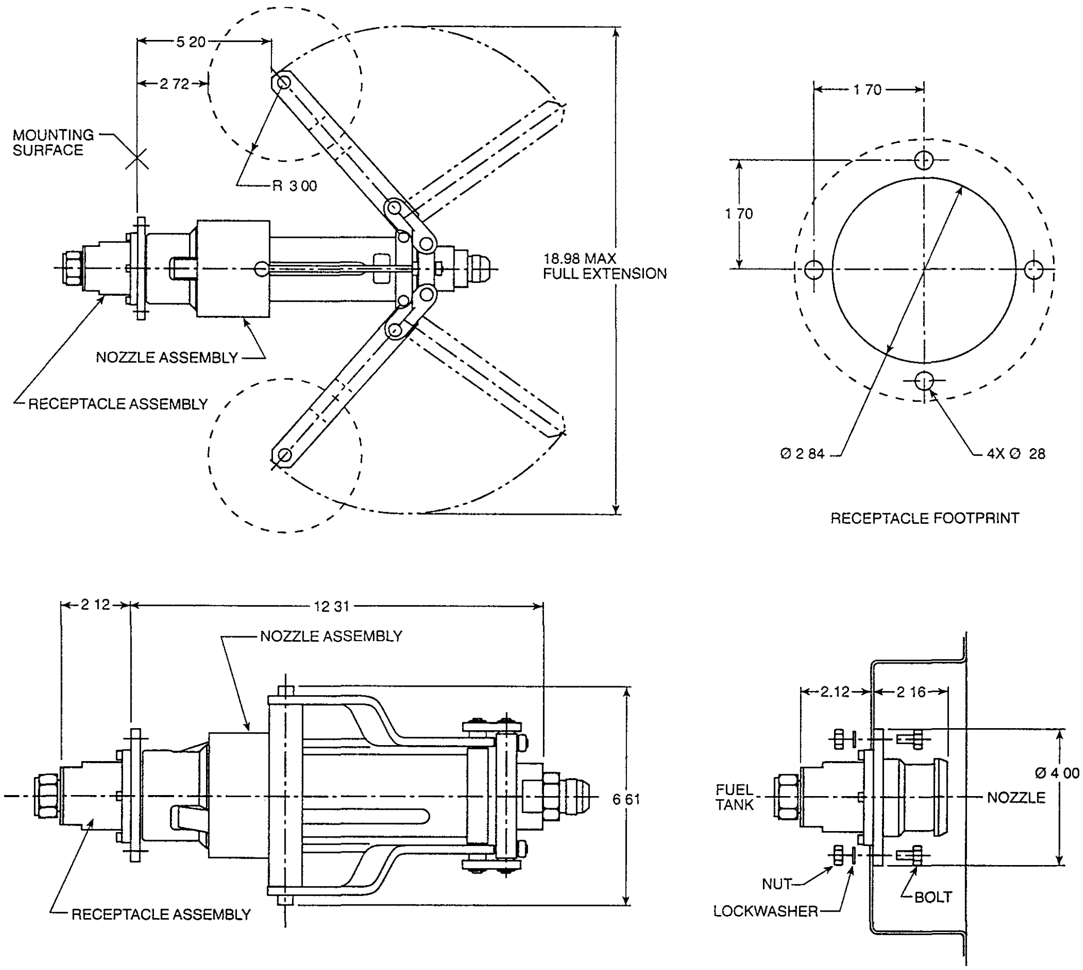


Figure 3.2 Example of Type B: Single-Action, Coaxially Coupled LNG Nozzle



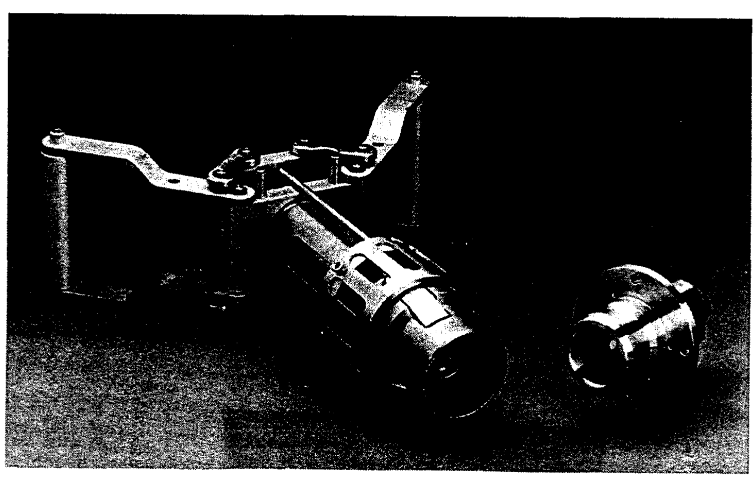
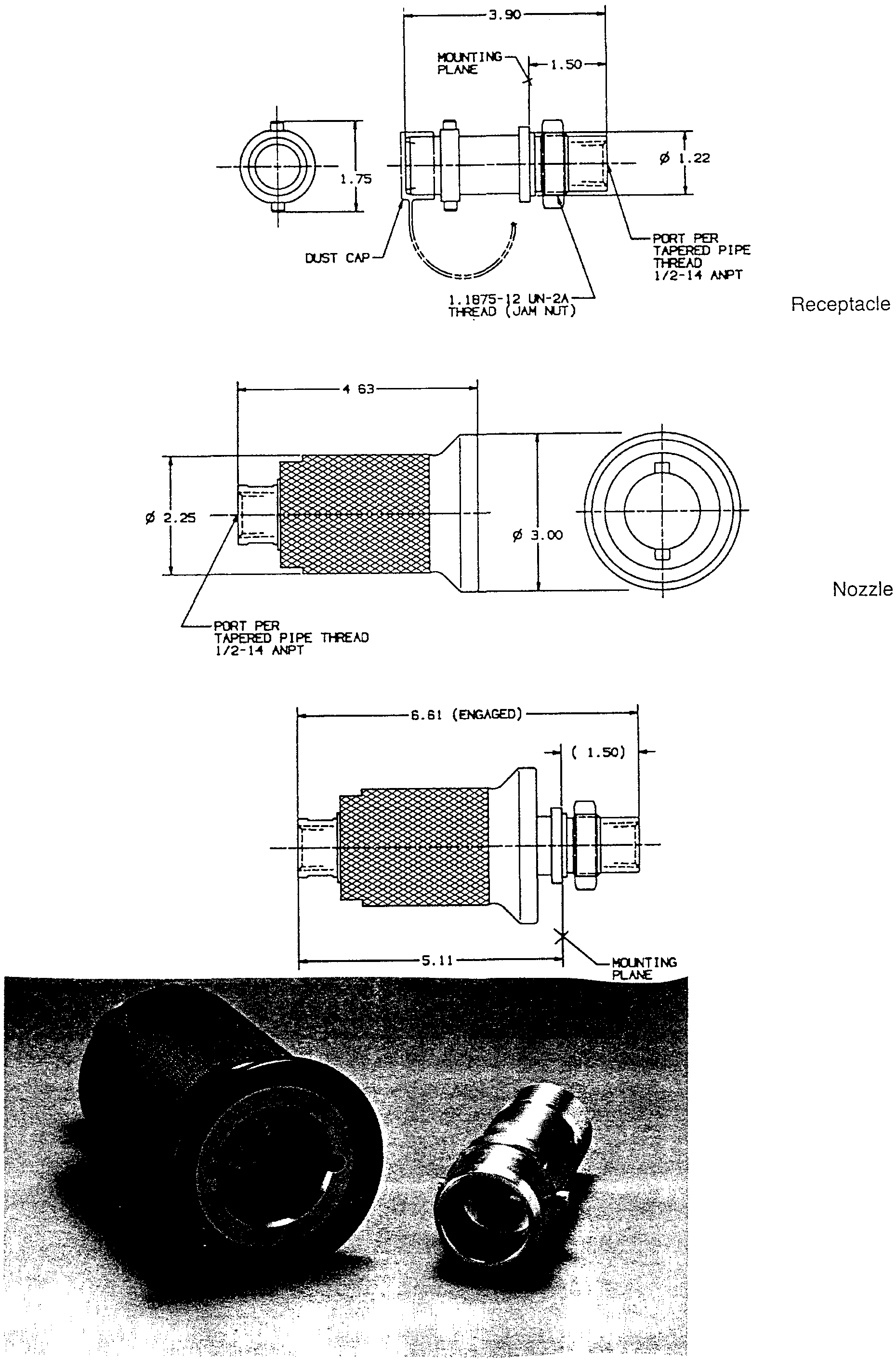


Figure 3.3 Example of Type C: Single-Action, Radially Attached LNG Nozzle



receptacle. The nozzle is designed for non-vent systems.
The internal components and the activation feature of the Type C nozzle are similar to those of Type B, but without the coaxial attachment and mating mechanism. This type of nozzle is designed for lightand medium-duty vehicles where flow rates of 10 gal per minute (gpm) are acceptable.

The development of LNG nozzle technology for use in vehicle fueling is primarily a product of U.S. research and development. Early fueling devices were developed in the 1970s. Improvements followed in the late 1980s, which were followed by the current family of LNG nozzle technologies.

Alternative Designs

The literature describes two early alternative systems. The first was used to fuel an experimental aircraft. A derivative of this technology is shown in Figure 3.4. This device uses a two-socket coupling to mate with a two-plug receptacle on the vehicle. The upper line is for vapor recovery; the lower line is for LNG supply.[17]

Another nozzle uses a coaxial, bayonet-style coupling for quick connect/disconnect. The vapor return is in a vacuum-jacketed fill hose and surrounds the LNG supply line. Fueling is initiated through the activation of a check valve. Figure 3.5 shows a schematic diagram of this nozzle.[18] These designs saw limited commercial use in the 1990s.

At least two LNG nozzle technologies are in the early stages of development or experimental use. One model was not examined or seen by the researchers. Because little is known about the design, the following detailed information is provided below, as supplied by the developer:

- **Special Features**--Contains two fluid fillings; two swivels to allow free rotation of the inlet and return lines for ease of operation; two shear seal valves that are driven through individual manual buttons; a quick-disconnect nozzle assembly comprising two zero-spill, zero-leak, male quick disconnects and a control mechanism activated by a button identified as "on" automatically opening flow to the adapter when the two are coupled.
- **Construction**--Construction materials: stainless steel fluid fitting, nozzle body, and locking arm; Teflon control mechanism, linkage and control circuit, and elastomeric seals.
- **Physical Features**--Weight: less than 12 lb; Size: 4 x 5 x 10 in. envelope; fail safe and automatic.
- **Operation**--Automatic, single-action connection, dual-line design; sleeve is pulled back uncoupling, insulated to allow glove-free handling.
- **Design Details**--"Non-spill," quick-disconnect couplings designed to enable the user to connect and disconnect fluid system lines under operating conditions. Features a flush-face valving design and an inherent free-floating sealed cartridge in the adapter half for reliability with zero spillage and zero air inclusion.
- **Safety Features--**Zero leakage or spillage if seal "hang-up" (valve closure is independent of sliding seal friction), zero valve opening until after connectors are mechanically locked together and pressurized, zero spillage on disconnect and zero air inclusion on connect (zero voids on mating faces).

Figure 3.6 illustrates the principle of operation of this technology, and Figure 3.7 illustrates a comparison with the conventional tubular valve and sleeve design. The other experimental design is shown in Figure 3.8. The approximate DSV is between 30 and 35 cm^3. (An additional 3 to 4 cm^3 of DSV is in the receptacle.) The DSV could be easily reduced to a fraction of its current volume, but not to the 2 cm^3 range. The nozzle weighs about 8 lb and contains one flow valve in the nozzle and one in the receptacle. It is a dual-action, radially attached LNG nozzle, with an in-line, manually activated valve. A radial turn of the latch attaches it to the receptacle. Successful attachment of the nozzle positions a slit on the latch into the open position, allowing the handle to be pulled and the fuel transfer to begin. The performance parameters of the device are not known because of limited use.

Principles of Operation

Because nozzle and receptacle characteristics are not standardized, there are major operational variations by manufacturer and type. A general description of the operation of these devices is provided below. Operational differences among the various devices are provided where necessary.

The operation of a nozzle used for LNG consists of the following steps:

1. Coupling--All LNG nozzles require positive coupling before fuel transfer. In Type A and Type C nozzles, attachment to the receptacle is achieved through a radially activated locking mechanism. In Type B nozzles, the push of a single-motion, serial-function handle attaches the nozzle to the receptacle.

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[17] Gas Research Institute, "LNG Vehicle Technology, Economics, and Safety Assessment," Final Report, Chicago, Illinois, February 1994 (GRI-94/0051).
[18] Gas Research Institute, op. cit., February 1994 (GRI-94/0051).

Figure 3.4 Two-Socket LNG Nozzle

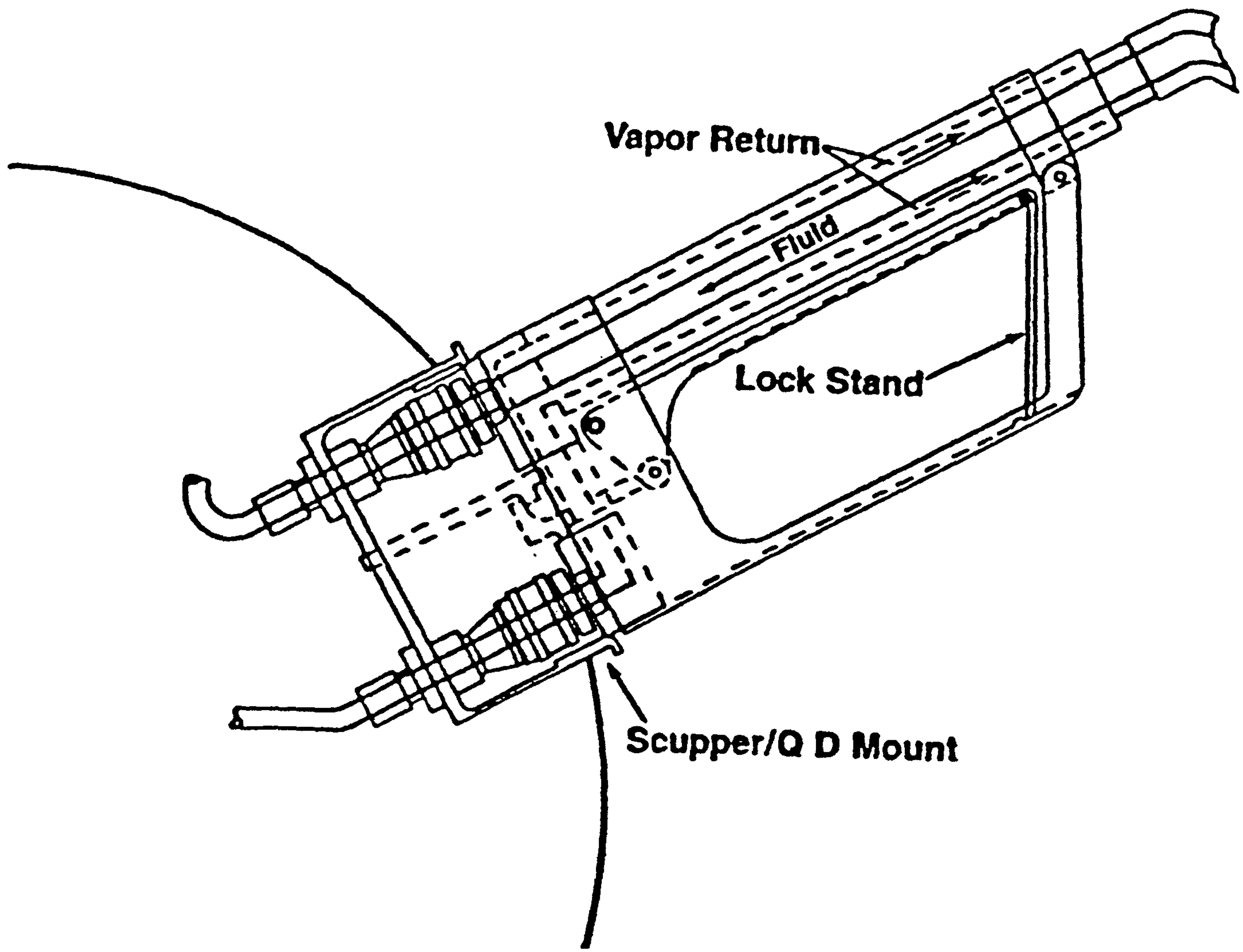


Figure 3.5 Coaxial, Vacuum-Jacketed LNG Nozzle

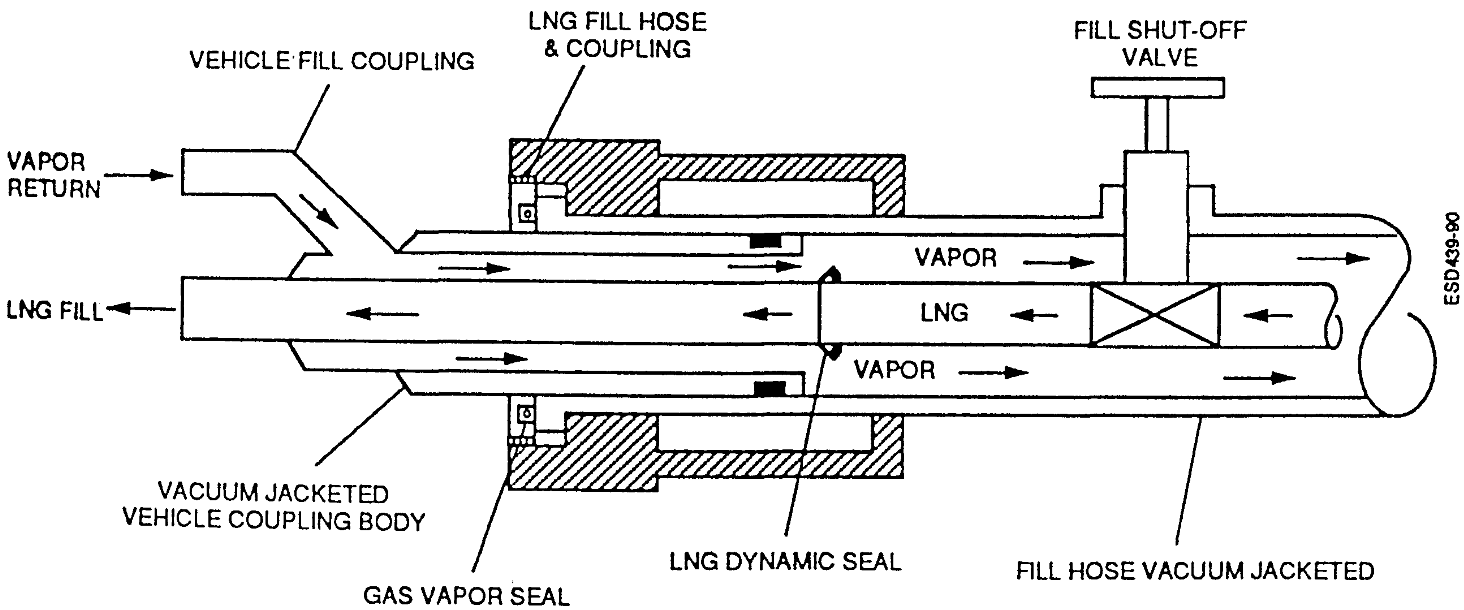
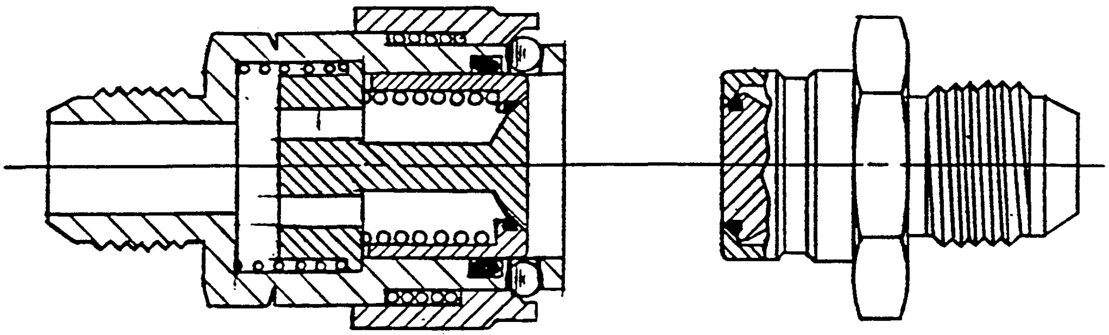
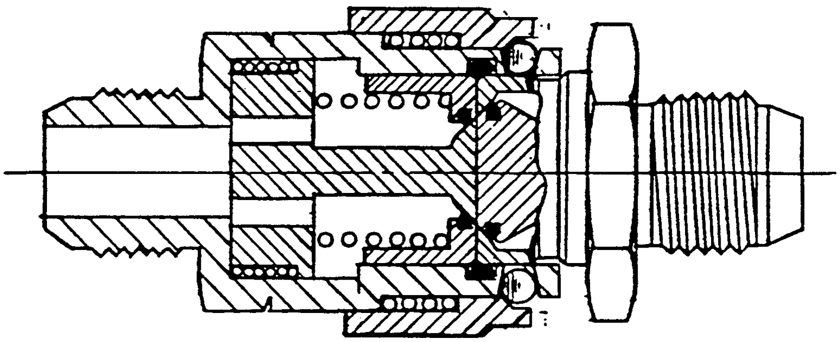


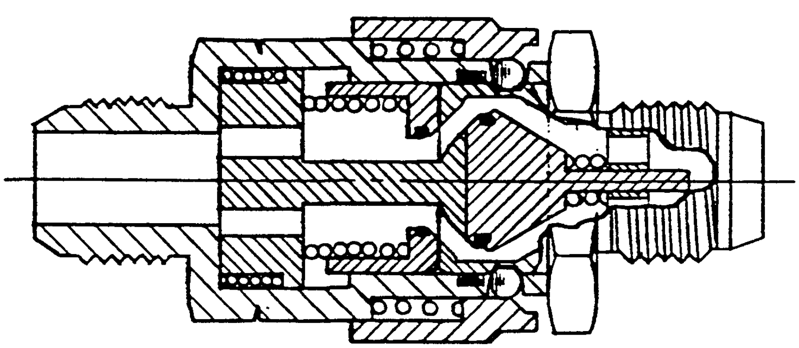
Figure 3.6 Principle of Operation



DISCONNECT HALVES IN DISCONNECTED POSITION - CARTRIDGE IN FORWARD POSITION



MALE CONNECTOR PARTIALLY CONNECTED, CARTRIDGE BOTTOMED, NO VALVES OPEN AT THIS TIME



CONNECTED AND LOCKED POSITION - VALVES OPEN FOR FULL FLOW

CONNECTING SEQUENCE

Figure 3.7 Comparison with Conventional Tubular Valve and Sleeve Design

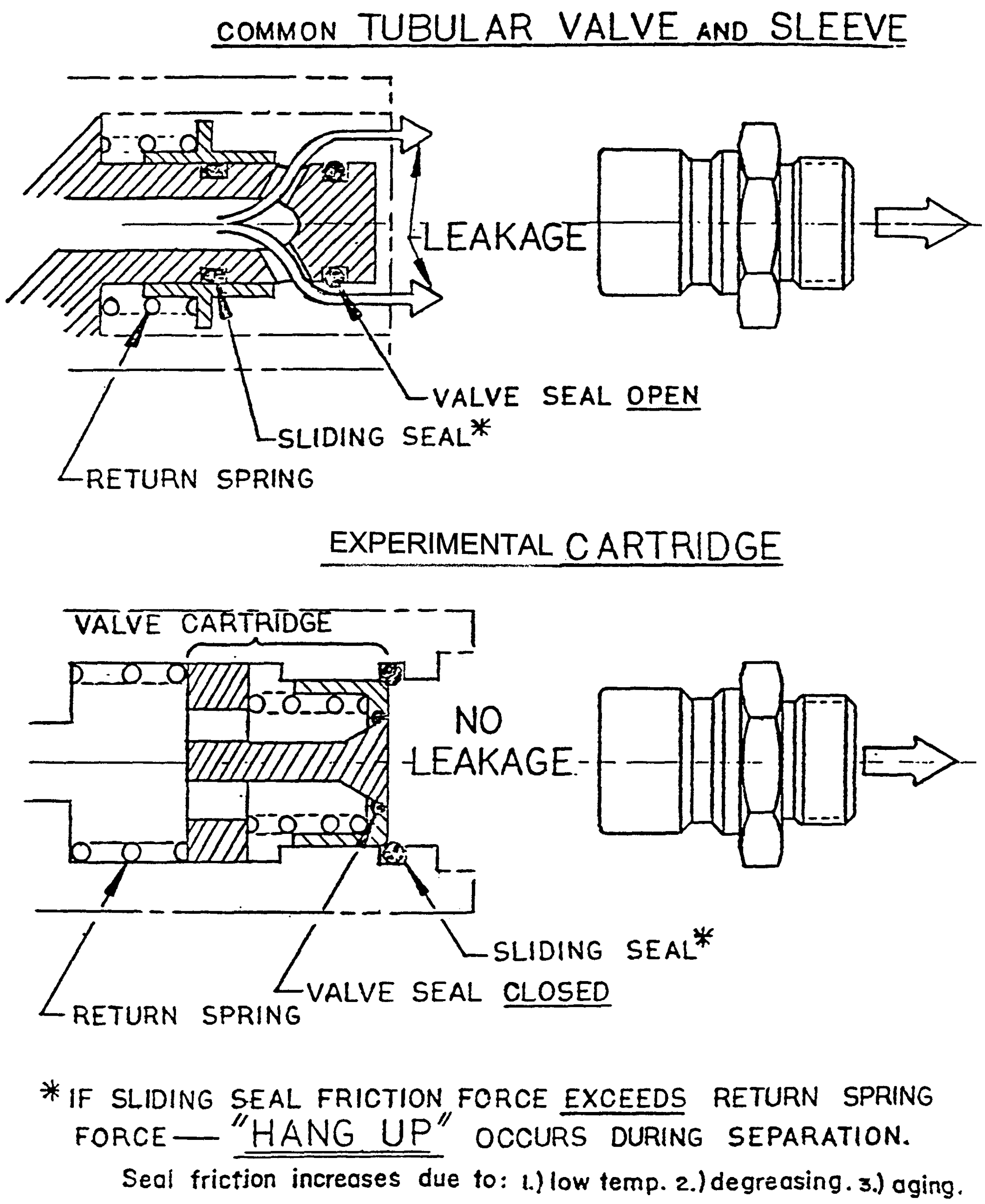
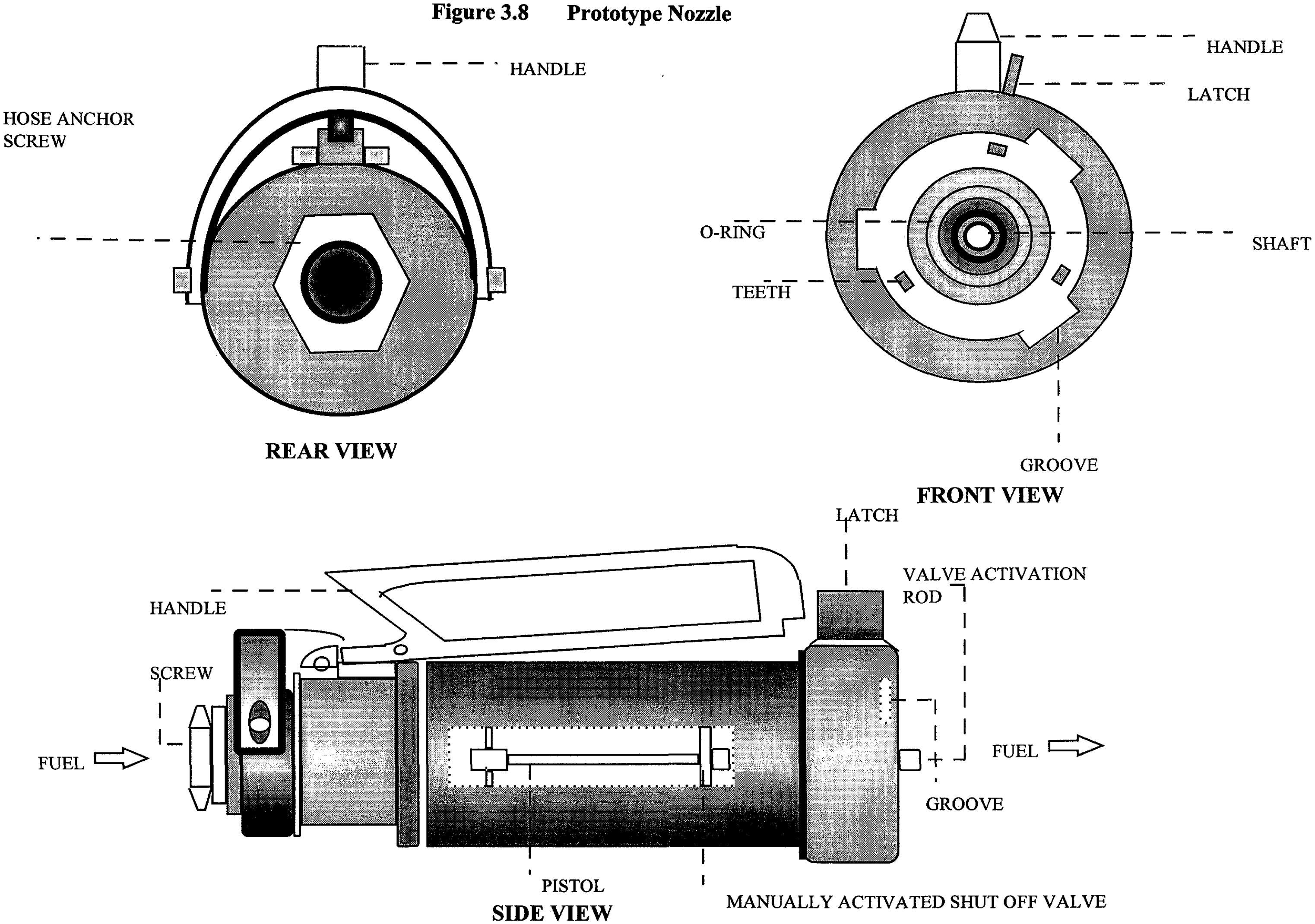


Figure 3.8 Prototype Nozzle



* Patent Pending

2. Valve Activation--Either as part of the coupling process or through a subsequent, separate action, at least one manually activated valve is opened to allow LNG to pass through the filler shaft in the nozzle. In Type A nozzles, fuel flow is initiated only after a handle on the nozzle is turned to open a valve. In Type B and Type C nozzles, flow is initiated by pushing a single-motion, serialfunction handle (also used to attach the nozzle to the receptacle) to open the valves on the nozzle and receptacle.

3. Fueling--Fueling is achieved by turning a lever on the Type A nozzle or activating the dispenser for the Type B and Type C nozzles. For vent systems, similar activation of the vent nozzle is required. Generally, no separate activation of the vent line at the dispenser is needed. For vent systems, if the vapor pressure in the fuel tank is greater than the supply pressure, then pressure reduction, by removal of the LNG vapor, is needed to obtain effective flow. Fueling proceeds until a set volume is transferred, until (liquid) LNG is sensed by the vent line, or until flow is manually interrupted. The fueling process is terminated at the dispenser, where a mechanically or electronically controlled valve is shut. This interrupts the supply of LNG but does not purge the nozzle or hose.

4. Decoupling--Decoupling is achieved by shutting the valve (or in two-nozzle systems, the valves) and reversing the coupling process.

5. Purging and Depressurization--After the supply nozzle is disconnected it may be reconnected to a purge receptacle on the dispenser. The vent line is not purged or depressurized. If another fueling is planned within a short period of time (a few minutes) purging of the nozzle and hose is not necessary.

Dead Space Volume (Nozzle and Receptacle)

DSV varies by type and manufacturer. Generally, Type A nozzles are designed with a face valve system that minimizes spillage during decoupling. The manufacturer specifies a maximum liquid spillage of 2.4 cm^3 during decoupling (there is no spillage associated with coupling). Type B and Type C designs generally use recessed check valves. These devices are specified to have maximum spillage of 5-20 cm^3 (of liquid) during decoupling. The volume specified depends on the design and size of the nozzle. The nozzles in various stages of development have DSVs measured at up to 40 cm^3.

In operations where fueling is infrequent and the nozzle and hose must be purged, pressurized vapor is vented when the nozzle is decoupled from the purge receptacle. In two-nozzle systems, the vapor recovery nozzle may contain liquid LNG.

Safety

LNG nozzles are designed to protect the user from the hazards associated with cryogenic liquids, combustible fuels, and high-pressure releases of combustible gases. Differences among manufacturers and designs have been observed. Among the major safety features are the following:

- Positive connection requirement to initiate and maintain LNG flow;
- Automatic check valve activation to shut off the fuel flow if there is accidental disconnection from the receptacle (Types B and C devices); and
- Interlocking system to prevent valve from opening while the nozzle is not connected and to prevent disconnection while the dispensing valve is open (Type A devices).

Operational requirements specify the use of protective clothing, face and eye protection such as goggles, and specially designed gloves. Fueling with LNG also requires the fuellers to be trained.

There are some operations-, weight-, and materials-related safety issues that can affect the risk from nozzle usage. In some cases, reducing the DSV may reduce some of these risks. These risk issues include the following:

- **Operations**--Before disconnection from the onboard receptacle, all LNG supply nozzles contain pressurized cryogenic liquid. LNG vapor recovery nozzles are also pressurized and rely on one valve to shut the system. Under certain conditions the vapor recovery valve may contain cryogenic liquid. Decreasing the DSV can reduce the associated hazard. Other safety issues and hazards, such as poor ergonomics associated with the connection and disconnection process, are not likely to be related to the DSV.
- **Weight**--There are substantial differences in the weight of the nozzles and the weight of the hose and nozzle assembly. Nozzle weight varies between about 1 and 8 lb. A closely related issue is the combined effect of weight and flexibility. Generally, the heavier nozzles use heavier hoses and present a weight and a flexibility issue, especially in the dual-line systems. System developers have addressed the weight issue by attaching the nozzle to a counterweight or a springloaded lever that helps to direct the nozzle and hose assembly. Reducing the DSV will probably not reduce the weight of these devices, but it will likely not increase their weight either.
- **Design**--All LNG nozzles are manufactured from aluminum or special cryogenic steel. Therefore, materials selection is of no particular concern.

However, design differences in valve type and location do seem to shift the risk from the fueling process (for Type A nozzles) to the connection and disconnection process (for the Type B and Type C nozzles). Observations indicate that Type A nozzles have a greater propensity to leak during the fuel transfer process because of the need to maintain a tight seal on a broad area. Type B and Type C nozzles, however, generally can maintain a tighter seal, but spill a greater amount of fuel during disconnection. For the Type B and Type C nozzles, reducing the DSV will reduce the hazard associated with the fuel leakage.

Performance Specifications

The two major nozzle manufacturers provide performance-related information, including flow rates (measured in gpm), pressure ratings, operating temperatures, and so on. Two nozzles have maximum flow rates of 50 gpm. The other nozzles examined have flow rates of 20 and 10 gpm. One manufacturer reports cycles of operation as 36,500. The other manufacturer does not specify cycles.

Operational Issues

The researchers are not aware of any statistical information regarding the operating experience with these devices. The available operations-related information is based on limited information from the manufacturers and SAIC's independent knowledge.

Operating and Maintenance Procedures

Each of the two key manufacturers provides limited operating instructions as part of its marketing literature. The fueling equipment systems developer/provider, or in some cases the fuel supplier, provides operation- and use-related maintenance information. Because of the novelty of LNG use and nozzle developments, manufacturers maintain close control of the nozzles and encourage manufacturer maintenance only.

Ergonomics

The ergonomics of nozzle use is important in the coupling and decoupling process. The nozzles designed for heavy-duty application are heavy and require precise positioning and the application of some force. Their connection to heavily insulated inflexible hoses makes them difficult to use (see the section on "Safety"). Because of the weight and limited flexibility of the hoses, the location of the onboard (vehicle) and purge receptacles is critical.

Reliability

Of the limited reliability-related information that is available, the following failure modes were noted:

- Seal deterioration leading to slow leaks (dripping) at the nozzle and at hose connections;
- Accumulation of foreign matter at the valves preventing a tight seal;
- Frost, making it difficult to achieve consistently tight connections;
- User abuse, such as the use of inappropriate tools for coupling and decoupling; and
- Incorrect operating procedures, such as dropping the hose and nozzle assembly, scraping the face seals, and forcing connections and disconnections.

The preceding list is not in order of importance or frequency of occurrence. A relatively frequent occurrence is a "drive-away," when a vehicle moves away from the fueling site while the fueling nozzle is still connected to the vehicle. One manufacturer reported seven such incidents. This is a procedural failure, not a component (nozzle) failure, even though it resulted in nozzle damage.

LPG NOZZLES

Currently, approximately 200,000 on-road vehicles and about an equal number of off-road vehicles use LPG in the United States.[19] In Canada an estimated 170,000 vehicles operate on LPG. Worldwide, the figure exceeds four million.

In the United States, LPG is delivered to refueling stations via truck and rail and is available nationwide. At the refueling stations, LPG is stored in liquid form at ambient temperatures. Depending on the ambient temperature, the pressure in both the vehicle and the storage tank is normally between 100 and 180 psig. Because vehicle and storage tank pressures are about equal, a pump is necessary to force flow. Typically, the pump is started in the recirculation mode, the dispenser nozzle is connected, and the nozzle valve is opened to initiate flow.

According to NFPA-58, the maximum fill level of the vehicle tank is 80 percent, based on the potential for thermal expansion. Operators are trained to monitor the tank level gauge constantly while filling a tank. Additionally, in the United States, LPG tanks are still equipped with an overflow vent valve that will begin to release a steady white mist of LPG when the tank is full. Procedurally, the operator should open this vent valve just before filling, continually monitor this valve during

[19] Source: Science Applications International Corporation, 1997 LPGV Survey.

filling, and use the existence of flow from this valve as the primary indication about when to stop filling. Then the operator should close the bleed valve, and recap the main fill valve. Newer vehicle tanks are equipped with float-operated stop valves that stop the filling process when the tank is 80 percent full. In other countries, such as Australia, equipping LPG vehicles (LPGVs) with overflow vent valves (commonly known as "spit valves") is specifically banned by relevant standards. In these countries automatic fill limiting (AFL) valves are used to automatically interrupt fuel transfer when the fuel level in the LPG tank reaches 80 percent of capacity.

LPG automobile tanks are constructed from carbon steel to meet the Boiler and Pressure Vessel Code of the American Society of Mechanical Engineers (ASME). A study conducted by the Research Institute for Road Vehicles TNO of Delft in the Netherlands concluded that vehicles fueled by LPG are safer in crashes than gasolinefueled vehicles.

This section provides a summary of information collected and planned to be collected on LPG nozzles.

Description and Features

Two technologies for nozzles are used in the United States. For simplicity, they will be called basic nozzles and enhanced nozzles in this digest. Basic nozzles have an operator and stem, a ball or globe, a seat, and a body. Enhanced nozzles have additional moving parts and flow paths to increase safety and reduce emissions.

Principles of Operation

Several aspects of refueling are common to both technologies. The onboard tank typically has a fuel capacity of 30-70 gal. NFPA code requires limiting the liquid volume in a tank to 80 percent of its rated water capacity to allow for LPG expansion. Depending on the fill level and ambient temperature, the pressure in the tank varies between 100 and 180 psig. The tanks include a single relief valve set to lift at 312 psig. The relief valve is designed to lift when a correctly filled tank is exposed to a fire or if a completely full tank is heated.

In the United States, an LPGV has a standard, male fueling receptacle. A cap is threaded onto the receptacle to protect the mating surface and gasket when refueling is not in progress. The exterior wall of the receptacle protects the gasketed mating surface. A valve (called a filler valve) is found just below the mating surface to keep the tank from leaking. The filler valve is normally a check valve, but occasionally, an operable check valve or an isolation valve may be used.

When preparing to refuel a vehicle, the nozzle collar is threaded onto the receptacle. The collar is made of spark-free brass or aluminum and is operated easily by hand. As the collar is tightened, the nose piece of the nozzle is drawn into the mating surface of the filler valve. When the refueling connection is completed, the vent valve on the vehicle and, if necessary, a filler valve are opened, the dispensing system is started, and the nozzle valve is opened.

Basic Nozzles

Figure 4.1 shows a basic nozzle in the closed position. A series of springs and detentes lock the valve in the open or closed position. For refueling operations, the lever (top of the figure) is lifted. This raises the valve from its seat (near the outlet) and allows flow to the vehicle. The lever is returned to the position shown in Figure 4.1 to stop the flow. The collar is loosened and removed, and any liquid or gas in the dead space is vented. Generally, these nozzles do not use a positive interlocking feature, and as a result fuel can be pumped through the nozzles without connection to the receptacle. This could result in the undesired release of fuel, a potential safety and environmental hazard.

Enhanced Nozzles

Although basic nozzles are more common than enhanced nozzles, heavy LPG users tend to use the enhanced technology. Figure 4.2 shows a sample enhanced nozzle. The system uses a trigger-like design that is easy to hold in one hand, much like a typical gas pump. The operator needs to use his other hand to attach the swivel nut, but could actuate the lever with one hand. Once the lever is locked in place, no hands are required for operation.

The operation of the enhanced nozzle is internally more complex than the basic nozzle. The initial connection is nearly identical, with the operator connecting the 1 3/4-in. swivel nut to the threads on the filler valve. Operation and venting of the fuel tank are identical to the basic case. Flow through the nozzle begins by squeezing the lever. The lever's action moves a pawl into the body of the swivel nut, making it impossible to turn the swivel nut and disconnect the fitting. Additionally, the action moves the strainer and valve assembly forward (in the direction of the flow) inside a sleeve. This action also moves the nose piece forward. If the nose piece is pressed against the fitting of a vehicle, however, it cannot move forward. The strainer and valve assembly will continue to move forward until the ball valve meets the back of the nose piece. The back of the nose piece will force the ball valve off its seat, allowing flow.

If the nose piece had moved forward but not connected to a filler valve, the back of the nose piece would not have opened the ball valve. Thus, if the lever is squeezed on a disconnected nozzle, no flow results.

Figure 4.1 Example of Basic LPG Nozzle (Shown in Closed Position)

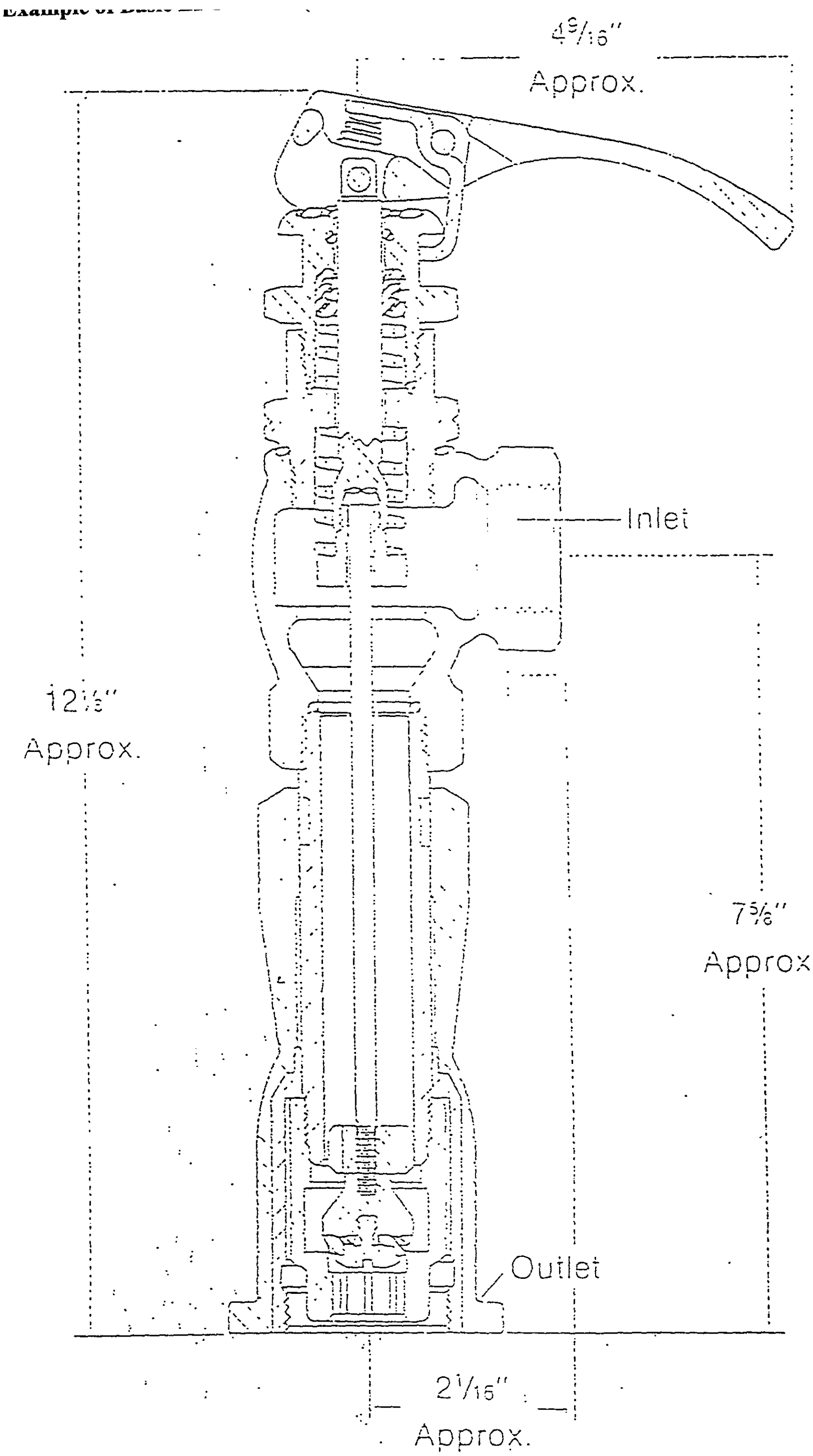
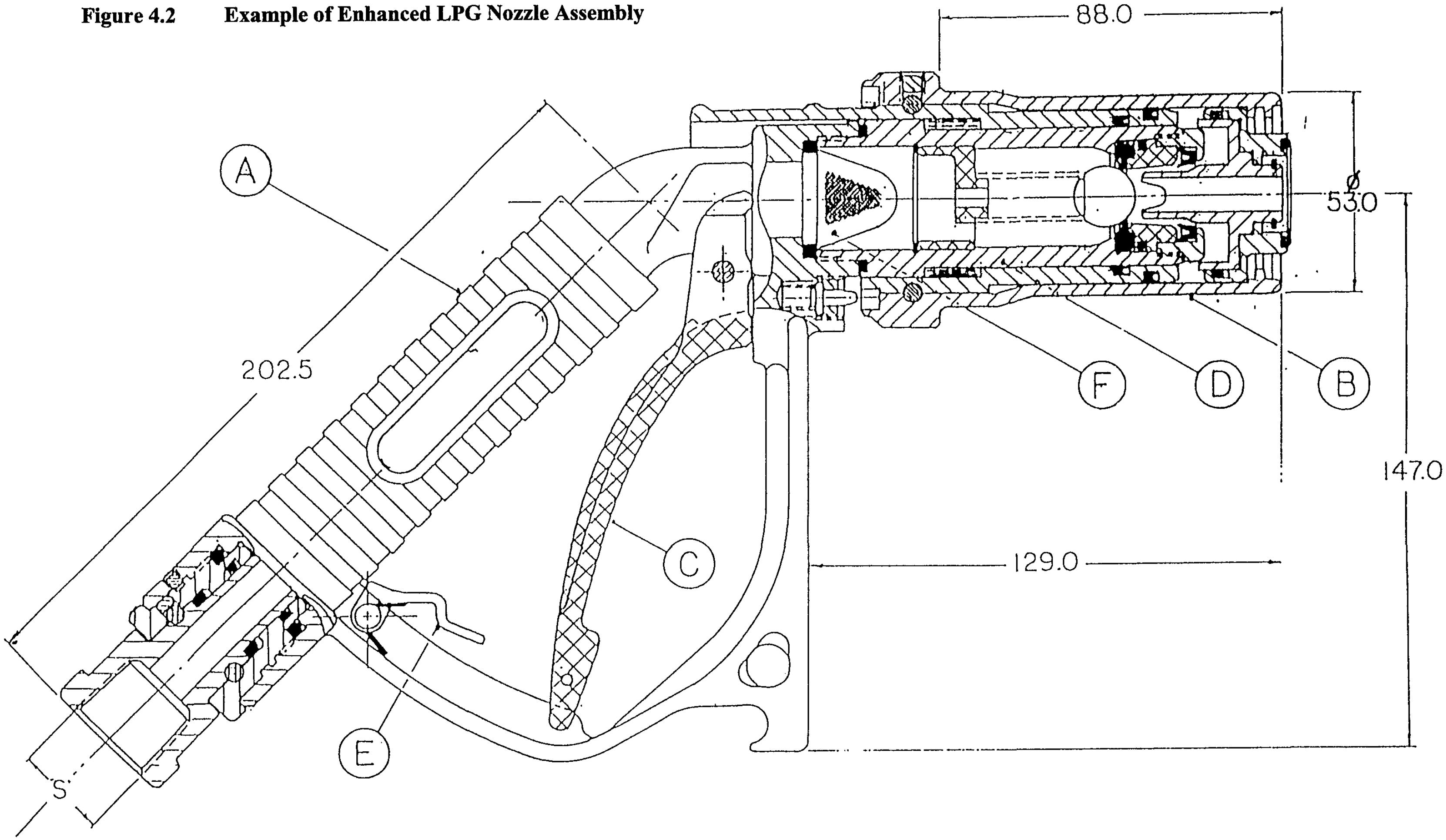


Figure 4.2 Example of Enhanced LPG Nozzle Assembly



When the lever is released, the large spring moves the valve and strainer assembly back into its original place. The valve spring reseats the ball valve and stops fuel flow. The pawl is removed from the swivel nut so the fitting can be disconnected. The LPG in the nose piece and filler valve is vented.

Dead Space Volume (Nozzle and Receptacle)

The enhanced nozzles are designed to reduce DSV. For example, one nozzle is designed so that 1.9 cm^3 is discharged from the nozzle on release of the lever. The other enhanced nozzles have DSVs of similar size. Although independent measurements were not conducted as part of this study, the basic nozzle technology has about 2 to 3 times more DSV than the enhanced nozzle.

The nozzle DSV might not be the major issue concerning LPG releases. The receptacle (filler valve assembly) appears to have a widely varying DSV, generally much larger than the nozzle DSV. Additionally, normal tank filling procedures include filling a vented tank until a visible white mist (LPG) comes from the tank. These two issues need further investigation.

Safety

LPG is typically stored at moderate pressures and ambient temperatures. Therefore, if gas is released, the pressure-related energy could cause life-threatening injuries, but this is unlikely. Small leaks from the nozzle could cause localized skin damage, but not the severe burns that LNG can cause. Unlike gasoline, ethanol, and methanol, LPG is nontoxic. NFPA-58 requires protective equipment because of the potential for cold burns. However, in other countries, where self-serve LPG fueling is available, equipment is designed to be safer and simpler to operate, requiring no protective gloves during refueling.

Fueling System

Several operational and design aspects affect the safety of LPG fueling systems:

- Location of storage tanks--Transit facilities designed for fleet use of LPG normally have the storage tank remotely placed from the dispenser. This fits the traffic patterns and allows for an uncluttered fuel island. The pumps and piping associated with the storage add some risk to the facility. However, a remote location makes it unlikely that a leak will contact an ignition source.
- Location of the dispenser--Transit facilities designed for LPG vehicles require the dispenser to be in a fueling and servicing island. This reduces the number of bus moves necessary for daily servicing. That island would likely already have diesel and gasoline dispensers. The addition of a heavier-than-air gaseous fuel to an area that already handles liquid fuel should not be a major safety issue. Service islands at transit facilities are open at least on two sides, and typically on three sides, and are covered by a canopy. Thus, even a light wind will move heavy LPG vapors from a small leak away from the vehicles before they reach flammable concentration.

Nozzles

All nozzles are designed to protect the user from the hazards of high-pressure releases. However, there are significant differences between the basic and enhanced nozzle technologies. One enhanced nozzle manufacturer describes the following features:

- Cannot discharge LPG to the atmosphere and must be connected to a filler valve to allow product flow;
- Cannot be disconnected from its filler valve while the lever is held in the open position (product flowing), thereby avoiding accidental gas discharge; and
- Plastic O-ring, securely housed in nose piece, positively seals to its mating filler valve even if the adaptor gasket is missing.

The basic nozzle, as shown in Figure 4.1, will allow flow any time it is operated. Additionally, the nozzle could be disconnected while flow is in progress.

Potential for Accidental Release

The most likely way for a large LPG release to occur would be for a vehicle to drive off while refueling. Some vehicles are equipped with electrical interlocks to prevent such an event from occurring. Some dispensers in the United States are equipped with breakaway check valves that prevent continuous releases if the dispenser hose breaks. However, because fueling is often performed at LPG facilities that are not designed specifically for vehicle refueling, these sites rarely incorporate breakaway systems, even though NFPA-58 3-9.4.5 specifies the need to install a listed emergency breakaway device designed to retain liquid on both sides of the breakaway point. Also, commonly, the vehicles do not use refueling shutoff switches to disable the engine. Reports of drive-aways are common, but there are no statistics available on the frequency or severity of these incidents. In Australia, sophisticated breakaway technologies are used that significantly limit the release of LPG in a drive-away situation and further limit fuel release during the reconnection of the hose to the breakaway valve.

Because LPG operates at moderate pressures, the potential for large releases from the nozzle area is small.

Even if the nozzle sticks open, or if an O-ring or other soft seal fails, the leak rates are small. In Corpus Christi, operators have emergency shutdown abilities at the dispenser, at the storage tank, and at several points around the fueling canopy. They are trained to shut down the system if they smell the odorant or suspect leakage.

Operational Issues

LPG fueling is different from other fueling operations commonly used in the transit industry in that it requires the operator to observe the filling of the tank directly. As the use of electronic controls increases, systems will allow operators to fuel without observing the fueling activity. Typically, dispensing equipment for vehicle servicing facilities consists of one or several storage tanks, a 20-gpm pump, a meter, and a hose/nozzle assembly.

The business approach used by LPG supply companies is an important factor in determining the direction of LPG nozzle developments. Supply companies typically provide LPG refueling stations (valued at $3,000 to $5,000) to customers (i.e., gas stations, fleets). The customer is required to provide a concrete pad; electrical power and ground; and barriers, fences, fire extinguishers, and signs required by the NFPA and the local fire marshal. The supply company supplies between one and four standard 1,000-gal tanks, a pump (typically 20 gpm), a totalizing meter, a basic nozzle, and associated pipes, valves, and supports. The supply company charges a maintenance fee for the equipment, which includes all preventive and corrective maintenance, as well as periodic replacement (3 to 5 years) of LPG nozzles.

The system typically provided by supply companies looks like an industrial facility. The pipes, valves, pump, and meter are exposed. Typically, local governments require vegetation or walls to screen this hardware from view. The same components can be enclosed in a dispenser that looks much like a common gas pump. Clean Fueling Technologies provides one such device. Dispensers are typically equipped with an enhanced nozzle. LPG systems with dispensers cost two to three times as much as standard systems. However, the increased cost is not generally driven by the enhanced nozzle, which typically adds only a few hundred dollars.

SAIC also observed fueling at a public LPG fueling station in Fairfax, Virginia. The station is set up as a public station and fuels smaller vehicles (cars, small trucks, and vans). The operation is performed by a fueller. The fueller has three nozzles for different receptacles, including one for filling utility tanks (e.g., barbecues).

Operating and Maintenance Procedures

When an LPG fuel supply company installs or operates an LPG fill station, it typically provides extensive operations, maintenance, and safety training, and offers ongoing training. Design and operational safety is addressed in NFPA-58, "Standard for the Storage and Handling of Liquefied Petroleum Gases." Additionally, they describe the procedures for operation of the equipment. The procedures are simple enough that they are learned and generally adhered to after an operator has reviewed them and operated the station several times

According to NFPA-58, the maximum fill level of the vehicle tank is 80 percent. Operators are trained to monitor the tank level constantly while filling a tank. Additionally, the tanks are provided with an overflow vent valve that releases a steady white mist of LPG when the tank is full. Procedurally, the operator should open the vent valve just before filling, monitor it during filling, and use the start of flow from the valve as the indicator to stop filling. Then the operator should close the bleed valve and recap the main fill valve. Newer vehicle tanks are equipped with float-operated stop valves that stop the filling process when the tank is 80 percent full. Gloves and face shields should be worn when handling LPG, but these rules are commonly ignored.

Ergonomics

According to several individuals in the LPG industry, ergonomics, not safety or reliability, is the main reason companies choose the more expensive, enhanced nozzle. However, manufacturers indicate that where self-serve refueling is permitted, safety and reliability, as well as ease of operations (as differentiated from strict ergonomics) are of paramount importance. Most nozzles that use the basic technology are heavy and poorly balanced. The basic nozzle requires two hands to open or close and may be difficult for operators who are unaccustomed to operating valves. The enhanced nozzles look and feel like self-service gasoline nozzles and incorporate the familiar (gasolinenozzle) look and feel.

Reliability

No quantitative information on reliability was available. However, a supply company reports that the basic nozzles require an overhaul after 2 to 5 years of service. Nozzles identical to those used for vehicle refueling are on the end of all truck-mounted hoses. These trucks service home and small commercial LPG systems. Although the nozzles are not used as frequently as nozzles at a busy refueling station, they are pulled to all locations and are not protected from the environment.

Operators of the fueling station are very sensitive to these problems. Historically, LPG supplies are very clean. Suppliers are careful not to introduce dirt or grit when filling LPG storage tanks. Dispenser and nozzle

maintenance activities are the most likely to introduce small amounts of foreign material into the system.

The following problems could be caused by foreign matter:

- Low flow due to foreign matter in the strainer;
- The nozzle swivel nut will not rotate because of matter between the nut and slide sleeve;
- The nozzle will not connect to the filler valve because of foreign matter caked on the filler valves;
- The nozzle remains open when the lever is released because of foreign matter between the nozzle valve assembly and the slide sleeve;
- The nozzle leaks when connected to a filler valve (when the lever is operated) because of foreign material on the nose piece face or filler valve gaskets.

Occasionally, basic nozzles develop small leaks. Leaks are detected by smell and usually repaired by replacing non-metallic internal parts (sometimes called "software"). LPG does not have a tendency to cut metal surfaces. If the software replacements become more frequent, maintenance personnel assume that the metal surfaces are degraded. The components are replaced with like components and sent to vendors or machine shops for reconditioning.

No information is available on the reliability of the more complex enhanced nozzles. However, their valves have more potential for spring wear problems and are expected to require more maintenance.

The maintenance manual of one enhanced nozzle states that the nozzle is sensitive to foreign matter (i.e., sand, dirt, and grit) in the flow paths. Other maintenance and reliability issues generally involve small leaks. Leaks occasionally occur at the inlet swivel joint and the nozzle area. The inlet swivel consists of an external swivel body that is sealed to the nozzle body and an internal body that is connected to the incoming pipe. Few problems are expected from the seal between the external swivel and nozzle body because it is locked in place by a locking screw. However, relative motion between the external and internal bodies causes the seal between these two bodies to degrade and eventually leak. Replacement is a standard maintenance action.

Nozzle area leaks that occur when the nozzle is not connected to a vehicle come from the main valve assembly. Likely causes are valve (ball) damage, seat damage, and body leaks due to the assembly coming loose or Oring deterioration. The root causes are normally wear and tear or foreign matter. The correction is replacement of internal parts with factory-supplied repair kits.

When the fueling operation begins, the sealing surfaces exposed to fuel pressure change from the main valve to the filler valve gasket, main valve assembly seal, and the nose piece O-ring. These seals and gaskets require occasional maintenance. After the lever is released, the pressure from the gas in the dead space is released from the internals to the swivel nut lip seals. If these seals allow excessive blowback, they must be replaced.

The nozzle is threaded onto 1/2-in. or 3/4-in. pipe. Because the hose is flexible and the nozzle has a swivel joint, there is little stress on the threaded connection. No problems are normally expected from the threaded connection.

FINDINGS

In this project, CNG, LNG, and LPG nozzles were reviewed for all types of vehicles. The review covered light-duty nozzles (even though the focus of the digest is on transit bus refueling) because the use of heavy-duty nozzles is limited and because there is a direct relationship between the technologies used for LDVs and HDVs. Additionally, many transit facilities that made the capital investment into alternate fuel-dispensing equipment for HDVs also have some LDVs operating on the same alternative fuel. The technological issue of greatest relevance is fuel loss from the coupling and decoupling processes. The findings are presented by fuel type and relate to all applications unless otherwise specified.

CNG Nozzles

CNG nozzles used for light-duty applications are commercially available with DSV of less than 2 cm^3. Only one commercially available CNG nozzle is specifically designed and used for heavy-duty application.

Comparative Status

CNG nozzles release gaseous fuel. Recovery during depressurization makes releases from CNG nozzles relatively insignificant. DSVs vary from less than 1 cm^3 to 30 cm^3, as follows:

- Type 1: 1 to 10 cm^3 (one nozzle has 30 cm^3)
- Type 2: 1 to 3 cm^3
- Type 3:0.5 to 2 cm^3

The federal standard (for LDVs) is 1.2 g released per disconnection. Existing fueling systems can be designed to depressurize the DSV to near atmospheric pressure, to depressurize the DSV to moderate pressure by venting gas to the compressor intake or to the service header, or to vent full operation pressure gas to the atmosphere. The DSVs that would meet the federal standards are summarized below, organized by release pressure:

- **Release at atmospheric pressures--A** fully recuperative system could conceivably depressurize the DSV to atmospheric pressure. Under these operating

conditions, a nozzle with a DSV of 1,700 cm^3 would comply with the federal standard. However, we know of no facilities that depressurize their nozzles to atmospheric pressures without venting. Depressurization and recovery generally leave the nozzle at the natural gas intake or service pressure.

- **Release at intake or service pressure (defined here as 50 psi)**--If the DSV pressure were lowered to this point, a 500 cm^3 DSV would comply with the standard. Most transit CNG fueling facilities recover the nozzle overpressure in this form. However, a few still vent the content of their nozzles to the atmosphere.
- **Venting operating pressure gas to the atmosphere**--If a DSV at full system pressure of 3,000 psi to 3,600 psi were vented to the atmosphere, the maximum nozzle DSV that would meet the federal standard would be 6 cm^3. This estimate would vary by a few cubic centimeters for higher or lower pressure systems. Only a few CNG transit facilities vent or fail to recover any of the CNG from the nozzle. These are the smaller CNG transit facilities, which operate a few buses and commonly do not use the heavy-duty nozzles.

From the above calculations, it is clear that as long as the fueling system is designed to vent gas at moderate pressure, all CNG nozzles easily comply with this standard. Nozzles in fueling systems that vent all the gas to the environment are releasing amounts approximately equivalent to the standard. More precise calculations would have to be performed to verify compliance.

In terms of fuel used and fuel lost, a heavy-duty nozzle transfers 5 to 10 times more fuel per fueling into a HDV (up to 16,000 scf for a transit bus) than a light-duty nozzle into a LDV (1,500 to 2,000 scf for cars, vans, and light-duty trucks). On this basis, heavy-duty nozzles emit fuel in about the same proportion as light-duty nozzles.

Developmental Status

The CNG nozzle evolved from the coupling technology. Until the promulgation of the EPA regulations, there was no need to focus on controlling emissions from the connection and disconnection processes. However, the inherent need for depressurization of the nozzle before disconnection makes the fuel control issue less a matter of nozzle design and more a matter of system configuration (i.e., venting versus recovery).

Nozzle Redesign Options

Recovery of vented fuel can reduce the amount of fuel loss by about 99 percent. This applies to both heavy- and light-duty nozzle and vehicle systems and could be accomplished with available but not uniformly implemented technologies.

Non-nozzle-related system improvements, specifically depressurization and recovery to atmospheric (rather than intake) pressure, can further reduce fuel emissions from CNG nozzles. This option requires the installation of active or passive recuperators. Depressurization to levels below atmospheric pressure to recover all of the natural gas in the DSV is not recommended, and the hazards associated with air intrusion because the cost/benefit trade-offs are not favorable.

For Type 2 and Type 3 nozzles, there are simple designs to reduce the DSV. These involve moving the fuel control valve closer to the receptacle and possibly reducing the diameter of the fuel shaft. For existing heavyduty (Type 1) nozzles, redesign is more complex because of the internal arrangement of components, including multiple valves. Such a redesign is estimated to cost approximately $30,000, which includes a $10,000 mandatory testing fee. In absolute terms, or compared to the cost of developing a commercial product, these costs are not significant. However, for a product that is currently sold at rates of several dozen per year, the cost is significant and would markedly affect the nozzle's retail price.

One manufacturer has stated its intention to increase the throughput of its light-duty nozzle to qualify it as a heavy-duty nozzle. SAIC estimates that the DSV of this nozzle would be only 3-6 cm^3. This nozzle is not yet available for review.

Other nozzle designs are possible, including the use of different types of valves. However, radical changes would likely require the redesign of the receptacle and could result in fuel transfer-related fuel losses and other issues. Yet, the development of nozzles with zero or nearzero losses are technically possible and may be economically attractive because such nozzles would not need to have the fuel recovery function.

Findings

Summary findings for CNG nozzle design are as follows:

- Redesigning existing CNG nozzles to reduce emissions from the decoupling operation is possible but not recommended because CNG nozzles already meet or exceed the requirements of the newly implemented emission regulations. This is true for nozzles used for both LDVs and HDVs and even in some cases where the fuel is not recovered (i.e., vented to the atmosphere).
- Significant fuel loss reductions are achievable through fuel recovery. Several states and technical specification

require such recoveries. However, these specifications are not universally followed. The use of fuel recovery on a widespread basis would make CNG emissions from the nozzle connection and disconnection processes relatively insignificant (see Appendix A) compared with losses from other sources and compared with those of other fuels.

- More radical redesigns, to offer zero or near-zero emissions, should be allowed to and may evolve through the market forces.

LNG Nozzles

Unlike CNG nozzles, most LNG nozzles are suitable for heavy-duty applications. At least one LNG nozzle designed specifically for heavy-duty applications has a DSV of 2.4 cm^3.

Comparative Status

The fuel contained in the DSV of an LNG supply nozzle is usually in liquid form. On release, the LNG quickly gasifies and may be detected through the resultant vapor cloud (the vapor cloud is water vapor). In a dualhose vapor recovery/liquid delivery system, the vapor recovery nozzle generally should not contain LNG. The size of the release varies by type and size as discussed in the section on "LNG Nozzles" (page 18). The total fuel released in a connection and disconnection operation includes liquid losses from the supply nozzle DSV after LNG transfer, plus losses from the nozzle DSV after vapor recovery, plus vapor losses (from the DSV only) after disconnection from hose purging operation. The liquid release constitutes more than 95 percent of the released fuel. Depressurization of the LNG nozzles, with recovery, is not practiced but is possible.

- Type 1: 2.4 to 10 cm^3
- Type 2: 5 to 20 cm^3
- Type 3: 5 to 20 cm^3

As for CNG, the federal standard (for LDVs) will be 1.2 g released per disconnection. Existing nozzles release from 1 to 5 g per disconnection. Precise calculations that include the receptacle DSV may show that no systems meet the federal standards. Clearly, these releases are much higher than for CNG operations. Some LNG nozzles would need significant modifications to meet federal standards for LDVs.

As in CNG operations, a heavy-duty nozzle transfers 5 to 10 times more fuel per fueling into a HDV (up to 150 gal for a transit bus) than a light-duty nozzle into a LDV (20 to 30 gal for cars, vans, and light-duty trucks).

Development Status

LNG nozzles are still in the development stage. There are two LNG nozzle manufacturers that have several nozzles in production and in use on a commercial scale. Two other manufacturers each have built one nozzle and have used them in limited commercial applications. There are also two developers that each have a nozzle in the development stage. However, the market for these devices is limited and growing slowly. For the near term, the market may not be able to support more than several manufacturers. Consolidation of the industry is likely.

Existing nozzle technology evolved from the cryogenic technologies, aircraft and spacecraft fueling technologies, and entrepreneurial development projects. The designs have focused on safety, throughput, reliability, and minimization of fuel transfer losses. Although one of the nozzles has a relatively small DSV, there has been regulatory reason to focus on controlling fuel losses during connection and disconnection.

Nozzle Redesign Options

By using readily available fuel recovery technology similar to that used in CNG nozzles, LNG fuel losses could be reduced by about 99 percent. However, this option would require further research, development, and testing. The following section on "LNG Vapor Recovery from the DSV" contains a more detailed discussion of this option.

For Type B and Type C nozzles, redesign options to reduce the DSV are relatively simple. As with CNG nozzles, these redesigns involve moving the fuel control valve closer to the receptacle and possibly reducing the diameter of the fuel shaft. One concurrent nozzle design has a small DSV and is effective in minimizing connection and disconnection losses.

Radical changes would likely require the redesign of the receptacle and could result in fuel transfer losses and other issues. Unlike CNG, however, there are no standardized receptacles and little chance of such standardization occurring in the near future. This leaves room for the introduction of new and potentially more effective nozzles, including the possibility of zero- or near-zero-loss nozzles. A review of this option indicates that there are no insurmountable technical barriers to the development of such a nozzle. Indeed, one manufacturer of an existing heavy-duty nozzle claims a 2.4 cm^3 DSV. Because this is only marginally larger than the requirement for light-duty LPG nozzles, it is clear that low-loss technology is feasible. For other manufacturers, however, the absence of a requirement to depressurize and recover the fuel from LNG nozzles suggests that

there is no economic justification for widespread technology development.

LNG Vapor Recovery from the DSV

During refuelings, LNG is transferred in liquid form at elevated pressures. Following disconnection of the LNG nozzle, LNG is released from the dead space, which quickly flashes to vapor and dissipates. The most feasible approaches for recovering this gas would take advantage of this flashing and use it as a motive force to recover most of the gas.

Flashing of the LNG contained in the DSV of an LNG nozzle could generate sufficient pressure to permit reinjection of the fuel into the storage tank. Off-the-shelf technology is available to test and verify the operability and practicality of this direct (passive) recirculation concept. The introduction of a recovery tube into the DSV and a manually operated external valve could be a simple and inexpensive way to accomplish direct recirculation recovery. This system would operationally resemble the Type 2 CNG nozzle. If it proves practical, the configuration of this system would resemble that of a CNG fuel recovery system. However, it is not clear that the flash rate is suitable for removing the LNG in a timely manner.

The recovered LNG (in gas form) could be disposed of by injecting it into the local gas mains, storing it in retainer tanks, or recirculating it into the LNG supply tanks or into the inlets to running compressors. The lowest pressure portion of a city gas main operates at a few pounds per square inch above atmospheric pressure, which is ideal for recovery. Retainer tanks may be a costly option because a compressor or liquefaction system would need to be installed to remove the accumulated vapors from the tank to keep the pressure low. On-site liquefiers would make this option expensive.

If the flash time is not acceptable, active recovery using a recuperation system may need to be considered. SAIC roughly estimated the cost of piping, compressors, mounting, and controls necessary to implement an active LNG recovery system. The estimated developmental costs are as follows:

- **System Development Costs**--$10,000 to $20,000 for each manufacturer;
- **Nozzle Development Costs**--Roughly $10,000 for each manufacturer;
- **Main Recuperating Equipment**--Between $10,000 and $25,000 (per station);
- **Site Specific Design Charges**--Between $2,000 to $5,000, depending on the physical layout of the facility and whether it is a new facility or a backfit; and
- **Nozzle Assembly Costs**--Roughly $1,000 to $3,000 per nozzle assembly.

These estimates assume only a few system sales by each manufacturer (or system integrator). As a result, system and nozzle development costs would be passed on to only a few users during the cost recovery period (assumed to be 3 years). SAIC also estimates that if manufacturers incorporated the recovery valve into the nozzles it would add 25 percent to 50 percent to the cost of the current LNG nozzles. However, an active recovery system would add only marginally to the cost of an LNG fueling station, which could cost several million dollars.

There is no financial incentive to recover fuel from the dead space. The only reason a recovery system would be implemented is to meet a regulatory requirement. The continued effort to build reliable LNG nozzles with minimum DSV is a more cost-effective way to reduce emissions than the implementation of an LNG recovery system.

Findings

Summary findings for LNG nozzles are as follows:

- Heavy-duty LNG nozzles are in common use with low fueling-related losses from a 2.4 cm^3 DSV.
- Another manufacturer reports the development of a low-emission nozzle.
- Further fuel loss reductions of more than 99 percent are achievable through nozzle depressurization and fuel recovery, a potentially expensive fuel recovery option.
- It is unlikely that any manufacturer will voluntarily implement the fuel recovery option because of the costs associated with such changes, and because existing nozzles meet or can be readily modified to meet emission regulations.
- Because of the anticipated frequency of fueling activities at LNG transit facilities, and the potential of indoor LNG fueling, transit facilities may voluntarily specify and use fuel recovery as part of their LNG fueling system. Therefore, market forces may lead to the adoption of LNG recovery systems, where necessary.

LPG Nozzles

There are many types and vintages of LPG nozzles in use in the United States and the rest of world. Unlike LNG, LPG is used predominantly in LDVs. As a result, nozzle developments are targeted to that market. Several nozzle designs already have a less than 2.0 cm^3 DSV. Few LPG nozzles were found for heavy-duty applications. These were noted to have DSVs several times the regulated volume of the light-duty nozzles. A manufacturer developing a new heavy-duty nozzle indicated that the new nozzle will need to incorporate a

DSV that is larger then the 2.0 cm^3 volume allowed for small vehicular use. Discussions and visits with LPG nozzle manufacturers did not reveal any efforts to reduce the DSV in heavy-duty nozzles. This is due to the limited number of nozzles used in heavy-duty vehicle applications, and because there are no regulations that require nozzle manufacturers or users to limit the DSV or associated emissions from these types of nozzles.

Status

As in the LNG nozzles, the fuel contained in the DSV of an LPG supply nozzle is in liquid form, even though at the time of release there may be no evidence of liquid emissions. On release, the LPG quickly gasifies and may be detected through the odor, a vapor cloud, or an audible puff. The size of the release varies by type of nozzle, as discussed in the section on "LPG Nozzles" (page 29). The DSV in LPG nozzles is not depressurized or otherwise purged. Depressurization, with fuel recovery, is not practiced, but it is technically feasible and would be a more effective emission control option.

Newer LPG nozzle valves are designed with a DSV just below the 2 cm^3 federal standard, but many of the nozzles currently in use in the United States have DSVs from 4 to 10 cm^3. However, LPG standards also require operators to limit releases to 0.15 g for each gallon dispensed. Nozzles that are designed to the regulatory limit will release about 1 gm of LPG per disconnect. These nozzles would meet the 0.15 g per gallon standard if the average fuel load is more than about 7 gal. If a system could be designed to allow the liquid in the dead space to flash to gas before the release, the released mass would be reduced by more than 99 percent.

The LPG nozzle market is dominated by a few manufacturers, generally one manufacturer in each of three countries: Italy, Germany, and Australia. Each has several nozzles in production and in broad commercial use. Several manufacturers are redesigning their LPG nozzles in response to environmental legislation in the United States and in response to efforts by European countries to standardize LPG receptacles.

Nozzle Redesign Options

Commercial light-duty LPG nozzles have DSVs of less than 2 cm^3. Manufacturers indicated that further reductions are possible through relatively minor redesign. These involve moving the fuel control valve closer to the receptacle and possibly reducing the diameter of the fuel shaft. Significant additional reduction in the DSV is possible through more radical redesigns, which may include the use of different fuel control valves, such as a face valve, and changing the connection mechanism and the receptacle. Such changes would be difficult to implement into the current population of LPG vehicles.

With or without nozzle redesign, a fuel recovery option similar to that in CNG nozzles would significantly reduce losses. The technology is available and is readily implementable. One European manufacturer is in the process of testing such a system for public refueling stations. In LPG nozzles, the use of depressurization and recovery requires modifications to the existing nozzles. It would also require the addition of a recovery tank or other methods of collecting the fuel. As in the case of LNG, an active recuperator may be required to quickly remove the LPG or the LPG vapors. Off-the-shelf technology is available to test and demonstrate its use. Depressurization to levels below atmospheric pressure to recover all of the residual LPG vapor in the DSV is not recommended because of the hazard of air intrusion. Reinjection (perhaps pump-assisted) into the fuel supply is an available option.

Depressurization and fuel recovery could reduce the amount of LPG released significantly. As with LNG, this option would require further research and development. It would also result in a more costly and operationally sensitive nozzle. Because existing LPG emission requirements can be met without depressurization and recovery, manufacturers have no reason to invest in research and development that would incorporate the fuel recovery option.

The incorporation of the fuel recovery option could, by one estimate, cost \$10,000 to \$20,000 in developmental costs. However, one manufacturer indicated that the recovery option would cost only \$5,600 per dispenser assembly. This would be incorporated in the incremental cost of this feature, estimated to be (for new construction) \$10,000 to \$15,000 per fueling station, plus \$1,000 per dispenser, plus \$500 per hose and nozzle assembly, including installation. Therefore, the cost of adding the fuel recovery capacity to a new fueling station with two dispensers and four hose and nozzle assemblies may cost an additional \$14,000 to \$19,000. There are no industry estimates for retrofitting an existing LPG fueling station with the fuel recovery system. However, SAIC estimates that retrofitting may be 20 percent to 50 percent more costly than adding this feature to a new fueling station. This is due to the need to bury equipment and replace existing components such as nozzles. While the recovery systems for LNG and LPG are similar, the cost of the LPG system is estimated to be lower because LPG systems do not need to comply with cryogenic specifications and because developmental cost could be spread among many more systems.

As with LNG, SAIC believes that, given the specified costs, neither the manufacturers of the equipment nor fuel station operators will voluntarily develop and deploy these systems in the United States. However, transit

operators and other fleet operators with significant numbers of LPG vehicles will engage in many refuelings and will dispense significant quantities of fuel at their properties. This could expose their staff to LPG vapors from heavy-duty nozzles with larger DSVs. This might cause fleet operators to specify the use of fuel recovery systems in their operations, particularly if the fueling operation is performed in a semi-enclosed structure.

Findings

The key findings for LPG nozzles are as follows:

- Several manufacturers have LDV nozzles that meet the 2 cm^3 emission requirements and other manufacturers are making the needed modifications to meet the imposed limits.
- Reductions in DSV below 2 cm^3 are possible in LDV nozzles through relatively minor nozzle redesigns.
- Heavy-duty LPG vehicle nozzles have significantly larger DSVs. Redesigns of these nozzles could lead to major reductions in the DSV.
- Emission reductions from the DSV of more than 99 percent are achievable through nozzle depressurization and fuel recovery, such as that used in CNG nozzles. It is unlikely that any manufacturer will implement this technology because of the costs associated with such changes, and because existing nozzles meet emission regulations.
- Because of the anticipated frequency of fueling activities at LPG transit facilities and the potential for fueling in a semi-enclosed structure, transit facilities and other fleet users may specify the use of fuel recovery systems in their operations, particularly if the fueling operation is to be performed indoors.

ABBREVIATIONS AND ACRONYMS

AFL	automatic fill limiting
AFV	alternative fuel vehicle
AGA	American Gas Association
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
ATA	American Trucking Association
cfm	cubic feet per minute
CFR	Code of Federal Regulations
cm^3	cubic centimeter
CNG	compressed natural gas
CNGV	compressed natural gas vehicle
DSV	dead space volume
EPA	U.S. Environmental Protection Agency
gpm	gallons per minute
GRI	Gas Research Institute
GVW	gross vehicle weight
HDV	heavy-duty vehicle
IAS	International Approval Services, Inc.
kPa	kiloPascal
LDV	light-duty vehicle
LNG	liquefied natural gas
LNGV	liquefied natural gas vehicle
LPG	liquefied petroleum gas
LPGV	liquefied petroleum gas vehicle
MSRP	manufacturers suggested retail price
NFPA	National Fire Protection Association
NG	natural gas
NGV	natural gas vehicle
O&M	operations and maintenance
ORVR	onboard refueling vapor recovery
psi	pounds per square inch
SAE	Society of Automotive Engineers
SAIC	Science Applications International Corporation
scf	standard cubic feet
scfm	standard cubic feet per minute
TCRP	Transit Cooperative Research Program

APPENDIX A
METHANE RELEASES IN PERSPECTIVE

Table A.1 shows the mass of methane released from the major U.S. sources. Note that landfills are the largest single source, followed by ruminant animals (primarily cows), mining, and oil and gas. An upper-bound estimate of the amount of natural gas released from nozzles could be made by assuming that there are 60,000 NGVs in the U.S. Further, assume that every nozzle has a 30 cm^3 DSV (the largest found in this study), that every refueling operation vents 3,000 psig gas to the atmosphere (which is overly pessimistic, most stations that refuel many vehicles collect the vented gas), and that all vehicles refuel every other day. Under these assumptions, alternate fueled vehicles would release about 50 metric tons of natural gas per year.

The 50 metric tons of natural gas represents a small component of the 27,230,000 metric tons of methane released in the U.S. Even when compared with the 240,000 metric tons of methane released by the transportation industry, the contribution of alternative fueled vehicles is negligible.

TABLE A.1 U.S. methane emissions from anthropogenic sources, 1992 (million metric tons of methane)

Category	Source	Emissions (million metric tons)	Total (million metric tons)
Energy sources	Coal mining Oil and gas Stationary combustion Transportation	4.21 3.30 0.51 0.24	8.26
Area Sources	Landfills	10.18	10.18
Agricultural Sources	Ruminant animals Animal waste Rice paddies	5.49 2.76 0.44	8.69
Industrial Processes		0.12	0.12
Total			27.23

Source: Energy Information Administration, Emissions of Greenhouse Gases in the United States 1987-1992 (DOE/EIA-0573). Washington, DC, November 1994.
Note: Totals may not equal sum of components because of independent rounding.

APPENDIX B
NOZZLE MANUFACTURER INFORMATION SURVEYS

Appendix B-1: Alternative Fuel Vehicle (AFV) Nozzle Manufacturer Information

AFV Nozzle manufacturers only: For inclusion in the Transportation Research Board's report *Technology Assessment of Refueling Connection Devices for CNG, LNG, and Propane,* please complete the company and product information in Tables 1 and 2. In Table 2, provide the information requested for all of your CNG, LNG, and LPG nozzles available for sale and return it in the enclosed envelope. Thank you.

Table 1: Company Information

Company Name:	Parker Hannifin Corp., Quick Coupling Division				
Street Address:	8145 Lewis Road				
City:	Minneapolis	State:	MN 55427	Country:	USA
Contact Person:	Greg Hallberg	Telephone Number:	(612) 525-4236		
E-Mail Address:	NA	Internet Location:	NA		

Table 2: Product Information-AFV Nozzles Only

Fuel Type[1]	Nozzle Name/Model Designation	Model or Reference Number	Throughput per Minute[2]	Weight in Pounds	Dead Space Volume in Cubic cm	MSRP[3] in U.S. $ (Dollars)	List the Codes and Standards The Nozzle Complies With
LNG	1" LNG Coupling	1169-60B	50	8.2	2.4		
LNG	½" LNG Coupling	LG0800-08F	12	3.3	0.4		
LNG	½" LNG Vent	LNG0810-08F	12	3.3	0.4		

1 Please indicate nozzle use by fuel type: CNG, LNG, or LPG.
2 For CNG use cubic feet per minute (cfm); for LNG and LPG use gal per minute (gpm).
3 MSRP = Manufacturers Suggested Retail Price.

Appendix B-2: Alternative Fuel Vehicle (AFV) Nozzle Manufacturer Information

AFV Nozzle manufacturers only: For inclusion in the Transportation Research Board's report *Technology Assessment of Refueling-Connection Devices for CNG, LNG, and Propane,* please complete the company and product information in Tables 1 and 2. In Table 2, provide the information requested for all of your CNG, LNG, and LPG nozzles available for sale and return it in the enclosed envelope. Thank you.

Table 1: Company Information

Company Name:	Sherex/OPW				
Street Address:	1400 Commerce Parkway				
City:	Lancaster	State:	NY	Country:	USA
Contact Person:	Peter J. Spyche	Telephone Number:		(716) 681-6250	
E-Mail Address:	lancaster@sherex.com	Internet Location:		http://ourworld.compuserve.com/homepages/sherex	

Table 2: Product Information-AFV Nozzles Only

Fuel Type[1]	Nozzle Name/Model Designation	Model or Reference Number	Throughput per Minute[2]	Weight in Pounds	Dead Space Volume in Cubic cm	MSRP[3] in U.S. $ (Dollars)	List the Codes and Standards The Nozzle Complies With
CNG	Fil-mate Type 2 or 3	CC 300	1200 SCFM	18 oz.	3.2	94.00	NGV-1, AGA, CGA, ASME
CNG	Fil-master Type 2 or 3	CC 600	1200 SCFM	21 oz.	3.6	174.00	NGV-1, AGA, CGA, ASME
CNG	Self-service Type 1	CT 1000	1500 SCFM	3.4 lb.	2.4	950.00	NGV-1, AGA, CGA, ASME
CNG	Bus/Heavy duty	CT 5000	5000 SCFM	8.0 lb	5.4	3,000.00	ASME, Railroad Commission of Texas

1 Please indicate nozzle use by fuel type: CNG, LNG, or LPG.
2 For CNG use cubic feet per minute (cfm); for LNG and LPG use gallons per minute (gpm).
3 MSRP = Manufacturers Suggested Retail Price.

Appendix B-3: Alternative Fuel Vehicle (AFV) Nozzle Manufacturer Information

AFV Nozzle manufacturers only: For inclusion in the Transportation Research Board's report *Technology Assessment of Refueling-Connection Devices for CNG, LNG, and Propane,* please complete the company and product information in Tables 1 and 2. In Table 2, provide the information requested for all of your CNG, LNG, and LPG nozzles available for sale and return it in the enclosed envelope. Thank you.

Table 1: Company Information

Company Name:	Stäubli Corporation				
Street Address:	201 Parkway West				
City:	Duncan	State:	SC	Country:	USA
Contact Person:	Larry Belanger	Telephone Number:	(864) 433-1980		
E-Mail Address:	NA	Internet Location:	NA		

Table 2: Product Information-AFV Nozzles Only

Fuel Type[1]	Nozzle Name/Model Designation	Model or Reference Number	Throughput per Minute[2]	Weight in Pounds	Dead Space Volume in Cubic cm	MSRP[3] in U.S. $ (Dollars)	List the Codes and Standards The Nozzle Complies With
CNG	Type 2-3 Nozzle	CMV08.1314/30	1800	1.1	6	119.65	AGA/NGV 1& CGA/NGV-1
CNG	Type 2-3 Nozzle	CMV08.1314/36	1800	1.1	6	119.65	AGA/NGV-1
CNG	Type 2-3 Nozzle	CMV08.1314/30/LH	1800	1.1	6	119.65	AGA/NGV-1 & CGA/NGV-1
CNG	Type 2-3 Nozzle	CMV08.1314/36/LH	1800	1.1	6	119.65	AGA/NGV-1
CNG	Type 1 Nozzle	GMV08.3314/30	2400	3.0	6	1200.00	
CNG	Type 1 Nozzle	GMV08.3314/36	2400	3.0	6	1200.00	

1 Please indicate nozzle use by fuel type: CNG, LNG, or LPG.
2 For CNG use cubic feet per minute (cfm); for LNG and LPG use gallons per minute (gpm).
3 MSRP = Manufacturers Suggested Retail Price.

Appendix B-4: Alternative Fuel Vehicle (AFV) Nozzle Manufacturer Information

AFV Nozzle manufacturers only: For inclusion in the Transportation Research Board's report *Technology Assessment of Refueling-Connection Devices for CNG, LNG, and Propane,* please complete the company and product information in Tables 1 and 2. In Table 2, provide the information requested for all of your CNG, LNG, and LPG nozzles available for sale and return it in the enclosed envelope. Thank you.

Table 1: Company Information

Company Name:	Charter Ground Fueling Company				
Street Address:	671 W. 17th St.				
City:	Costa Mesa	State:	CA 92627	Country:	USA
Contact Person:	Razmik Melikan	Telephone Number:	(714) 548-3421		
E-Mail Address:	cgf_sales@jccarter.com	Internet Location:	WWW.JCCARTER.COM		

Table 2: Product Information-AFV Nozzles Only

Fuel Type[1]	Nozzle Name/Model Designation	Model or Reference Number	Throughput per Minute[2]	Weight in Pounds	Dead Space Volume in Cubic cm	MSRP[3] in U.S. $ (Dollars)	List the Codes and Standards The Nozzle Complies With
LNG	ICEBREAKER	TBD	10 GPM	1-2	5	TBD	NFPA
LNG	ICEBREAKER	TBD	20 GPM	14	10	TBD	NFPA
LNG	ICEBREAKER	TBD	50 GPM	12	20	TBD	NFPA

1 Please indicate nozzle use by fuel type: CNG, LNG, or LPG.
2 For CNG use cubic feet per minute (cfm); for LNG and LPG use gallons per minute (gpm).
3 MSRP = Manufacturers Suggested Retail Price.

Appendix B-5: Alternative Fuel Vehicle (AFV) Nozzle Manufacturer Information

AFV Nozzle manufacturers only: For inclusion in the Transportation Research Board's report *Technology Assessment of Refueling-Connection Devices for CNG, LNG, and Propane,* please complete the company and product information in Tables 1 and 2. In Table 2, provide the information requested for all of your CNG, LNG, and LPG nozzles available for sale and return it in the enclosed envelope.
Thank you.

Table 1: Company Information

Company Name:	Brevetti Nettuno s.r.l.				
Street Address:	Via Bergonzoni, 1/A - Cap : 40133				
City:	Bologna	State:		Country:	Italy
Contact Person:	Mr. Fiumi Piero Mr. Frascaroli Franco	Telephone Number:	Tel. - 0039/51 385655 Fax - 0039/51 385399		
E-Mail Address:		Internet Location:			

Table 2: Product Information--AFV Nozzles Only

Fuel Type[1]	Nozzle Name/Model Designation	Model or Reference Number	Throughput per Minute[2]	Weight in Pounds	Dead Space Volume in Cubic cm	MSRP[3] in U.S. $ (Dollars)	List the Codes and Standards The Nozzle Complies With
LPG	Pincer PSA 93	PSA 930	11.9	4.00	4.7	174	
LPG	Pincer PSA 95	PSA 950	2.9	3.23	1.1	247	
LPG	Pincer GE1	GE 100	38.3	4.19	15.6	255	
LPG	Pincer GE2	GE200	10.0	5.00	1.8	258	
LPG	Pincer GE3	GE 300	23.8	3.90	9.6	262	
FREON	Pincer F40	OF 400	9.8	4.41	(***)	460	

1 Please indicate nozzle use by fuel type: CNG, LNG, or LPG.
2 For CNG use cubic feet per minute (cfm); for LNG and LPG use gallons per minute (gpm).
3 MSRP = Manufacturers Suggested Retail Price.