29 March 1996

Ms. Patricia Starkey
U.S. Department of Energy
Philadelphia Regional Support Office
1880 JFK Blvd, Suite 501
Philadelphia, PA 19103

Dear Ms. Starkey:

Enclosed are the four Final Technical Reports as required by your office (Grant #DE FG43-93ER340424). According to our records, we have submitted all other required documentation to your office.

Please note that one of the TOPTEC technical reports ("LNG: Strengthening the Links") cannot be located, however, a detailed technical summary ("SAE TOPTEC Highlights") is enclosed. It provides the same technical summary as the other three reports, if not more. It was provided to us by one of the participating companies.

Please let me know if you will be needing any additional information or documentation.

Sincerely,

[Signature]

Brian Taylor
Program Developer
Professional Development Division

cc: Doug Alpem
e-mail address: brian@sae.org
tel: (412) 772-8524
fax: (412) 776-4955

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The Society of Automotive Engineers held its fourth TOPTEC on natural gas vehicle technology in Austin, TX, on April 17-20, 1994. There were a record 175 in attendance, including speakers, fuel and vehicle industry representatives, faculty members, students, NGV users, natural gas industry equipment suppliers, and consultants. A variety of topics were covered by speakers representing OEMs from Chrysler, Ford, General Motors, Cummins, Detroit Diesel, and Tecogen; regulatory government representatives involved in the development of NGV standards and NGV fleets from CARB, EPA, and DOE; gas utility members from Consolidated Natural Gas and Pacific Gas & Electric; fuel metering developers from Impco Technologies, MESA Environmental, Southwest Research Institute, and BKM, Inc.; distributorless ignition system manufacturer Altronic, Inc.; fuel measurement specialist Micro Motion; gas cylinder developers EDO Corporation and Michigan Consolidated Gas Company (MichCon); and compressor manufacturers Hurricane Compressors and FuelMaker. The TOPTEC was held concurrently with Texas' 5th Annual Alternative Vehicle Fuels Market Fair & Symposium, sponsored by the Texas General Land Office and the Texas Conservation Fund. Here, the participants were able to visit an exhibition which displayed NGV-related equipment for vehicles and refueling.

The TOPTEC agenda was organized into various areas of concentration over the two-day technical symposium. The first day focused on presentations of light-duty OEM vehicle development, aftermarket supplier systems, fuel storage technology, government regulations, CNG fuel control, and engine management. The second day included updates on the progress of developing heavy-duty natural gas engines, new compressor technology, the status of federal fleets and fueling infrastructure, and fuel composition issues.

The keynote address, delivered during the second day's luncheon by SAE Fellow Charles A. Amann, covered a comprehensive array of issues of concern to those developing gaseous fuel technology for automotive applications.

The following major points and conclusions emerged from the TOPTEC:

1. Manufacturers have passed the point of deciding which alternative automotive fuels, if any, are the most attractive to utilize in terms of low emissions, fuel efficiency, performance, cost, domestic fuel availability, safety, cold startability, ease of fuel distribution and dispensing, and other factors. Gaseous fuels stack up very well compared with other alternatives such as alcohols, electricity, hydrogen, fuel cells, and reformulated gasoline.

2. Optimized dual-fuel and dedicated natural gas prototype vehicles and engines are either entering production, or are very close to being introduced as viable
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alternatives and worthy competitors to gasoline vehicles and diesel engines in response to meeting very stringent LEV and ULEV mandates.

3. Fuel storage technology and packaging is improving in terms of lighter weight vessels, more rigorous construction, and increased energy storage capacity per unit volume. These developments should help to alleviate vehicle range and safety concerns of which recent seemingly-avoidable though potentially disastrous accidents have made the industry more acutely aware.

4. Reliable, durable, low cost closed loop control of lean burn natural gas engines is still needed.

5. Due to tax incentives, fleet programs, and private investment, fueling infrastructure, distribution, and dispensing are less difficult issues as deterrents to NGV proliferation than they have been in previous years.

This TOPTEC summary was prepared by Robert I. Bruetsch, Senior Research Engineer, Research & Development, Automotive Products Laboratory, Hitachi America, Ltd.
Technical Topics:
Safety Aspects of Alternatively Fueled Vehicles TOPTEC

The Society of Automotive Engineers held its first TOPTEC on alternative fueled vehicle safety in Diamond Bar, California on May 26-27, 1994. Nearly 100 people attended, including speakers, panelists, moderators, and sponsors. The safety-related topics covered the five currently utilized alternative transportation fuels (ATFs) in five fuel-specific sessions. The fuels covered were liquid petroleum gas (LPG), compressed natural gas (CNG), liquefied natural gas (LNG), alcohol, and electricity. Each fuel-specific session consisted of two or three presentations, followed by a moderated panel discussion of safety issues. Panelists included the fuel-specific presenters and several other safety experts representing manufacturers, fleet operators, fuel suppliers, government, and research organizations.

The five ATF-specific topic areas were complemented by four presentations on cross-cutting safety issues. These presentations summarized the safety perspectives of ATFS by insurers, fire marshals, government personnel, and air toxic researchers. The keynote luncheon address was on the ATF safety perspective of the South Coast Air Quality Management District.

The following summary points emerged from the TOPTEC:

1. ATF projects are not always well-coordinated with insurers and fire marshals. Improved liaisons with these organizations can facilitate the safety objectives of all involved.

2. More open sharing of both good and bad learning experiences with these fuels can significantly reduce the learning curve for new users.

3. Toxic emission from ATFs have primarily involved only methanol and reformulated gasoline. Although there are changes in relative amounts of specific toxic species, the overall toxicity of methanol and current gasoline vehicles is similar. Further studies on toxic emissions from all ATFs are needed, particularly for natural gas and LPG.

4. Alcohol fuels, being most similar to the conventional liquid fuels, have less obvious safety concerns than other alternatives. Primary safety concerns for alcohol fuels are toxicity of incomplete combustion products and imbibed fuel, flammable air/fuel mixtures in fuel tanks, and flame luminosity of neat fuels. Flame luminosity improvements and improved combustion/catalyst development are areas of current research. Coordinated public education efforts are lacking.

5. Electric vehicle safety concerns include issues related to component voltage, system design safety during failures and tampering, qualification of service personnel, cradle-to-grave battery handling, and vehicle crashworthiness. Manufacturers and standards organizations are addressing many of these issues. However, safety-related issues for some specific components (e.g., fuses) are only now beginning to be addressed. Regulations for electric vehicles are evolving and
public education and emergency response efforts are largely uncoordinated. Organizational capability exists to address known safety issues although continued long-term funding is less certain.

6. LPG has been the most common ATF used in the U.S. However, LPG-related safety issues have not been formally and thoroughly assessed. Statistical data is not readily available to provide a historical understanding of relative or absolute safety. A thorough review of LPG-related safety needs to be conducted. Organizational capability to manage safety work and to ensure that LPG-related safety issues will be addressed in a timely manner is not in place.

7. CNG related safety issues have been explored by the Gas Research Institute (GRI), private industry, and to a lesser extent, the Federal government. Many but not all safety issues are well understood. Critical issues such as cylinder integrity and gas dispersion are now being addressed. However, guidelines and standards for some aspects of CNG use have not been developed. The risks of CNG use and storage need to be determined through more rigorous risk assessments. Organizational capability to guide the safety work exists with GRI. Additional work has been sponsored by the Department of Transportation (DOT). The Department of Energy is only in the evaluation stage of CNG safety research.

8. The safety of LNG as a transportation fuel was addressed in the 1970s and reassessed in the early 1990s. The issues are similar to those of CNG. However, the cryogenic nature of the fuel is unique among transportation fuels. This difference requires additional technological developments and greater safety education efforts for the users. The limited experience with the fuel indicates that it can be safe, although a number of safety issues need to be resolved. Many operations-level safety issues have been addressed by Houston Metro and, on a broader level, by GRI and DOT. GRI’s and DOT’s commitment to resolve the remaining safety issues are not clear. The Department of Energy is only in the evaluation stage of LNG safety research.

The presentations and panel discussions showed that all fuels, not just ATFs, have real but controllable elements of risk. The specific risk factors among fuels vary but the consequences may not be all that different. One consequence common to all ATFs is that a serious incident with any ATF will seriously impede the acceptance of that ATF and will have a negative impact on the acceptance of all ATFs. Therefore, there is a need to address and ensure the safety of all ATFs in an organized and constructive manner.

This summary was prepared by the TOPTEC Organizer, David Friedman, Director of Energy & Fuels, Science Applications International Corporation.
The Society of Automotive Engineers (SAE) held a TOPTEC ("topical technical") program on catalysts and emission control on September 20-21, 1994, at the Troy Marriott, Troy, Michigan. Attendance topped 175 for the two-day technical event, featuring industry experts, academia, students, and government officials. Some of the major companies and institutions represented with contributing speakers at the conference were General Motors (NAO R&D), Ford Motor Company, Engelhard Corporation, W.R. Grace & Co., Rhone-Poulenc, Inc., Johnson-Matthey, AlliedSignal, Inc., Corning, Inc., AC Delco Systems, and Southwest Research Institute.

The TOPTEC was organized into two days. The organizer for Day One was Dr. Jerry C. Summers, North American Director - Diesel Propre Project, Specialty Chemicals Division of Rhone-Poulenc, Inc. The Day Two organizer was Dr. David R. Monroe, Senior Staff Research Engineer, Research & Development Center, General Motors Corporation.

Dr. Kathleen C. Taylor, Department Head of Physical Chemistry Department at General Motors NAO Research & Development, presented an overview and history of the subject. The remainder of the morning session featured presentations by Jeffrey S. Hepburn ("Roles of Noble Metals"), Principal Engineering Specialist, Ford Research Laboratory; John J. Steger ("Roles of Base Metals"), Director of Environmental Catalysts Group, Engelhard Corporation; and Joseph E. Kubsh ("Cold Start Emission Control"), Staff Engineer, Commercial Development Division, W.R. Grace & Company. The afternoon session on Day One featured presentations by Michael J. D'Aniello, Jr. ("FTP Testing"), Technology Director, Catalytic Systems Division, Johnson Matthey; David R. Monroe ("Catalyst Poisoning"), Senior Staff Research Engineer, Research & Development Center, General Motors Corporation; and Heinz J. Robota ("Thermal Durability"), Acting Technical Director, Research & Technology Division, AlliedSignal, Inc. Following the presentations, small group break-out sessions were held to formulate questions and issues for the panel discussion session, which followed.

On Day Two, presentations were made by Suresh T. Gulati ("Catalyst Substrates"), Research Fellow, Technology Division, Corning, Inc.; Stephen Mahan ("On-Board Diagnostics"), Development Engineer, AC Delco Systems, General Motors Corporation; John Mooney ("Role of the Engine in Emissions Control"), Manager, New Applications Division, Engelhard Corporation; William
The field of automotive emission control has been evolving continuously over the last 20 years; first striving to meet the regulated emission levels, then working to make the emission systems more robust and less expensive. However, more stringent emission standards that are scheduled to be phased in over the next ten years in the United States are forcing manufacturers to redesign their emission systems. Many of the speakers at this conference address this issue and expanded upon what their company (or institution) is doing to meet the legislative requirements in the future. With redesign, new demands are being placed on the catalytic converters, demands for improved performance and durability while operating under more extreme conditions. These changing demands, coupled with the spread of emission standards throughout the world, were addressed at this program. Speakers, panelists, and audience members engaged in a productive and informative debate over the rapidly changing environmental issues facing the industry today.

This summary report was prepared by Brian Taylor, program developer, SAE International based on summary reports provided from the TOPTEC.
Twenty-one speakers presented information concerning LNG vehicle activities at the third annual TOPTEC on LNG. The objective of the TOPTEC was to focus specifically on development efforts underway to strengthen the technical linkage of LNG vehicles from the liquefier to the engine.

The conference included a half day tour of the LNG fueling facility and fleet terminal at Greater Austin Transportation Company. Highlights from about half of the formal presentations are provided below. Summaries of the remaining presentations will be provided in the March issue of the LNG Express.

# Houston Metro's 1993 Experience

**George Herman**  
Deputy Assistant General Manager of Maintenance  
Houston Metropolitan Transit Authority

George Herman reported that since the arrival of the first Stewart & Stevenson Marco Polo buses a little over four years ago, the LNG-powered bus count at Houston Metro has climbed to about 300 buses (see table). Moreover, during the next four years, the transit authority expects to purchase an additional 535 units, raising the total to over 800 buses.

<table>
<thead>
<tr>
<th>Bus Type</th>
<th>Length (Feet)</th>
<th>Manufacturer</th>
<th>Scheduled Delivery Date</th>
<th>Quantity</th>
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</thead>
<tbody>
<tr>
<td>Articulated</td>
<td>60</td>
<td>Neoplan</td>
<td>Received</td>
<td>54</td>
</tr>
<tr>
<td>Commuter</td>
<td>45</td>
<td>Neoplan</td>
<td>Received</td>
<td>61</td>
</tr>
<tr>
<td>City</td>
<td>40</td>
<td>Ikarus</td>
<td>Received</td>
<td>62</td>
</tr>
<tr>
<td>City/Suburban</td>
<td>29</td>
<td>Stewart &amp; Stevenson</td>
<td>Received</td>
<td>85</td>
</tr>
<tr>
<td>Suburban</td>
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<td>Stewart &amp; Stevenson</td>
<td>Received</td>
<td>20</td>
</tr>
<tr>
<td>Mini</td>
<td>26</td>
<td>Stewart &amp; Stevenson</td>
<td>Received</td>
<td>9</td>
</tr>
<tr>
<td>City</td>
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<td>GMC</td>
<td>Received</td>
<td>3</td>
</tr>
<tr>
<td>Non revenue vehicles</td>
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</tr>
<tr>
<td><strong>TOTAL</strong></td>
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<td></td>
<td></td>
<td>296</td>
</tr>
<tr>
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<td>TBA</td>
<td>Fiscal year 95-97</td>
<td>135</td>
</tr>
<tr>
<td>Low floor/Articulated</td>
<td>60</td>
<td>TBA</td>
<td>Fiscal year 95-97</td>
<td>155</td>
</tr>
<tr>
<td>Low floor/city</td>
<td>40</td>
<td>TBA</td>
<td>Fiscal year 95</td>
<td>30</td>
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<tr>
<td>Commutera</td>
<td>45</td>
<td>TBA</td>
<td>Fiscal Year 95-96</td>
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<tr>
<td>Non revenue vehicles</td>
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<td>TBA</td>
<td>Under contract</td>
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<tr>
<td><strong>GRAND TOTAL</strong></td>
<td></td>
<td></td>
<td></td>
<td>831</td>
</tr>
</tbody>
</table>

The Houston Metro LNG-Powered Buses table summarizes below:

1. On-board cryogenic pump failure. Most buses are equipped with hydraulically driven positive displacement pumps designed to deliver vaporized LNG to the engine at 300 PSI. Many of the pumps were failing after relatively short operating intervals.

Resolution: Metro reports that it and the pump manufacturer, CVI Incorporated, have reduced the temperature of the hydraulic oil driving the pump, installed in-line fuel
filters, and updated the pump design to better accommodate the transit bus operating environment.

2. On-board fuel tank contamination. Metro reported that it has also discovered substantial amounts of metal shavings in some fuel tanks. Since the gaseous fuel injectors on the engines are sensitive to foreign matter, millings in the tanks could lead to injector malfunction and engine damage or failure.

Resolution: Metro has added filtration screens at two locations in the fuel delivery system and cleaned the existing gas injectors and fuel lines. New tanks are closely inspected for residual millings at the manufacturer.

3. Gas Detection Systems. Herman said that Metro has erred towards overly stringent precautions in its effort to ensure safety. As a result the transit authority has experienced numerous false alarms from gas detection systems. The sensors were so sensitive that hydrocarbons from any number of sources would trigger an alarm. Moreover, the problem increased as the sensors aged, since they were designed to become even more sensitive.

Resolution: Metro is limiting the number of sensors to critical areas, increasing the minimum detection levels and reducing the mileage interval for scheduled testing and maintenance.

4. LNG Fuel Nozzle Leaks. Metro must fuel numerous buses in rapid succession. Couplings, cooled by LNG to temperatures below freezing, accumulate ice as water vapor in the atmosphere condenses, freezes and sticks to exposed surfaces. The ice accumulation can lead to poor connections and leakage between the coupling and receptacle on the bus. Since LNG is transferred to the bus under moderate pressure, liquid can spurt through a poor fitting connection.

Resolution: Coupling manufacturers supplied improved designs that include non-stick metallic coatings. Second, Metro uses pressurized nitrogen gas to purge ice from the couplings. Pure nitrogen gas is especially effective because it is dry and safe, and it liquefies at a temperature much colder than LNG, so condensation is not a problem.

5. Excess Vapor. Metro's objective is to operate a zero vapor loss fuel delivery system. The station is designed to recover and store boil-off gas in the main storage tank until it is recondensed by incoming cold liquid. Vapor pressures in the main storage tank, however, have often exceeded hold limits before new deliveries are made.

Resolution: Metro expects that greater use of the fueling facilities will decrease vapor loss from the storage tank. Metro also intends to compress boil-off vapor to power CNG vehicles in the near future.

6. Electronic Gas Valves. In a previous report, Metro officials said they had lost over 15 engines due to metallic particles clogging open injector seats, leading to cylinder overfueling and engine damage (See LNG Express Project Survey, Nov/Dec 1993). Initially, Metro sources speculated that the metal shavings left behind in the on-board fuel tanks caused the injector problems.

However, further tests have indicated that some particles came from the exhaust of the engine. Metro sources believe this occurred because pressure in the cylinder during the exhaust stroke exceeded the opposing pressure on the injector seat, forcing minute amounts of debris into the fuel system through the injector orifice. Lab analysis of the particles clogging the injectors indicated that some were made of chrome from the cylinder piston.

Resolution: Metro is exploring several avenues, including increasing the pressure on the injector seats to a level that would prevent any back surge.

In closing, Herman noted that Metro intends to test eight new components during coming months. They include: (1) Detroit Diesel's Series 50 natural gas spark ignited engine; (2) Moog's new LNG fuel coupling; (3) six prototype electronic gas detectors; (4) Stewart & Stevenson's Gas Fuel Injector Electronic conversion kit; (5) on-board and station filtration units (6) single fill nozzles (designed to recondense vapor in the on-board fuel tank rather than return it to the main storage tank); (7) on-board pressure building coils; and (8) new electric on-board pumps manufactured by ACD.
Collison provided an overview of the LNG experiences at Maryland Mass Transit Administration (MTA). MTA has completed about six months of an eighteen month LNG bus demonstration program with four Flexi®le full sized coaches.

The purpose of the program, Collison said, is to determine the operating characteristics of using LNG, i.e., cost, durability, reliability, etc. in comparison to diesel. MTA purchased each Flexi®le bus for about $30,000 and the interim fueling station for about $650,000.

The 40 foot buses are equipped with a Cummins L10 natural gas engine, a 180 gallon capacity CVI Incorporated fuel delivery system, and methane detection and fire suppression systems. According to Collison, they are achieving about 2.5-2.9 miles per gallon of LNG, which provides a range of roughly 400 miles.

Richard Beciold, Senior Engineer at EA Engineering and Science Technology Inc., who is the technical advisor to the project, reported the refueling station is principally comprised of a fuel trailer, a dispenser and a concrete pad with canopy. The trailer, which was manufactured by Hydra Rig at a cost of about $137,000, according to Collison, supports a 3,000 gallon LNG storage tank, a vent heat exchanger, pressure building coils, a cryogenic pump (20 gallons per minute at 100 psi), piping and connectors.

When the storage tank is near empty, the trailer is disconnected from the dispenser and towed to Baltimore Gas and Electric’s peak shaving facility to be refueled. Three thousand gallons provides the buses with about two weeks fuel supply, reported Collison. The tank was trailer mounted because it would be difficult to get truck deliveries for volumes this small.

The dispenser, which was also manufactured by Hydra Rig at a cost of about $100,000, according to Collison, contains two mass flow meters: one to measure the weight of gas flowing into the bus and the other to measure the weight of return vapor. A programmable control unit allows the dispenser to be operated from a face mounted panel, from a remote control panel about 100 feet away or via modem from Hydra Rig’s headquarters.

The dispenser can be operated in automatic or manual mode, Collison reported. In automatic mode, the face mounted control panel provides the operator with step by step instructions. About ten minutes is required to cool down the pump, dispenser and hoses before buses are fueled.

The concrete containment area includes a refueling island, a containment pit, a canopy, lights and a kiosk. The facility includes methane detectors, infrared fire sensors and fire suppression equipment with 2,000 pounds of dry fire retardant.
LNG Purification Systems for Existing LNG Supply Sources

John O'Brien, Vice President, Process Design
Tom Driscoll, Sales Manager, Custom Services
Process Systems International

John O'Brien began the presentation by reporting that a number of existing facilities might be modified to produce pure liquid methane at competitive prices (see LNG Express January 1994). The key questions addressed were (1) which existing facilities might be modified, (2) what purity LNG is required, and (3) what advantages might existing facilities offer over dedicated plants.

O'Brien divided existing facilities in the USA into two categories: LNG plants, which include base load receiving terminals and peak shaving facilities, and gas plants, which include natural gas liquids plants and nitrogen rejection units. Given current engine technology and their associated fuel delivery requirements, O'Brien suggested that high purity LNG is most ideally suited for transportation. Spark ignition engines, he noted, run better with 95+% methane LNG. Furthermore, once LNG is loaded on-board a vehicle, it "weathers" rapidly (a condition where methane warms and boils to gas inside the tank, leaving enriched concentrations of heavier hydrocarbons in the liquid). As a result, higher purity LNG (99+% methane) is better for infrequently fueled vehicles.

When considering locations to produce high purity LNG, O'Brien described five different types of facilities: (1) LNG terminals, (2) LNG peak shavers, (3) nitrogen rejection units, (4) NGL plants, and (5) dedicated plants. He noted, however, that other facilities, such as refineries and landfills might also provide advantages to liquefaction.

Because LNG is currently manufactured or stored at import terminals, peak shaving plants and nitrogen rejection units, these facilities require only minor modifications to purify liquid to 99+% methane, O'Brien noted. Furthermore, there might also be advantages to re-liquefying boil-off gas from these facilities to produce transportation grade LNG.

Tom Driscoll then reported that more than 160 facilities in the United States might be modified to produce high purity LNG. Most modifications would require less than twelve months to complete.

The possible advantages of facility conversions compared to new plants are: (1) substantially lower cost per LNG gallon, (2) faster construction time, (3) easier LNG permitting, (4) availability of low cost surplus equipment and infrastructure, and (5) previously justified capital costs for the original plant. The primary disadvantages are the location might be too remote or the plant might be fully committed for other purposes.

Driscoll estimated the incremental cost of producing a gallon of LNG from an existing facility capable of producing 20-100,000 gallons per day would be less than 0.2 cents for a nitrogen rejection unit, or 0.5 to 1.5 cents for a peak shaver or import terminal. He further estimated a modified natural gas liquids plant might produce LNG for as little as $0.35 to $0.45 per gallon, compared to a new plant's estimated cost of $0.50 to $0.60 cents per gallon.

LNG Station Development & Future Issues

Ed Owens, Manager, Fuels & Lubricants Engineering, Engine, Fuel and Vehicle Research
Southwest Research Institute

Ed Owens described LNG fueling facilities, focusing specifically on the transfer of LNG from track side storage to trains. His presentation covered fueling system assumptions, current and state-of-the-art equipment, and developmental needs to support LNG use in railroad revenue service.

Owens reported that currently most locomotive designs are dual fueled, requiring 70% to 90% LNG and 10% to 30% diesel. For this reason, track side fueling facilities must provide both LNG and diesel fuel. The LNG is stored in a separate tender car, where as the diesel is stored directly on the locomotive.

Most conventional fueling
stations, Owens reported, require one or two people to transfer fuel to the locomotives. Personnel will need to be trained to transfer LNG to tender cars while transferring diesel to one or more locomotives.

According to Owens, an advantage to LNG is that the industrial gases and energy industries have extensively developed cryogenic storage and transfer equipment. Much of the technology needed for LNG railroad fueling systems is currently available (i.e., pumps, sensors, piping, valves & unions).

Two components that need further development, however, are high volume meters to measure LNG flow rates and couplings designed to meet the rigorous requirements of a railroad refueling environment. LNG meters, Owens said, must be capable of measuring both liquid and vapor flow. Two design options have both advantages and disadvantages. The first, vibrating tube mass flow meters, can measure both liquid and gas flow, yet are sensitive to size constraints and pressure differentials. The second, turbine meters, are less sensitive to size, but also less accurate when LNG is in both liquid and gaseous phases.

Couplings used in the traditional LNG and cryogenics industry that are capable of accommodating flow rates of 1,000 gallons per minute or more, are generally hammer unions and valves. These designs, Owens noted, require well trained operators who can closely monitor fuel flow and liquid levels. Railroad fueling operators, however, will be busy with many other tasks while the train is being fueled. For this reason, the rail industry requires dry disconnect seals and break-away connectors with automatic fuel shut-off features.

Other areas that Owens highlighted as requiring further development to make LNG ready for full revenue service are automated monitoring controls and liquid level measurement devices. He encouraged designers to adopt an integrated systems approach linking together the design of the fueling facility, tender and locomotive.

In summary, Owens' appraisal was that "all systems to safely and efficiently handle LNG is available or feasible with existing technology."

Easy and Safe Fueling with LNG
Anker Gram, President
Gram & Associates, Ltd.

Anker Gram proposed several design innovations to reduce the hazards of fueling LNG so that the fuel would be safer and more cost effective to handle. He suggested that many station designers approach LNG storage and transfer from the perspective of massive base load and peak shaving storage facility design, which he believes is inappropriate for small fueling stations.

"Now we are trying to adapt rules developed for the bulk operations for facilities and flows 1,000 times smaller, and this cannot be done - in the same way as the rules for bulk chlorine cannot be used to determine how to put chlorine in our swimming pools," Gram reported.

Specifically, Gram proposed several design modifications to make fueling stations more user friendly. First, he suggested putting LNG storage tanks underground. This would allow designers to contain liquid and control vapor dispersion, possibly by channeling vapor up a ventilation stack, in the event of tank rupture (See LNG Express, Jul/Aug 1993, pages 2-5). Gram believes that in the event of a major spill, station designers should be more concerned with vapor dispersion than liquid containment.

To pump LNG from the underground tank to vehicles, Gram proposed to use a slow action, positive displacement pump. The pump, according to Gram, can operate with a negative suction head of as much as 25 feet, providing 30 to 50 gallons of liquid per minute at pressures as high as 200 psi.

The second difficulty Gram noted with current fueling station designs is the requirement for operators to wear bulky, protective aprons, gloves and face shields. Gram proposed a new coupling design with vacuum insulation right up to the tip of the hose. He said his new design would eliminate the need for fueling attendants to wear gloves or special protective gear.

To further simplify fueling, Gram has designed an on-board vehicle tank that will provide an automatic fuel flow shut-off feature. The tank contains a false bulk head that divides the inner container into two spaces: a liquid space containing 80% to 90% and a vapor space containing 10% to 20% of tank
FEATURE

Furthermore, recent health reports indicate particulate matter of 3 microns or smaller may be much more dangerous to respiratory health than previously believed.

Goldhand acknowledged LNG can be used to reduce or eliminate many of these problems. Yet, she challenged the industry to solve several technical and environmental issues. First, she said that LNG proponents must find ways to reduce both methane and non-methane hydrocarbon emissions. She is concerned that reducing NOx, only to see a rise in HCs will not reduce ozone gases effectively.

Second, she challenged the industry to find ways to increase power. Additional fuel consumed to compensate for lost power is an offset to emissions reductions.

In closing, Goldhand stated she believed that LNG would play a significant role in reducing emissions from heavy-duty transportation. In 1996, the EPA will issue emission reduction rules for off-road sources. This spring, the draft rule will be submitted to the public for review.

Station Safety Design
Scott Stookey, Fire Protection Engineering Associate
Austin Fire Department

Scott Stookey said that he had been approached about 5 years ago to approve an LNG station design. Initially, he was reluctant for several reasons pertaining to the fuel's temperature, vaporization, and composition. However, when Greater Austin Transportation Company (GATC), Minnesota Valley Engineering (MVE) and Liquid Carbonic Industries (LCI) approached Stookey, he agreed provided several design criteria were met. First, he required that in the event of a spill, vapor concentrations would not exceed 25% of the lower flammability limit at any property line.

Second, he required that in the event of a fire, the thermal radiation flux would not exceed 5KW/M² at any property line. This would allow fire fighters to contain and fight even the most severe fire.

Third, Stookey required designers to use accepted procedures, i.e., fault tree analysis with probability risk assessment, to determine the likelihood and severity of worst case events. And finally, he required designers to quantify vapor dispersion and thermal radiation consequence analysis through the use of accepted computer models. Stookey listed two available models, including Degadis, which is a Dense Gas Dispersion model provided free of charge from Gas Research Institute.

To meet Stookey's criteria, the design group came up with both engineering and administrative safety controls. One of the engineering controls was that the station would sit in a six foot deep insulated concrete containment basin. By constructing a basin made of insulated concrete, called "Gunnite concrete," the boil-off rate of a major spill, Stookey said, would be 30% lower.

Additional engineering controls, Stookey mentioned, included automatically closing flow valves, supervised gas and spill detection systems, redundant temperature and pressure limit controls and relief devices, and a programmable logic controller to supervise the dispensing of fuel.

The administrative controls included limiting the fuel station operation to trained technicians, trained employees would be screened and tested periodically for drug usage.

Second, designers would document the procedures for station filling, vehicle refueling, and station shutdown. The station would undergo periodic maintenance and inspections. And last, the Fire Department would develop response protocols and tactics to respond to incidents in the event of an accident.

In closing, Stookey provided several recommendations for future station designers. First, he urged designers to use realistic risk assessment and consequence analysis. Second, he recommended a thorough evaluation of the site in relation to fire safety exposures. Third, he strongly suggested that the surface area and materials be designed for spill containment. And last, he encouraged designers to open dialogue early with local approving authorities.

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NFPA Draft Standard 57 Status
Theodore C. Lemoff, Senior Gases Engineer
National Fire Protection Association (NFPA).


Lemoff outlined three stages that all new standards must complete: the proposal, comment and presentation stages. Draft NFPA 57 has completed the proposal stage and was in the later part of the comment stage when it was delayed by about six months due to a controversy over station siting provisions (see LNG Express, January 1994, page 7).

The Committees for draft NFPA 57 and NFPA 59A could not agree on which was responsible for storage of LNG at vehicle fueling facilities. The chairs of the two committees referred the matter to the NFPA Standards Council for resolution as to which committee has primary responsibility for storage of LNG. The Standards Council voted to limit the scope of draft NFPA 57 to LNG vehicular fueling systems, dispensing facilities, LNG to CNG transfers and other aspects of LNG vehicular systems not addressed within NFPA 59A. The Council left the responsibility for stationary storage containers and the associated piping within NFPA 59A.

The Standards Council further instructed the NFPA 57 Committee to incorporate material to make NFPA 57 a complete comprehensive standard from NFPA 59A, either by reference or extract, thus the reason for the six month delay. Presentation to the Association is not expected until November 1994.

To reduce the burden of station siting, the NFPA 59A committee has proposed a Tentative Interim Amendment (TIA) to NFPA 59A. The TIA would provide a method for siting LNG tanks of 70,000 gallons or less, provided the tanks are equipped with additional safety devices to reduce the possibility of LNG release (see article under Industry News in this issue). Copies of the TIA can also be obtained from the NFPA at the above address.
Panel: On-Board Fuel Delivery System Issues and Challenges

John Rodgers (Panel Chair), Manager Vehicle Engineering, Roadway Express
Lawrence A. Carlstrom, CVI, Inc.
Robert Crowl, ACD, Inc.
John Gibson, Ecogas Cryogenics, Inc.
George W. Kalet, Minnesota Valley Engineering
Rick Young, Cryenco

Rodgers opened the panel discussion by describing some of the operational experiences at Roadway. Overall, he said, Roadway has demonstrated that LNG can work, the current objective is to make it economical.

He encouraged fuel equipment suppliers to simplify systems so that cost of equipment and maintenance can come down. He quoted an axiom in the trucking industry, "the ideal truck has no moving parts." Rodgers noted that Roadway operates thousands of distribution trucks; a seemingly minor expenditure can add up to millions of dollars when multiplied by the total units in operation.

Rick Young of Cryenco followed Rodgers by providing a brief overview of on board fuel delivery systems. Young classified fuel delivery systems into three categories: low, medium and high pressure systems. Low pressure systems provide fuel to the engine at pressures under 70 psi, the medium-range from 70 to 150 psi, and the high pressure systems at pressures above 300 psi. However, because most new over-the-road engines being built by original equipment manufacturers require delivery pressures in the 100-150 psi range, medium range systems are receiving the most attention.

Young described the Cryenco pressure boost system, a pumpless fuel delivery system that builds pressure by adding limited amounts of heat to the fuel. The heat is obtained from engine coolant or an electronic heating element in the tank (See LNG Express, Sep/Oct 1993, page 11).

Young explained that the major benefits of the Cryenco system is that the need for an on-board pump is eliminated. Yet the system can receive fuel at relatively low saturation pressure (50 psi) and still deliver 100 to 150 psi pressure to the engine. Cryenco systems are being demonstrated on-board buses in Mexico, Houston Independent School District and other locations.

Lawrence Carlstrom of CVI Incorporated described on board pump operations. He discussed the pump delivery systems that CVI has provided Houston Metro.

Carlstrom explained that the primary benefit of using an on board pump is that the fuel delivery system can provide consistent pressure to the engine regardless of the liquid pressure in the tank. CVI pumps are designed to operate with zero suction head, so the pump will operate as long as the tank contains enough liquid to cover the inlet port.

George Kalet of MVE presented a video that demonstrated the crash worthiness of LNG vehicle tanks. In the demonstrations on the video, MVE dropped a tank full of liquid from a crane to pavement 30 feet below, the tank was baked over a fire to 800-1,000°F and shot with various sized bullets. In each of the demonstrations, the inner tank remained unharmed with no leaks or damage. During the tank bake test, the tank's internal pressure increased about one-quarter pound per square inch for each 15 minutes the tank was in the fire. Temperatures on the bottom of the tank exceeded 1,000°F.

During the gun shot test, two rounds hit the same location, causing a small crack in the outer tank that released the vacuum between the outer and inner tanks. However, no damage resulted to the inner tank or insulation material surrounding it. (See Industry News, this issue).

Robert Crowl of ACD described his company's work with cryogenic pumps. ACD is currently testing two on board pumps, one designed to provide 500 psi fuel delivery and one designed to deliver 4,000 psi fuel. Crowl explained that his company's pumps will use 24 volt DC electrical power to provide consistent pressure fuel to the engine.

John Gibson of Ecogas Cryogenics began his presentation by addressing the questions that were provided each of the panel members. Ecogas Cryogenics, formerly Gibson Technical Services, will provide the system design, engineering and equipment for Ecogas Corporation's natural gas vehicle projects, the largest being the conversion of 25% of the State of Louisiana's fleet to LNG or CNG derived from LNG.

The questions Gibson addressed were subsequently opened to
the entire group for discussion. The questions centered around the advantages and disadvantages of various system designs. Two conclusions were worth special note.

First, LNG fuel delivery systems are adapted to be placed on board vehicles that were designed for diesel or gasoline. If vehicles were designed specifically for LNG, designers would provide more of a cubical storage space for LNG tanks so that the surface to volume ratio would maximized and heat-leak minimized. Hold times for vehicle tanks could be extended significantly if tanks were configured in more of a spherical shape.

The second point of particular interest was that seemingly minor decisions on the part of engine designers to increase the minimum fuel delivery pressure to the engine can have monumental effects on the fuel delivery system all the way up the chain to the liquefaction system.

Much effort is made to keep LNG as cold as possible. However, fuel system designers must add heat to fuel or manufacture pumps to provide LNG at pressures above about 40 psi. An engine designed to use much lower delivery pressures would reduce the cost and complexity of fuel systems considerably.
Detroit Diesel's Family of Natural Gas Engines
Douglas L. Graham, Director of Design and Special Projects, Detroit Diesel Corporation

Graham described the natural gas engine development programs at Detroit Diesel Corporation (DDC). DDC plans to introduce natural gas powered versions of four of its four stroke models.

Graham reported that DDC is achieving fuel efficiencies with its spark ignited natural gas (SING) engines within 15% of diesel fuel efficiency. When asked why DDC was able to achieve better fuel efficiency than other spark ignited, throttled engines, Graham speculated it was due to DDC’s electronic controls.

DDC will soon offer its Series 50G SING engine (8.5 liter, 250-300 HP) that is targeted towards the transit bus market. California Air Resources Board Certification of the Series 50 engine is expected to be complete in March or April, 1994, Graham said. Houston Metro and Golden Empire Transit of Bakersfield, California are among the transit properties that will receive and use some of the SING engines with LNG.

Series 30 SING engine (7.3 liter, 200-250 HP) development is fast on the heels of the Series 50 program. The Series 30 engine will be targeted towards the school bus and medium-duty truck markets. Also, both SING versions of DDC’s Series 40 and 60 engines are under development. DDC does not anticipate making any design changes between LNG and CNG powered engines. Liquid Carbonic, Walmart and other companies will receive limited quantities of the Series 60 prototypes to conduct LNG demonstration trials with heavy-duty tandem axle tractors.

Graham reports that DDC is continuing to develop direct injection natural gas (DING) engine technology for off-road, two stroke per cycle applications. DDC is reported to be developing a natural gas version of its 16V-149 two stroke engine, which is commonly used by the mining industry.
Jackson provided an overview of an LNG demonstration program being coordinated by Acurex Environmental where three trucking companies, Walmart, Lucky and Unocal, will provide trucks for an LNG demonstration. He first outlined the importance of heavy-duty vehicles to California's environment. Though heavy-duty trucks and urban buses represent only about 4% of the vehicle population in California, according to Jackson, they generate more than half of the state's oxides of nitrogen (NOx) emissions. Natural gas offers a means of reducing the NOx emissions substantially, reductions of as much as 60% of 1994 diesel standards.

For this reason, California regulators have devised market based incentives to encourage the use of alternative fuels. Jackson described mobile source emission reduction credits (MERCs) as being one such incentive program.

The California Air Resources Board has defined a mechanism for measuring NOx emissions reductions, Jackson said. Each of the local air districts are issuing rules to regulate trades of MERCs.

For clean air reasons, several fleets have been testing natural gas use in California. Heavier-duty fleets, however, have been constrained by CNG range and weight limitations. For example, Vons, a California-based grocery distribution fleet, has converted a Caterpillar G3406-powered tandem axle tractor to CNG. The range, however, is limited 250 miles or less.

For this reason, several fleets are considering LNG. The potential advantages LNG offers, according to Jackson, are: potentially lowest life cycle costs, significant vehicle range, substantial air quality benefit, and tax and other incentives.

Jackson notes that DDC, Caterpillar and Mack are developing natural gas powered engines for Class 8 tractor applications. For this reason, Acurex recognized the need for a project coordinator to pull together engine manufacturers, government agencies, gas companies and transportation fleets to demonstrate the viability of LNG. Acurex has identified five sites for potential programs, including: Walmart in Porterville, Lucky in Buena Park, Unocal in Los Angeles, Vons in El Monte, and GWF in Hanford.

Acurex's first step is to contract with engine manufacturers to develop and provide field test engines. Second, Acurex intends to work with OEMs to design and install on-board fuel systems. Third, Acurex intends to perform chassis dynamometer emissions test and on-road vehicle test. And last, Acurex intends to gather data on fuel economy, maintenance and operating costs, and downtime.

South Coast Air Quality Management District has awarded a sponsorship contract to Acurex for almost $500,000. Other sponsors are evaluating the program. At least three fleets have agreed to the program, and engine manufacturers are well underway with development programs.
FEATURE

Emission Reduction Credits
Kenneth D. Smith, Clean Fuels Director, Sacramento Metropolitan Air Quality Management District

Smith described the complexity of regulations at the Federal, state and local levels of government with regard to mobile-source emissions reduction credit (MERCs) -- credits that fleets might generate by using cleaner fuels. The EPA, he said, requires five criteria for tradeable credits, whether from mobile or stationary sources: surplus, real, quantifiable, enforceable and permanent.

With regard to vehicles, regulatory officials find it especially difficult to meet the quantifiable, enforceable and permanent criteria. Consequently, Smith said, regulators are often overly cautious, "skimming" to ensure their jurisdiction's air quality targets met. Skimming is the term to describe a practice where regulators require credit recipients to reduce emissions 20% to 100% more than they are awarded, thereby imposing a significant regulatory burden. In theory, skimming is meant to improve air quality. In practice, however, it serves to stifle credit trades.

For this reason, on January 19, 1993 the California Air Resources Board published independent MERC trading guidelines. The guidelines address both mobile to stationary trades as well as mobile to mobile trades. Their purpose was to establish guidelines similar to the EPA's, but more appropriate for mobile source credits.

CARB instituted four criteria instead of EPA's five. The primary difference is that CARB's guidelines do not require the MERCs to be permanent. Instead, the life of the reduction can be a defined period, i.e. the engine life.

Smith gave several examples of ways to generate and trade MERCs, from using cleaner fuels to scrapping old cars.

The key for a fleet to generate MERCs, Smith said, is to use CARB certified, cleaner engines. Under CARB's program, an engine can produce no more than 3 grams of NOx per brake horsepower-hour. Clean engines are classified into certification bins based upon NOx emissions levels. CARB currently requires standard bus engines, for example, to emit no more than 5.0 grams per brake horsepower-hour. Bins are defined in 0.5 gram increments starting at 3.5 grams. Consequently, an engine must be certified by CARB to emit no more than 3.5 g/bhp-hr.

However, one example of "skimming," according to Smith's criteria, is that CARB requires that every vehicle be placed into the next higher bin. For example, if a bus were powered with an engine certified to emit 2.0 grams of NOx, the law requires the bus to be rated at 2.5 grams. Consequently, the engine must be certified at no more than 3 g/bhp-hr to obtain emissions credits.

In addition to EPA and CARB MERC regulations, Smith identified two local programs: the South Coast and Sacramento Air Quality Management Districts. He reported that Sacramento needed its own MERC program because mobile sources account for 60% of reactive hydrocarbons and 90% of NOX emissions in the Sacramento area. And EPA and CARB requirements are insufficient to allow Sacramento to attain clean air attainment deadlines.

The Sacramento Air Quality Management District has instituted the 1000 Series Rules. Rule 1005 specifically governs MERCs.

In conclusion, Smith said that he was more optimistic about the future of mobile to mobile source trades than mobile to stationary trades. As Sacramento regulations become more stringent, more and more businesses will be adversely affected by mobile emission regulations, and credits generated by alternative fueled vehicles should grow more valuable. However, regulators will remain reluctant to apply credits generated from mobile sources to stationary sources.

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Mexico LNG Status
Alfredo Avila', Director Administrativo, (substituting for Luis Manuel Guerra, Exec. Director General) Autonomous Institute of Ecological Investigations, A.C.

Avila' reported that Mexico City is conducting studies and beginning to build the infrastructure to power automobiles with natural gas. He said that two natural gas liquefaction plants with combined capacity of 2,200 liters per day, and one CNG station, capable of fueling 300 vehicles have been built.

Moreover, fifty police cars and one Ruta Cien bus have been converted to natural gas. Certification tests are being carried out by the Mexican Petroleum Institute.

To further promote conversions to natural gas, Avila' said, the government has established a preferential price for liquid petroleum gas and natural gas in relation to gasoline. Furthermore, vehicles that use LPG or natural gas are not subject to the Government's "boy no circula" program that prohibits many vehicles from operation at least one day a week.

Avila' noted that LPG has been the most successful alterative fuel. Low prices have encouraged widespread conversions. Six LPG fuel stations serve an estimated 8,000 vehicles daily.

Yet, alternative fuels are not the only option. The government has also introduced low sulfur diesel, catalytic converters and reformulated gasoline.

According to Avila', the Mexico City Government has a five part plan to improve the City's environment: (1) promote local research and environmental education; (2) switch to clean fuels; (3) modernize industry with pollution control measures; (4) reforest the valley; and (5) encourage greater use of public transportation.

In closing, Avila' noted that improving air quality in Mexico City is especially challenging, however, because of the geographic and demographic characteristics of the valley. Mexico City is located at a high altitude in a rarified atmosphere with mountain peaks surrounding all sides. About 18% of the Mexican population lives in the valley, consuming 17% of the nation's energy. Transportation in the region consumes 24 million liters of fuel daily.
Texas Railroad Commission Forthcoming LNG Safety Regulations and Training Programs
Thomas Petru, Division Director, LP Gas Division, Texas Railroad Commission

Petru summarized the Texas Railroad Commission's (TRC's) efforts to publish codes that will govern LNG vehicles and associated equipment. He said that the TRC is making efforts to ensure the regulations and subsequent enforcement will be "user friendly."

On November 15, the TRC issued the first draft of its regulations for LNG. Then on December 8, the state held a meeting to review the draft and solicit comments. The TRC is currently integrating information from this meeting into the draft. Once complete, the TRC will hold a second meeting to discuss the updated version. Petru had expected this second meeting to be held in March; however, TRC staff report the date has been postponed.

With information obtained from the second meeting, the TRC will further update the draft for submission to the three TRC Commissioners, Chairman James E. (Jim) Nugent, Commissioner Mary Scott Nabers, and Commissioner Barry Williamson. If approved, the draft will be published in the Texas Register for public comment. Petru expects the public comment period to last 60 to 90 days.

Once any pertinent public comments are integrated into the draft, the TRC will resubmit it to the Commissioners to authorize adoption. If approved, the TRC will publish the code in final form in the Texas Register to be adopted 30 to 60 days.

Petru said the State will employee two to three inspectors to review LNG facility designs. Each LNG facility will be required to obtain licenses certifying compliance with TRC code. He further said the Texas Energy Commission and the Texas Department of Labor have budgeted $600,000 and $1,100,000, respectively, for training and certification. Persons who work with LNG or LNG-to-CNG systems will be required to pass one or more State proficiency exams.
Off-Road Applications
Kevin Beaty, Manager, Technology Development, Engine, Fuel, & Vehicle Research Division, Southwest Research Institute

Beaty assessed a range of LNG projects in varying transportation modes by comparing each mode's incentives to use LNG, profiling active projects, and considering the importance of off-road LNG applications. In his presentation, he reviewed eight off-road categories: aircraft, airport ground-support, marine, rail, construction, farming, mining, and landfill.

According to Beaty's statistics, rail, marine and off-highway transportation use almost 30% of total diesel consumed in the USA, representing a market worth more than $20 billion a year. The primary benefits LNG could offer to these fleets is energy diversity, decreased maintenance expense and reduced fuel cost.

However, several other advantages to alternative fuels will provide little benefit to off-road transportation. First, off-road fleets generally pay little or no federal or state excise tax on fuel. Farm and mining vehicles pay no tax. Consequently, any excise tax advantages offered by alternative fuels have little effect, Beaty said.

Second, most off-road vehicles are unaffected by clean air requirements. Third, construction and farm equipment utilization is low, so fuel savings have less importance than equipment cost. And last, air and marine transportation fleets can ill afford to lose power due to technical problems associated with pioneering new fuel.

For these reasons, Beaty noted, fleet operators of many off-road applications are not considering alternative fuel use. Railroads and marine are the two primary areas of interest due to high fuel consumption and growing concern for emissions.

Beaty profiled three LNG rail demonstration programs and one marine program. He noted that off-road LNG demonstrations represent less than 10% of the total vehicle programs. Furthermore, each off-road project has different objectives and therefore, will require differing technical approaches. For example, Burlington Northern's principal objective is to determine the technology cost of LNG compared to the benefits, while Southern California Regional Rail Authority's primary goal is to meet strict emission standards.

Beaty stressed the importance of fuel economics to high utilization, off-road fleets. One out of every ten dollars spent by railroads, for example, is used to purchase fuel.

Beaty suggested that cooperative research and development programs are the best approach to commercialize LNG. He reported that the Southwest Research Institute has coordinated a four year $9.3 million LNG demonstration program for seven clients: the Southern California Regional Rail Authority, the South Coast Air Quality Management District, Gas Research Institute, Electromotive Division of General Motors, the Department of Energy and Union Pacific.

The Objectives of the program are to develop and demonstrate low emissions, LNG locomotives in freight and passenger trains. Key issues include combustion technology, high pressure gas injectors, cryogenic pumps, fueling issues and cost benefit and market analysis.