ENERGY CONVERSIONS INC.

alternative fuel systems for high output engines

The ECI Dual Fuel Sourcebook

An essay on Natural Gas and its use as a fuel source for locomotives and power generation.

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To The Reader

The uncertainty of today's petroleum market with its declining oil reserves, on going tensions in oil producing nations, and environmental regulatory activity soaring to new heights, has industry seeking new ways to provide power for fuel hungry, high horsepower applications. Among possible alternatives, natural gas stands alone as the one fuel that will benefit both the environment and the bottom line.

But while natural gas is looking more and more attractive to operators of high fuel consumption applications, serious and legitimate questions remain: Is natural gas safe? Is it as reliable as diesel? Will it really save money?

These are the concerns that The ECI Dual Fuel Sourcebook addresses, in a concise, no–hype, easy to understand style. It brings the reader up to speed on natural gas, covering its physical characteristics, economics, environmental impact, and safety. Then the discussion shifts to the technological means of obtaining the gas advantage: the ECI EMD 645 conversion system. The Sourcebook introduces the system, its installation, potential applications, and ECI's auxiliary technical services.

Much of the information in the Sourcebook is compiled from ECI's extensive experience in the high horsepower natural gas conversion industry. When information is followed by a numeral in brackets [], the reader should consult the References section at the back of the publication. Many of the references listed here and many others are available from ECI upon request.

We at ECI sincerely hope that this publication will serve as a sound basis of no-nonsense facts about natural gas and its use in high horsepower engines. ECI will be happy to discuss further topics with the reader; please don't hesitate to contact us.

Note: The following is a discussion of the economic, mechanical, and environmental viability of using natural gas in high output engines within the locomotive and stationary power industries. We hope you find the enclosed information helpful and informative. This is in PDF format so it may be printed on your printer if you so desire to have a printed copy.

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Natural Gas

Fuel Characteristics

Natural gas is composed principally of methane (CH4), with smaller quantities of other hydrocarbons, carbon dioxide, and water. A typical breakdown of pipeline natural gas is given in the table. The non–methane hydrocarbons are known as "heavies"; multiple carbon atoms in their molecules give added molecular weight. The added carbon atoms also provide more available energy within their additional atomic bonds with hydrogen atoms. The heavies, therefore, contribute more BTUs (British Thermal Units) per volume of gas than pure methane would alone. Gas whose composition of methane and heavies results in a BTU content of over 1100 BTU per standard cubic foot (SCF) is known as "hot gas". Hotter gas is not necessarily better gas for engine use.

Combustion Characteristics of Gas

A high octane (130) fuel, methane exhibits ideal knock characteristics for typical spark–ignited engines. Unfortunately, the characteristics that make for a good fuel for spark ignited engines generally make the fuel less desirable for compression ignited engines, such as the high horsepower diesels we are discussing. Such fuels require an extremely high compression ratio, or the introduction of heat energy into the cylinder from an external source. The compression ratio required to enable methane to compression ignite is too high to implement on these engines without seriously compromising engine reliability and performance.

The solution adopted by the ECI system is to use a small amount of diesel oil as a pilot charge to initiate combustion of the natural gas/air mixture. Near the bottom of the piston stroke, the natural gas charge is admitted to the cylinder via the gas inlet valve (GIV), after air is inducted through the air intake ports. The fuel is mixed with the air and compressed as the piston rises. Near the top of the stroke, the pilot fuel is injected. The diesel fuel, with its lower ignition temperature, ignites, igniting the gas mixture along with it.

Component	Molar %
Nitrogen	0.323
Carbon Dioxide	0.174
Methane	92.241
Ethane	6.500
Propane	0.551
Iso Butane	0.042
N Butane	0.055
Hexanes +	0.045
Oxygen	0.069
BTU/cu. ft.	1071.000

This approach requires a lower compression ratio than standard, to avoid engine knock. As the combustion proceeds from the diesel injection, pressures spike within the combustion chamber. If pressures become too great, combustion can be triggered within the unburnt gas mixture ahead of the original flame front. This so-called auto-ignition causes destructive knock.

A lower compression ratio generally spells lower efficiency. ECI's specially designed piston crowns and cylinder heads minimize this loss and allow for full diesel–rated horsepower in either dual fuel or diesel mode.

Why Dual Fuel?

Besides being a convenient method for initiating combustion, a dual fuel system offers other advantages. The most obvious one is the constant availability of a backup fuel system, if a breakdown in gas operation occurs. Imagine one scenario from a marine application: a gas powered ferry preparing to dock. Gas detection equipment is employed in the engine room, to alert the gas control to leaks. If a leak is detected, the gas is shut off immediately and automatically at the source. Suppose this ferry, outfitted with a single fuel system, develops a very small gas piping leak. The leak is not enough to be immediately dangerous, but the gas sensors do their job, and instantly shut off the fuel. The reverse thrust the docking ferry must now provide is suddenly unavailable. A seriously damaged dock and possible injuries to passengers and crew is the result. The ECI system, when a gas leak is detected, automatically shuts off the gas, and switches the engines to full diesel operation, resulting in no loss of power, and a smooth, normal docking.

Low– vs. High–Pressure Injection

There are two ways to deliver natural gas to the cylinder: under low (100–200 psi) pressure, and under high (3000+psig) pressure. Low pressure injection, implemented in the ECI conversion system, involves the admission of the natural gas into the combustion chamber when the piston is near the bottom of its travel. Pressure within the chamber is near ambient. High pressure injection entails forcing the gas into the already compressed air along with the pilot fuel near the top of the piston stroke.

The low pressure process offers many advantages over high pressure. Safety is an important concern in any high pressure application. A high pressure system requires more stringent materials specifications for gas delivery to insure against dangerous leaks. Ship's engineers on steamers would hunt for steam leaks with the aid of a broomstick. Holding the broomstick out in front of them, they would wave it near possible leaks. If the broomstick was suddenly chopped in two, they had found a leak. We are speaking of similar pressures in a high pressure gas injection system.

The proponents of high pressure gas injection claim they will achieve higher horsepower output without knock from their engines. This may turn out to be the case. But it will be at the expense of horsepower lost on boosting the gas to intended delivery pressures. In addition, high pressure systems will tend to have higher peak combustion temperatures. This may worsen emissions performance in the most critical area, that of NOx production.

ECI was present at a recent (January 1993) Society of Automotive Engineers Topical Technical Workshop, Liquefied Natural Gas as a Transportation Fuel: a Progress Update (Houston). There, Detroit Diesel Corporation (DDC) discussed a high-pressure, dual fuel model of their 6V92 series engine, a high–speed, high horsepower two cycle. DDC was able to obtain good NOx emissions, in comparison to standard diesels of this class. Whether high-pressure technology applied to the larger medium–speed diesels of the EMD 645 class will produce similar reductions remains to be seen. One thing is certain: the ECI low-pressure conversion reduces NOx production in the EMD 645 over 60% from baseline diesel operation, and is available now.

Economics of Dual Fuel

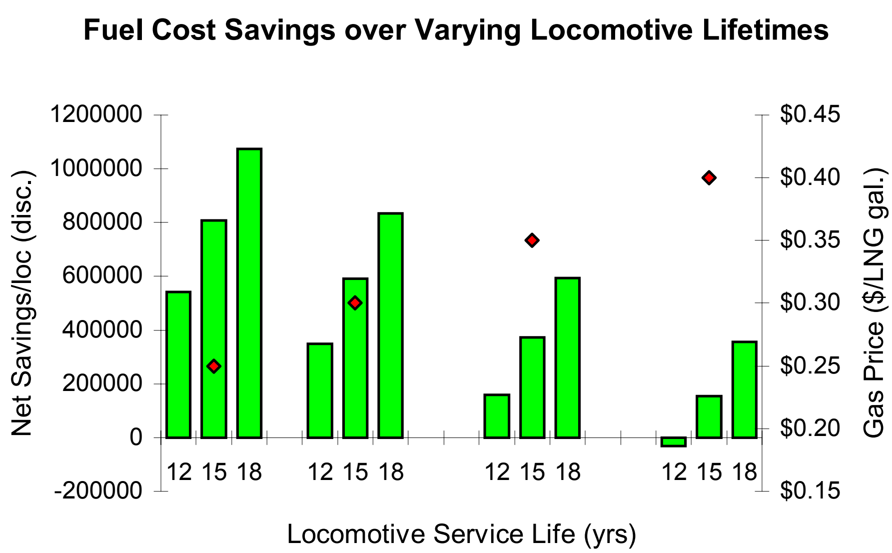
Perhaps the greatest motivation behind a conversion to natural gas is the promise of smaller fuel bills. Prices of $2.00/MMBtu for pipeline gas or $3.00/MMBtu for LNG look very inviting to someone paying $4.35/MMBtu ($.60/gallon) for diesel fuel. Up until now, however, gas engines have been able to produce only 60% to 75% of horsepower of diesels of comparable size, displacement, and efficiency. Converting to gas had meant investing in more power or reducing power availability, neither a viable economic option.

The ECI conversion kit has changed the ground rules. It is the only high horsepower, medium speed conversion available that will obtain full diesel–rated power from the engines it converts. With a full horsepower gas engine a reality, it becomes more than an academic exercise to consider what returns, in the form of fuel savings, are possible through natural gas conversion.

ECI has examined two scenarios in detail: a locomotive conversion, and a stationary power generator conversion. On the basis of fuel cost savings alone, a conversion can pay for itself in five years or less. The following discussion summarizes ECI's study; a copy of the full report [6] can be obtained from ECI upon request.

Locomotive Application

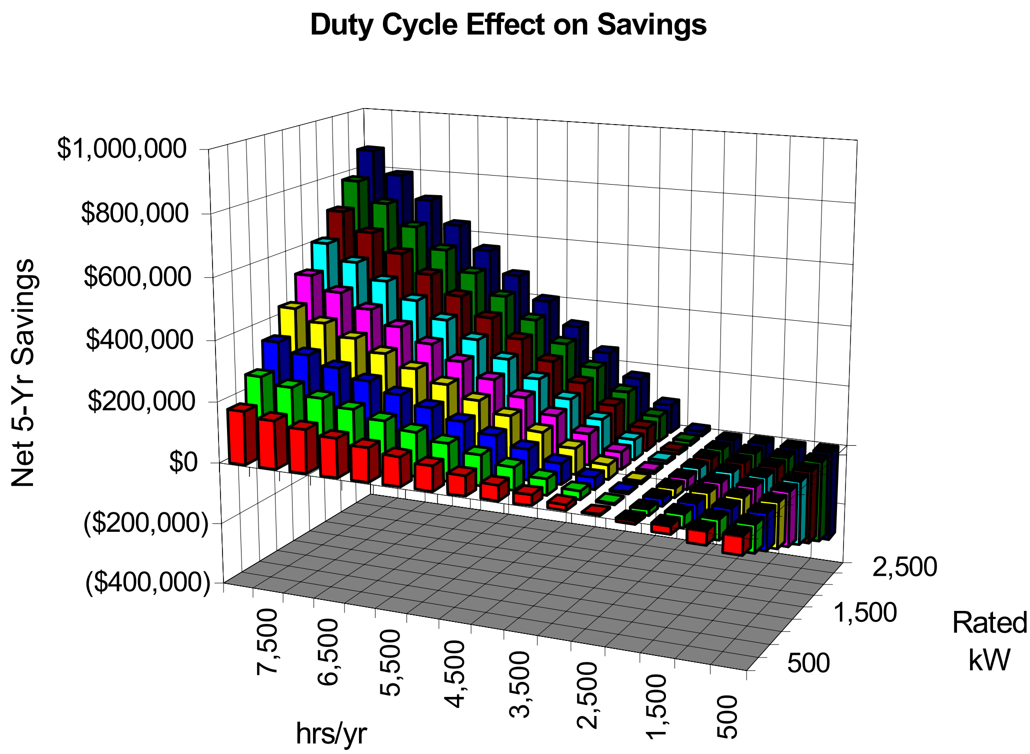
Consider a typical coal haul locomotive, the General Motors model SD–40. It is outfitted with an EMD model 645 E3B engine, one the ECI kit supports. Pulling trains of 15,000 tons of coal 1800 miles every three days, these locomotives burn between 350,000 and 400,000 gallons of diesel every year. A conversion to natural gas involves the conversion kit cost, plus the cost of an LNG tender car for every two converted locomotives. Taking into consideration this cost, the price of diesel ($.60/gallon), and a range of reasonable natural gas prices, ECI has estimated rates of return on investment (ROI) in terms of fuel cost savings.



At a natural gas price of $.30/LNG gallon, a current industry rule of thumb, one can obtain an ROI of about 15%. Better prices are possible, if one can guarantee to the gas supplier a given level of consumption, and negotiate accordingly.* According to a rail industry source, converting 125 locomotives in a unit–train fleet would require an LNG facility capable of liquefying 20 million standard cubic feet (20 MMcf) of gas per day; that is a production capacity of 240,000 gallons of LNG. It would be profitable for a supplier to build a 20 MMcf/day plant, according to the same source, if its gas could be sold at $.23/LNG gallon. This price will generate fuel cost savings that make up the conversion/tender car outlay in less than five years. At $.30/LNG gallon, net savings over the 12–year life of the locomotive will amount to about $300,000 per locomotive. At $.23/gallon, that figure climbs to $450,000.

Power Generation Application

The stationary power application enjoys its greatest gas price advantage when the generator is situated on or near a gas pipeline. Without the added service costs present in a mobile LNG application for liquefaction, storage and fueling facilities, pipeline gas can be 40% cheaper than LNG. In this range of gas prices, full time generator applications break even in about two years, regardless of the size of the generator.



Often, potential users will inquire about converting standby generator sets. This is an excellent option, if the user's main priority is air quality. Converted engines that operate 2000 hours/year or less, however, will not recover conversion investment within five years, at least on the basis of fuel cost savings alone. On the other hand, a generator that provides peak power or better (4000+ hours/year) will pay for itself in five years, even at gas prices as high as $3.25/MMBtu. The best route to large fuel savings is to insure that any converted generator runs as often as possible.

The ideal power generation scenario would involve converting a full-time diesel generator with a capacity of 2 MW or more, on a site with direct access to a gas pipeline. This would ensure maximum diesel replacement and minimum gas cost. Even if gas needed to be transported from off sight, incurring service charges, a large enough generator operating year round could still provide excellent returns. The largest generators that ECI converts will manifest savings approaching $900,000 after five years, if they run 8000 hours/year.

Other Economic Benefits

Fuel savings do not tell the whole story. Use of natural gas as the primary fuel yields cleaner lube oil and reduced engine wear. This will imply direct cost savings in increased time between overhauls. It also extends the economic life of the engine, which means a greater overall return per locomotive. In the case of $.25/LNG gallon gas, a locomotive with a 15 year life span nets upwards of $800,000 in real dollars of savings, at a 7.5% discount rate.

Other avenues of return are opening up. Active railroad lobbies are pursuing tax credits for locomotives similar to the credit now offered for road truck conversions; the railroads hope to obtain a credit of $250,000 per locomotive. This alone could account for over 50% of the conversion/tender car cost. Environmental economics also plays an important role; see Environmental Enhancement.

Finally, industrial consumers of electricity could benefit greatly from on–site power generation. At $2.00/MMBtu pipeline gas, a generator equipped with the ECI system could make power for 2¢/kW–hr, inclusive of conversion costs. This is significantly cheaper than even the cheapest local utility rate.

Environmental Enhancement

Air quality improvement is a principal motivator in the decision for natural gas conversion. In some locations, known as non-attainment regions, it overshadows the economic considerations for natural gas. In Southern California, proving ground for all new air quality enhancement strategies, legislation has been brought to bear on high–horsepower diesel emissions. There, diesel locomotives alone account for 4.7% of NOx emissions from mobile sources [1]. That comes to roughly 99 tons of NOx yearly/locomotive in the South Coast Basin. Diesels also emit significant levels of particulate matter, non-methane hydrocarbons, carbon monoxides, and oxides of sulfur.

ECI Conversion Emissions Performance

The ECI conversion delivers improvement on all these points. The table summarizes results from emissions testing performed in August 1991 by the Southwest Research Institute. Levels of HC, CO, particulate, and NOx emissions from an ECI converted locomotive were monitored, as the locomotive engine underwent its stationary 500–hour durability test. Both dual–fuel and baseline diesel emissions were sampled at each throttle notch, or preset level of speed and load, as indicated on the table.

ECI 645 Conversion Emissions

Speed (rpm)/ HP	Mode	HC	HC (non CH4)	CO	NOx	Particulate
900/3062	D/F	7.7	0.8	10.0	4.2	0.2
900/3082	D	0.6	0.6	0.2	8.4	0.4
835/2633	D/F	7.0	0.2	7.9	4.2	0.2
835/2718	D	0.2	0.2	0.3	8.5	0.4
750/2072	D/F	5.4	0.3	6.3	4.3	0.2
Standard E3B 645 Emissions						
900		0.3		0.7	11.4	0.27
800		0.2		0.4	10.3	0.3
750		0.2		0.5	10.0	0.3

Emissions levels given in grams/hp-hr; D:diesel mode, D/F: dual fuel mode.
HC: hydrocarbons, CO: carbon monoxide, NOx: oxides of nitrogen.
Source: Southwest Research Institute

Consider notch 8 (full speed and load) emissions in particular. Particulate (soot and smoke) emissions are improved under gas operation. Hydrocarbon emissions consist primarily of methane, which is currently unregulated. Unlike other hydrocarbons, methane is relatively non-reactive and does not promote formation of ozone. Though it is classified as a greenhouse gas, the amount of naturally occurring methane in the atmosphere is much greater than the amount that might be released in the process of fueling internal combustion engines. Finally, note that the CO level, while relatively high, still falls within regulatory guidelines for these engines. CO in excess of future limits can be catalyzed out with standard emissions control technology.

The NOx Factor

NOx reductions are the most significant benefit. In dual fuel mode, the ECI conversion kit emits NOx at a rate 60% less than the unmodified diesel, 4.0 g/hp–hr. Using the figure above, that represents a decrease of 60 tons of NOx yearly/locomotive in Southern California. In a stationary application, running at high loads over longer periods, this yearly savings would be greater. Note too that even in full diesel mode, the ECI converted engine emits less NOx than the standard 645.

This improved emissions profile has the potential not only to ensure regulatory compliance and enhance company image, but also to increase the bottom line. According to a recent report commissioned by the Gas Research Institute, current NOx reduction technologies incur a cost of between $2,000 and $20,000 per ton of NOx [9]. These are technologies, such as converting to clean diesel or catalytic exhaust scrubbing, to which accrues none of the economic benefits of natural gas. Using the high end of these figures, the report estimates that locomotive conversion to natural gas could generate NOx emissions credits with a market value of over $100,000 per locomotive. This alone could offset one–third of the cost of conversion.

Low Pressure NOx Advantage

When considering the environmental benefits of natural gas, one must keep in mind that natural gas is not automatically a clean fuel in the internal combustion engine. Emissions levels depend greatly upon the behavior of the fuel combustion in the cylinder. NOx is formed of two elements found in the combustion air, and neither in methane nor diesel fuel in any quantity. NOx is formed in greater quantity when peak combustion temperatures are hotter. Systems based on high pressure gas injection will experience hotter combustion than a low pressure system such as ECI's. High pressure systems might therefore be expected to produce higher levels of NOx. Some preliminary testing on high pressure systems has shown this to be the case. In the cases where high pressure systems have shown good NOx results, sophisticated air/fuel ratio control has been employed. The low pressure technology of the ECI system obtains good emissions without added complexity.

Safety

Any discussion of the safety of natural gas as a fuel must be had with the proper perspective. Natural gas is a fuel; as such, it can be expected to burn. The use and handling of any fuel involves risk. Natural gas, when handled properly, poses no greater risk than more familiar petroleum fuels.

If people are mistrustful of gas, it is only because they are unfamiliar with it. Millions of Americans drive to work every day, each individual sitting atop two million BTUs of gasoline. They pump this volatile, potentially explosive fuel by themselves without special training; they park it near their homes and families, often in an enclosed, poorly ventilated place. Gasoline and other petroleum fuels and their vapors are poisonous. Large scale spills of petroleum fuel can wreak havoc on wildlife, contaminate water supplies, and sterilize cropland.

Yet petroleum fuels are completely accepted, and their safety is taken for granted. This is as it should be. A common sense has developed around the use of petroleum fuels. Equipment that supplies and burns petroleum fuels is designed with safety and reliability in mind.

Natural gas handling and engine design is also governed by common sense. The design of natural gas vehicles certainly gives even greater attention to safety, because of public wariness toward gas. As an illustration, consider that over a ten year period, 1360 CNG vehicle collisions occurred in automotive fleet operations in this country. None of these resulted in either fire or explosion [10]. As the public learns more about the properties of gas, it will find itself more at ease with the prospect of natural gas vehicles of all sizes.

Several areas of potential concern are discussed below. Most of the comments address natural gas in general. Liquid natural gas, as a cryogenic (super cold) substance, has certain properties that require separate discussion.

Flammability

Methane is a very stable fuel. Its flammability limits (least and greatest volume percentage of gas in air that will result in an ignitable mixture) are quite narrow-between 5% and 15%. At 1350°F, its hot surface ignition temperature is 600° higher than that of gasoline: a striking match will ignite it, but the coal of a cigarette will not [11].

Because of the narrow flammability range, unconfined clouds of methane generated by a large outdoor leak or LNG spill present little danger of explosion. Methane is lighter than air, and quickly dilutes beyond the lean flammability limit and floats away. If ignition should occur, burning will take place only along the air/gas interface in which flammability requirements are met. In an unconfined space, pressure will not build, and flame speed will be relatively slow, about 1 foot/second. A flash or detonation (flame speeds greater than the speed of sound in air, 1100 feet/second) is very unlikely.

Natural gas, unlike petroleum fuels, burns with very little soot formation. Visibility of firefighting personnel is not impaired. Low soot formation also results in less radiant heat from a methane cloud fire, in comparison with a petroleum fire. Demonstrations of such fires can be observed on the Burlington Northern video, Cryogenic Methane Fundamentals, available from ECI [2].

Natural gas presents the greatest safety risk when leaks or LNG spills occur in confined areas. Confinement of gas allows large, local flammable or detonable vapor clouds to form, and increases possibility of ignition. Once ignited, pressure will build in an enclosed area, speeding up flame travel to potentially explosive levels. This risk is eliminated by providing good ventilation in structures that house natural gas vehicles or storage tanks. Ventilation allows the naturally rising gas to escape and dilute beyond flammability. Providing ventilation is simply part of the common sense of natural gas fuel handling.

Toxicity

Natural gas is nontoxic; it will not cause immediate physical damage or death upon inhalation. It is classified as a simple asphixiant; it is no replacement for oxygen. A gas/air mixture containing greater than 40% gas by volume will not support life [8]. Therefore, personnel responding to a leak in an enclosed area require self-contained breathing apparatus and an electronic methane level detector. In the event of a large indoor leak, evacuation of the facility is also required on this basis.

The non–toxicity of gas is an advantage in the event of an outdoor LNG spill. The liquid will boil away, leaving behind no poisonous hazard to humans or wildlife.

Cryogenic Factors

Liquid natural gas, at –260° F, presents its own unique handling challenges. From the flammability and ignition standpoint, however, it offers some distinct safety advantages over petroleum fuels.

Cryogenic "burns" are a potential risk in the handling of LNG, from contact with either the liquid itself, or the cold boil–off vapors. Fueling personnel need to be familiar with the basics of cryogenic liquids: "It's really cold; don't touch it," is the gist of this training. LNG fueling is made somewhat complicated by cryogenic considerations. Airtight seals between fuel tanks and fueling lines are made, to prevent the escape of super cooled gas and liquid. The fuel lines incorporate one line for LNG delivery, and a second line to vent vapor or return it back to the storage unit. Once personnel are adequately trained, there is generally very little risk of cryogenic injury. The BNRR locomotive test has continued for four years with no cryogenic injuries sustained.

Small spills of LNG present little fire risk. Evaporating LNG warms and floats away, in contrast to petroleum fuel vapors, which linger near the ground. LNG does not adhere to surfaces as petroleum fuels do. Therefore, a fire involving an LNG spill does not mean a fire on everything the LNG contacts. The low temperature of LNG does its part to retard ignition of the gas. In the film referred to above, this property is demonstrated by pouring LNG onto a hot frying pan. No flash fire ensued [2].

Large LNG spills involve a greater risk of fire. Vapor boiling off a large pool of LNG will tend to be cooled by the liquid, remaining denser than air. This will cause the vapor to hover around the spill site, until it warms and regains its buoyancy. As more vapor comes off the spill, a flammable vapor/air plume can form that can drift away from the spill site. In an open space, the combustion of this plume will have characteristics already described: low soot, not explosive, less radiant heat present than in a comparable petroleum fire. Spills that occur in enclosed spaces must be immediately well ventilated, for reasons outlined above. Spills of LNG into drainage systems can be particularly hazardous, as flammable natural gas mixtures can then build up in culverts and pipes. In any spill, possible sources of ignition should be removed from the site.

Cold LNG vapors, especially from outdoor spills, is difficult to ignite. One must keep in mind that a spill does not automatically mean a fire. If ignition sources are kept away, and ventilation is made adequate, the methane will have an opportunity to dilute and float away without incident.

Current storage technology of LNG involves double walled, vacuum insulated tanks of 8% nickel stainless steel [10]. This material retains its ductility at cryogenic temperatures; it will not become brittle and crack like ordinary carbon steel. The double walled construction improves a tanks resistance to damage, especially important in the event of a railroad tender car derailment. The BN video [2] includes a dramatic demonstration of double walled tank integrity. A tank of LNG was fired upon by a high-powered rifle with incendiary bullets. The experimenters required three tanks before igniting one. In that case, only a small fire and no explosion occurred.

ECI Kit Gas Safety Features

The ECI conversion kit uses the best available methods and materials to make gastight connections between all gas hoses and piping. Should a leak occur, integrated leak detection electronics alert the central electronic control unit, which instantly and automatically shuts off the gas at the source. It then switches the engine transparently to diesel operation, so that the system experiences no downtime. In a railroad application, the ECI system is in constant, seamless communication with the LNG tender car, isolating the engine from the gas should the tender experience any difficulties.

Energy Conversions, Inc.

Energy Conversions, Inc. is a Washington State corporation. It was formed in 1984 for the express purpose of managing the development of natural gas retrofit conversions for medium and high speed diesel engines. It supplied the conversion technology for the first full horsepower natural gas locomotives in the US, the Burlington Northern's BN 7890 and BN 7149. ECI personnel consists of experts in many fields, including mechanical engineering, computer science, mathematics, marketing, finance and graphic design.

Conversion Kit Basics

The ECI dual fuel conversion system is designed for use in the General Motors Electro–Motive Division (EMD) model 645 and 710 two-cycle diesel engine. These engines furnish power for many high output applications.

The kit allows the converted engine to operate in a dual–fuel mode (92% natural gas, 8% diesel) or 100% diesel. In either case, the engine provides full diesel–rated horsepower. The conversion involves replacement of standard pistons and cylinder heads, together with the addition of gas transport and injection equipment, pilot fuel control apparatus, and electronic control processors and sensors. Stock diesel injectors are retained, as is the existing engine's governor in most cases. The following describes certain key components of the kit in more detail. Spark ignition , 100% gas is also available.

Kit Components

Pistons and Cylinder Heads: The pistons and cylinder head modifications ensure proper gas/air mixing, and along with the adjusted compression ratio insure good combustion. The cylinder head is designed to accept the standard diesel injector along with the ECI gas inlet valve.

Gas Inlet Valve (US Patent Nos. 5,136,986; 4,865,001): The gas inlet valve provides a reliable method of metering and injecting gas into the cylinders. It is a hydraulic device, electro-hydraulically actuated, whose timing can be precisely controlled by electronic means. A principal advantage of the GIV is that it does not need to be activated during full diesel operation, as a mechanical injector would have to be. This preserves the part and increases its life and reliability.

Electronic Control Unit (US Patent Nos. 5,136,986; 4,641,625): The patent for the electronic control method was purchased by the ECI partnership in 1984. Using copyrighted software developed in-house, the ECU controls critical engine functions such as engine speed and, in locomotive applications, generator excitation, while monitoring engine temperatures and pressures for safety and data logging purposes. The ECU incorporates constant electronic and mechanical equipment checking into a comprehensive safety system, designed to switch the engine immediately to full diesel operation in the event of an irregularity, without service interruption.

Pilot Fuel Control: To make the retrofit feasible, it was important to be able to run equally well on full diesel or on natural gas at operator discretion, while retaining as many native parts as possible. The pilot fuel control system employs an electronically controlled device that attaches to the governor/fuel rack linkage. During gas operation, the device overrides the diesel governor, and allows a small amount of diesel to be injected into the cylinder as a pilot fuel. On diesel, the device relinquishes control to the governor, which then allows a completely conventional diesel operation.

Low Emission Idle (US Patent No. 5,195,485): At very low engine loads, the ECI system operates the engine on full diesel only. The LEI system allows for improved pollutant emissions at low engine speeds while in full diesel operation. The LEI electronic controller and mechanical linkage cause the engine to operate alternate banks of cylinders: e.g., for 2 minutes the right half of the engine is powered, then for 2 minutes the left half of the engine is powered. Even wear and load is maintained, but fuel consumption is reduced by 15%, reducing emissions during idle.

Installation

ECI has designed its conversion system to be installed efficiently, using straightforward, general shop techniques. Much of the more tedious or error prone detail work has been integrated into the kit manufacture; thus, parts are shipped with special bends or welds already performed, wiring harnesses already loaded with wire and labeled, etc. Still, the overall time of installation will vary with the application. Certain applications, because of more demanding output specifications, will make certain subsystems (e.g., air-cooling) more extensive or complicated. ECI estimates of installation times range from 200 man-hours over standard rebuild time in the case of a locomotive conversion, to about 100 man-hours over rebuild time for a stationary power generator.

Applications

The ECI conversion, as it currently exists, converts the General Motors Electro–Motive Division (EMD) model 645 medium–speed, high–horsepower engine. This two–cycle diesel is extremely versatile, providing power in applications as varied as rail locomotives, stationary electrical generators, industrial installations such as ore crushing or irrigation, and marine propulsion. Each of these uses involves slight differences in engine configuration, since each needs to optimize different performance characteristics of the basic engine.

The conversion kit has been engineered to accommodate the requirements of these various applications. Its flexible modular design enables ECI to tailor a conversion system to the needs of the end user, costing no more than is necessary to provide adequate engine performance in the target application.

A separate kit designed for retrofit application to the Caterpillar 399, 379, and 398 engines is also available. for more information on this system, please visit our page on the Caterpillar system

Application Considerations Affecting Conversion

One can broadly define a gas application of the EMD 645 or similar engine using the following questions:

Is the application mobile or stationary?

Is full diesel rated horsepower output required?

What is the engine aspiration assist: turbocharger, or Roots blower?

What is the gas quality (i.e., methane content over heavy gas content) and availability of natural gas to the application?

Which of pipeline gas, CNG, or LNG is most appropriate to the application and most readily available?

What are the expected ambient conditions (temperature, altitude) in which the engine will operate?

A more detailed questionnaire is available at http://www.energyconversions.com/contact.htm. This covers most of the information ECI needs to know from the customer in order to better assess the necessary requirements for a particular application.

The answers to these questions will determine the final configuration of the conversion system. In general, a mobile application with constantly varying speed or load will require more sophisticated engine control. If the engine spends much time idling, the system will include the Low Emission Idle module. Horsepower required, available gas quality, and ambient conditions will affect the sophistication and extent of charge air cooling. The presence of a turbocharger will require the inclusion of exhaust wastegate apparatus with the conversion kit.

Therefore, there may be quite a difference between a quote for a locomotive conversion, which requires speed and load control and extensive auxiliary cooling for all weather, full output operation, and a 1000–kW generator set that operates at a fixed optimum speed in a moderate ambient temperature. ECI, in close consultation with the user, will develop the configuration most appropriate to the use.

ECI Technical Services

ECI offers over 15 years experience in large engine natural gas and LNG conversions to customers with serious interest in this fuel of the future.

Product Support

In addition to the supplied installation manual, reference manual, and video, ECI offers technical support in person and over the phone. ECI provides service support as part of the conversion system purchase. Arrangements can be made to schedule training sessions for the users personnel, at either the users or ECI facilities.

Technical Consulting

While ECI is not a supplier of natural gas or cryogenic hardware, it has developed extensive experience in these areas during its ten year research and development effort. ECI is willing to share this experience with the prospective customer. The customer seeking information on the economics of gas conversion, the storage and vaporization of LNG, emissions characteristics of gas and diesel engines, or a host of other topics can benefit from ECI's broad expertise and extensive railroad, diesel, and gas industry contacts.

R&D Contracting

ECI has performed research and development work in many technical areas. In addition to EMD 645 conversion kit development, ECI has undertaken and completed the following projects:

- Natural gas quality testing, determining the effect of methane concentration on engine power output limits (for Air Products & Chemicals;, Allentown, PA, and Burlington Northern Railroad Co., May/June 1993 [4]);
- Development of a graphically oriented PC interface to an experimental locomotive ranging and monitoring system (for Burlington Northern Railroad Co., 1992–1993);
- A detailed study, quantifying the economic benefits of fuel cost savings of natural gas, in the cases of locomotive conversion and power generator conversion (with Dr. John V. Krutilla, Resources for the Future, ECI technical report, June 1993 [6]);
- Development of a Cat 399 series product for Nabors Offshore was completed in 1999.

Some projects in progress include:

- Testing of a low-pressure natural gas conversion for the EMD model 710 engine
- Development of a spark ignited version of our conversion system to allow an EMD to run on dedicated (100%) natural gas. Spark ignited version installed for Napa Valley Wine Train.
- Micro pilot injection system to test the effects of lower pilot fuel on performance and emissions.
- Combustion pressure monitoring system to improve the accuracy and monitoring of the gas combustion event in order to further improve performance.
- Testing of emission reducing diesel piston designs for EMD engines.

As ECI's independent efforts listed above indicate, the customer with R&D interests will find an able collaborator in ECI. Our expertise in the field of alternative fuel engines

References

[1] Booz, Allen & Hamilton, Inc., "Locomotive Emission Study", for California Air Resources Board, 1990.

[2] Burlington Northern Railroad, "Cryogenic Methane Fundamentals", videotape with commentary by Leslie E. Olson, BNRR.

[3] Ditmeyer, Steven R., "A Natural Gas Locomotive Project", Railway Technology International '93.

[4] Gillispie, Mitchel et al, "Natural Gas Fuel Quality Tests", ECI Technical Report for Air Products & Chemicals, Inc. and Burlington Northern Railroad Co., June 1993

[5] Jensen, Paul, "Development of Dual Fuel Locomotive Type Engines", Diesel & Gas Turbine Worldwide, July/August 1992.

[6] Jensen, Mark A., "Fuel Savings Economics of High Horsepower Natural Gas Conversions", ECI Technical Report, June 1993.

[7] Jensen, Mark A., "High Horsepower NGVs? Making Gas Pay for the Long Haul", Natural Gas Fuels, June 1993.

[8] Kidman, R. B. et al, "Safety Assessment of Alternative Locomotive Fuels", Los Alamos National Laboratory for Burlington Northern Railroad, Report #1.12.8/90, September 1990.

[9] Pera, Charlotte J. and C. Moyer, "A Topical Report: LNG as a Fuel for Railroads: An Assessment of Technology Status and Economics", Acurex Environmental Corporation for Gas Research Institute, Report #GRI 93/0132, January 1993.

[10] Powars, Charles et al, "A White Paper: Preliminary Assessment of LNG Vehicle Technology, Economics, and Safety Issues (Revision 1)", Acurex Environmental Corporation for Gas Research Institute, Report #GRI 91/0347, April–August 1991.

[11] RLM Material Safety Data Sheet, Air Products and Chemicals, Inc.

[12] Schultz, Jeffrey T., "Diesel/Liquid Natural Gas Locomotives: a Dual–Fuel Solution", Diesel Era, November/December 1992.

[13] Stoddard, Brooke, "You Can Take It to the Bank", American Gas, July 1992.

Warranty

Energy Conversions Inc. (hereinafter referred to as ECI) warrants each of its Conversion Systems (hereinafter referred to as ITEM or ITEMS) for the period of one year from the time of startup or 18 months from the time of delivery, whichever comes first, to be free of defects in materials and workmanship and to operate under recommended loads, usage and conditions with competent supervision. This WARRANTY will not cover misuse, negligence, or accidents.

ECI's sole and only obligation, indirect or otherwise, by virtue of this WARRANTY is expressly limited to the replacement or repair, at the option of ECI, of any ITEM returned to ECI's plant in Tacoma, Washington with all transportation charges prepaid, which after inspection by ECI is found to be defective in material or workmanship. Repairs or replacement will be shipped freight collect, F.O.B. ECI's plant in Tacoma, Washington. In no event or circumstance will ECI be obligated to the purchaser or any person for the expense of labor or equipment required to load or unload any ITEM or ITEMS that is covered under this WARRANTY, nor be liable for any transportation charges on warranted ITEMS to or from ECI's plant in Tacoma, Washington. This WARRANTY does not obligate ECI to assume costs of travel time or normal expenses incurred by its service personnel to, from, or while on location in connection with repairs of ITEMS that are covered by this WARRANTY. ECI will not assume any expense of labor, travel expense, lodging or mileage charges to, from, or while on location in connection with replacement or repair of any ITEM that is regarded as accessory equipment, accessory equipment being defined as an assembled product that was purchased new by ECI and sold as a part of this conversion system including but not limited to sensors, actuators, valves or electronic control hardware. The only WARRANTY on these ITEMS is the WARRANTY extended to ECI by the manufacturer of that particular ITEM.

ECI shall in no event be liable for consequential damages or contingent liabilities arising out of the failure of any ITEM or ITEMS to operate properly, or for repairs of replacements made by others without ECI's express authorization in writing. Corrections of defects by repair or replacement by ECI shall constitute the purchaser's sole remedy.

Responsibility for proper installation, including machinery alignment, piping, electrical wiring and testing, rests with the purchaser and/or his installing contractor.

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