High-Horsepower NGVs? Making Gas Pay for the Long Haul

By Mark A. Jensen

When you imagine "natural gas vehicles," what comes to mind? A fleet of private cars, certainly. Maybe a transit bus, or even a semi. But how many of us would think "ship," "mining truck," or "locomotive?" While high-horsepower, heavy-duty engines have long used natural gas for stationary electric-power generation, large-engine transportation applications for the most part have been neglected.

Why should this be? After all, Rudolph Diesel himself experimented with burning gas in his engine as early as 1903. The question, though, is not one of technological possibilities, but economics. Diesel engines provide the power in nearly all earthbound high-horsepower applications. Diesel fuel shared all the former advantages of gasoline: it was abundant, its supplies were stable, and so it was cheap. Much is known about diesel engines; their performance has been optimized over the years, and they can be built relatively inexpensively.

But times are changing. Diesel is no longer the stable, abundant energy source it once was. The big machines are no longer exempt from mandated emissions reduction. A Btu tax looms, which specifically targets petroleum fuel use. Sitting in the shadow of these woes are firms which, in difficult economic times, must make their extensive capital investment in diesel engines, fueling facilities and labor experience produce for just that much longer; sweeping transitions to alternate technologies and brand-new engines are simply not an option. For a company whose existence is based on high-consumption diesel applications, natural gas seems to offer the greatest and most expedient hope for a way out.

However, preserving the value of capital by converting existing engines in itself is not enough. Any conversion effort that hopes to maintain a company's competitiveness, especially in a transportation application where speed and reliability are of the essence, must ensure that it has as much engine coming out as it had going in.

THE ECONOMICS OF HORSEPOWER

It's not as though high-horsepower natural gas engines don't exist, or even that diesel-to-gas conversions don't exist. The problem is known as the "de-rate." Diesel engines have express maximum horsepower ratings given them by their manufacturers. The ratings essentially indicate how hard the operator can safely push the engine. When certain configurations of a given engine are used, or that engine is modified to run on natural gas for example, this maximum power rating often must be revised downward, or derated.

Up to now, this is the difficulty that has faced large-engine conversion to gas. Natural gas, while a great fuel for spark-ignited engines like those in automobiles, is a poor fuel for diesel engines. In diesels, heat for ignition is produced simply by the compression of the fuel in the engine cylinder. If natural gas is used in an unmodified diesel engine, the result is destructive knock. The modifications required to make a diesel suitable for natural gas operation have, up until now, always induced this decrease in maximum output. A derated gas engine will generate only 50-to-75 percent of total diesel power. Manufacturers will sometimes play games: they will convert a high-horsepower diesel engine to gas, give the resulting engine a new model number, call it a "gas engine," and use the lower power-limits as the rated specification for their "new" model. One still must buy more gas engine for a given power requirement than an ordinary diesel engine.

Horsepower equals revenue. Consider a railroad example: long-distance coal-hauling trains. A unit train of coal weighs upward of 15,000 tons. To move it requires between four and six locomotives, each pulling at 3,000 to 4,000 horsepower. Converting the locomotives to natural gas may allow the railroad to save 20 percent on its fuel bill, but with a 25 percent derate, it needs at least one, perhaps two more locomotives to move the same amount of coal. The cost of operating these extra locomotives cancels any savings gained from using natural gas. Since coal moved is money made, and coal moved is limited by the number of available locomotives, revenue potential itself is also lost through reduced locomotive availability.

So technical and consequent capital-utilization difficulties have established barriers to the widespread use of natural gas in high-horsepower mobile applications. Prevailing engineering wisdom had been that no modified diesel engine would ever be able to produce full-diesel horsepower on natural gas. Gas therefore never gained much serious consideration as an alternative fuel for high-consumption transportation uses, either from the big-engine manufacturers or the fuel customers. At least, not until 1983.

A RISK AND A BREAKTHROUGH

In that year, the Burlington Northern Railroad undertook the first large-scale test of natural gas as a fuel for a high-consumption transportation application. Using a vintage 1950s conversion package, the only technology available, the BNRR and its gas company partners converted their Locomotive No. 1961 to run on compressed natural gas. To carry the fuel, they used a full-sized railroad flatcar, modified to accommodate a large array of CNG tanks. The locomotive hauled general freight between Minneapolis and Duluth for two years, with no safety incidents or major malfunctions. The 1961 experienced the expected engine derate, obtaining only about 75 percent of standard diesel horsepower. This initial test, however, served to prove the concept.

Though the technology was not economically viable, this experiment piqued our company's interest. Energy Conversions Inc. (ECI) had been involved as a parts supplier for this conversion, and had previously performed several gas conversions for large power-generation applications. We were convinced that *full* diesel power could be developed by a converted engine, and we set out alone to prove it. If accomplished, it would mean literally a brand-new era in rail power, and high-consumption transportation in general, since natural gas would finally become an *economically* sound option for large-engine use. Burlington Northern agreed to purchase a conversion, if ECI could meet the full-horsepower stipulation.

ECI set its sights on converting an engine model one larger than the one that powered the 1961. This engine, the General Motors Electro-Motive Division model 645, is a widely used, general-purpose diesel found in vehicles as varied as locomotives, ferries and mining trucks. The strategy was to redesign the piston crown and cylinder head to promote optimum combustion of the natural gas/air mixture, design an electronically controlled injector that would admit natural gas into the combustion chamber at precise intervals and amounts, and assemble a flexible computer control capable of accurately adjusting gas flow and timing in response to changing engine parameters. To avoid the knock problem, the converted engine would operate in a dual-fuel scheme, with a reduced compression ratio, so that some diesel would be necessary to initiate fuel combustion. Finally, as an added challenge, the conversion was to provide full power not only on gas, but also on diesel alone.

One by one these challenges were surmounted, and in the spring of 1991, our test engine was running on natural gas with full diesel-rated horsepower. The ECI system, in fact, is still the only large-engine conversion that can make that claim.

COAL TRAINS ON NATURAL GAS

Plans for a new locomotive conversion test followed hard upon this success. Because of the high rate of fuel consumption for these large engines, CNG was ruled out as impractical, either because many flatcars of CNG would be required, or locomotive range would be severely curtailed. Liquefied natural gas would be used instead; being much more energy-dense, LNG contains three times as much energy as CNG at 2,500 psi occupying the same amount of space. A 20,000-gallon LNG "tender car" was designed for use in the new project. By summer, BN Locomotive No. 7890 had been converted to dual-fuel operation using the ECI system.

Following an extensive 500-engine-hour durability test, BN 7890 went into coal-haul service in December of 1991, along the most difficult stretch of BN's coal lines, from Glendive, Mont. to Superior, Wis. It was used as assistive power to aid the 15,000-ton trains over the particularly steep Beaver Hill between Glendive and Dickinson, N.D. The prototype performed extremely well, and provided full horsepower in both gas and diesel modes, as advertised. A second locomotive, BN No. 7149, was converted using an improved version of the system in August 1992. It was also sent to Glendive. The 7890 subsequently underwent a conversion upgrade itself. The two units are now in fulltime coal-haul service, and are part of the standard power rotation at BN's Glendive yard. They have experienced no significant failures due to the conversion system, and are currently working every day.

THE NEW ECONOMICS OF LARGE-ENGINE CONVERSION

Achieving full horsepower on a large-engine conversion changes all the rules. Now the price and stability advantages of gas can be realized, since its use no longer requires that payloads or power availability suffer. In the rail example, diesel and dual-fuel locomotives are now totally interchangeable. The only difference is that one pays perhaps 20 percent less for fuel, a margin that promises to grow ever wider.

In an effort to assess what this means in terms of real figures, we have examined a basic locomotive-conversion scenario. Using savings in fuel cost, how fast can one pay off the cost of conversion, and what would projected savings amount to over the economic life of a locomotive? Suppose that a long-term take-or-pay gas contract provides the equivalent of $.30 per gallon of LNG over 15 years, and that diesel at $.60 per gallon inflates in price at the rate of five percent per year. A locomotive on coal service can burn around 380,000 gallons of diesel a year; suppose with a conversion we can replace 85 percent of that with natural gas. We determine, even accounting for slight efficiency losses, projected Btu taxes, and a 7.5 percent discount (inflation) rate, that fuel-cost savings will compensate for the conversion cost in *less than five years* of operation. At the end of 10 years, fuel-cost savings net of conversion cost will amount to *$375,000 per locomotive.* We expect gas operation to lengthen the life of the engine. If we assume, then, an economic life of 15 years for the converted locomotive, savings at the end of that time will have accrued to $775,000.

We can be even more optimistic. Industry sources say LNG can be produced and sold on a long-term contract basis for as little as $.23 per gallon, assuming the liquefaction and storage facility produces enough fuel for 125 locomotives. In this case, all other factors remaining the same, payback time decreases to 3.5 years. In 10 years, fuel savings leaves $615,000, inflation-adjusted, in one's pocket. After 15 years, real-dollar savings jumps to *$1.08 million per converted locomotive.*

Capital costs are accounted for implicitly in this analysis. Cost of conversion and fuel storage, as noted above, are already subtracted from the present values given. The LNG price reflects gas feedstock costs plus liquefaction and infrastructure development costs distributed over fuel used. According to a recent GRI-commissioned report on LNG fuel use for railroads which attempts to determine the impact of conversion, storage and infrastructure costs on a cents-per-LNG-gallon basis, $.30 per gallon is a legitimate all-inclusive figure. We have reason to assume even more optimistic figures for LNG production than those provided in this report, which lead to a price of $.23 per gallon. Either way, we feel these numbers offer a realistic idea of the benefits that natural gas conversion can have within the heavy transportation sector, now that the horsepower barrier has been broken.

As you read this, the operational fruit of a decade of R&D is running on natural gas, pulling 15,000 tons of coal in revenue service. We believe there is every reason to be encouraged about the future of high-horsepower NGVs. The large-engine manufacturers certainly are; General Motors, General Electric and Caterpillar have all thrown their hats in the ring. However, we feel, despite their projections, that they are two-to-three years away from full-horsepower retrofit conversions.

As the initial efforts continue, more information will be generated which illuminates the benefits of natural gas in large engines. We believe, for instance, that gas operation offers the promise of reduced engine repairs, less-frequent overhaul requirements and longer engine life. Whatever the future holds, the present successful developments in conversion technology confirm the status of natural gas as a legitimate fuel alternative for large-engine transportation uses.

Editor's Note: Mark A. Jensen is coordinator of printed communication and an inhouse technical consultant for Energy Conversions, Inc., a Tacoma, Wash.-based firm committed to the research and development of large-engine natural gas conversion. He holds a B.S. in mathematics from Washington State University and an M.Sc. in the Mathematics of Nonlinear Models from Heriot-Watt University, Edinburgh, Scotland.

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