DUAL-FUEL CONVERSION

Diesel Engine Natural Gas Conversion Locomotive Retrofit

engenious™ engineering, llc.

Burlington Northern 7149, one of two SD40-2 locomotives converted by Engenious Engineering.

The First Long-Haul Locomotive Full Horsepower Rated Dual-Fuel LNG Conversion

LOCATION

Tacoma, WA

POWER

Two EMD 16-645 E3B

ENGINE TEST CELL

One EMD 8-645 E3B

OBJECTIVES

Workable conversion to liquid natural gas over long distance while retaining 100% diesel function.

SOLUTION

Dual-fuel retrofit, including custom electronic control and bank idling systems.

RESULTS

100% Full Power in Both Diesel and LNG Dual-Fuel Modes

90%+ Natural Gas Substitution

68.4% Reduction in NO_x

27.7% Reduction in Particulate Matter

No Thermal Efficiency Loss

Extended Long-Haul Train Operation

Customer Requirements

Burlington Northern Railroad (BN) uses diesel-fueled locomotives to haul freight across the Pacific Northwest, Central, and Midwest regions of the United States. BN had previously converted an EMD locomotive diesel engine to operate with compressed natural gas (CNG) to reduce diesel consumption and realize fuel cost savings. While achieving 70% diesel substitution, this early conversion derated the engine horsepower by around 25% to avoid engine damaging detonation, caused by the use of natural gas on high compression engines.

The early engine conversion proved acceptable at the time for BN, but continued significant increases in diesel fuel prices turned BN's interest toward maximizing substitution and achieving full-rated horsepower in dual-fuel and diesel mode. To extend haul distances, liquid natural gas (LNG) was chosen due to LNG's increased energy density. The locomotive selected was equipped with an EMD 645 turbocharged engine, also commonly used in marine and power generation applications.

Burlington Northern Railroad required this conversion to:

- Ensure safe operation of natural gas on the locomotive and engine.
- Achieve greater than 85% diesel substitution.
- Retain at least 90% of diesel-rated horsepower in dual-fuel natural gas mode.
- Retain full horsepower diesel only mode.
- Demonstrate durability to withstand long-haul locomotive operating conditions.
- Retain at least 90% of the existing thermal efficiency.
- Retain existing NO_x and particulate matter (PM) emissions without aftertreatment.
- Operate using dry LNG.
- Integrate the dual-fuel control system with new LNG fuel tender.

Solution

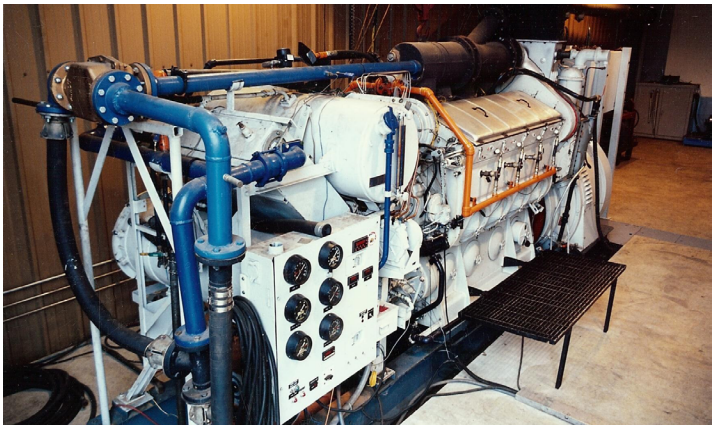
A conversion performed by Energy Conversions, Inc. (ECI)—now Engenious Engineering, LLC. (E^2)—employed an advanced control system and redesigned engine components, eliminating the need to derate engine horsepower while achieving lower exhaust emissions.

A new digital engine control unit (ECU) was designed and installed on the engine. Additional sensors were installed to verify the safe enabling of dual-fuel mode. These sensors also allow the ECU precise control of injection timing with the use of solenoid operated valves. These valves inject natural gas directly into the combustion chambers while controlling the release of diesel pilot fuel.

To optimize combustion performance in dual-fuel mode, newly designed cylinder heads, pistons, and turbocharger wastegate were manufactured, dynamometer tested, and

installed. The cylinder heads allow the injection of pressurized natural gas into the combustion chambers after the closure of intake ports and exhaust valves. Redesigned pistons provide improved gas/air fuel mixing and knock avoidance. A turbocharger wastegate controls compressed air intake in dual-fuel mode during higher horsepower operation, increasing fuel efficiency.

Additional aftercooler radiators were installed to provide greater charge cooling and fuel efficiency, resulting in lower emissions during full power and warm air intake during low load idling.



Top: *Converted EMD 8-645 E3B test cell at E² facility in Tacoma, WA.* ***Below:*** *Burlington Northern Railroad logo.* ***Bottom:*** *Converted SD40-2 locomotive BN 7890 with LNG fuel tender, hauling coal.*

"The internal components of the [Engenious Engineering] conversion package are ingenious."
– Jeffrey T. Schultz, *Diesel Era*

As locomotives spend a majority of their operation idling, a Low Emissions Idle (LEI) bank idling system was designed. It deactivates half of the running cylinders during idle conditions. This resulted in the active cylinders running more efficiently and reduced visible smoke at idle. To ensure the cylinder duty cycle is distributed evenly, the LEI cycles to the other cylinder bank after a preset period of time.

Evaluation of the system was performed by Southwest Research Institute to examine factors, such as thermal efficiency and exhaust emission levels.

Results

After testing at the E² Tacoma facility's dynamometer, the engine was found to successfully produce 100% full-rated power in the new dual-fuel mode. 100% diesel operation was also maintained, with comparable thermal efficiency to an unmodified EMD 645.

After approval by the Federal Railroad Authority (FRA), this conversion was put into coal haul service from Glendive, MT to Superior, WI late 1991. A second, improved conversion was purchased by BN and put into service the following year between Glendive and Dickinson, ND, with the initial conversion undergoing an upgrade following shortly after. The promised full-rated performance of the conversion in dual-fuel and diesel mode was maintained under in-use conditions.

Nitrogen oxides and particulate emissions were significantly reduced after conversion. Compared to an unmodified EMD 645, NO_x emissions fell from 11.4 to 3.6 g/hp-hr, while PM fell from .27 to .195 g/hp-hr, amounting to reductions of 68.4% and 27.7%.

During evaluation, E² found three additional points of savings. First, due to lower CO_2 emissions, it is expected the converted engine will have cleaner lube oil and reduced engine wear. This will mean longer periods of time between maintenance and longer overall life on the engine before remanufacturing or overhauling is necessary. Second, as energy density is not as crucial for stationary power generation, cheaper natural gas options become viable, making return on investment even faster. Last, many natural gas providers provide fuel at even lower interruptible rates for making the switch. This can make for even lower fuel costs than industry prices might suggest.

Engenious Engineering, LLC continues its commitment to the improvement and development of innovative diesel engine conversions to natural gas, renewable natural gas, and other alternative fuels.

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Engenious™ Engineering, LLC is the recognized global leader in dual-fuel conversions and alternative fuel retrofitting systems.

Engenious™ Engineering, LLC is a subsidiary of Peaker Services, Inc.

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