Executive Summary

Paper Title
Case Study: Highway 401 Clean Air Corridor HPDI Demonstration Project

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The objective of the 401 Clean Air Corridor Demonstration Project is to demonstrate the technical and economic feasibility of operating heavy-duty (Class 8) trucks in a line-haul application using liquefied natural gas as the primary fuel. The 401 project will showcase the High Pressure Direct Injection (HPDI) technology operating at equivalent to diesel fuel efficiency, with all the benefits of a natural gas engine including fuel price, and NOx and Particulate Matter emissions reduction. The project involves five new trucks equipped with HPDI fuel systems running for a period of one year between Toronto and Windsor using liquefied natural gas as the primary fuel.

This demonstration is designed to build market awareness of the advantages of LNG in transportation in Canada, specifically in the Class 8 heavy duty market. In addition, the demonstration is expected to show that the Westport HPDI technology provides sufficient horsepower, torque, and engine efficiency to service the Class 8 sector. After six months of operation, the HPDI equipped trucks have demonstrated fuel efficiency on par with diesel equivalent engines in similar applications, engine reliability at expected levels and excellent driver satisfaction at it relates to engine power and torque.

Case Study: Highway 401 Clean Air Corridor HPDI Demonstration Project

Background

Heavy-duty trucks consume large amounts of diesel fuel and are therefore major contributors of criteria air contaminants (CACs) and greenhouse gases. The use of liquefied natural gas (LNG) will result in significant reductions of nitrogen oxides (NOx) and particulate matter (PM) by 40 and 60% respectively and well-to-wheels greenhouse gas (GHG) emissions reductions of 13 per cent.

High Pressure Direct Injection (HPDI) technology relies on late-cycle high-pressure injection of a gaseous fuel, such as natural gas, into a diesel engine combustion chamber in exactly the same fashion as diesel fuel. Natural gas is injected at the end of the compression stroke; just like diesel fuel is injected at the end of the compression stroke in a diesel engine. Ignition is provided by pilot diesel fuel. This principle of operation is the basis for the key characteristics of the technology. With late injection, the HPDI technology approaches the diesel cycle and diesel engines operating characteristics are fully retained. This characteristic allows HPDI technology to take full advantage of advancements in diesel engine technology. HPDI does not require a different engine to be assembled. It shares the majority of the same components. The turbo charging strategy remains the same, although engine optimization may require a slightly different match. Westport HPDI engines are dedicated natural gas engines. At all conditions, natural gas is the predominant fuel, on average providing approximately 95% of the energy release.

High Pressure Direct Injection (HPDI) technology is ideally suited to applications such as line-haul trucking where good drivability characteristics are required, fuel costs are high and emissions are a concern. The use of HPDI will mitigate harmful emissions from truck engines that would otherwise burn diesel fuel. The emissions characteristics of HPDI are as follows:

- Natural gas has lower carbon content per unit energy, yielding CO_2 emissions that are 20 to 25% less than diesel if burned at the same efficiency. A range is given to reflect the dependency of this reduction on the methane content of the natural gas. The actual reduction also depends on the diesel pilot fraction utilized.

- NO_x emissions are reduced by virtue of the lower flame temperature of natural gas as compared to diesel combustion flame temperature. Results on engines tested so far indicate a reduction of approximately 35-50% over diesel fuelling (NTD: cycle results depend on base engine used – on the Challenger application, it is actually 1.0 to 1.5 g/bhp-hr). The combustion still relies on a diffusion flame; consequently further efforts to reduce NO_x must target techniques that can reduce the temperature of the reaction zone, such as exhaust gas recirculation (EGR). HPDI in combination with EGR has the potential to reduce NO_x emissions to less than 1.0 g/bhp-hr.

- PM emissions are reduced by virtue of the lower carbon content of the natural gas per unit energy and by virtue of the lower propensity of natural gas combustion to form soot. Results on engines tested so far indicate a reduction of 50-70% over diesel fuel. Recent HPDI engine testing has demonstrated the ability to achieve less than 0.01 g/bhp-hr PM emissions on standard test cycles. Approximately 50% of the PM emissions is carbonaceous with the remainder consisting of volatile components.

- Because the combustion is of the diesel type, carbon monoxide (CO) and non-methane hydrocarbons (nmHC) emissions are expected to be low. Diesel cycle engines have inherently low CO and nmHC emissions when compared to untreated spark-ignited engines. Today, HPDI engines emit slightly more CO and nmHC than diesel fuelled engines but lower levels than spark-ignited natural gas engines. CO and nmHC emissions can be easily treated with an oxidation catalyst, permitted by the inherently low sulphur content of natural gas.

- CH_4 emissions can also be quite low if the combustion is well optimized. Emissions are typically approximately 1.0 g/bhp-hr, compared to three to five on lean burn natural gas engines. Methane is a Green House Gas and methane emissions must therefore be considered in the overall environmental impact.

LNG is the fuel of choice for heavy-duty trucks because it offers fleets greater range while reducing the weight constraints presented by compressed natural gas. A small on-board high-pressure cryogenic pump draws saturated liquid natural gas from LNG storage tank(s) at a low pressure and temperature of about 25 psi and -160°C, and pressurizes it up to a maximum gas injection pressure required by the HPDI fuel injectors of about 4000 psi. The LNG is vaporized after pumping before being injected.

Purpose of Demonstration

The objective of the "Clean Air Corridor" is to demonstrate the technical and economic feasibility of operating heavy-duty (Class 8) trucks in a line-haul application using liquefied natural gas as the primary fuel.

LNG is currently used in transit bus, refuse truck, and some heavy duty hauling in California and Texas. The engines employed in these applications are typically spark ignited engines that are typically less than 85% of the efficiency of the diesel engine. The advantages of using LNG in these applications are fuel price, engine performance, and reduced smog precursor emissions. The 401 project will showcase the HPDI technology operating at equivalent to diesel fuel efficiency, with all the benefits of a natural gas engine including fuel price, and NOx and Particulate Matter emissions reduction.

From a fuel supply perspective, this project is designed to build market awareness of the advantages of LNG in transportation in Canada, specifically in the Class 8 heavy duty market. The Westport HPDI technology provides sufficient horsepower, torque, and engine

efficiency to service the Class 8 sector (the spark ignited natural gas engines lack sufficient power and torque). The project will demonstrate the fuel efficiency, emissions performance, driver satisfaction, power, torque, and engine reliability for the engine. Importantly, this project will enable the project consortium to build government, regulator, customer, and general public awareness of the use of LNG in transportation applications. We plan communications around the safety, price, and environmental benefits of LNG as a transportation fuel.

Over the course of the pilot we will be comparing the performance of the LNG powered trucks with diesel powered vehicles in side by side tests. Compared with business as usual, we are forecasting the following targets will be achieved:

- 450,000 Litres of diesel replaced with natural gas
- 750,000 total kilometres hauled by LNG powered trucks
- Energy equivalent fuel economy compared with the incumbent diesel technology
- Total LNG consumed: 630,000 litres (19,000 GJ)
- 112 tonnes of CO2 emissions avoided
- 1.5 tonnes of NOx emissions avoided
- 98 kilograms of PM avoided

Project Description

The project involves five new trucks to be equipped with HPDI fuel systems and run for a period of one year between Toronto and Windsor using liquefied natural gas as the primary fuel. These trucks will refuel at a LNG station that will be built in London, Ontario expressly for the corridor project.

The project partners include Westport Innovations, Enbridge Gas Distribution, and Challenger Motor Freight. Westport is the lead contractor on the project, with general responsibility for Engine development, up-fitting the 5 Challenger trucks, supply of the fuelling station, and upgrades to Challenger's maintenance facility.

Challenger Motor Freight will provide and operate the 5 trucks in regular hauling routes. Enbridge is responsible for sourcing and transporting LNG fuel to the fuelling station on London, Ontario.

The scope of work required for Enbridge Gas Distribution to supply LNG fuel to the project is broad. Gaz Metro plans to modify their facility to accommodate truck loading of LNG. The work required includes the installation of a new pump, running a new LNG loading pipe run, and development of procedures for the truck loading. In addition, as the originator of the LNG product, Gaz Metro will be responsible for developing and gaining approval of the Emergency Response Action Plan under Transportation of Dangerous Goods (TDG) legislation. EGDI will be contracting with Clean Energy (an LNG hauling specialist) to provide LNG hauling services for the project. Clean Energy will supply the required LNG trailers, logistics support, and hauling for the fuel. All of the costs to perform the work described above will accrue to EGDI.

The Challenger Motor Freight trucks will be used to haul beer (2 trucks) and refuse (3 trucks). The brewery products will be hauled from London to Michigan, while the refuse will be hauled from Toronto to Michigan. The trucks will be fuelled at the single fuelling station located in London, Ontario. London will also serve as the base for all maintenance activities for the LNG powered trucks for the duration of the project. Challenger plans to continuously operate the LNG powered trucks on these routes for a period of one year. These routes are currently serviced by diesel trucks and the monitoring activities include benchmark emissions performance testing for the diesel trucks prior to the launch of the LNG powered hauling trial. EGDI will sell LNG fuel to Challenger Motor Freight at a price not to exceed the price of diesel.

The key focus of the demonstration is the fuel economy, emissions, reliability, and driver satisfaction performance of the LNG powered trucks.

Program Deliverables

1. One year in-use demonstration of five ISX-G high-performance, low-emissions engines in heavy-duty applications, operating in commercial service in Canada.
2. Comparative exhaust emissions and fuel consumption data for ISX-G and diesel-fuelled engines over heavy-duty, on-road driving cycles.

Results after Six Months of Operations

The following are the key conclusions and observations from the first six months of operations

- The two HPDI trucks running on the Challenger beer route averaged 12,209 KM per truck per month, while the three HPDI trucks running on the garbage route averaged 13,715 KM per truck per month during the first 6 months. The five HPDI trucks have compiled 335,000 Km on HPDI operation using LNG as the primary fuel up to October 31, 2005.
- The HPDI trucks have delivered high availability (99%) during the first 6 months but were utilized less than similar diesel vehicles due to range and operator constraints such as:
    - When commodity of refuse supply was low and the HPDI trucks were not needed on there regular routes, they could not be easily redeployed to alternative routes due to limited fuelling infrastructure
    - When drivers had vacation or leave, the vehicles could not be easily reassigned because the HPDI specific training was required.
- The average fuel economy of the LNG vehicles on both the beer and garbage routes met expectations and was within approximately 3% of the average diesel baseline fuel economy.
- Lessons learned from this demonstration project have resulted in improved reliability each month of the reporting period

- The base vehicle system (excluding the HPDI system) on the HPDI trucks needed on average, one maintenance event every 5857 KM. The HPDI truck as a whole required an average, one maintenance event every 4217 KM (excluding HPDI system upgrade maintenance).
- Drivers have been satisfied with performance and operating characteristics to date. They have reported that the HPDI vehicles behaviour is similar to other diesel vehicles in Challenger's fleet.

Project Partners

Westport Innovations Inc.- the leading developer of environmental technologies that allow engines to operate on clean-burning fuels such as natural gas, hydrogen, and hydrogen-enriched natural gas (HCNG). Westport has technology development alliances in place with Ford, MAN, BMW and Isuzu, and an ownership interest in Clean Energy, the largest provider of vehicular natural gas in North America. Cummins Westport Inc., Westport's joint venture with Cummins Inc., manufactures and sells the world's widest range of low-emissions alternative fuel engines for commercial transportation applications such as trucks and buses.

Challenger Motor Freight Inc. recent winner of Canada's 50 Best Managed companies (2001-2004), is the largest privately owned trucking company in Canada. Challenger provides a full range of transportation, logistics and integrated services to Canadian, U.S. and Mexican markets. As a recognized leader in the field of safety, Challenger has often been involved with pilot projects involving safety, technology and environmental issues.

Enbridge Gas Distribution Inc., Canada's largest natural gas distribution company, provides natural gas to about 1.7 million industrial, commercial and residential customers in Ontario, Quebec, New Brunswick and New York State. It is owned and operated by

Enbridge Inc., a leader in energy transportation and distribution in North America and internationally.

Sustainable Development Technology Canada (SDTC) - a foundation created by the Government of Canada that operates a $550 million fund to support the development and demonstration of clean technologies that address issues of climate change, clean air, water quality, and soil. These solutions deliver environmental, economic and health benefits to Canadians. An arm's length, not-for-profit corporation, SDTC works with private, financial, academic and public sectors, and with the Government of Canada to build a sustainable development technology infrastructure in Canada.

Natural Resources Canada

Natural Resources Canada (NRCan) plays a pivotal role in helping shape the important contributions of the natural resources sector to the Canadian economy, society and environment. NRCan conducts innovative science to generate ideas and transfer technologies, and represents Canada's international interests to meet our global commitments related to natural resources. By promoting the responsible use of our natural resources, NRCan builds on the Government of Canada's commitment to ensuring the quality of life in our communities, a healthy environment and continued economic prosperity.