Final Report

Engineering and Design of the Natural Gas Dual Fuel Blend System for Heavy Duty Vehicles

CCEMC Project # C110142

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CCEMC Hold back:	$54,631.40

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Executive Summary

Hitec's proposed dual fuel technology is a conversion technology system that is added to an existing heavy duty (HD) vehicle diesel engine, enabling the HD diesel engine to operate on a high proportion of natural gas (NG) blend. Potentially, up to 60% (or greater) of the diesel fuel can be substituted with natural gas – in the form of compressed natural gas (CNG) or liquefied natural gas (LNG) - when utilizing the Hitec dual fuel technology.

CNG, the cleanest of all the fossil fuels, contains less carbon than diesel, consequently producing lower CO2 emissions per vehicle mile traveled. Installing the Hitec dual fuel system in HD vehicle engines throughout Alberta and Canada will produce tangible, long-term, and sustainable CO2 emission reductions.

Technology allows the introduction of (NG) into the diesel/air fuel mix by monitoring and utilizing several key parameters:

- Engine revolutions per minute (RPM)
- Boost pressure
- Exhaust gas temperature
- Air temperature
- Fuel temperature (both NG and diesel)

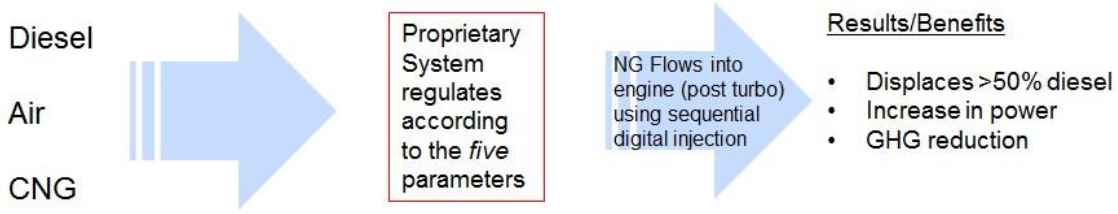

Figure 1: Hitec dual fuel system overview

The project's development goal is to reach up to 50%, or higher, NG blend on all types and sizes of HD engines, thus allowing more GHG emission reductions, higher fuel savings, and expanded use of NG.

Technology development was done with two HD tractors owned by Hitec and five other HD trucks from an Edmonton-based refuse trucking company. The following trucks, with various types of engines were installed with the Hitec technology:

- 2008 Freightliner Columbia Cat C15 500HP
- 2007 Volvo D16 500HP (16L)
- 2012 Mack Maxforce Tridrive (16L)
- 2011 International Pinnacle (11L)
- 2008 International Workstar (11L)
- 2007 International Workstar (10L)
- 2004 Freightliner CAT ACERT (14L)

In one (1) year of operation, we have calculated that the five (5) HD trucks have cumulatively reduced GHG emissions by 91 tonnes of GHG, measured in CO2e, carbon dioxide equivalent.

Diesel GHG emissions (grams CO2e)/km	1456
CNG GHG emissions (grams CO2e)/km	1220
GHG emissions savings (grams CO2e)/km	236
Average travel per year (km)	140000
CNG/Diesel Fuel Blend Mix	55%

# of Trucks	Tonnes of GHG from 100% Diesel	Tonnes of GHG from Dual Fuel	Tonnes of GHG Savings from Dual Fuel
5	1019	928	91

Table 1: Hitec dual fuel GHG emissions savings from project

Cumulatively, a reduction of more than 450,000 tonnes of GHG emissions can be achieved over a ten (10) year period by utilizing the Hitec dual fuel technology [this is cumulatively savings over ten (10) year period with close to 7000 trucks utilizing dual fuel in tenth year]. Given potential of the technology, we believe the adoption rate can be considerably higher, thus yielding much higher GHG emissions savings.

Project Description

Introduction and Technology overview

Hitec's proposed dual fuel technology is a conversion technology system that is added to an existing heavy duty (HD) vehicle diesel engine, enabling the HD diesel engine to operate on a high proportion of natural gas (NG) blend. Potentially, up to 60% (or greater) of the diesel fuel can be substituted with natural gas – in the form of compressed natural gas (CNG) or liquefied natural gas (LNG) - when utilizing the Hitec dual fuel technology.

CNG, the cleanest of all the fossil fuels, contains less carbon than diesel, consequently producing lower CO2 emissions per vehicle mile traveled. Installing the Hitec dual fuel system in HD vehicle engines throughout Alberta and Canada will produce tangible, long-term, and sustainable CO2 emission reductions.

Our technology system contains several components: CNG tank, unique tank valve, Safety Pressure Relief Device (PRD), engineered brackets, high pressure stainless steel line, pressure solenoids, sensor, injectors, and an Electronic Control Module (ECM). These components are added to a diesel engine and the engine can be easily placed back to a mono fuel application. Our technology does not change any of the original equipment manufacturers' (OEM) programming, or engine components.

Technology allows the introduction of (NG) into the diesel/air fuel mix by monitoring and utilizing several key parameters:

- Engine revolutions per minute (RPM)
- Boost pressure
- Exhaust gas temperature
- Air temperature
- Fuel temperature (both NG and diesel)

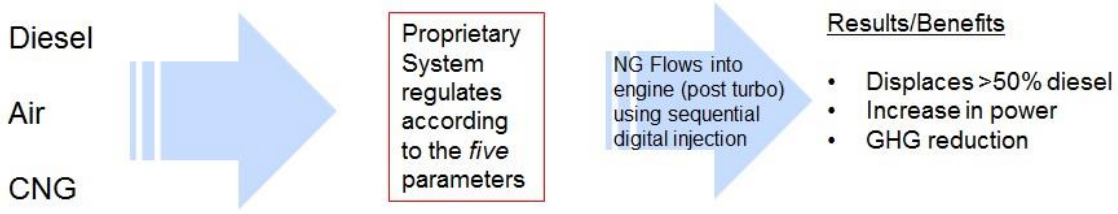

Figure 2: Hitec dual fuel system overview

Project goals

Prior to this project we were able to achieve 50% NG blend on specific engines. However, for this project the development goal is to reach up to 50%, or higher, NG blend on all types and sizes of HD engines, thus allowing more GHG emission reductions, higher fuel savings, and expanded use of NG.

Outcomes and Learnings

Technology development, installation and commissioning

Technology development was done with two HD tractors owned by Hitec and five other HD trucks from an Edmonton-based refuse trucking company. The following trucks, with various types of engines were installed with the Hitec technology:

- 2008 Freightliner Columbia Cat C15 500HP
- 2007 Volvo D16 500HP (16L)
- 2012 Mack Maxforce Tridrive (16L)
- 2011 International Pinnacle (11L)
- 2008 International Workstar (11L)
- 2007 International Workstar (10L)
- 2004 Freightliner CAT ACERT (14L)

The refuse trucking company provides waste management of 3 waste streams:

1. Recyclables - items that have value that can be extracted. Make the most of our Earth's limited resources.
2. Organics - biodegradable items. Processing generates clean energy, water and replenishes soil
3. Waste - what doesn't go to the first two streams

The refuse trucking company has a fleet of 30 heavy duty tractors. Since these tractors were doing the same return to base (RTB) run, they thought they would be a good candidate for the Hitec dual fuel kit as they would be able to fill up with CNG in Edmonton and have that entire CNG tank supply the entire RTB run.

The company decided to convert 5 tractors and evaluate the economics. If the economics were compelling, they would build their own CNG station. The dual fuel technology that was installed on the five (5) HD trucks was purchased by the refuse trucking company and is still being used in their operations as of April 2016. The refuse trucking company continues to enjoy fuel savings and performance enhancement resulting from the Hitec dual fuel technology.

Figure 3: Hitec dual fuel Freightliner demonstration truck

Figure 4: Hitec dual fuel Volvo demonstration truck

Figure 5: Milk hauler heavy duty truck with Hitec dual fuel system

Figure 6: Edmonton refuse hauler heavy duty truck with Hitec dual fuel system

Results of experiments

One of the key metrics of the testing was diesel displacement. The refuse trucking company initially converted one HD truck, with intent to convert more trucks if the HD truck would show economically viable diesel fuel displacement and if the HD truck could run as well, or better, in dual fuel mode.

Initially, refuse trucking company tested the operability of the truck, especially when pulling maximum load. The Hitec dual fuel system, according to refuse trucking company, delivered more power.

After a week of driving truck, diesel displacement test was done. Three (3) tests over several days showed a diesel displacement of approximately 55%.

Given the diesel fuel consumption and the cost savings of CNG over diesel, refuse trucking company was able to show good economic payout for the dual fuel technology. A decision was quickly made to convert the reminder of the HD trucks.

Project outcomes, Technology Enhancements, and Lesson Learned

The installation of our dual fuel system on seven (7) types of heavy duty engines provided significant data to further engineering and design of our dual fuel system. This, in turn, has allowed us to move closer to having a dual fuel system that can be used as a base template for various types of engine sizes and models.

One of the goals of this project was to ensure our dual fuel system as robust enough to work on various engine types, sizes, models, and other variable parameters. We converted various types of engines on different brand of trucks:

- 2008 Freightliner Columbia Cat C15 500HP
- 2007 Volvo D16 500HP (16L)
- 2012 Mack Maxforce Tridrive (16L)
- 2011 International Pinnacle (11L)
- 2008 International Workstar (11L)
- 2007 International Workstar (10L)
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We converted 4 different engine platforms: 10L, 11L, 14L and 16L engine designs.

We worked with and converted engines using 3 separate EPA emission platforms:

- DEF (Diesel Emission Filter)
- DPF (Diesel Particulate Filter)
- SRS (Single Regeneration System)

We worked with and converted using 2 separate emission protocols

- TEIR 3
- TEIR 4

We worked with 2 separate working environments: city refuse operation and highway transport heavy haul.

With similarities to all yet each with a non-conventional operating engine management system, we had both successes and challenges designing our system for full adaptability for an agnostic product that was to work on all types of engines, sizes, and models.

We created a core product that is universal yet our software flexible enough to provide current and future expansion and code for further engine optimization for all types of engines and sizes

We created a dual fuel system that allows operation of the different grades of diesel fuel. We found various differences in our burn characteristics depending upon the customer's use of lubricity additives to overcome the low sulphur fuels.

Greenhouse Gas and Non-GHG Impacts

GHG savings from project

To calculate the greenhouse gas (GHG) savings resulting from the project, we utilized the data from the Natural Resource Canada (NRCan) GHGenius model (Version 4.03), which is a model for lifecycle assessment of transport fuels. The GHGenius model provides the true lifecycle GHG emissions resulting from both diesel and natural gas (in CNG form).

HEAVY-DUTY ICE VEHICLES, FOSSIL OR NUCLEAR FEEDSTOCKS (g/km and % changes) (Year 2013) Canada		
Results for HDDV Trucks		
General fuel -->	**Petrol diesel**	**Natural gas**
Fuel specification -->	**0.0015% S**	**CNG**
Feedstock -->	**Crude oil**	**NG100**
Vehicle operation	1,076.7	947.2
C in end-use fuel from CO2 in air	0.0	0.0
Net Vehicle Operation	1,076.7	947.2
Fuel dispensing	1.9	21.0
Fuel storage and distribution	7.6	41.4
Fuel production	150.0	43.3
Feedstock transport	12.2	0.0
Feedstock recovery	76.1	48.0
Feedstock Upgrading	38.5	0.0
Land-use changes, cultivation	1.8	0.0
Fertilizer manufacture	0.0	0.0
Gas leaks and flares	55.3	53.7
CO2, H2S removed from NG	0.0	17.3
Emissions displaced by co-products	-1.2	0.0
Subtotal (fuelcycle)	1,419.1	1,171.9
% changes (fuelcycle)	--	-17.4
Vehicle assembly and transport	*5.5*	*7.0*
Materials in vehicles	*31.2*	*41.4*
Grand total	**1,455.9**	**1,220.3**
% changes (grand total)	--	-16.2

Table 2: GHGenius diesel and CNG emissions data

In one (1) year of operation, we have calculated that the five (5) HD trucks have cumulatively reduced GHG emissions by 91 tonnes of GHG, measured in CO2e, carbon dioxide equivalent.

Diesel GHG emissions (grams CO2e)/km	1456
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Table 3: Hitec dual fuel GHG savings from CCEMC project

Future GHG Savings

Hitec believes given the GHG emissions savings and fuel cost savings, more fleets throughout Canada will convert their HD trucks to run the Hitec dual fuel system. A ten (10) year implementation and resulting fuels savings are provided below.

Year	Cumulative # of Trucks	Tonnes of GHG from 100% Diesel	Tonnes of GHG from Dual Fuel	Tonnes of GHG Savings from Dual Fuel
1	50	10,191	9,367	824
2	150	30,573	28,100	2,473
3	450	91,719	84,300	7,419
4	950	193,628	177,967	15,661
5	1,950	397,447	365,300	32,147
6	2,950	601,267	552,634	48,633
7	3,950	805,086	739,967	65,119
8	4,950	1,008,905	927,301	81,604
9	5,950	1,212,724	1,114,634	98,090
10	6,950	1,416,543	1,301,968	114,576
				466,546

Table 4: Hitec dual fuel GHG projected savings over 10 years

Cumulatively, more than 450,000 tonnes of GHG emissions can be reduced over a ten (10) year period by utilizing the Hitec dual fuel technology. Given potential of the technology, we believe the adoption rate can be considerably higher, thus yielding much higher GHG emissions savings.

Non-GHG savings and positive impacts from project

Hitec's dual fuel technology has good chance for widespread adoption not only because of GHG savings, but also the following:

- **Fuel Costs Savings**: Abundant supply of NG has historically traded at a discount to crude oil-based fuels on. On an equivalent basis, CNG is between 30% and 50% cheaper than diesel – even with current (2016) low Canadian diesel prices. Hitec payout models indicate an 18 month payout on the Hitec Dual fuel technology for a HD truck when a HD truck uses at least 400L per day. There are many fleets that utilize 400L or more per day.

- **Job Creation**: Building out and supporting the CNG/LNG refuelling infrastructure, along with expanded NG economy operations to support NG transportation industry, will most certainly create jobs.
- **Expanded use of NG**: The oversupply of NG has suppressed NG prices. Expanding use of NG as a transportation fuel will help the NG economy, which is a very important segment in the Alberta economy.

Our dual fuel technology can be used for the entire life of a HD engine. With potential widespread adoption adopted in over 89,000 HD **trucks in** Alberta and 326,188 HD **trucks in** Canada, the reduction of GHG emissions from our solution is significant. If our dual fuel technology was applied to 5% of the HD trucks in Canada, it would yield 2,814,567 tonnes of GHG emissions savings for the total lifecycle of the HD engine (i.e. 1 million km). Additionally, our solution is a sustainable solution that has long lasting viability, as long as there are HD diesel engines (over 30+ years).

Overall Conclusions

The project was successful in achieving several key results:

1. Further enhanced technology using internal trucks, but also several trucks from a fleet that paid for the technology. The ability to test and enhance the technology using results from real operational vehicles was invaluable.
2. Created dual fuel technology platform that was flexible enough to be utilized on various types of engine models and sizes:
    - 2008 Freightliner Columbia Cat C15 500HP
    - 2007 Volvo D16 500HP (16L)
    - 2012 Mack Maxforce Tridrive (16L)
    - 2011 International Pinnacle (11L)
    - 2008 International Workstar (11L)
    - 2007 International Workstar (10L)
    - 2004 Freightliner CAT ACERT (14L)
3. Creation of a core product that is universal yet our software flexible enough to provide current and future expansion and code for further engine optimization for all types of engines and sizes.
4. Creation of a dual fuel system that allows operation of the different grades of diesel fuel.

Most importantly, the development efforts from this project have shown that the Hitec dual fuel system can be utilized by many different types of engine models and engine sizes. Furthermore, this was confirmed when a refuse trucking fleet was able to successfully use, and continues to use, our technology in their operations.

Communication Plan

Non-confidential results from the project have been included on our marketing material, and will soon be available on our upgraded website.

As the Hitec dual fuel technology is adopted by more fleets, Hitec will commence media (newspaper, television, industry blogs, etc.) engagement; however, given the lack comprehensive rollout of our technology, Hitec feels it is best to wait.