Class 8 CNG / Diesel System Cost Analysis

United States Environmental Protection Agency

Class 8 CNG / Diesel System Cost Analysis

Assessment and Standards Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

Prepared for EPA by
FEV North America, Inc.
EPA Contract No. EP-C-12-014 WA3-03

NOTICE

This technical report does not necessarily represent final EPA decisions or positions. It is intended to present technical analysis of issues using data that are currently available. The purpose in the release of such reports is to facilitate the exchange of technical information and to inform the public of technical developments.

EPA United States Environmental Protection Agency

EPA-420-D-15-003
June 2015

List of Contents

List of Figures

List of Tables

Disclaimer

The statements and conclusions in this report are those of FEV and not necessarily those of other entities. The mention of commercial products, their source, or their use in connection with this report is not to be construed as actual or implied endorsement of such products.

Acknowledgements

Many individuals contributed to this study. FEV gratefully acknowledges the FEV personnel and outside organization(s) that contributed or collaborated with FEV in some way throughout this project. Although these outside organizations may not necessarily endorse or validate this report FEV appreciates their continued support.

Executive Summary

The United States Environmental Protection Agency (EPA) contracted with FEV, Inc. to determine the incremental delta costs for a CNG (Compressed Natural Gas) fuel system, including the differences in the engine components, the fuel system components and the exhaust system components as compared to the standard Diesel fuel system and its system components in a Class 8 truck.

The standard Diesel system has been the mainstay in the trucking transportation industry for many years. However, the CNG system is a progressive alternative to achieving future fuel economy requirements as it is a cleaner burning fuel which significantly reduces carbon and particulate emissions during vehicle operation when compared to a gasoline or Diesel vehicle equivalent.

The Energy Collective group published an article entitled 'A New Debate Emerges: LNG or CNG for the Long Haul' on July 16, 2013 which discusses the CNG alternative in depth. The following excerpts from that article provide a strong supporting opinion for CNG as an alternative to traditional Diesel fuel.

'Compressed natural gas (CNG) is the mostly likely choice for any return-to-base, short mileage vehicles, and liquefied natural gas (LNG) is the option for long-haul on-highway Class 8 trucks. The reasoning behind this is inherent to gaseous rather than liquid fuel (energy density, tank storage capacity, re-fueling time). CNG and LNG are both proven forms of natural gas storage, with distinct advantages over Diesel and gasoline when used as a transportation fuel. To produce CNG, natural gas is taken directly out of the United States' expansive network of natural gas pipelines, whereas LNG must be cryogenically liquefied to -260 degrees F (to become a liquid) this adds more expense the product.

CNG is compressed immediately and enters a truck in a process that is almost identical to traditional fueling. On the other hand, LNG requires drivers to wear a mask and gloves to protect themselves against cryogenic burns.

Compared to CNG, LNG contains 2.4 times more energy per Diesel gallon equivalent (DGE). Since LNG, like Diesel and gasoline, is a liquid, one could achieve comparable refueling speed, whereas the level of compression required to "fast-fill" with CNG is very high (~3,600 psi). As a result, for the long-haul trucking sector, the energy density and associated cost(s), weight and on-board storage capacity of LNG have long been viewed as the more attractive, viable option for long hauling.'[1]

For the FEV study, both the CNG (new) and the standard Diesel (baseline) technologies were evaluated and compared for the Class 8 truck. The specific systems reviewed by FEV were the Cummins ISXG11.9 liter CNG spark plug ignition engine and the ISX11.9 liter compression ignited Diesel engine. The study precisely identified and included all engine components which were different between the two.

The engines used for both the CNG new technology configuration (i.e., CNG vehicle system) and

[1] The Energy Collective – "A New Debate Emerges: LNG or CNG for the Long Haul", accessed on May 2015, http://theenergycollective.com/simonsylvesterchaudhuri/250096/new-debate-emerges-lng-or-cng-long-haul

the Diesel baseline (i.e., conventional vehicle system) utilized the same size family engine. The engine blocks were identical but the heads were slightly different. The main engine hardware difference included the CNG spark ignited engine with an ignition control module for the ignition coils as opposed to the conventional compression Diesel ignition with an injector system.

The fuel systems proved to be the primary difference between the two technologies. The fuel system comparison for the Diesel and the CNG engines included the diesel side mounted fuel tanks that store liquid diesel fuel versus the enclosed rear mounted CNG tanks and all associated equipment. The use of CNG requires no fuel pump or primer system but does require a fuel control module with pressure regulator valves. The CNG system also requires high pressure storage tanks, mounted on the back, top or side rail of the truck depending on the application and distance needed for the truck to travel. In some cases, two or more of the CNG configurations can be used together to meet long distance requirements.

The exhaust systems for both the Diesel and CNG systems were also evaluated. The Diesel fuel system has a SCR (Selective Catalytic Reduction) system with urea dosing unit for After-treatment of the diesel exhaust. The CNG exhaust system does not require the SCR unit as it is similar to a gas engine exhaust system with a 3-way catalyst.

This study considered Class 8 vehicles for local and day time runs only. Long haul trucks have more requirements and additional needs when running a CNG system. Additionally, the study is based on the use of CNG fuel and only references LNG Fuel, although the Cummins ISX12G can use either CNG or LNG fuel.

The delta cost evaluation was done at the component level through the full assembly, excluding any parts that were the same for both systems. Identical parts were not evaluated or added into the cost structure.

The overall cost differences of CNG as compared to the Diesel at a system level are shown below.

CNG vs. Diesel Cost & Weight Differences

	Diesel Base Technology		CNG New Technology		Delta Difference	
	Cost	Weight KG	Cost	Weight KG	Cost	Weight KG
Engine	$1,508	102.74	$1,621	82.96	-$113	19.79
Exhaust	$5,390	400.41	$2,689	69.08	$2,702	331.34
Fuel	$4,067	275.24	$17,067	1460.11	-$13,000	-1184.88
Total	$10,964	778.39	$21,376	1612.15	-$10,412	-833.75

(1) "+" = mass decrease, "-" = mass increase
(2) "+" = cost decrease, "-" = cost increase

Note: 1) Fuel and exhaust components that are attached to the engine are considered engine components.
2) Fuel systems weight does not include the fuel.

1. Introduction and Program Objectives

1.1 Objectives

The objective of this work assignment was to determine the incremental direct manufacturing delta costs for the CNG (Compressed Natural Gas) fuel system, including the differences in the engine components, the fuel system components and the exhaust system components as compared to the standard Diesel fuel system and system components in the Class 8 truck configuration. The study used the costing methodology, existing databases, and supporting worksheets developed in the previously concluded EPA study: Light-Duty Technology Cost Analysis [EP-C-12-014, WA 1-9].

1.2 Study Methodology

The costing methodology was heavily based on teardowns of both new and baseline technology configurations with similar driver performance metrics. Only components identified as being different within the selected CNG (new) and the standard Diesel (baseline) configurations were evaluated for cost.

All component costs were calculated using a ground-up costing methodology analogous to that employed in the automotive industry. All incremental costs for the new technology were calculated and presented using transparent cost models consisting of eight core cost elements:

- Material
- Labor
- Manufacturing Overhead/Burden
- End Item Scrap
- SG&A (Selling General and Administrative)
- Profit
- ED&T (Engineering, Design, and Testing)
- Packaging.

1.3 Manufacturing Assumptions

When conducting the cost analysis for the various technology configurations, a number of assumptions were made in order to establish a consistent framework for all costing. The assumptions can be broken into universal and specific case study assumptions.

- The universal assumptions applied to all technology configurations under analysis.
- The fundamental assumptions used are listed in Table 1-1.
- The specific case study assumptions were those unique to a given technology configuration and included volume assumptions, weekly operation assumptions (days, shifts, hours, etc.), packaging assumptions, and Tier 1 in-house manufacturing versus Tier 2/3 purchase part assumptions.

Table 1-1: Summary of Universal Cost Analysis Assumptions

Item	Description	Universal Case Study Assumptions
1	Net Incremental **Direct** Manufacturing Costs (NIDMC) (Included in the analysis)	A.Net Incremental **Direct** manufacturing cost is the incremental difference in cost of components and assembly, to the OEM, between the new technology configuration (i.e., mass-reduced components/assemblies) and the baseline technology configuration (i.e., the production stock Chevrolet Silverado components/assemblies). B. This value does not include **Indirect** OEM costs associated with adopting the new technology configuration (e.g. tooling, corporate overhead, corporate R&D, etc.).
2	Incremental **Indirect** OEM Costs (Not included within the scope of this cost analysis)	A. Indirect Costs are handled through the application of "**Indirect Cost Multipliers**" (ICMs) which are not included as part of this analysis. The ICM covers items such as ..... a. OEM corporate overhead (sales, marketing, warranty, etc.) b. OEM engineering, design and testing costs (internal & external) c. OEM owned tooling B. Reference EPA report EPA-420-R-09-003, February 2009, "Automobile Industry Retail Price Equivalent and Indirect Cost Multiplier" for additional details on the develop and application of ICM factors. C. Reference EPA and NHTSA Joint Final Rule "2017 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions and Corporate Average Fuel Economy Standards", Federal Register / Vol. 77, No. 199 / Monday, October 15, 2012 / Rules and Regulations (http://www.gpo.gov/fdsys/pkg/FR-2012-10-15/pdf/2012-21972.pdf) for additional details on the develop and application of ICM and learning factors.
3	Incremental Production Tooling Costs (Included in the analysis)	A. Incremental Production Tooling cost is the differential cost of tooling to the OEM, between tooling up the new technology configuration (i.e., mass-reduced components/assemblies) versus the baseline technology configuration (i.e., the production stock Silverado components/assemblies). B. Analysis assumes all tooling is owed by OEM C. Tooling includes items like stamping dies, plastic injection mold, die casting molds, weld fixtures, assembly fixtures, gauges, etc.
4	Product/Technology Maturity Level	A. Mature technology assumption, as defined within this analysis, includes the following: a. Well developed product design b. High production volume (+450K/year) c. Products in service for several years at high volumes c. Significant market place competition B. Mature Technology assumption establishes a consistent framework for costing. For example, a defined range of acceptable mark-up rates. a. End-item-scrap 0.3-0.7% b. SG&A/Corporate Overhead 6-7% c. Profit 4-8% d. ED&T (Engineering, Design and Testing) 0-6% C. The technology maturity assumption does not include allowances for product learning. Application of a **learning curve** to the calculated incremental direct manufacturing cost is handled outside the scope of this analysis.

Table Continued next page

Summary of Universal Cost Analysis Assumptions – Continued

Item	Description	Universal Case Study Assumptions
5	Selected Manufacturing Processes and Operations	A. All operations and processes are based on existing standard/mainstream Industrial practices. B. No additional allowance is included in the incremental direct manufacturing cost for manufacturing learning. Application of a **learning curve** to the developed incremental direct manufacturing cost is handled outside the scope of this analysis.
6	Annual Capacity Planning Volume	50,000 Vehicles
7	Supplier Manufacturing Location	United States of America
8	OEM Manufacturing Location	United States of America
9	Manufacturing Cost Structure Timeframe (e.g. Material Costs, Labor Rates, Manufacturing Overhead Rates)	2012/2013 Production Year Rates
10	Packaging Costs	A. Calculated on all Tier One (T1) supplier level components. B. For Tier 2/3 (T2/T3) supplier level components, packaging costs are included in T1 mark-up of incoming T2/T3 incoming goods.
11	Shipping and Handling	A. T1 supplier shipping costs covered through application of the Indirect Cost Multiplier (ICM) discussed above. B. T2/T3 to T1 supplier shipping costs are accounted for via T1 mark-up on incoming T2/T3 goods.
12	Intellectual Property (IP) Cost Considerations	Where applicable IP costs are included in the analysis. Based on the assumption that the technology has reached maturity, sufficient competition would exist suggesting alternative design paths to achieve similar function and performance metrics would be available minimizing any IP cost penalty.
13	Platform Synergies Considerations	No consideration was given (positive or negative) to x-platform synergies. Both the baseline and mass-reduced technology configurations were treated the same. a. Common parts used across different models b. Parts homologated / validated / certified for various worldwide markets
14	Derivative Model Considerations	No consideration was given to derivative models. Both the baseline and mass-reduced technology configurations were treated the same. a. 2 wheel, 4 wheel or all wheel drive applications b. Various engine / transmission options with models c. Various towing / loading / carrying capacities
15	Material Cost Reductions (MCRs) on analyzed hardware	Only incorporated on those components where it was evident that the component design and/or selected manufacturing process was chosen due to actual low production volumes (e.g. design choice made to accept high piece price to minimize tooling expense). Under this scenario, assumptions where made, and cost analyzed assuming high production volumes.
16	Operating and End-of Life Costs	No new, or modified, maintenance or end-of-life costs, were identified in the analysis.
17	Stranded Capital or ED&T expenses	No stranded capital or non-recovered ED&T expenses were considered within the scope of this analysis. It was assumed the integration of new technology would be planned and phased in minimizing non-recoverable expenses.

1.4 Cost File Structure

Normal Cost File Structure

In previous EPA studies, the team used a design BOM approach, in which an engine for example, would be broken out into systems which included specific subsystems and parts. For costing purposes, FEV normally used existing databases that had been used in previous EPA powertrain studies as shown in the following list.

- **Material, Labor, Markup and Machine Overhead** databases.
- **Summary Sheets** used for Upper level costing.
- **VCMAT** (Vehicle Cost Model Analysis Templates) used for vehicle level cost deltas between new and old technologies.
- **SCMAT** (System Cost Model Analysis Templates) used for system rollups, this template is also used for subsystem - SSCMAT and sub-subsystems - SSSCMAT.
- **MAQS** (Manufacturing Assumption Quote Summaries) used for assembly, and component detail costing.
- **CBOM** (Cost Bills of Materials) Used for compiling systems, subsystems, sub-subsystems, assemblies and components weights, part numbers, quantities, and picture numbers to be costed.

Unique Cost File Structure

However, the cost file structure for this study is unique and falls outside the normal parameters of previous studies. For this study, all systems, subsystems and sub-subsystems were identified by the Cummins (Quick-serve) Parts website which uses a product build BOM approach.

Cummins product build BOM method combines some assemblies and components that would have been separated in the design approach. Using the Cummins web site and their exploded views for the parts break down, each system/subsystem/sub-subsystem etc. was loaded into the FEV BOM template for identification and costing purposes.

Figure 1-1 shows an example of a Cummins sub-subsystem exploded view.

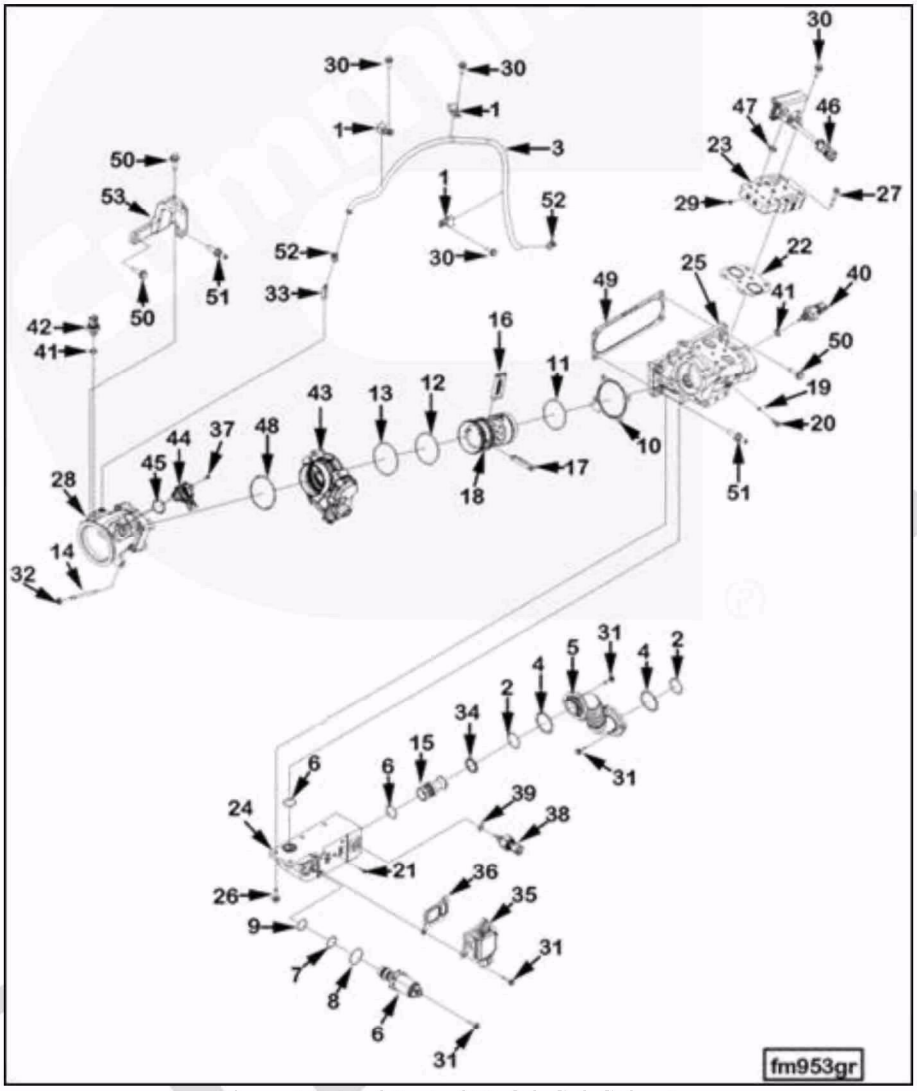


Figure 1-1: Fuel Control Module Sub-Subsystem

(Source: Cummins parts website https://quickserve.cummins.com/info/index.html)

Once the sub-subsystems were identified in the FEV BOM template, they were further broken down to the assembly level by FEV. Using the expanded parts view above, individual assemblies were broken out as shown in the example below.

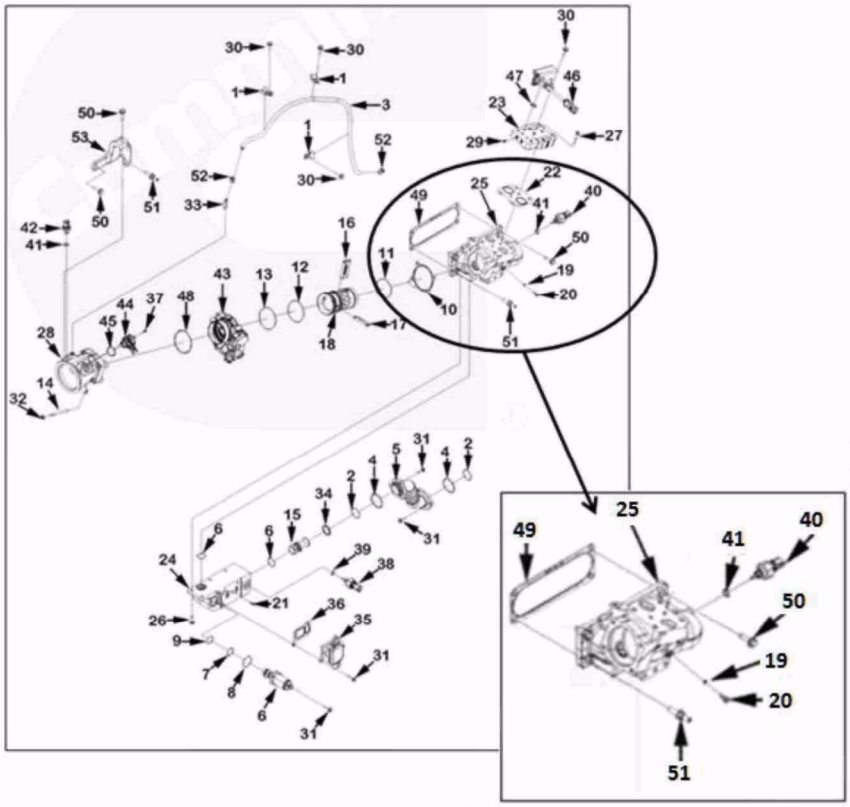


Figure 1-2: Intake Manifold Cover Assembly

(Source: Cummins parts website https://quickserve.cummins.com/info/index.html)

Costing Level Identification:

Once all the parts were identified, the costs could be broken down into the system, subsystems, and sub-subsystem, assembly and component levels.

Level 1. System: The first set of digits describes the system / vehicle level – Example 01 is the Diesel system (Base technology) & CNG (new technology) comparisons.

Level 2. Subsystem: The second set of digits describes the subsystem level – Example 01-01 would identify the 01 CNG/Diesel systems and the 01-01 Cylinder block subsystem.

Level 3. Sub-subsystem: The third set of digits describes the sub-subsystem level – Example 01-01-01 would identify the 01 CNG/Diesel systems, the 01-01 Cylinder block subsystem and the 01-01-05 Cyl block plumbing sub-subsystem.

Level 4. Assembly: The fourth set of digits describes the assembly level – Example 01-01-

05-01 would identify the 01 CNG/Diesel systems, the 01-01 Cylinder block subsystem and the 01-01-05 Cyl block plumbing sub-subsystem and the 01-01-05-01 Threaded plug assembly.

Usage: At the end of the description one of the following was used to clarify how it is to be used.

- CNG or Diesel only
- No Costing/Identical

Costing Level Summary Example:

Level 1. 01 Diesel/CNG Systems– (SCMAT - System Level Roll Up)

Level 2. 01-01Cyl block subsystem – (SSCMAT - Subsystem Level Roll Up)

Level 3. 01-01-01 Cyl block sub-subsystem – (SSSCMAT – Sub-subsystem Level Rollup) No Costing/Identical

01-01-02 Front gear housing sub-subsystem – (SSSCMAT – Sub-subsystem Level Rollup) No Costing/Identical

01-01-03 Cyl liner sub-subsystem – (SSSCMAT – Sub-subsystem Level Rollup) No Costing/Identical

01-01-04 Crankshaft sub-subsystem – (SSSCMAT – Sub-subsystem Level Rollup) No Costing/Identical

01-01-05 Cyl block plumbing sub-subsystem – (SSSCMAT – Sub-subsystem Level Rollup)

Level 4. 01-01-05-01 Threaded plug assembly – (MAQS & SSSCMAT (Subsystem Level Roll Up) CNG Only

1.5 Case Study Hardware Evaluated

For the CNG/Diesel analysis, the Cummins quick serve online web site was used to evaluate the differences between the two internal combustion engines:

- The Cummins ISXG11.9 liter CNG spark plug ignition
- The ISX11.9 liter compression ignited Diesel engine

The team used an International Class 8 Diesel truck onsite at FEV for the Diesel fuel tanks, After-treatment system and all associated hardware evaluation. The team then used a combination of quoting models developed by FEV and reference quotes from Mainstay Fuel Technologies® for quoting the CNG storage tanks and fuel module system with all the associated hardware.

In reviewing the two engines, there were some accessory differences that were not related to this study and therefore were not quoted.

In any questionable cases, published service and internet documentation was used to support the team's assumptions on the differences between the two technology configurations.

1.6 Case Study Discussion and Result Layout

Results for the CNG/Diesel comparison are provided within each report section. Discussion topics include:

- **Technology:** A brief description of the technology under comparison is discussed.
- **Key Hardware Overview:** A high level overview of key hardware content is included for the technology evaluated.
- **Manufacturing Cost Impact:** The increment direct manufacturing cost impact is generally summarized at a subsystem and/or system level Cost Model Analysis Template (CMAT). For subsystems and systems in which there were both CNG and Diesel technology costs, the Diesel technology costs are subtracted from the CNG technology costs developing the incremental direct manufacturing cost. In subsystem and systems where there are no Diesel costs (i.e., credits to offset CNG technology costs), the CNG technology direct manufacturing costs are the incremental direct manufacturing costs.

Because a case study consists of a large quantity of component and assembly Manufacturing and Assumption Quote Summary (MAQS) worksheets, hard copies were not included as part of this report. However, electronic copies of the MAQS worksheets, as well as all other supporting case study documents (e.g., Subsystem CMATs, System CMATs), can be accessed at http://www.epa.gov/otaq/climate/publications.htm.

2. CNG/Diesel Cost Analysis

2.1 Vehicle & Cost Summary Overview

Both the Diesel baseline (i.e., conventional vehicle system) and CNG new technology configuration (i.e., CNG vehicle system) utilized the same size family engine. The engine blocks are identical but the heads were slightly different. The main engine hardware differences include the CNG spark ignited engine technology as opposed to the conventional compression Diesel ignition and the new CNG technology added an ignition control module to the CNG engine for the ignition coils which replaced the Diesel engines injector system.

The fuel systems are the main difference between the two engines, as CNG requires no fuel pump or primer system but does require a fuel control module with pressure regulator valves.

3. CNG Vehicle Hardware Overview

A compressed natural gas vehicle is powered by the combustion of Compressed Natural Gas

(CNG) as an alternative to other fossil fuels. CNG is a cleaner burning fuel, significantly reducing reducing carbon and particulate emissions during vehicle operation when compared to a gasoline or Diesel vehicle equivalent.

The two common types of natural gas used today are CNG (compressed natural gas) and LNG (Liquefied natural gas). For this study CNG was used.

Figure 3-1 provides an overview of the typical CNG gas supply. CNG is piped in direct from the local utility company, then through a dryer to the compressor and is then stored on site. This allows for easy fill from the tank directly into the vehicle.

Note: Fast Fill stations require storage for the compressed natural gas while Slow Fill overnight systems do not require storage systems.

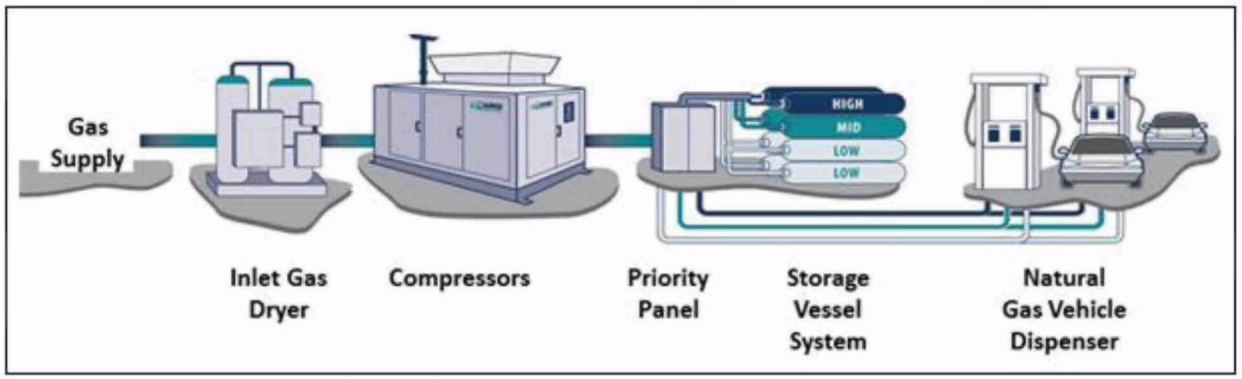


Figure 3-1: CNG Gas Supply Overview

(Source: http://cngcenter.com/wp-content/uploads/2013/05/164449_ANGI_Fastfill_diag_v1.jpg)

The fuel tanks are another area where big differences are apparent. The CNG system requires high pressure storage tanks, sometimes mounted on the back, top or side rail depending on the application and distance needed for the truck to travel. In some cases, two or more of the configurations can be used on the same vehicle to meet long distance requirements.

The Diesel systems have side mounted tanks that store liquid Diesel fuel. The Diesel fuel system also has an SCR (Selective Catalytic Reduction) system with urea unit for After-treatment of the Diesel exhausts and will be further discussed in the Diesel section. The CNG systems do not require the SCR unit.

The exhaust system also has some differences due to the CNG not requiring a SCR to reduce oxides of nitrogen emitted from engines. The CNG system uses a catalytic converter system. The differences in the engines, fuel systems and exhaust will be examined in detailed in their respective sections.

An overview of the CNG system is shown in .

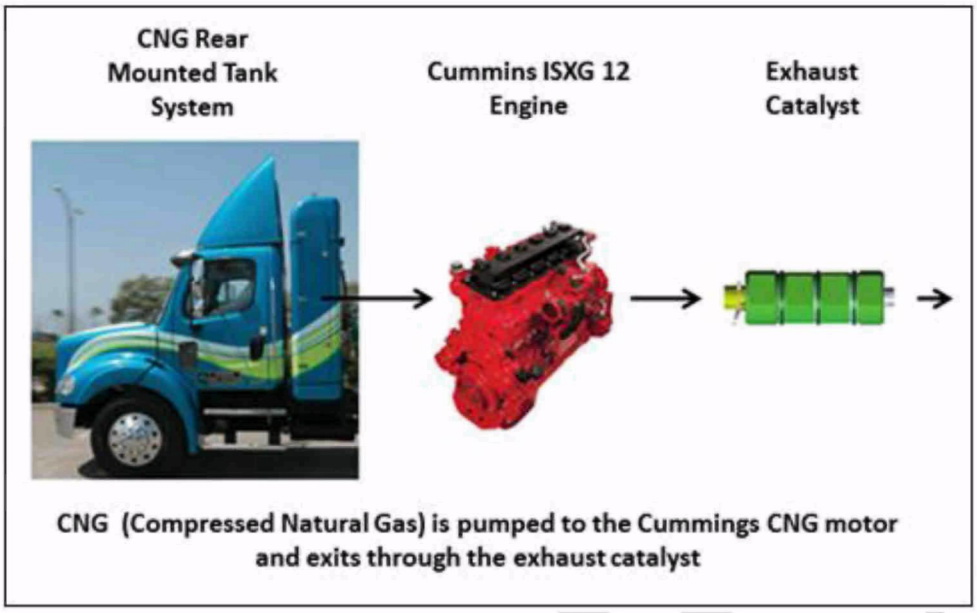


Figure 3-2: CNG System Overview
(Source: Tank picture from www.vehicleservicepros.com
Engine picture from Cummins web site http://www.cummins.com
Exhaust Catalyst picture from http://www.cleanvehicle.org/committee/pdfs/ILTA-NGVs_liquid_fuel_terminals_8_2_2013Final.pdf)

Figure 3-3 overviews the spark plug coil. Putting ignition coils directly over each spark plug eliminates the need for high voltage spark plug cables. The use of Coil on Plug systems also provides additional benefits, such as packaging, emissions, performance, and maintenance.

Using separate coils for each cylinder gives each coil more time to recharge between firings which lead to fewer misfires, greater fuel economy and cleaner combustion.

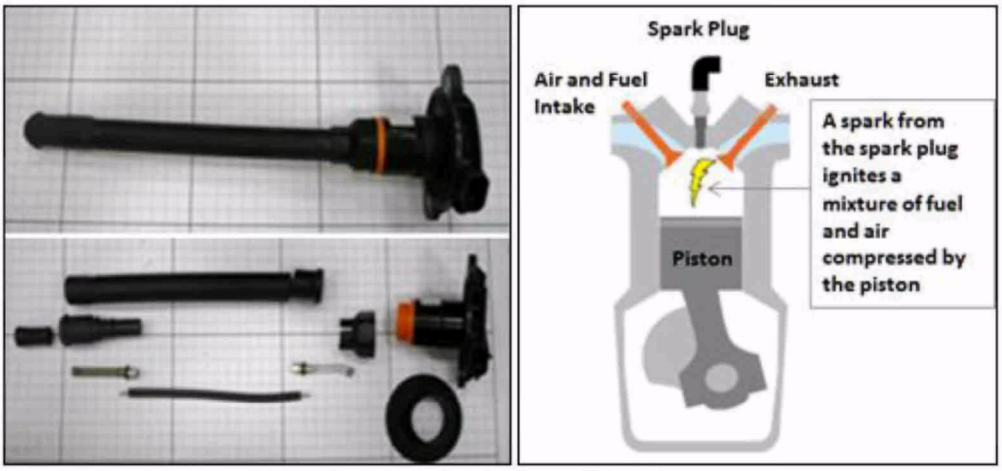


Figure 3-3: Spark Plug Coil Overview
(Source: FEV)

The fuel can be either Compress Natural Gas (CNG) or Liquefied Natural Gas (LNG). For this study CNG will be used. The CNG systems offer a low emissions alterative to the Diesel engine that needs an extensive After-treatment system for the exhaust. Figure 3-4 provides a detailed

picture of the CNG fuel system.

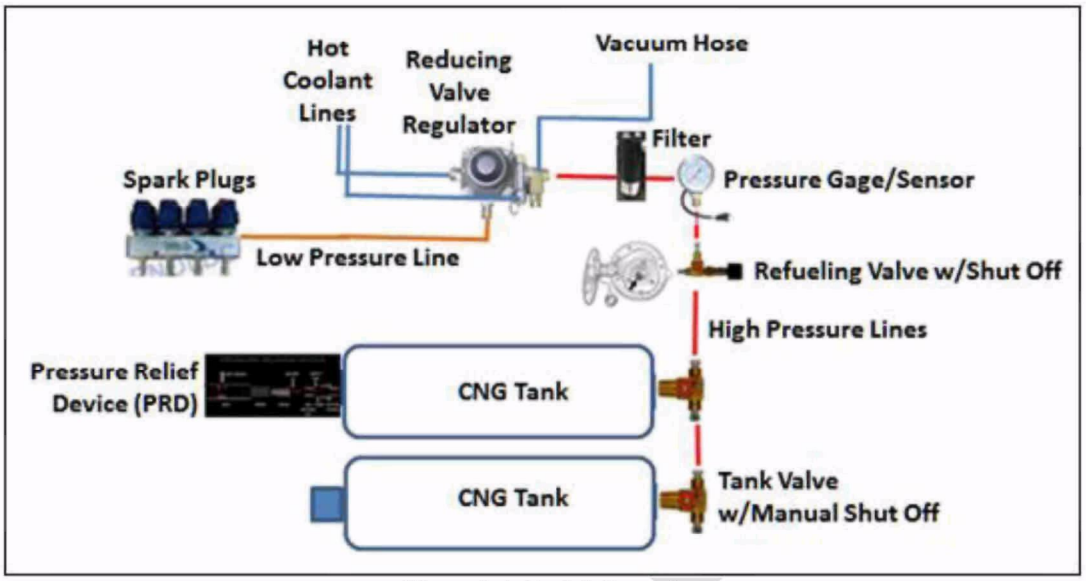


Figure 3-4: Fuel & Controls
(Source: Cummins Westport brochure)

3.1 CNG System Hardware Overview

The CNG system consists of the 3 subsystems:

1. Five type 3 CNG fuel tanks
   1.1 The back of cab CNG tank enclosure
   1.2 CNG system fuel module
2. Cummins ISX12G CNG engine
3. Exhaust 3-way catalyst

3.1.1 CNG Fuel & Fuel Tanks

The CNG system tank and enclosures can be different configurations depending on the needs and usage of the system. This study focuses on Class 8 vehicles which can use a variety of tank systems. Some vehicles use tanks made of steel and mounted to the top while others use side saddle mounted tanks in place of the standard Diesel tank, but the most widely used system for long hauling is the behind cab mounted tanks and enclosure.

In addition to the various cab mounts, some companies are looking at putting the tanks on the trailer and not the cab. Figure 3-5 shows some of the CNG tank configurations.

Figure 3-5: CNG Tank Mounting Overview

(Source: http://en.wikipedia.org & http://www.showtimesdaily.com & http://www.truckinginfo.com)

Using gases instead of liquids for vehicles is not a new concept. During World War I and especially during World War II, liquid gases were very hard to obtain so inventive solutions were required. One of them was gas bag vehicles. Countries like England, France, Germany, and the Netherlands used what was known as "town gas" or "street gas" on cars, trucks and buses. This gas was made from a by-product left over from the process of turning coal into coke which was used to make iron. The result was a non-compressed gas that could be filled at street side fueling stations. Figure 3-6 shows some of the cars, trucks, and buses of the day and a fueling station.

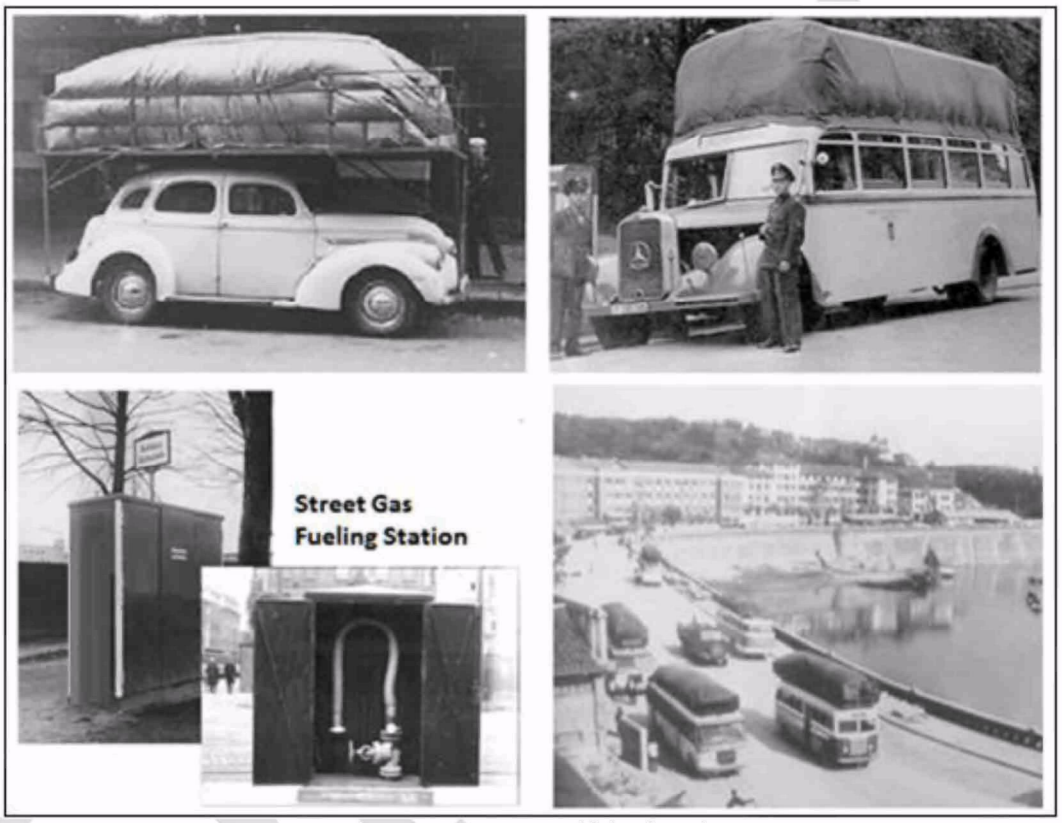


Figure 3-6: Gas Bag Vehicles Overview
(Source: http://www.lowtechmagazine.com/2011/11/gas-bag-vehicles.html)

3.2 CNG Fuel Tank Overview

There are four types of CNG fuel tanks typically used today as shown in Figure 3-7. This is due to the various application usages and the weight of the tank. The tank size can also be a usage factor due to the space restrictions or mileage requirements.

The one piece A6061 aluminum liner with a full carbon and or fiberglass wrap is one of the most common tanks in use today.

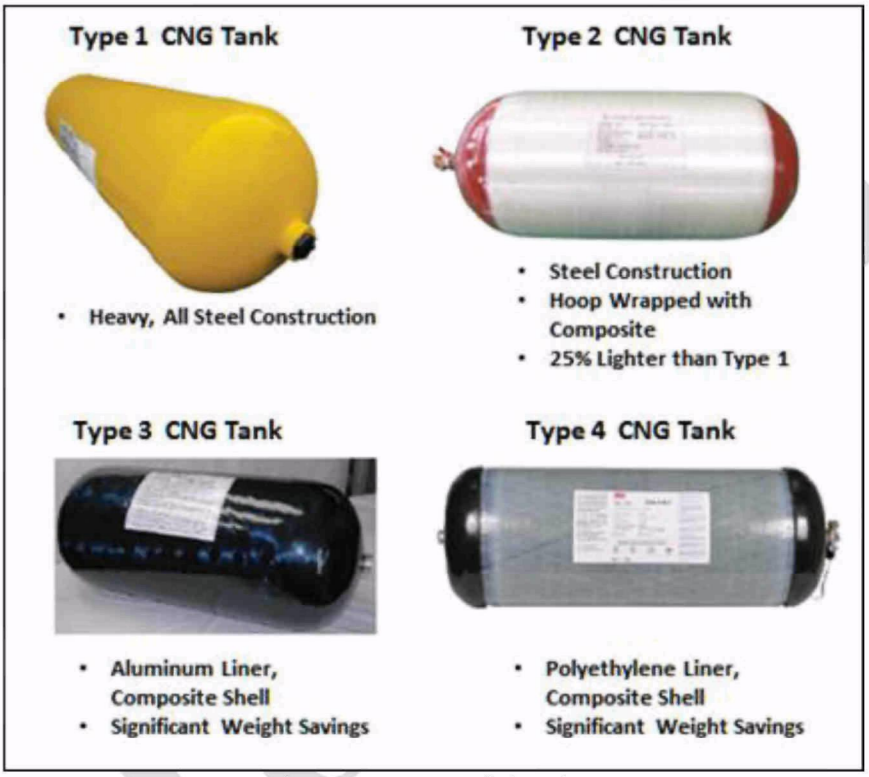


Figure 3-7: CNG Tank Overview
(Source: http://server405.webhostingpad.com/~cngpitst/wp-content/uploads/2014/01/04-Tanks.jpg)

The construction of the four types of tanks varies as much as the tanks themselves. The tanks life span is also a factor as tanks produced after 2007 have a 20 year life span and anything before 2007 is only 15 years.

Figure 3-8 shows the construction layers of the tank.

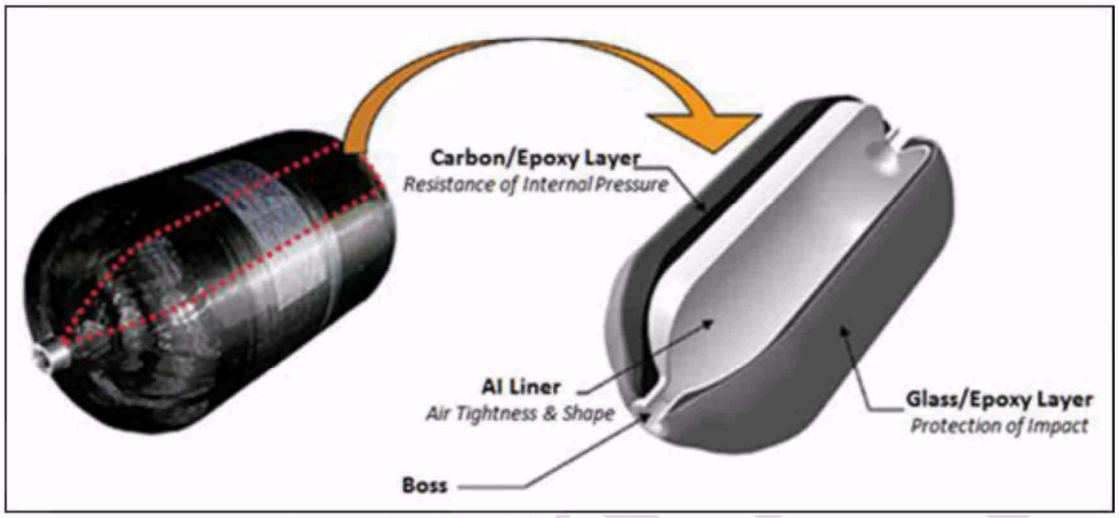


Figure 3-8: CNG Tank Construction Layers Overview
(Source: http://www.metal-mate.com/web/dinsorweb/en/product.php?name=ngv_cylinder)

The construction steps are not always the same for each manufacturer, but the images in Figure 3-9 display the general steps as listed below.

1. Ultra sonic scanning of tube
2. Fixture a seamless 6061 aluminum tube on the roll forming machine
3. Apply a small amount of heat and start roll form process
4. Anneal/heat treat
5. Apply carbon fiber or fiber glass wrap (sometimes both)
6. Cure of wrap
7. Leak/pressure test
8. Machine boss ends

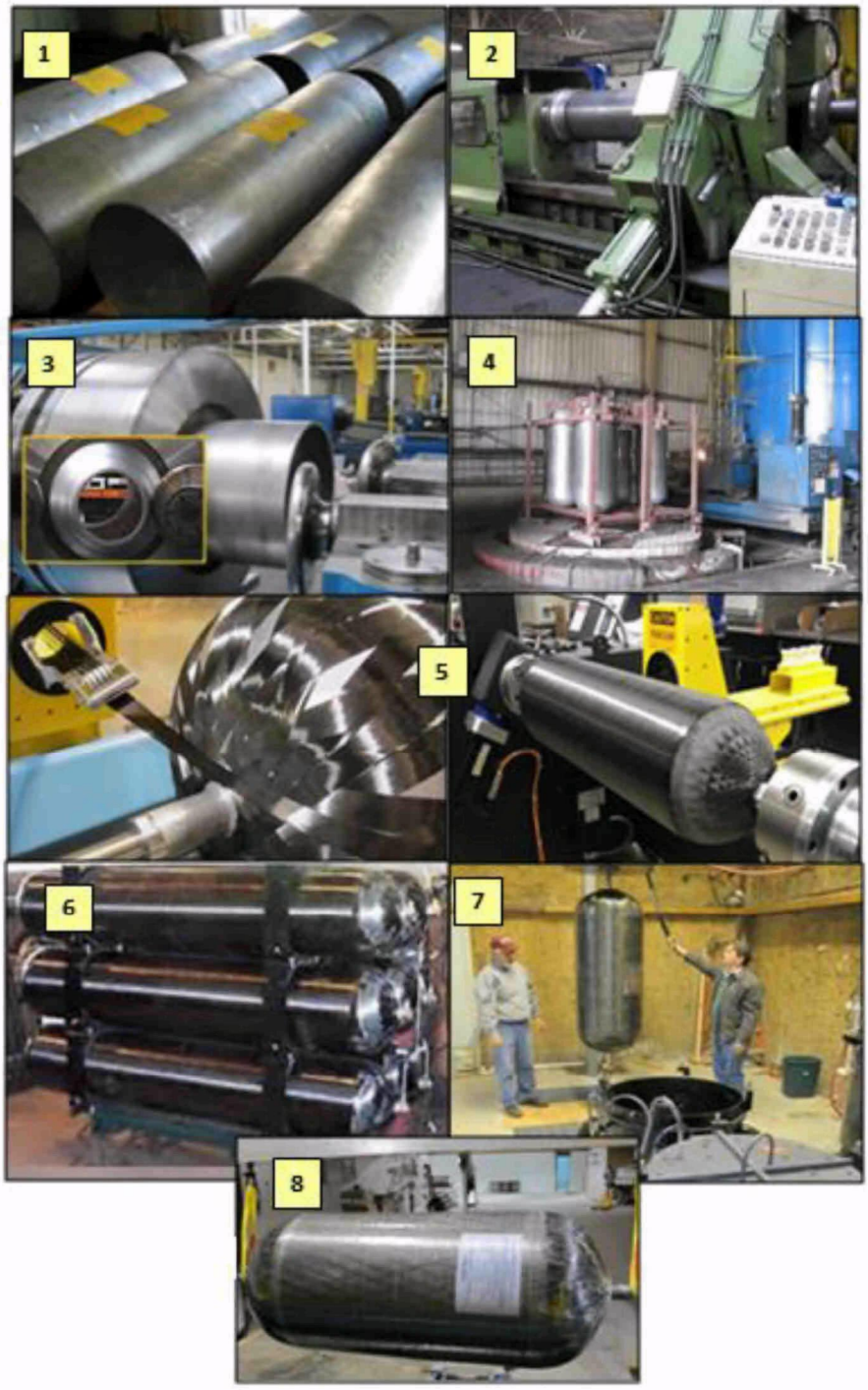


Figure 3-9: Construction Steps For Type 3 CNG Tanks
(Source: http://www.youtube.com/watch?v=-NDvGYfwTxs & www.fibacanning.com)

A 120 gallon Diesel tank contains approximately 112.89 useable gallons of fuel. This is a .059322% reduction of fuel to the total tank capacity. The Diesel system average is about 6 miles per gallon of Diesel fuel.

For this study, a type 3 tank was used and is rated for 3600psi and tested at 5500psi.

To get equal mileage from a CNG system when compared to a Diesel fuel system, the CNG required five fuel tanks as opposed to two 120 gallon Diesel fuel tanks. Table 3-1 shows the capacity and usability assumptions.

Table 3-1: Diesel/CNG Usage Table

Fuel	Tank size (mm)	Useable fuel in gal. or DGE*	Qty of tanks	Total useable fuel	Miles per system	Drive time per system @ 60 miles per hour
Diesel	120gal.	112.89	2	225.78	1354.68	22.58
CNG	635dia x 2032lg	40.60	5	203.00	1218.00	20.30

** DGE for the CNG fuel was provided from the tank manufacturer for the 25" x 80" CNG tank.*

- **GGE** - Gasoline Gallon Equivalent (aka: GEG – Gasoline Equivalent Gallon) is the amount of alternative fuel it takes to equal the energy content of one liquid gallon of standard gasoline. 1 GGE = 0.88 DGE

- **DGE** – Diesel Gallon Equivalent is the amount of alternative fuel it takes to equal the energy content of one liquid gallon of Diesel gasoline. Diesel has a higher energy content than gasoline (129,500 BTUs standard). 1 DGE equals 1.136 GGE.
- **Calculation** – To calculate the gallons of DGEs (diesel) in any quantity of GGE (CNG), divide the total GGE by 0.88. For example, 200 GGE would equal 227.272 DGE.

The CNG tanks are piped together inside the enclosure through a piping system to a main header as shown in Figure 3-10. This allows the system to achieve a better fill time.

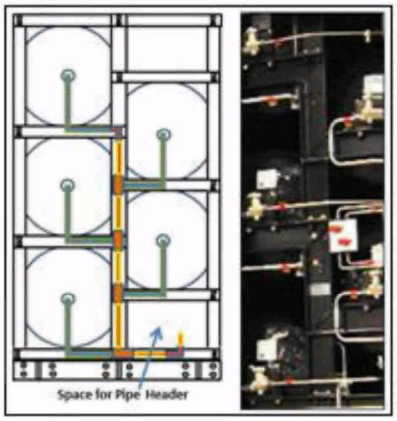


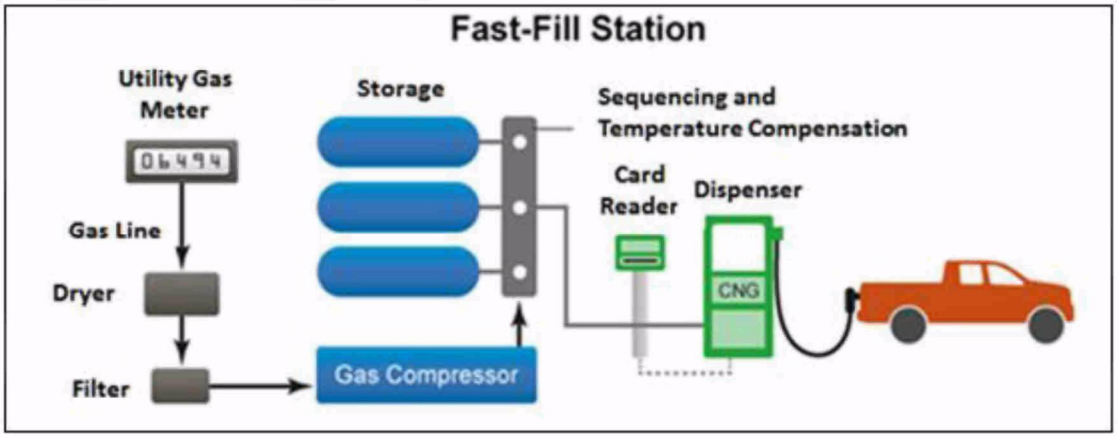
Figure 3-10: CNG Tank Piping System Overview
(Source: FEV& http://www.mcicoach.com/public-sector/publicCng.htm)

Tanks can be filled in two ways as shown in the following illustrations:

- **Fast:** Typically fills a 125 DGE (Diesel gallon equivalent) tank system in about 10 minutes, but as the gas is pumped into the tank the temperature increases making the gas expand. This pressure buildup reduces the amount of fuel that can be put into a tank during a fast fill. The loss is about 25%, as compared to a slow fill process.

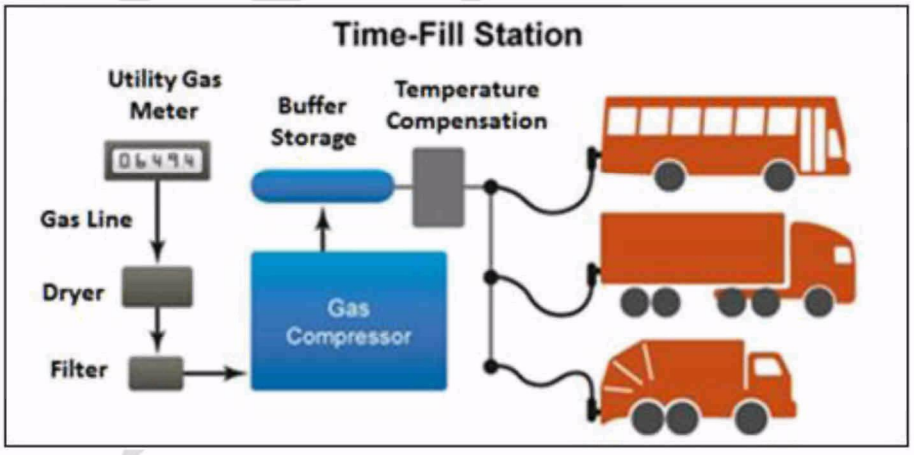
  Fast fill configurations require a compressor to store the CNG at pressures up to 5000psi in a properly rated storage tank. (In the following Fast Fill illustration, the storage tanks can be seen in the left background.) Fast-fill stations are more like regular gas stations, in that fuel is dispensed into the fuel tanks the same as if regular gas were being used and it takes about the same amount of time. Typically there is a conventional dispensing unit similar to a standard gas station with a card reader for dispensing and paying transactions.

Figure 3-11: Fast Fill CNG Fuel Station (3 Pump Capacity)
(Source: http://trilliumcngblog.com/2015/02/25/amp-trillium-opens-jacksonville-floridas-first-public-access-compressed-natural-gas-station/*)*



- **Slow:** Typically an overnight process also known as a Time Fill, the slow fill method will allow more CNG fuel to be dispensed into the tanks without the pressure buildup. The slow fill system can be configured to dispense the required amount of fuel within a specific period of time or the vehicle can be hooked to the overnight fueling station and allowed to fill at the standard dispensing rate with no human attendance required.

Figure 3-12: Slow Fill CNG Fueling Station (10 Pump Capacity)
(Source: Pensacola Energy, Emerald Coast Utilities Authority (ECUA): www.government-fleet.com)



This study assumes that after twenty hours of continuous driving the vehicle will be parked overnight for a CNG Slow fill.

With the current national average cost of $2.11 per DGE for CNG fuel and the current national average cost of Diesel fuel at $3.89 per gallon, CNG is 54% cheaper in cost. The cost savings is significant when spread over 200 gallons and will save approximately $356.00 [2] as shown in Table 3-2.

Table 3-2: Diesel/CNG Fuel Savings Table

Fuel	Avg. cost per gallon	Total gallons	Total fuel cost	Total fuel savings per fillup
Diesel	$3.89	200	$778.00	$356.00
CNG	$2.11	200	$422.00	

Does not include CNG system investment costs

For safety, each tank has a temperature and pressure relief valve and a manual safety shut off. Depending on the manufacturer, there are two possible configurations for these safety mechanisms. Either setup is acceptable.

- The tank may have both the safety shut off and temperature and pressure relief valve combined on one end of the tank.
- The tank may have the safety shut off on one side and the temperature and pressure relief valve on the other.

A CNG Shutoff & Pressure/Temperature Valve is illustrated in Figure 3-13.

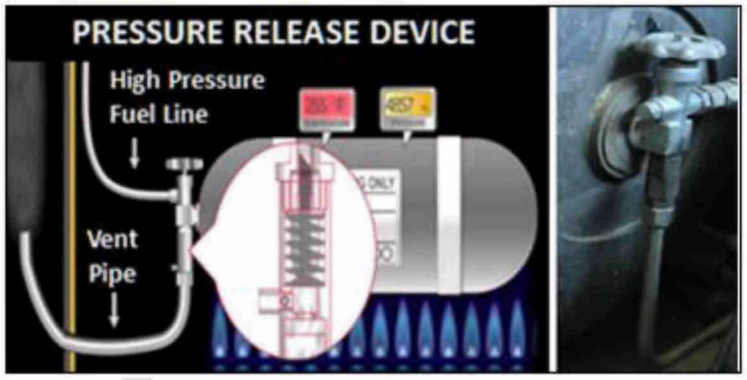


Figure 3-13: CNG Shutoff & Pressure/Temperature Valve Overview
(Source: http://www.afdc.energy.gov/fuels/natural_gas_cng_stations.html)

The CNG system in this study used five type 3 tanks that were 635 mm dia. x 2032 mm lg. each. Each tank supplied the equivalent of 40.6 Diesel gallons of fuel and weighed 187 kg empty and 265 kg full. The total weight for all five tanks was 937 kg empty and 1326 kg when filled with CNG fuel.

[2] U.S. Energy Information Administration – "Gasoline and Diesel average prices, updated monthly", accessed on June 2014, http://cngnow.com/average-cng-prices/pages/default.aspx

3.3 CNG Fuel Tank Enclosure Overview

The enclosure for the CNG fuel tanks was approximately 2286 mm L x 2286 mm H x 1270 mm D and made from a steel angle iron bottom cradle with an upper aluminum structure, surrounded by 6061 aluminum screwed on to the plate skin. The enclosure also had an access door and venting. The enclosure bolted to the truck frame rails which allowed a sleeper cabin to be mounted behind the cab. The enclosure weighed approximately 588 kg without tanks.

Figure 3-14 illustrates the rear cab mount configuration.

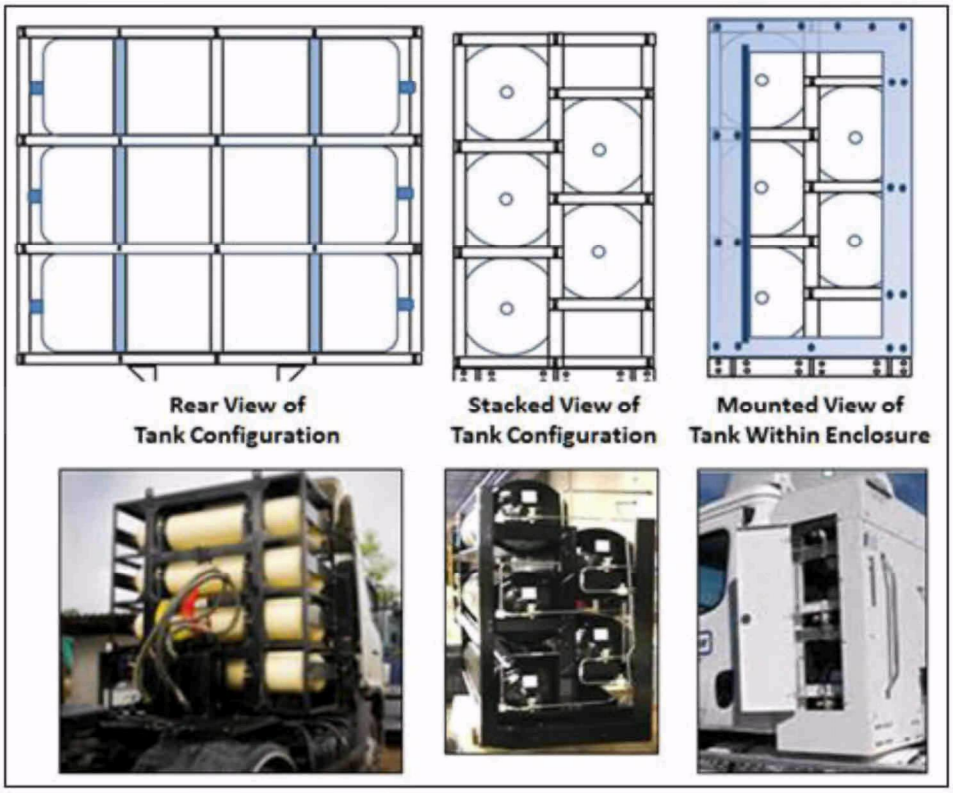


Figure 3-14: CNG Rear Cab Mount Configuration
(Source: FEV & http://www.kenworth.com/news/news-releases/2013/october/paper-transport.aspx & http://www.watsoneng.com/fabricated-metal-parts/ & Dreamstime.com & www.onlinetes.com)

3.4 CNG Fuel Module Overview

The CNG fuel system includes a CNG fuel management module which controls all aspects of the CNG fuel system, including fill, defuel, high/low pressure and monitoring.

The module consists of:

- Coated steel enclosure with product schematic and warning labels
- Large fast fill receptacle
- High and low pressure gages
  - 2-way emergency shut-off ball valve

  - Defueling receptacle
- 12.7 mm stainless steel high and low pressure tubing
- 12.7 mm stainless steel high pressure check valve
- High pressure coalescing filter with purge/bleed valve
- High pressure CNG regulator with coolant line connections 110psi
- Solenoid valve with electrical wiring
- 12 pin Deutsch wiring connector
- Pressure transducer with 8-32 VDC input &. 5-4.5 VDC output

Some modules are integrated into the tank enclosure and some are mounted to the frame rails as standalone modules. The module used for this study is a stand-alone unit, mounted to the frame rail and purchased from Mainstay Fuel Technologies®.

The module includes a pressure regulator. The fuel enters the module at a pressure of 3600 psi and is then reduced down to 70 psi min/150 psi max for typical engine operation. In cold temperatures, the pressure regulator is protected from freezing by warm engine coolant which is circulated through the module.

Figure 3-15 provides an overview of the CNG fuel management module.

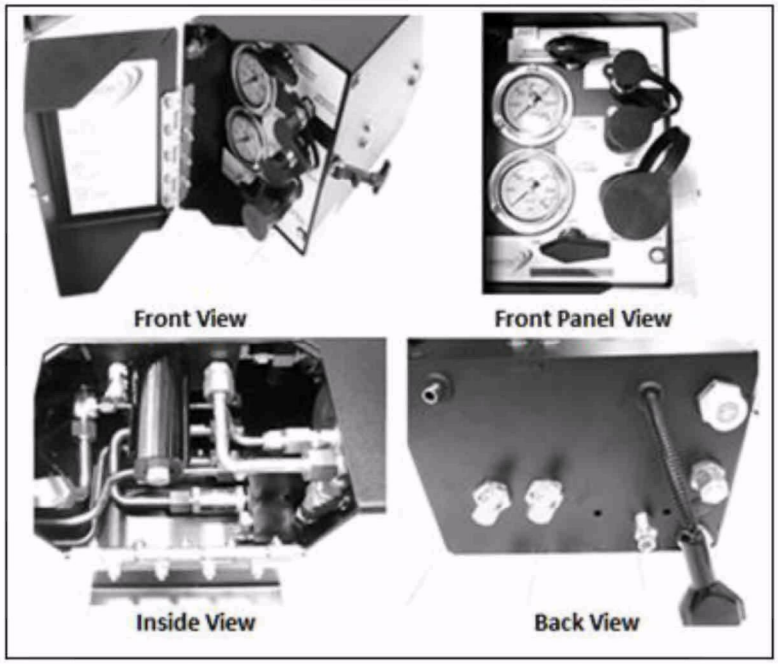


Figure 3-15: CNG Fuel Management Module Overview
(Source: FEV)

3.5 CNG Engine Overview

The Cummins ISX12G 11.9 liter CNG engine was introduced in 2012 and went into production in 2013 and is currently manufactured in Jamestown, New York. The engine is a factory built dedicated natural gas engine for heavy duty truck applications. The most optimal setup for CNG fuel economy is to have the ISX12G geared to cruise at a 1400-1500 rpm range. Also for regional hauling 80,000 lbs gross vehicle weight or less is recommended. The ISX12G is based on the Cummins ISX12 Diesel engine platform as shown in Figure 3-16.

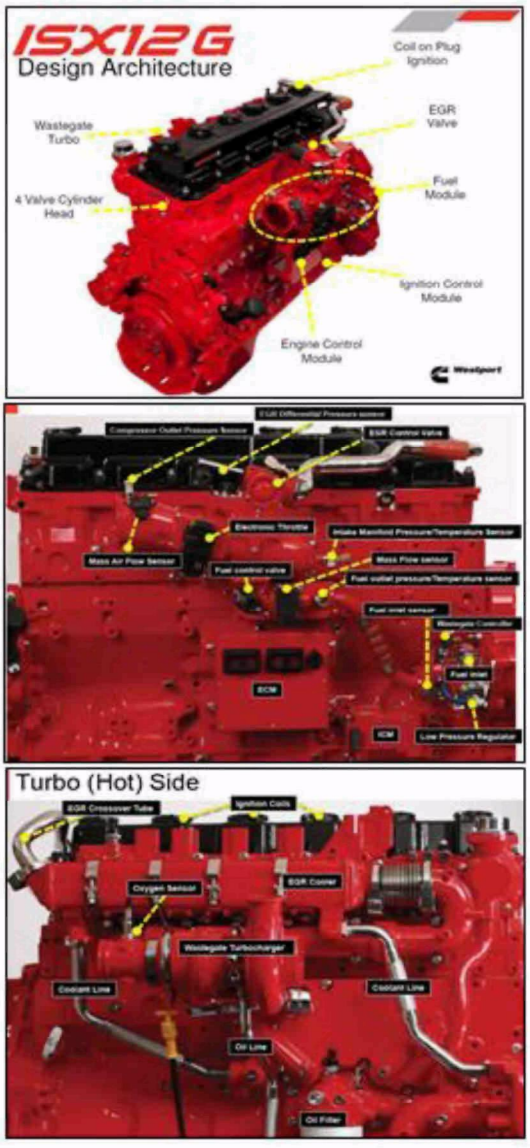


Figure 3-16: Cummins ISX12G Engine Overview
(Source: Cummins)

The ISX12G can operate on either CNG (Compressed Natural Gas) or LNG (Liquid Natural Gas). Additionally, the engine was designed to also run on 100% Bio-methane.

In both CNG and LNG fuel systems, an automatic shut-off valve opens in the key "ON" position and closes when the key is in the "OFF" position.

LNG is a compressed natural gas that is cryogenically cooled to below -250°F (-157°C) at which point, it condenses into a liquid form. Due to LNG cold storage temperature requirements, the onboard tanks must be comprised of double walled, vacuum insulated stainless steel.

If the fuel temperature rises, the LNG will begin to expand causing the pressure in the tank to rise which will then cause the tank to vent. Because of the extreme cold temperatures of LNG, fueling operators must wear protective gloves, eye wear and clothing, to prevent freezing burns.

Because LNG is odorless and does not include mercaptin – the "skunk" smell added to pipeline natural gas, a methane detection system is also required.

The Cummins Westport's ISX12G engine has a proprietary spark ignited Stoichiometric cooled Exhaust Gas Recirculation (SEGR) combustion technology which was first introduced with the 8.9 liter ISLG engine. The primary engine specifications are listed in Table 3-3.

Table 3-3: Isx12 G Specifications

Maximum Horsepower - 400 HP (298 kW)
Peak Torque - 1450 LB-FT (1966 N•m)
Governed Speed - 2100 RPM
Clutch Engagement Torque - 700 LB-FT (949 N•m)
Type
Engine Displacement - 726.2 CU IN (11.9 LITERS)
Bore and Stroke - 5.11 IN x 5.91 IN (130 MM x 150 MM)
Operating Cycles - 4
Oil System Capacity - 12 U.S. GALLONS (45.4 LITERS)
Coolant Capacity - 26.5 U.S. QUARTS (25.1 LITERS)
System Voltage - 12 V
Net Weight (Dry) - 2,650 LB (1,202 K)
Fuel Type CNG/LNG/RNG
After-treatment Three-Way Catalyst (TWC)
4-cycle, spark-ignited
In-line 6-cylinder
Turbocharged, Charge Air Cooler (CAC)

(Source: http://www.cumminswestport.com/content/506/Cummins%20Westport%20ISX12%20G%20Brochure%20-%204971420_0313.pdf)

3.6 CNG Exhaust 3-Way Catalyst Overview

Natural gas engines burn cleaner and generate fewer pollutants and require only the use of a three-way catalyst (TWC) which is maintenance free, much like a typical car, just a little bigger. Unlike diesel, the CNG system does not need a DPF (Diesel Particulate Filter) or a SCR (Selective Catalytic Reduction) unit. The 3-way catalyst uses a metallic or ceramic substrate with coatings of alumina, ceria, other oxides and precious metals such as platinum, palladium and rhodium and an oxygen sensor to regulate the air-fuel ratio on engines. The catalyst can then oxidize CO and HC to CO2 and water, while reducing NOx to nitrogen. Figure 3-17 shows an example of a TWC unit.

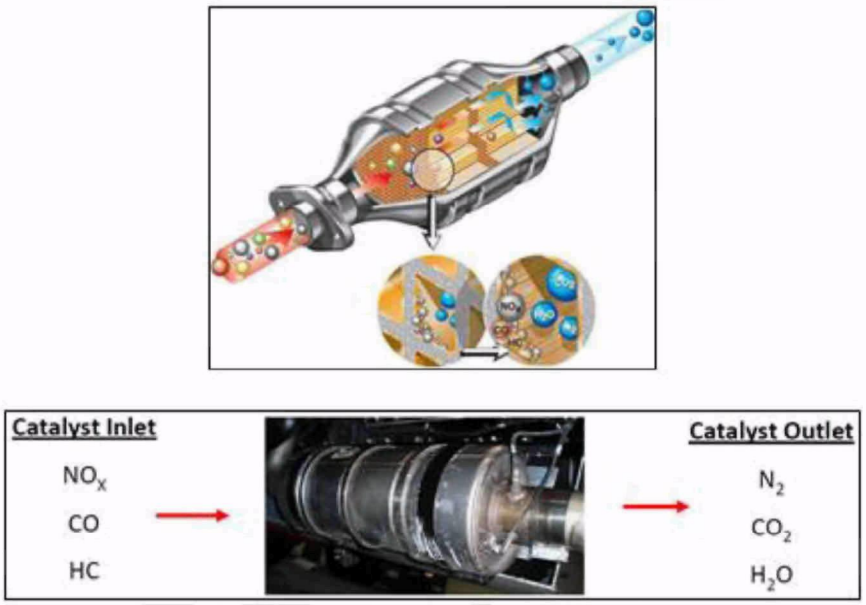


Figure 3-17: Exhaust 3-Way Catalyst Overview

(Source: http://www.airquality.org/mobile/ctf/Events/20090915-2010Tech-CumminsNG.pdf & http://www.preciousmetals.umicore.com/recyclables/SAC/CatalyticConverter/)

4. Diesel Vehicle Hardware Overview

German inventor Rudolf Diesel patented the compression ignition engine in 1892 which is the origin of the term "diesel". Diesel engines require a specific type of fuel, the most common being petroleum based (aka: petro-diesel), which is obtained from fossil fuels that are distilled from crude oil. Alternative Diesel fuel can also be obtained from different sources such as animal fat, biomass, biogas, etc. but this is not currently a common practice.

Diesel engines have a number of important advantages over gasoline engines. They provide reliability, long life, and good fuel economy. Diesel fuel is pumped from the fuel tanks through a filtering system to ensure the fuel is clean which prevents clogging of the injectors. Once the fuel reaches the fuel pump, it is pumped into the fuel rail that feeds fuel into the cylinder injectors at high pressure.

The Diesel fuel is then injected into the engine's combustion chamber when that chamber's piston

is near the end of the compression stroke. The high pressure in the chamber ignites the Diesel fuel as shown in Figure 4-1.

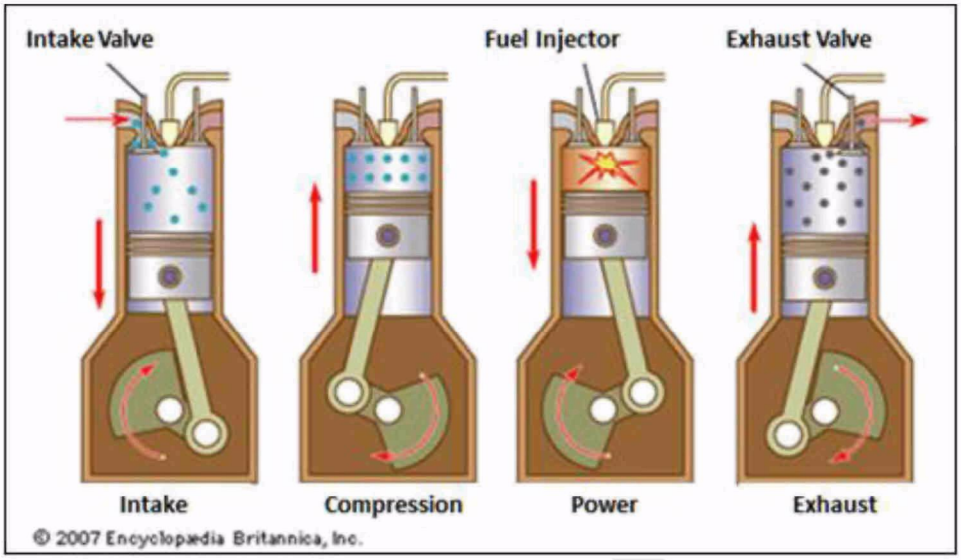


Figure 4-1: Compression Process

(Source: http://chembloggreen1.files.wordpress.com/2012/11/24075-004-613c6f141.gif)

When the fuel has been burned, the exhaust gas exits the combustion cylinder through the exhaust system. The Diesel engine exhaust system requires a DPF (Diesel Particulate Filter) or a SCR (Selective Catalytic Reduction) unit to clean the exhaust gas of the harmful pollutants before it is released into the atmosphere.

The Diesel fuel system flow overview is provided in Figure 4-2. As the fuel is pulled from the fuel tank, it passes through a filter/water separator with a 10 micron filter and then through the mechanical lift pump. The lift pump helps the priming and runs for 60 seconds after the key is turned ON. The fuel then passes through the 5 micron fuel filter located on the engine and then enters the injector pump. The system is under low pressure prior to the injector pump.

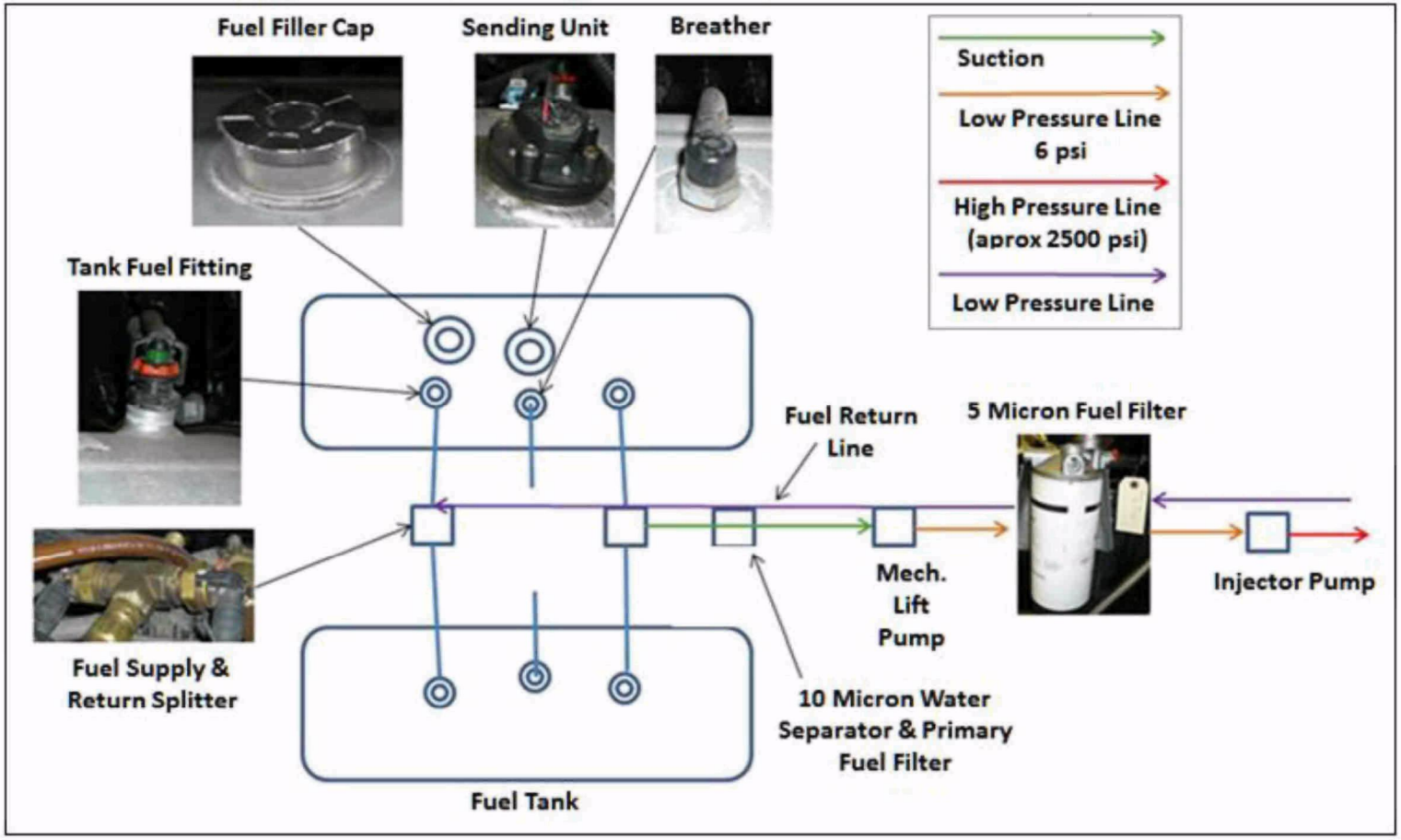


Figure 4-2: Diesel Fuel System Flow Overview
(Source: FEV)

An overview of the Diesel system is shown in Figure 4-3.

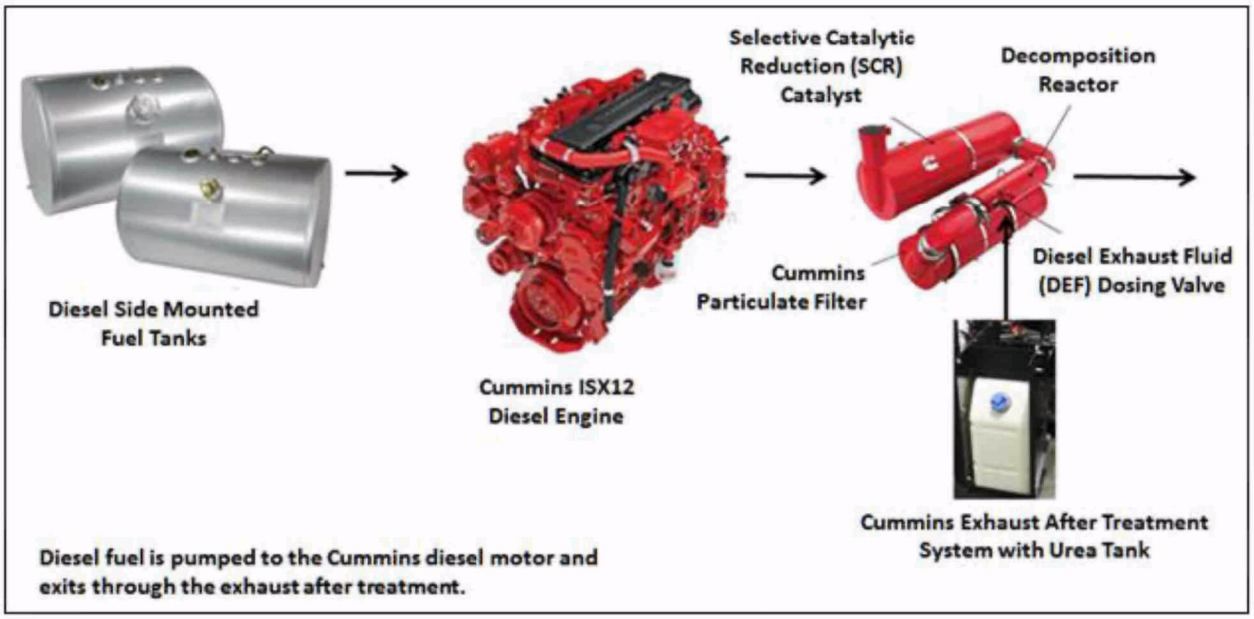


Figure 4-3: Diesel System Overview

(Source: Tank pictures from Cleveland Tank & Supply http://www.clevelandtank.com/aluminum-fuel-tanks.html Engine & After-treatment system pictures from Cummins web site http://www.cummins.com Urea Unit picture from RVcruzer.com http://www.rvcruzer.com)

4.1 Diesel System Hardware

The Diesel system consists of the three (3) subsystems

1. Two (2) 120 gal. Diesel fuel tanks
2. The Cummins ISX12 Diesel engine
3. The exhaust After-treatment

   3.1 Urea tank subsystem

4.2 Diesel Tank Overview

The Class 8 Diesel fuel system for this study consists of two Diesel 120 gallon fuel tanks.

Fuel tanks can be made from steel, aluminum or stainless steel. The most widely used material for fuel tank manufacturing is 5000 series aluminum, specifically 5052, 5083, 5086 and 6061 aluminum. These alloys are more pliable which simplifies the manufacturing process. The pattern for the tank is cut with a laser, plasma or water jet cutter. After the pattern is cut, the tanks holes are typically cut with a punch press. The end caps are manufactured using a stamping press.

The welding of the parts is critical in the tank manufacturing process because there must be good penetration of the welding to ensure a tank will meet the required pressure and leak testing.

While both steel and aluminum have advantages and disadvantages, the aluminum tanks are 75% lighter, less corrosion inside and out, have a longer life span and are better for resale. However, aluminum is more costly than steel.

Figure 4-4 shows some Diesel fuel tank configurations.

Figure 4-4: Diesel Fuel Tank Configurations Overview
(Source: http://www.clevelandtank.com)

4.3 Diesel Engine Overview

The Cummins ISX12 11.9 liter Diesel engine was updated in 2011. The updates allowed approximately a 5% increase in regional hauling fuel savings while increasing the power range through refined calibrations. The engine has a cooled exhaust gas recirculation (EGR) system with a single variable geometry turbocharger unit. The engine's common fuel rail system is part of the Cummins® proprietary XPI system.

Figure 4-5 shows the Cummins ISX12 Diesel engine.

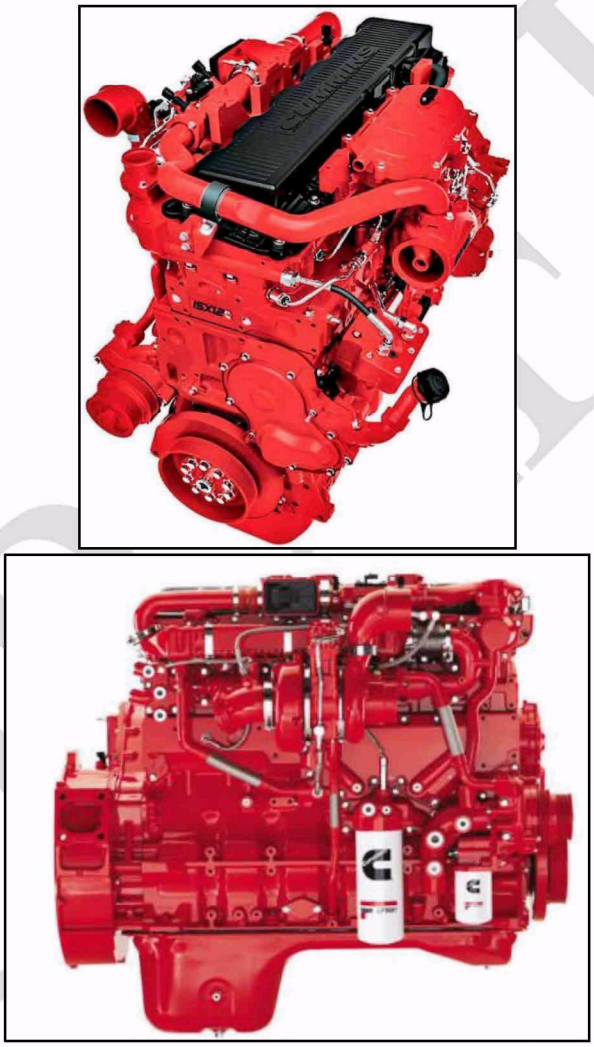


Figure 4-5: Cummins ISX12 Diesel Engine Overview
(Source: Cummins)

The Cummins Westport's ISX12 Diesel specifications are listed in Table 4-1.

Table 4-1: ISX12 Specifications Table

Maximum Horsepower - 425 HP (317 kW)
Peak Torque - 1650 LB-FT (2237 N•m)
Governed Speed - 2100 RPM
Clutch Engagement Torque - 800 LB-FT (1085 N•m)
Engine Displacement - 726.2 CU IN (11.9 LITERS)
Bore and Stroke - 5.11 IN x 5.91 IN (130 MM x 150 MM)
Oil System Capacity - 12 U.S. GALLONS (45.4 LITERS)
Coolant Capacity - 26.5 U.S. QUARTS (25.1 LITERS)
System Voltage - 12 V
Net Weight (Dry) - 2,640 LB (1,197 kg)
Fuel Type: Diesel
After-treatment: Hydrocarbon Doser System/DPF-SCR
In-line 6-cylinder
Turbocharged

(Source: http://cumminsengines.com/isx12-heavy-duty-truck-2013#specifications)

4.4 Diesel Exhaust SCR After-treatment System Overview

In order to reduce Diesel exhaust gas emissions, a system called the Selective Catalytic Reduction (SCR) is used on all Diesel truck applications.

Figure 4-6 is an example of a SCR system.

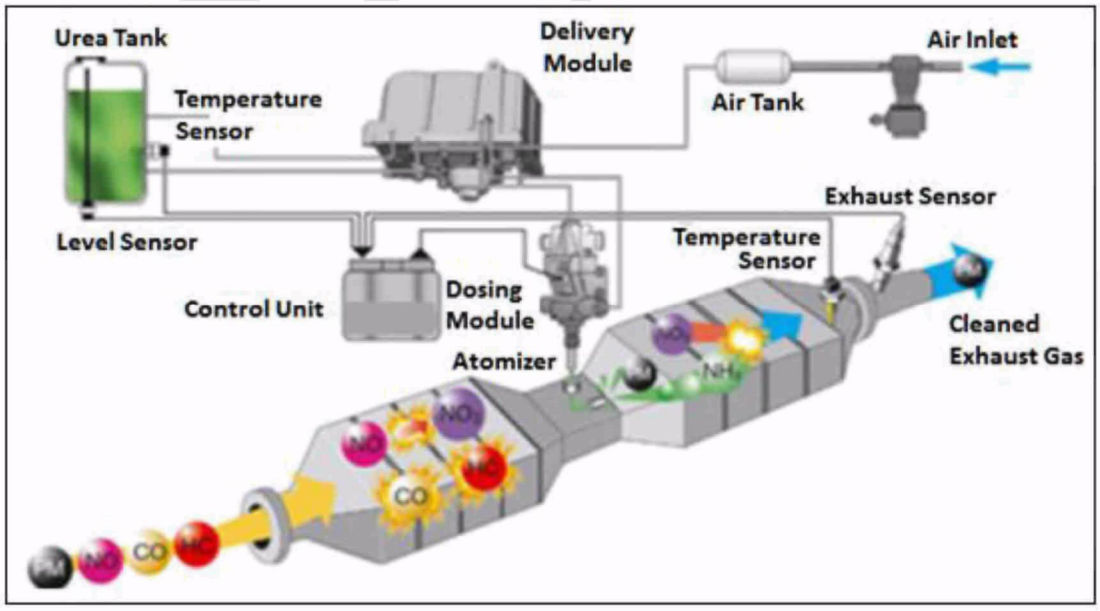


Figure 4-6: SCR System Overview

(Source: http://naftcenews.wvu.edu/naftc_enews/2005/11/07/automakers-consider-urea-injection-to-meet-epa-standards*)*

4.4.1 The Diesel SCR System

The Oxidation Catalyst (DOC) & Diesel Particulate Filter (DPF)

Once the exhaust gas enters the After-treatment system it passes through the Diesel Oxidation Catalyst (DOC). The oxides of nitrogen, hydrocarbons, and carbon monoxide are converted into nitrogen dioxide, carbon dioxide and water. The harmful gases are passed through a cordierite honeycombed brick which is washed with Aluminum oxide. This coating is porous and increases the surface area, allowing more reactions to take place and may contain some precious metals such as platinum, rhodium, and palladium. See Figure 4-7.

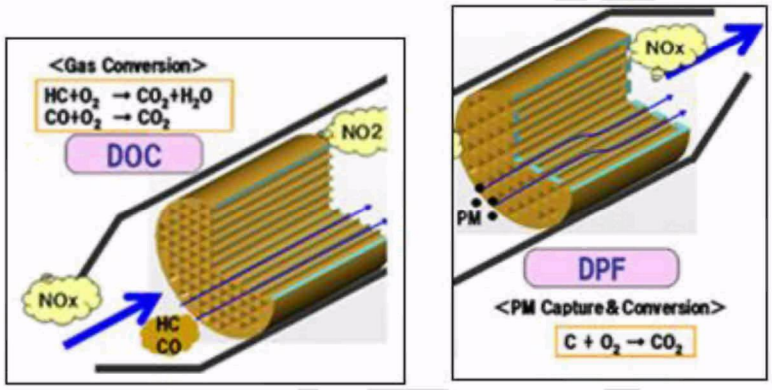


Figure 4-7: Diesel Oxidation Catalyst (Doc)
(Source: http://news.panasonic.com/press/news/official.data/data.dir/en100622-3/en100622-3.html)

The next phase of the After-treatment is done in the same section of this system but this time the gases pass through the Diesel Particulate Filter (DPF).

The DPF is a honeycomb structure with alternate channels plugged at opposite ends. The Diesel exhaust gases pass through the open end of a channel. At the opposite end is a plug that forces the gases through the porous channel wall, allowing the exhaust to escape through the neighboring channel (Figure 4-8) while trapping as much as 90 percent of the solid particle matter (soot). The particulate filters may contain precious metals, but this is not a given.

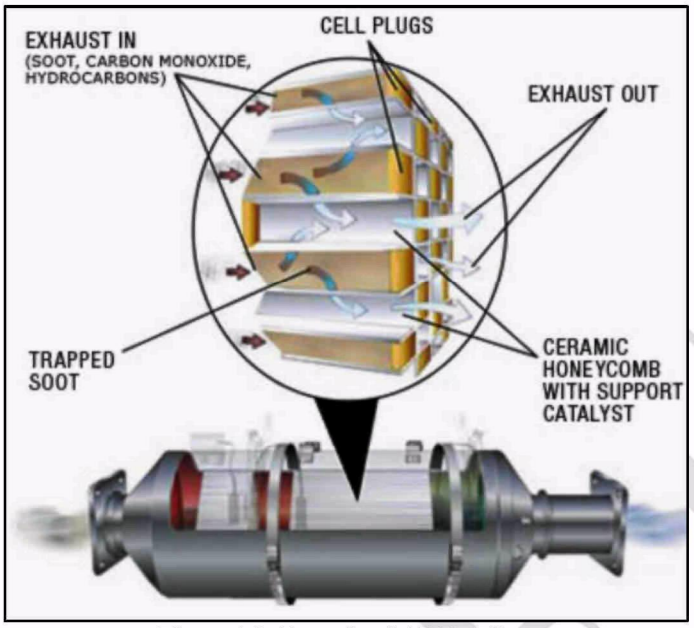


Figure 4-8: Example of A DPF Filter

(Source: http://news.panasonic.com/press/news/official.data/data.dir/en100622-3/en100622-3.html & http://www.demanddetroit.com/parts-service/parts/emissions.aspx)

As particles block the filter, it causes a restriction which creates more back pressure than desired. When this happens, the Diesel Particulate Filter (DPF) must be cleaned. A "regeneration cycle" that reduces the soot to ash is the most common method. There are two ways to do a regeneration cycle.

- **Passive Regeneration:** Soot can be removed by using exhaust heat. Some systems such as Cummins use the truck's own fuel to pump Diesel fuel into the exhaust system.

- **Active Regeneration:** Soot can be removed by using the exhaust heat, but it must be actively started by the operator while the engine is not running. The difference between Passive regeneration and Active regeneration is that active regeneration does not have minimum temperature requirement.

'There are currently two methods verified by CARB, diesel-fired heaters and electrically powered heaters. Diesel-fired units generally cost around $14,000 to $25,000 for single systems (dual systems can be twice as expensive). Electrical units cost around 12,000-$20,000 installed. Electrically powered units require a high-voltage, land-based structure that have additional infrastructure costs associated with them.' [3]

It must be noted that regeneration is not the same as cleaning. Cleaning of the ash must still be completed on a routine maintenance schedule.

4.4.2 Urea System

[3] Emissions Retrofit Group – "Products, Diesel Particulate Filters", accessed on February 2015, http://emissionsretrofit.com/products/diesel-particulate-filters/

The next section of the SCR is the Diesel Exhaust Fluid (DEF) which is a fine mist that is injected into the exhaust gas stream from a dosing valve after the gas comes out of the DPF. Figure 4-9 is an example of a DEF dosing unit (left) and urea tank assembly (right).

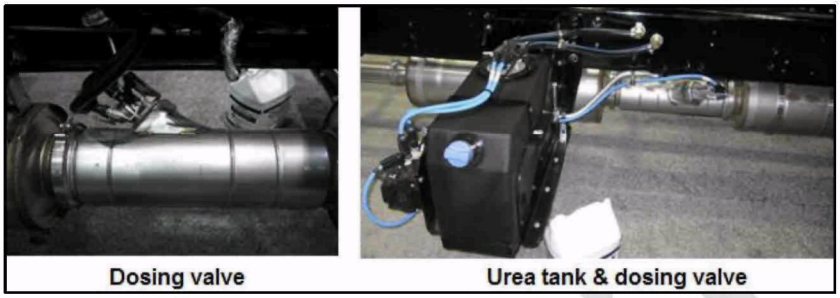


Figure 4-9: Example of A DPF Dosing Unit System
(Source: http://www.irv2.com/wp/wp-content/uploads/2012/11/IMG_6385.jpg)

The DEF urea tank is mounted on the side frame rail of the truck and holds the DEF fluid or urea fluid. DEF/urea fluid is a harmless solution of (67%) purified water and (33%) urea. This combination is the most effective way to reduce NOx emissions.

At the 67% / 33% combination, the solution will begin to freeze at 12° F (-11° C) causing both the urea and water to freeze and thaw at the same time. This ensures that the fluid does not become diluted or over concentrated. Thawing and unthawing does not cause harm to the urea fluid.

The urea lines and tank are heated. As the engine heats up, it sends heated coolant to the urea tank. The lines and connectors have heating elements with Temperature-sensing technology which provide freeze prevention control for very cold climates.

SCR systems are designed to heat the DEF tank and supply lines. If DEF freezes when the vehicle is shut down, start up and normal operation of the vehicle will not be inhibited. The SCR heating system is designed to quickly return the DEF to liquid form.

The electronic control unit adjusts the dosing input of the fluid for parameters such as engine operating temperature and speed.

The EPA requires truck makers to incorporate a staged warning system to let the operator know when the system is close to empty. The vehicle will go into one of several modes: "limp home", reduced engine power, or limited engine starts. At some point the engine will not start if the warning is ignored. So to prevent the engine from not starting, do not ignore the warnings.

A Class 8 vehicle requires only 2-3 gallons of DEF/urea fluid for every 100 gallons of Diesel fuel that is used.

- Annual miles for average truck = 120,000 miles per yr.
- MPG for average truck = 6 mpg
- 120,000 miles / 6 mpg = 20,000 gallons Diesel fuel per year
- DEF usage @ 2 to 3% of fuel consumption = 400 gallons of DEF per yr.
- With a 20 gallon tank (average size) = 20 DEF fill-ups / year.
- DEF pricing will be at or below the price of Diesel fuel.
- Using $3 per gallon = $1,200 per yr.

The use of a Selective Catalytic Reduction (SCR) results in a fuel savings of about 5% or 6.3 miles per gallon.

120,000 miles / 6.3 mpg = 19,048 gallons Diesel fuel per year – 20,000 @ 6 mpg = 952 gallon savings per year @ $5 per gallon = $4,760 per year. This is a substantial savings!

Figure 4-10 shows the referenced urea tank used in this study.

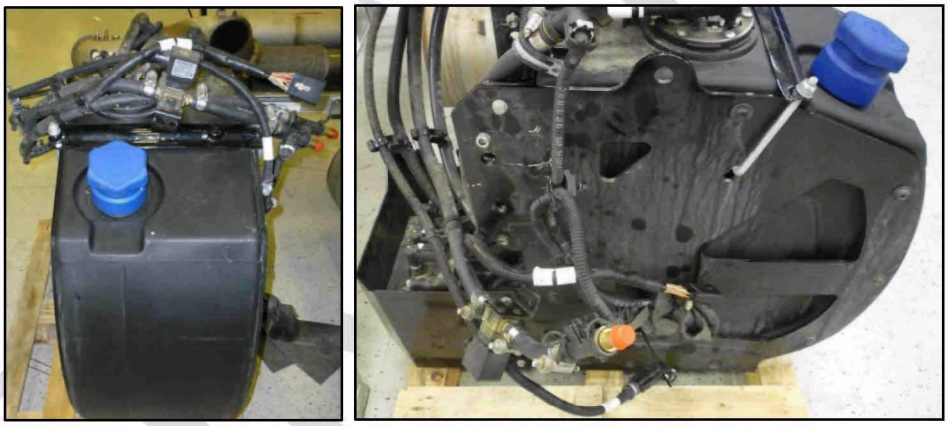


Figure 4-10: Example of A DPF Urea Tank System
(Source: FEV)

After the DPF urea fluid is injected into the exhaust SCR system, it passes through the decomposition reactor where the urea fluid is converted into ammonia via a chemical reaction called hydrolysis. The (mono-nitrogen) NOx from the exhaust gases and ammonia (NH3) pass into the SCR element where a catalytic reaction takes place and the NOx is converted into harmless nitrogen gas (N2) and water vapor (H20). Once the hydrolysis is complete the gasses are passed through a secondary selective catalytic reduction catalyst. This secondary catalyst converts any leftover traces of ammonia before the exhaust exits the system. This reaction produces near zero emissions. See Figure 4-11.

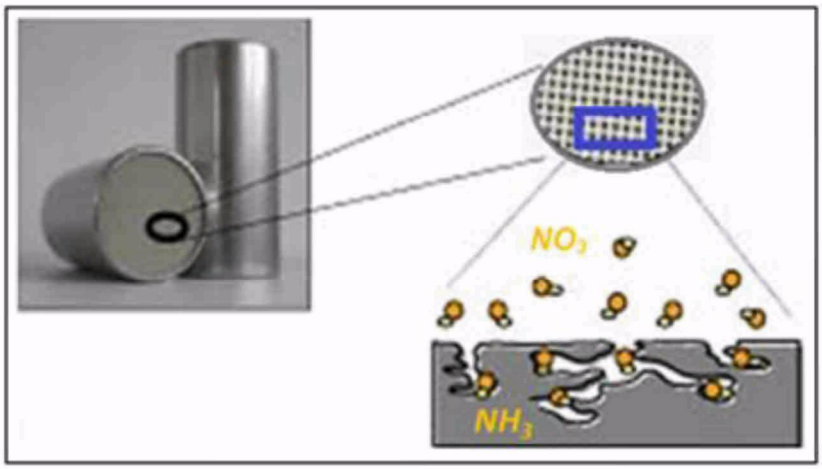


Figure 4-11: Selective Catalytic Reduction (SCR)
(Source: http://www.aecc.be/en/Technology/Catalysts.html)

5. Diesel (Base Technology) and CNG (New Technology) Functionality Overview

The Diesel engine for this study is broken down into 9 major systems.

- Whole engine
- Engine block
- Engine cylinder head
- Engine rocker levers
- Fuel system
- Oil system
- Cooling system
- Air system
- Exhaust system

Each system will be examined for functionality and how it relates between the Diesel (Base technology) and the CNG (New technology) being examined in this study.

5.1 Whole Engine

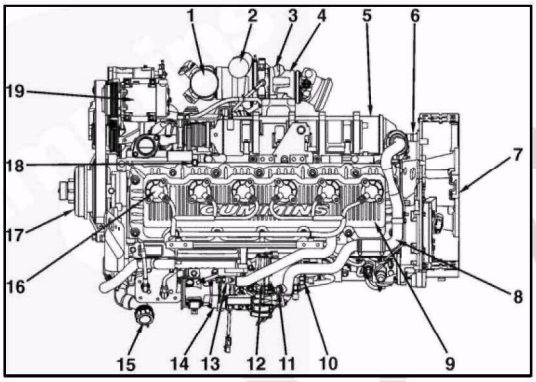
The Diesel and CNG engines top view: Figure 5-1, front view: Figure 5-2, left side view: Figure 5-3, right side view: Figure 5-4 and rear view: Figure 5-5 show the location of major external components on the engines. Some components may be located in different locations on different engine models.

Some CNG and Diesel components or assemblies may not have been included if they were exactly the same or outside the scope of this study.

The following information is for reference only.

CNG
Top View

1. Turbocharger air inlet
2. Turbocharger compressor outlet
3. Turbocharger
4. Turbocharger exhaust outlet
5. EGR cooler
6. Rear gear housing
7. Flywheel housing
8. EGR crossover tube
9. Rocker lever cover
10. Intake manifold pressure/temperature sensor
11. EGR temperature sensor
12. EGR valve
13. EGR differential pressure sensor
14. Air intake manifold
15. Lubricating oil fill tube
16. Ignition coil
17. Fan hub
18. Coolant temperature sensor
19. Refrigerant compressor



Diesel
Top View

1. Turbocharger air inlet
2. Turbocharger compressor outlet
3. Variable geometry turbocharger, electric
4. Turbocharger exhaust outlet
5. EGR cooler
6. Rear gear housing
7. Flywheel housing
8. Rocker lever cover
9. Air intake manifold
10. EGR crossover tube
11. Lubricating oil fill tube
12. Fan hub
13. Coolant temperature sensor
14. Refrigerant compressor

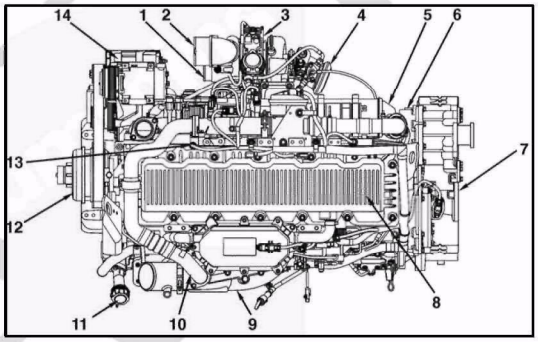


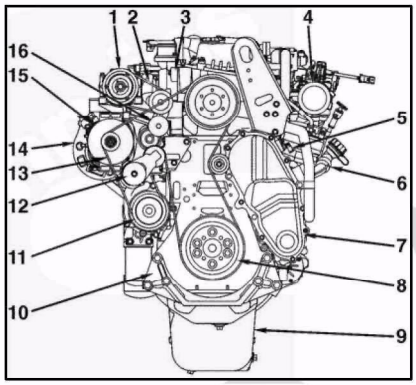
Figure 5-1: Whole Engine Top View Diesel & CNG
(Source: Cummins parts website https://quickserve.cummins.com)

CNG
Front View

1. Refrigerant compressor
2. Drive belt, refrigerant compressor
3. Thermostat housing
4. Air intake connection
5. Camshaft position sensor
6. Lubricating oil fill tube
7. Front gear housing cover
8. Vibration damper
9. Lubricating oil pan
10. Front engine mount
11. Dual outlet water pump
12. Belt tensioner, alternator
13. Drive belt, alternator
14. Turbocharger
15. Alternator
16. Belt tensioner, refrigerant compressor

Diesel
Front View

1. Refrigerant compressor
2. Drive belt, refrigerant compressor
3. Thermostat housing
4. Exhaust gas recirculation (EGR) crossover tube
5. Air intake connection
6. Camshaft position sensor
7. Lubricating oil fill tube
8. Front gear housing cover
9. Vibration damper
10. Lubricating oil pan
11. Front engine mount
12. Dual outlet water pump
13. Belt tensioner, alternator
14. Drive belt, alternator
15. Variable geometry turbocharger
16. Alternator
17. Belt tensioner, refrigerant compressor



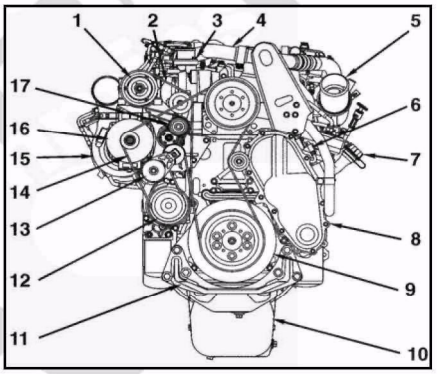
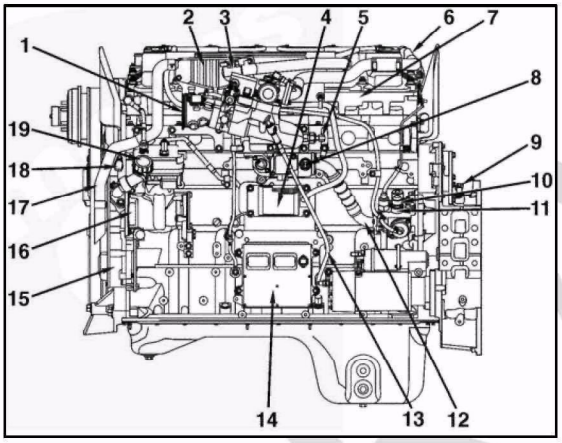


Figure 5-2: Whole Engine Front View Diesel & CNG
(Source: Cummins parts website https://quickserve.cummins.com)

CNG
Left Side View

1. Air intake connection
2. Crankcase breather housing
3. Crankcase breather pressure sensor
4. Ignition control module (ICM)
5. Intake manifold temperature/pressure sensor
6. EGR crossover tube
7. Cylinder head wiring harness pass-through
8. Fuel control assembly
9. Crankshaft position sensor
10. OEM fuel supply connection
11. Fuel pressure regulator assembly
12. Fuel transfer tube
13. Lubricating oil dipstick
14. Engine control module (ECM)
15. Front gear housing
16. Air compressor
17. Crankcase breather vent tube
18. Camshaft position sensor
19. Lubricating oil fill tube



Diesel
Left Side View

1. Air intake connection
2. EGR crossover tube
3. Crankcase breather housing
4. Crankcase breather pressure sensor
5. Intake manifold temperature/pressure sensor
6. Fuel rail
7. Injector supply line
8. Aftertreatment purge air solenoid
9. High-pressure relief valve
10. Cylinder head wiring harness pass-through
11. OEM fuel return
12. Fuel rail supply line
13. Aftertreatment fuel shutoff manifold
14. Fuel pump actuator
15. Crankshaft position sensor
16. Fuel pump, high-pressure
17. Fuel pump gear pump
18. Lubricating oil dipstick
19. Pressure-side fuel filter
20. Electronic control module (ECM)
21. OEM fuel supply connection
22. Fuel lift pump (behind ECM)
23. Air compressor
24. Front gear housing
25. Crankcase breather vent tube
26. Lubricating oil fill tube
27. Camshaft position sensor

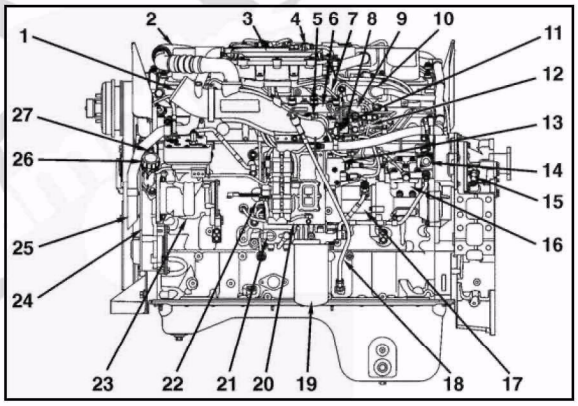
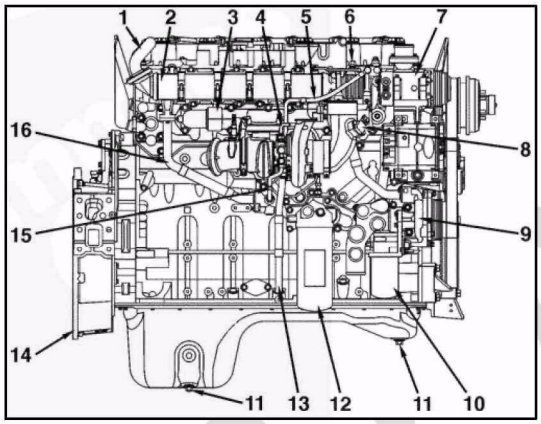


Figure 5-3: Whole Engine Left Side View Diesel & CNG
(Source: Cummins parts website https://quickserve.cummins.com)

CNG
Right Side View

1. Exhaust gas recirculation (EGR) crossover tube
2. EGR cooler
3. Exhaust manifold
4. Turbocharger oil supply line
5. Turbocharger coolant return line
6. Coolant temperature sensor
7. Thermostat housing
8. Humidity Sensor
9. Dual outlet water pump
10. Coolant filter
11. Lubricating oil pan drain plugs
12. Lubricating oil filter
13. Turbocharger oil drain tube
14. Flywheel housing
15. Turbocharger coolant supply line
16. EGR cooler coolant inlet tube.



Diesel
Right Side View

1. Flywheel housing
2. EGR cooler coolant return line
3. Aftertreatment coolant supply port
4. EGR cooler
5. Aftertreatment fuel injector
6. Aftertreatment intake NOx sensor
7. Turbocharger heat shield
8. EGR valve
9. Electric variable geometry turbocharger actuator
10. EGR orifice pressure sensor
11. EGR differential pressure sensor
12. EGR temperature sensor
13. EGR crossover tube
14. Thermostat housing
15. Exhaust manifold heat shield
16. Exhaust manifold
17. Dual outlet water pump
18. EGR cooler coolant inlet tube
19. Coolant filter
20. Lubricating oil pan drain plugs
21. Turbocharger oil supply line
22. Lubricating oil filter
23. Turbocharger oil drain tube

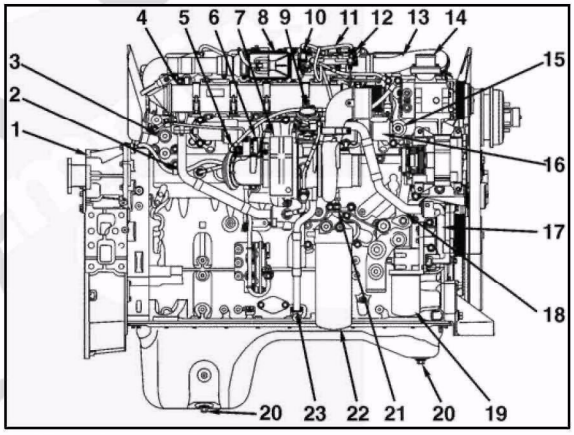
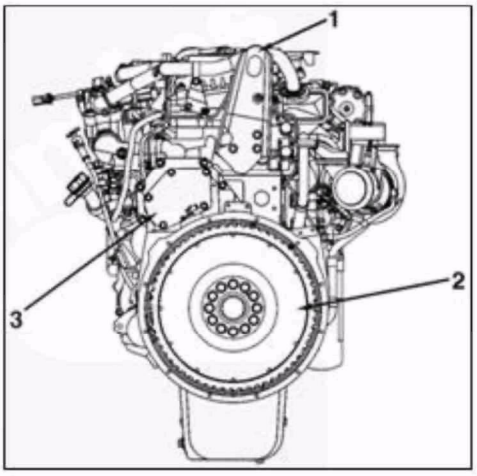


Figure 5-4: Whole Engine Right Side View Diesel & CNG
(Source: Cummins parts website https://quickserve.cummins.com)

CNG
Rear View

1. Lifting bracket
2. Flywheel
3. Rear gear cover



Diesel
Rear View

1. After treatment fuel injector fuel supply line
2. After treatment fuel injector coolant supply line
3. After treatment fuel injector
4. After treatment fuel injector coolant return line
5. Flywheel
6. Rear gear cover

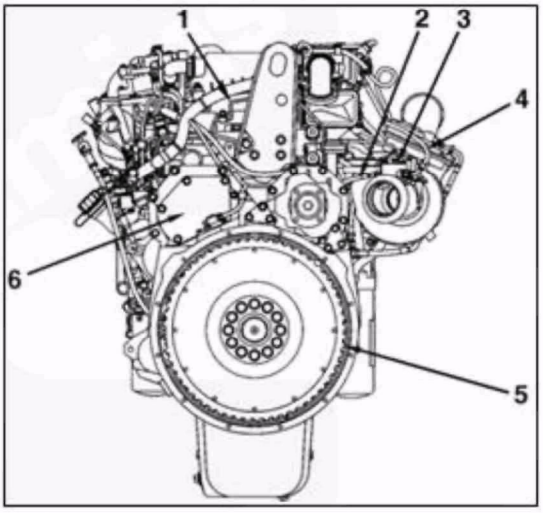


Figure 5-5: Whole Engine Rear View Diesel & CNG
(Source: Cummins parts website https://quickserve.cummins.com)

5.2 Engine Block

The engine block Figure 5-6 of the Cummins ISX11.9 liter Diesel engine is a cast iron block, inline 6 with the camshaft designed into the block. The block also has induction hardened cylinder liners.

It is the same block used for the ISXG11.9 liter CNG engine used is this study and therefore not quoted. The CNG block does have an added threaded plug to block off the dosing port that is not required for the CNG engine due to no After-treatment requirements. The threaded plug will be quoted under the 01-01-05 Cylinder Block Plumbing section. All other components are the same and not quoted.

Both Diesel and CNG

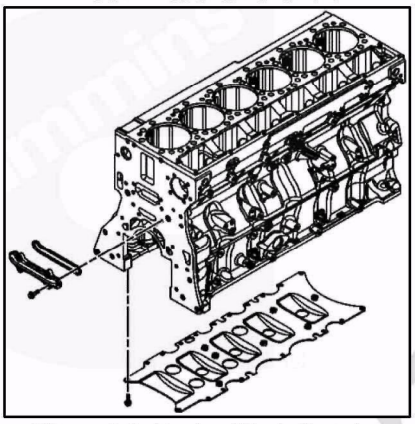


Figure 5-6: Engine Block Overview
(Source: Cummins parts website https://quickserve.cummins.com)

The engine blocks front gear train Figure 5-7 of the Cummins ISX11.9 liter Diesel engine has the same components of the ISXG11.9 liter CNG engine and not quoted.

Both Diesel and CNG

1. Camshaft gear
2. Idler gear
3. Air compressor gear

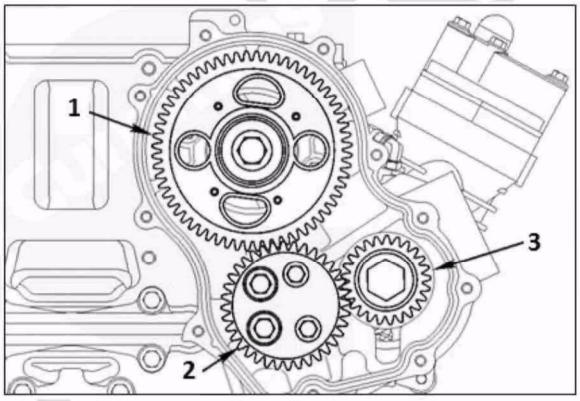


Figure 5-7: Engine Block Front Gear Train Overview
(Source: Cummins parts website https://quickserve.cummins.com)

The engine blocks rear gear train Figure 5-8 of the Cummins ISX11.9 liter Diesel engine has an added gear for the fuel pump callout # 2. This gear is quoted under the 01-05 fuel and controls subsystem.

CNG

1. Camshaft gear
2. Lubricating oil pump idler gear
3. Idler gear (compound)
4. Crankshaft gear
5. Lubricating oil pump gear

Diesel

1. Camshaft gear
2. Fuel pump gear
3. Lubricating oil pump idler gear
4. Idler gear (compound)
5. Crankshaft gear
6. Lubricating oil pump gear

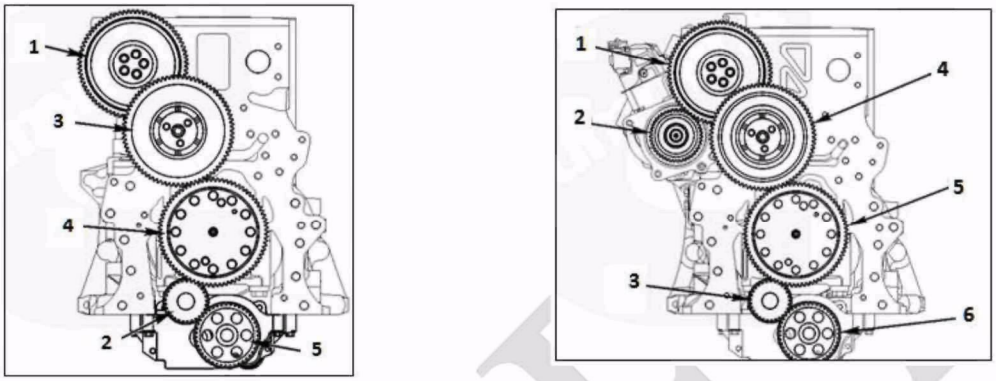


Figure 5-8: Engine Block Rear Gear Train Overview
(Source: Cummins parts website https://quickserve.cummins.com)

5.3 Engine Block Cylinder Head

The engine block cylinder head Figure 5-9 is a 4 valve system with a single slab head design per Cummins for the Cummins ISX11.9 liter Diesel engine. The heads for both the Diesel and the ISXG11.9 liter CNG engine are the same used is this study and therefore not quoted.

Both Diesel & CNG

Cylinder Head Intake and Exhaust Valve Pattern - Bottom View of Cylinder Head

E = Exhaust Valve
I = Intake Valve

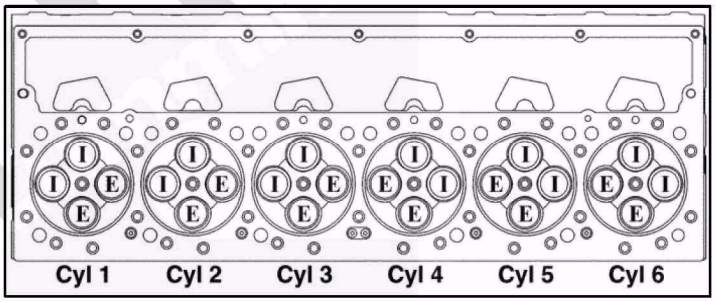


Figure 5-9: Engine Block Cylinder Head Overview
(Source: Cummins parts website https://quickserve.cummins.com)

5.4 Engine Rocker Levers

The engine block cylinder head Figure 5-10 is a 4 valve system with a single slab head design per Cummins for the Cummins ISX11.9 liter Diesel engine. The heads for both the Diesel and the ISXG11.9 liter CNG engine are the same used is this study and therefore not quoted.

Both Diesel and CNG

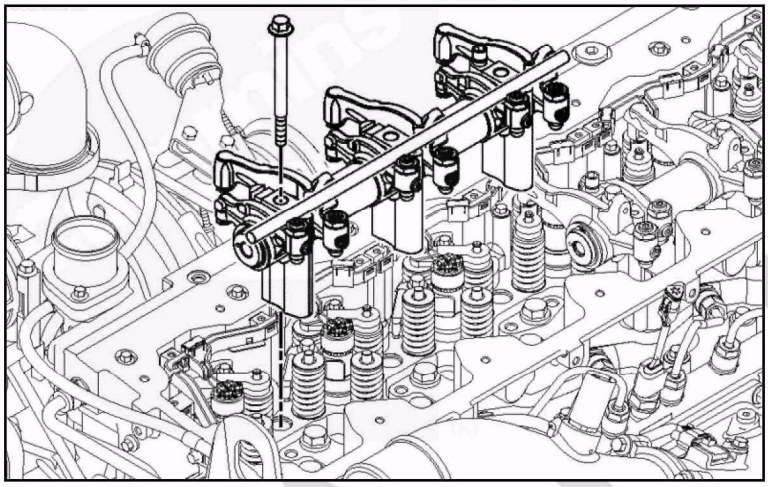


Figure 5-10: Engine Block Cylinder Head Overview
(Source: Cummins parts website https://quickserve.cummins.com)

5.5 Fuel System

The Diesel fuel system and the CNG fuel system are to totally different systems and the primary base of this study. Due to the differences, each system must be looked at separately in the following sections.

5.5.1 Diesel Fuel System

The Diesel fuel system must be supplied with clean fuel at all times; this means the system must have multiple fuel filters in place.

Figure 5-11 shows the 5 micron filter that is located on the engine and the fuel pump which is driven off the crankshaft idler gear. The pump is also lubricated with engine oil that is pumped in through the pump housing.

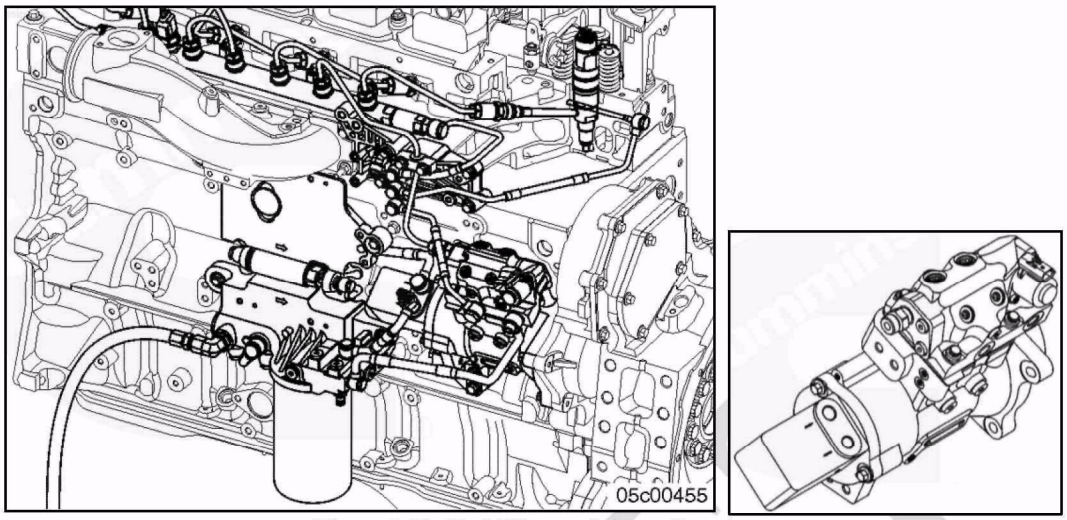


Figure 5-11: Fuel Filter and Pump Overview
(Source: Cummins parts website https://quickserve.cummins.com)

The fuel pump also has an 86 micron filter located in the banjo bolt shown in Figure 5-12.

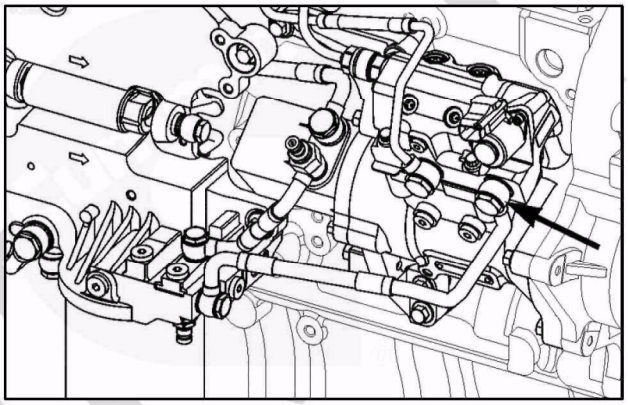


Figure 5-12: 86 Micron Filter Located In the Banjo Bolt Overview
(Source: Cummins parts website https://quickserve.cummins.com)

The fuel injectors are supplied fuel from the high pressure injector supply line and as the high pressure fuel flows to the injector, the solenoid is activated which lifts a small needle, whereby the fuel is injected into the cylinders. Since the Diesel fuel system is under such high pressures, the nozzle hole is very small so if any contaminates get into the fuel system it could become clogged. For that reason, there are redundant filters along the path of the Diesel fuel. Figure 5-13 and Figure 5-14 show the fuel system flow.

1. OEM fuel supply connection
2. Fuel lift pump supply line
3. Fuel lift pump
4. Fuel lift pump return line
5. Fuel pump gear pump supply line
6. Fuel pump gear pump inlet
7. Fuel pump gear pump
8. Fuel pump gear pump outlet
9. Pressure side fuel filter inlet
10. Fuel filter head
11. Pressure side fuel filter (5-micron)
12. Pressure side fuel filter outlet
13. High-pressure fuel pump inlet (with 86-micron filter)
14. Fuel pump actuator
15. High-pressure fuel pump
16. Fuel rail supply line
17. Fuel rail
18. Fuel pressure sensor
19. High-pressure injector supply lines
20. High-pressure fuel connector
21. Fuel injector
22. Fuel injector drain check valve (banjo type)
23. High-pressure relief valve
24. Injector drain line
25. High-pressure relief valve drain line
26. Fuel pump drain line
27. Fuel drain manifold
28. OEM fuel return connection
29. Lift pump OFF (check valve open)
30. Lift pump ON (check valve closed)

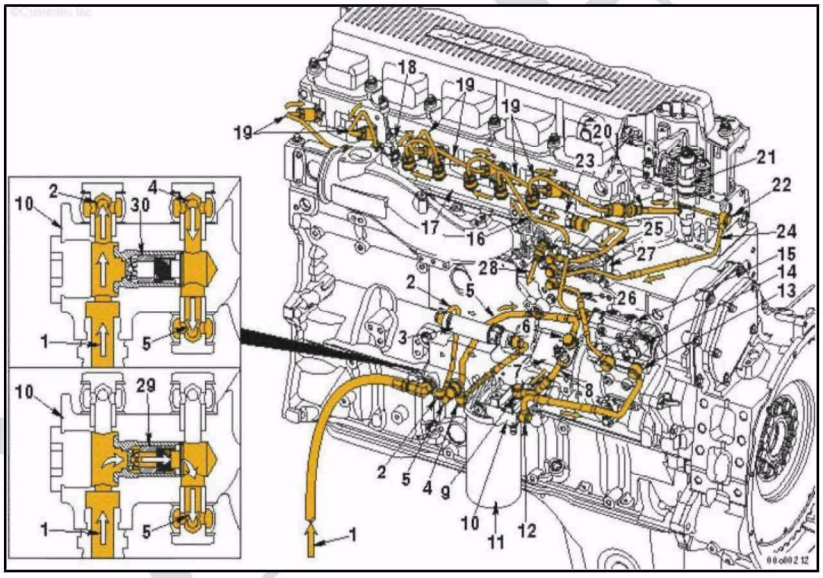


Figure 5-13: Fuel Flow Overview

(Source: Cummins parts website https://quickserve.cummins.com)

1. Fuel supply from fuel filter head to the aftertreatment fuel injector fuel manifold
2. Aftertreatment fuel injector fuel manifold
3. Fuel shutoff valve
4. Fuel pressure sensor
5. Fuel supply to aftertreatment fuel injector
6. Aftertreatment fuel injector

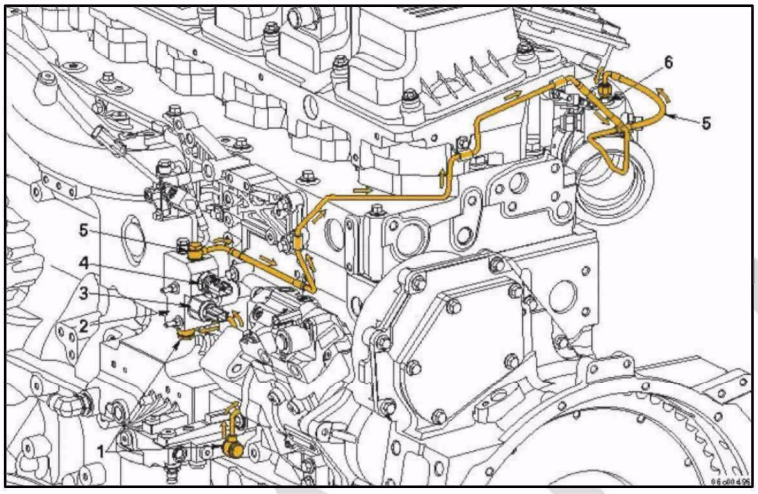


Figure 5-14: Fuel Flow Overview
(Source: Cummins parts website https://quickserve.cummins.com)

Diesel engines use a direct fuel injection system that directly injects fuel into the cylinder under high pressure. The injectors are very complex and must be able to withstand great temperatures and pressures in the cylinders to deliver a fuel mist. See Figure 5-15.

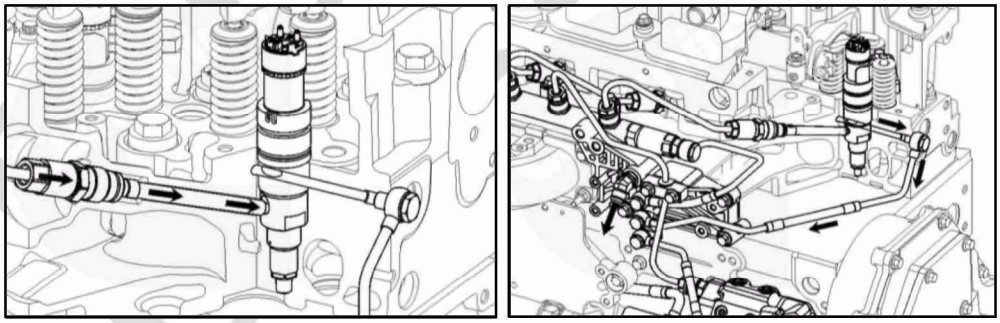


Figure 5-15: Injector & Flow Overview
(Source: Cummins parts website https://quickserve.cummins.com)

The air is compressed by the pistons and the fuel is injected into the cylinders. This is known as a compression process as shown in Figure 5-16.

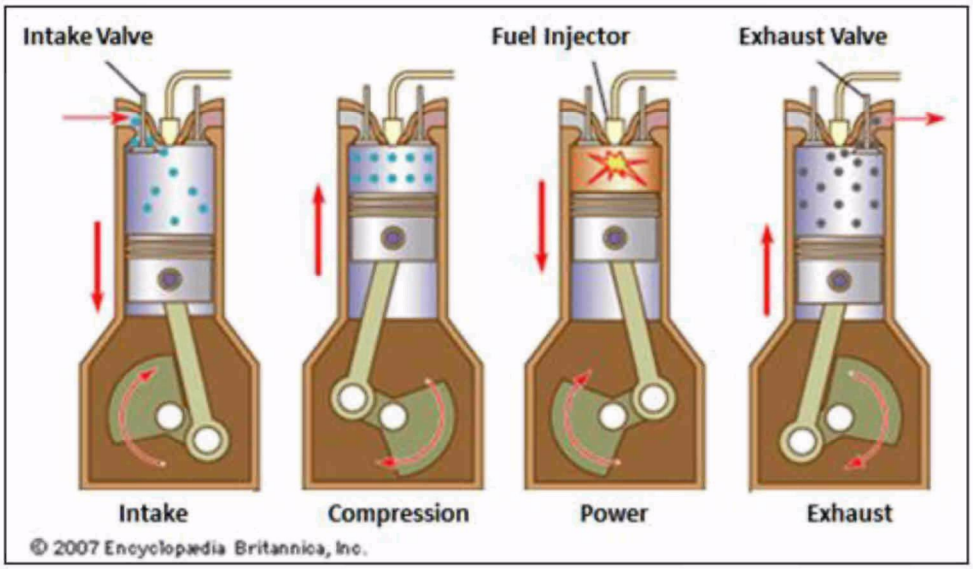


Figure 5-16: Compression Process
(Source: http://chembloggreen1.files.wordpress.com/2012/11/24075-004-613c6f141.gif)

5.5.2 CNG Fuel System

The ISX12 G is a much quieter engine than the diesel, and that has a lot to do with the way the fuel burns. The compression ratio in the CNG engine is lower than a Diesel so the fuel combustion event is less violent causing it to feel and sound more like a gasoline engine than a diesel.

In a typical vehicle Compressed Natural Gas (CNG) fuel system, the compressed gas is stored in high-pressure cylinders that can be mounted inside an enclosure at several different but selected locations on the vehicle. The cylinders pressure is 209 to 248 bar [3000 to 3600 psig] at a working level. The cylinders are connected to a fuel manifold and a safety vent system.

Each cylinder may have a high-pressure solenoid shutoff valve located between the cylinders and the fuel manifold. The CNG gas moves through a fuel module that can contain many of the parts required to bring the CNG gas to a useable pressure for the engine, including high pressure gages and valves as well as the low pressure output to the engine gage. The module in some cases also provides fill, de-fill and a manual shutoff.

The reduced high-pressure gas is pumped through a remote mounted gas fuel filter. This filter is a coalescent type filter that captures oil contaminants and moisture typically found in compressed natural gas.

The gas then passes through the fuel transfer tube and into the fuel control housing. From the fuel control housing, the gas passes into the air intake manifold where it is introduced into the charge-air flow. Figure 5-17 shows the CNG fuel system overview in the Cummins ISX12G.

1. Fuel inlet from remote mounted gas filter
2. Low-pressure regulator
3. Fuel inlet pressure sensor
4. Fuel shutoff valve
5. Fuel transfer tube
6. Fuel outlet pressure/temperature sensor
7. Gas mass flow sensor
8. Fuel control valve
9. Air inlet
10. Throttle actuator
11. Air/fuel mixer
12. Exhaust gas to exhaust gas recirculation (EGR) valve
13. EGR valve
14. Intake manifold.

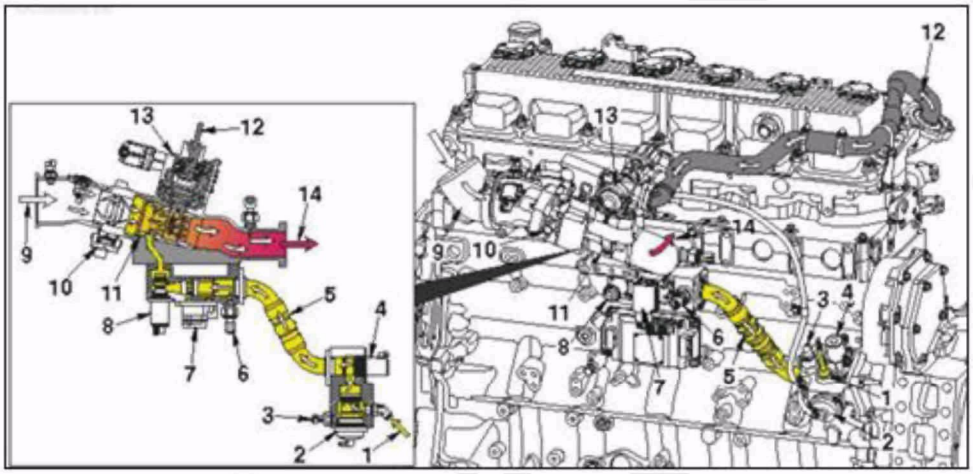


Figure 5-17: CNG Fuel Flow Overview
(Source: Cummins parts website https://quickserve.cummins.com)

5.6 Oil System

The oil systems for both the CNG and the Diesel are only slightly different, with only one exception. The exception is the oil in a CNG system does not darken and look dirty as Diesel oil does. CNG engines use a different type of oil than the diesel.

The oil system is under high pressure when the engine is started in cold weather so with the help of a lubricating oil pump, a pressure sensitive regulator circuit and high pressure relief valve, the oil system returns to normal operating pressures when the engine is running at normal temperatures. Figure 5-18 shows the oil pump configuration.

(1) lubricating oil pump
(2) pressure-sensitive regulator circuit
(3) high-pressure relief valve

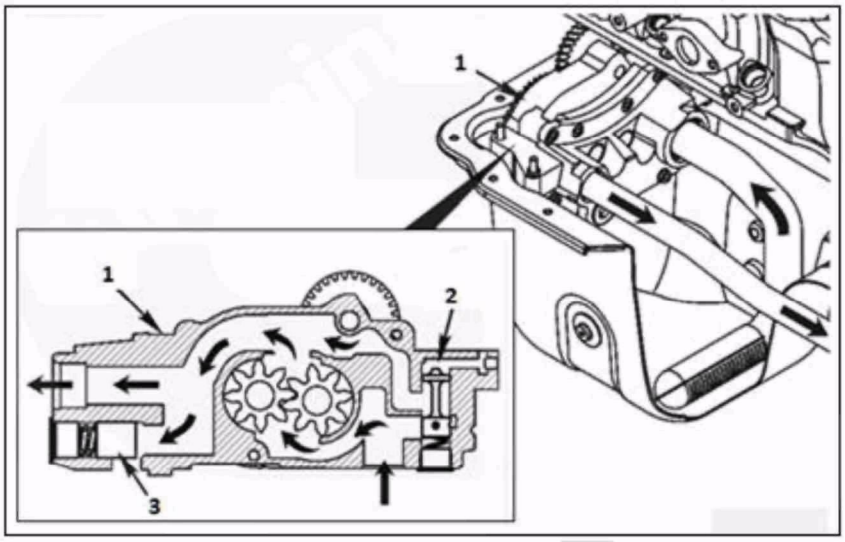


Figure 5-18: Oil Pump
(Source: Cummins parts website https://quickserve.cummins.com)

Figure 5-19 provides an overview of the engine oil system flow.

1. Lubricating oil supply from the lubricating oil pan
2. Lubricating oil pump
3. Lubricating oil pressure sensing line from the main oil rifle
4. Lubricating oil pressure regulator
5. High pressure relief valve
6. Oil return to the lubricating oil pan
7. Lubricating oil transfer tube
8. Lubricating oil transfer connection
9. Oil flow through the cylinder block to the lubricating oil filter head
10. Oil flow from the filter head to the main oil rifle
11. Right oil rifle
12. Oil flow to the rear idler gear
13. Left oil rifle
14. Oil flow to the overhead
15. Oil flow to rocker lever shaft
16. Rocker lever shaft
17. Rocker levers
18. Lubricating oil flow to the push tubes
19. Oil supply to crosshead
20. Lubricating oil supply to the cam followers
21. Cam followers
22. Lubricating oil flow to the camshaft
23. Lubricating oil flow around the camshaft
24. Lubricating oil flow to the main bearings
25. Crankshaft main bearing journal
26. Crankshaft connecting rod journal
27. Connecting rod
28. Lubricating oil flow around the piston pin
29. Front gear housing
30. Lubricating oil flow to the air compressor

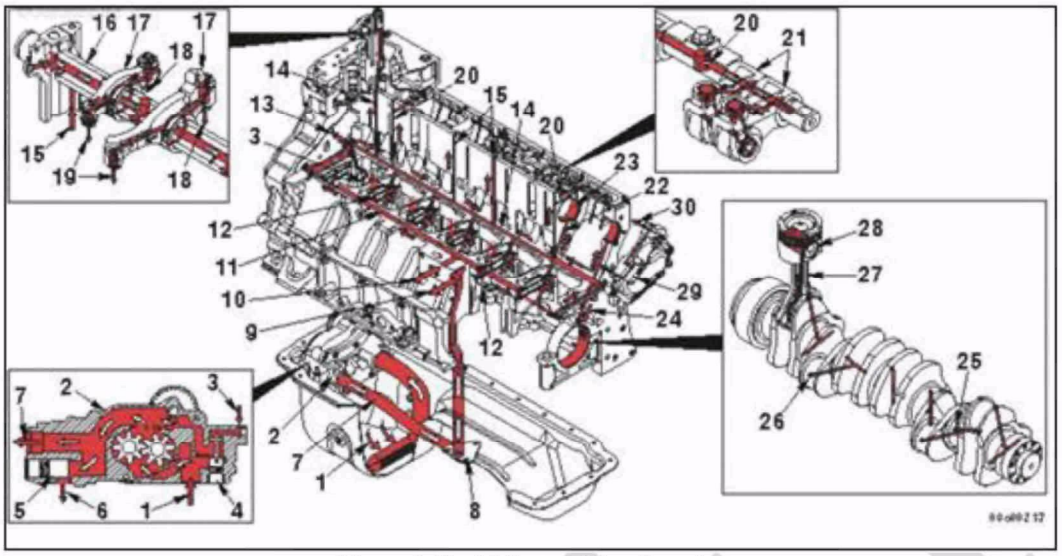


Figure 5-19: Oil System Flow Overview
(Source: Cummins parts website https://quickserve.cummins.com)

The turbo system is also lubed by the oil system, as shown in Figure 5-20.

1. Lubricating oil supply to the turbocharger bearing housing
2. Lubricating oil return to the lubricating oil pan
3. Lubricating oil main rifle
4. Lubricating oil passage from the cylinder block to the rear gear housing
5. Lubricating oil flow through the rear gear housing
6. Lubricating oil supply to the fuel pump
7. Fuel pump.

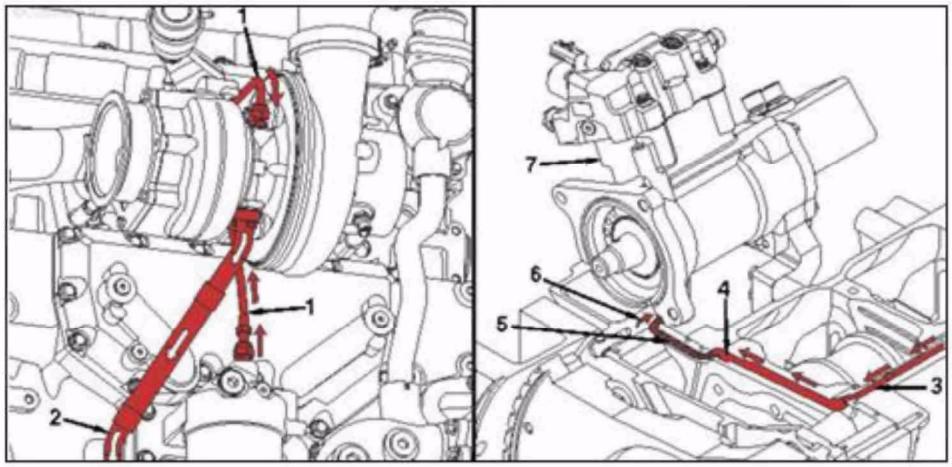


Figure 5-20: Turbo Oil System Flow Overview
(Source: Cummins parts website https://quickserve.cummins.com)

Figure 5-21 and Figure 5-22 show the oil flow through the oil filter system.

1. Lubricating oil flow from the lubricaing oil pump
2. Lubricating oil thermostat closed
3. Lubricating oil through the oil filter head to the oil filter
4. Lubricating oil filter
5. Lubricating oil flow to the main oil rifle
6. Lubricating oil thermostat open
7. Lubricating oil flow to the lubricating oil cooler
8. Lubricating oil flow through the lubricating oil cooler core
9. Lubricating oil flow to the lubricating oil filter head.

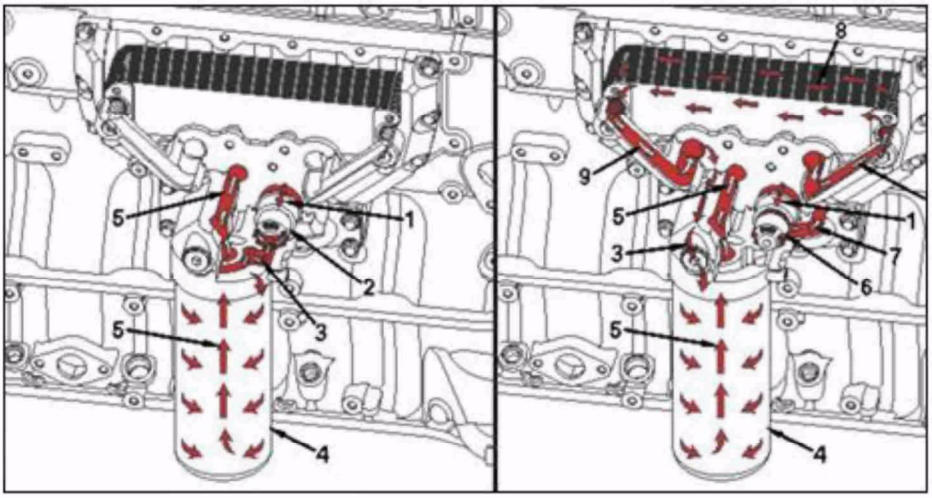


Figure 5-21: Oil Filter Lube System Overview
(Source: Cummins parts website https://quickserve.cummins.com)

1. Lubricating oil supply from the lubricating oil cooler
2. Lubricating oil filter bypass valve closed
3. Lubricating oil flow to the lubricating oil filter
4. Filtered lubricating oil flow to the main oil rifle
5. Lubricating oil filter bypass valve open
6. Unfiltered lubricating oil flow to the main oil rifle.

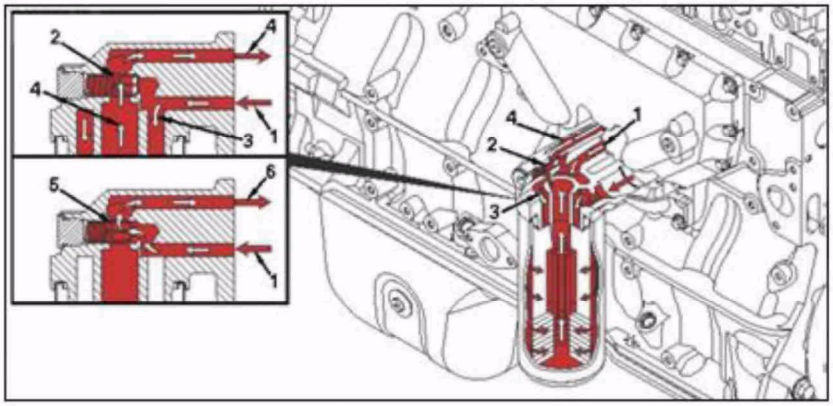


Figure 5-22: Oil Filter Lube System Overview
(Source: Cummins parts website https://quickserve.cummins.com)

5.7 Cooling System

The cooling systems for both the CNG ISX12G and the Diesel ISX12/11.9 are almost identical. However, there are two distinct differences.

- The Diesel system has a SCR cooling capability and Diesel injector cooling *(refer to Exhaust System).*
- The CNG system has neither.

Early ISX engine designs had two thermostats but in 2002 Cummins introduced a one thermostat design. This design uses the same thermostat from the older designs which opens at 180°F (82°C).

The ISX design was equipped with an exhaust gas recirculation (EGR) valve and used an impeller in the water pump similar to the QSX15 engine to get the most cooling capacity from the water pump.

There was also some redesign of the drive ratio on the water pump pulley to increase water pump speeds for additional cooling. This was increased due to the flow and heat associated with the EGR. Shown in Figure 5-23 is the coolant system configuration.

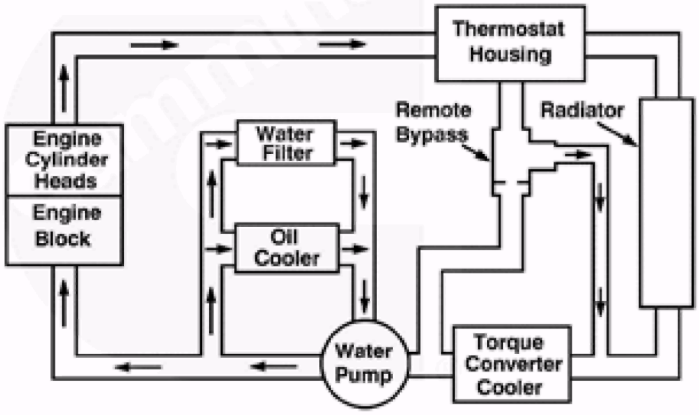


Figure 5-23: Coolant System Overview - 1
(Source: Cummins parts website https://quickserve.cummins.com)

Conventionally cooled engines with automatic transmissions typically use an oil-to-water transmission torque converter cooler plumbed between the radiator and the engine water pump.

A torque converter cooling system with a remote bypass allows the torque converter to receive coolant flow when the thermostat is closed (engine cold). Figure 5-24, Figure 5-25, Figure 5-26 and Figure 5-27 display overviews 2-5 which show the coolant system configuration.

CNG

1. Coolant inlet flow from radiator
2. Coolant inlet connection
3. Coolant from inlet to water pump
4. Coolant from water pump to coolant filter
5. Coolant filter, if equipped
6. Coolant flow to water pump
7. Coolant from water pump to cylinder block inlet
8. Coolant from water pump to exhaust gas recirculation (EGR) cooler
9. EGR cooler
10. Coolant from EGR cooler to lubricating oil cooler
11. Lubricating oil cooler
12. Coolant from rocker lever housing
13. Thermostat closed
14. Coolant through bypass tube to coolant connection
15. Thermostat open
16. Coolant to radiator
17. Torque converter bypass.

Diesel

1. Coolant inlet flow from radiator
2. Coolant inlet connection
3. Coolant from inlet to water pump
4. Coolant flow to water pump
5. Coolant filter, if equipped
6. Coolant flow to water pump
7. Coolant from water pump to cylinder block inlet
8. Coolant from water pump to exhaust gas recirculation (EGR) cooler
9. EGR cooler
10. Coolant from EGR cooler to lubricating oil cooler
11. Lubricating oil cooler
12. Coolant from rocker lever housing
13. Thermostat closed
14. Coolant through bypass tube to coolant connection
15. Thermostat open
16. Coolant to radiator
17. Selective Catalyst Reduction (SCR) system coolant supply.

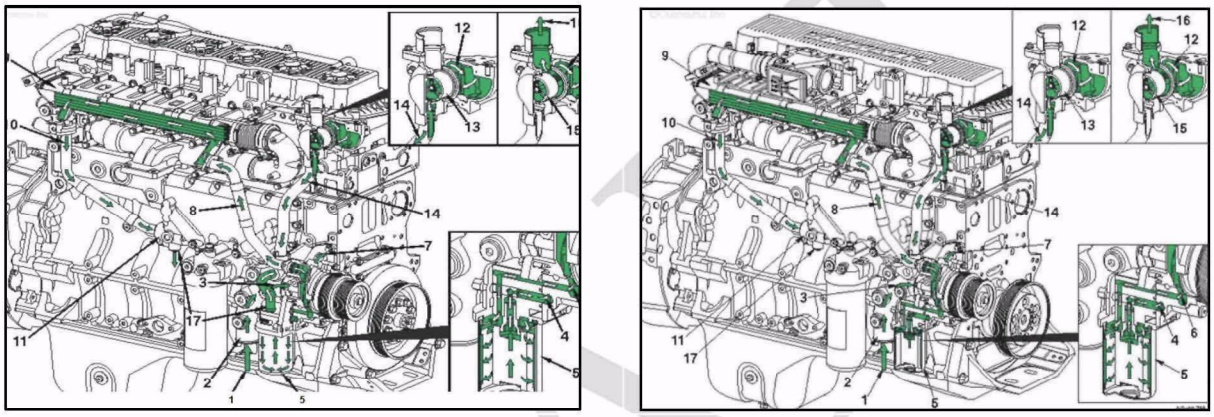
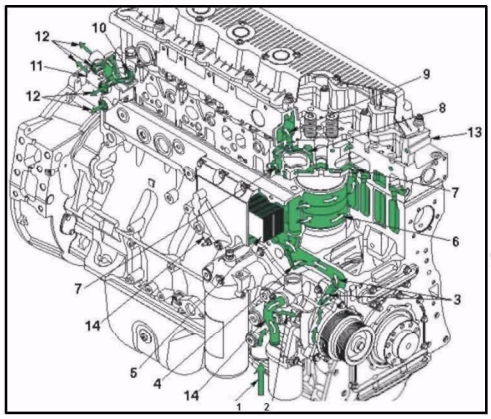


Figure 5-24: Coolant System Overview - 2

(Source: Cummins parts website https://quickserve.cummins.com)

CNG

1. Coolant inlet from radiator
2. Coolant inlet to water pump
3. Coolant from water pump to cylinder block
4. Coolant to lubricating oil cooler
5. Lubricating oil cooler
6. Coolant flow around cylinder liners
7. Coolant to lower cylinder head
8. Coolant to upper cylinder head
9. Coolant to rocker lever housing
10. Coolant from cylinder head to OEM coolant manifold
11. OEM coolant manifold supply
12. OEM coolant manifold
13. Rocker housing vent
14. Torque converter bypass.



Diesel

1. Coolant inlet from radiator
2. Coolant inlet to water pump
3. Coolant from water pump to cylinder block
4. Coolant to lubricating oil cooler
5. Lubricating oil cooler
6. Coolant flow around cylinder liners
7. Coolant to lower cylinder head
8. Coolant to upper cylinder head
9. Coolant to rocker lever housing
10. Coolant from cylinder head to OEM coolant manifold
11. OEM coolant manifold supply
12. OEM coolant manifold and Selective Catalyst Reduction (SCR) system coolant return

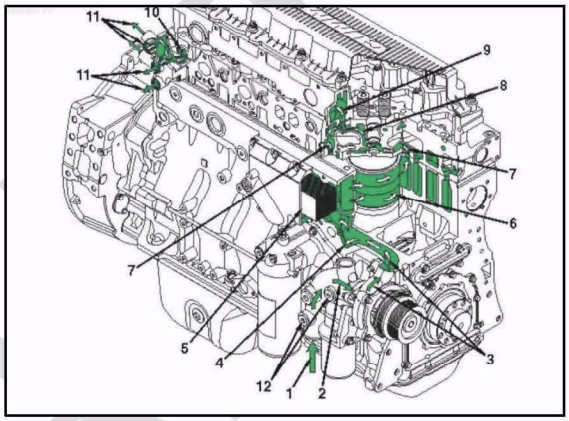


Figure 5-25: Coolant System Overview - 3
(Source: Cummins parts website https://quickserve.cummins.com)

1. Coolant from cylinder block to air compressor
2. Air compressor
3. Coolant from air compressor to rocker lever housing

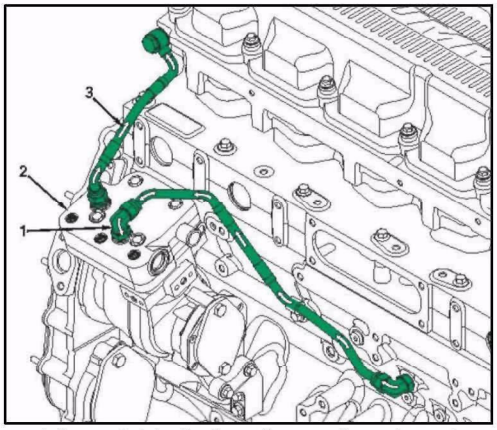


Figure 5-26: Coolant System Overview - 4
(Source: Cummins parts website https://quickserve.cummins.com)

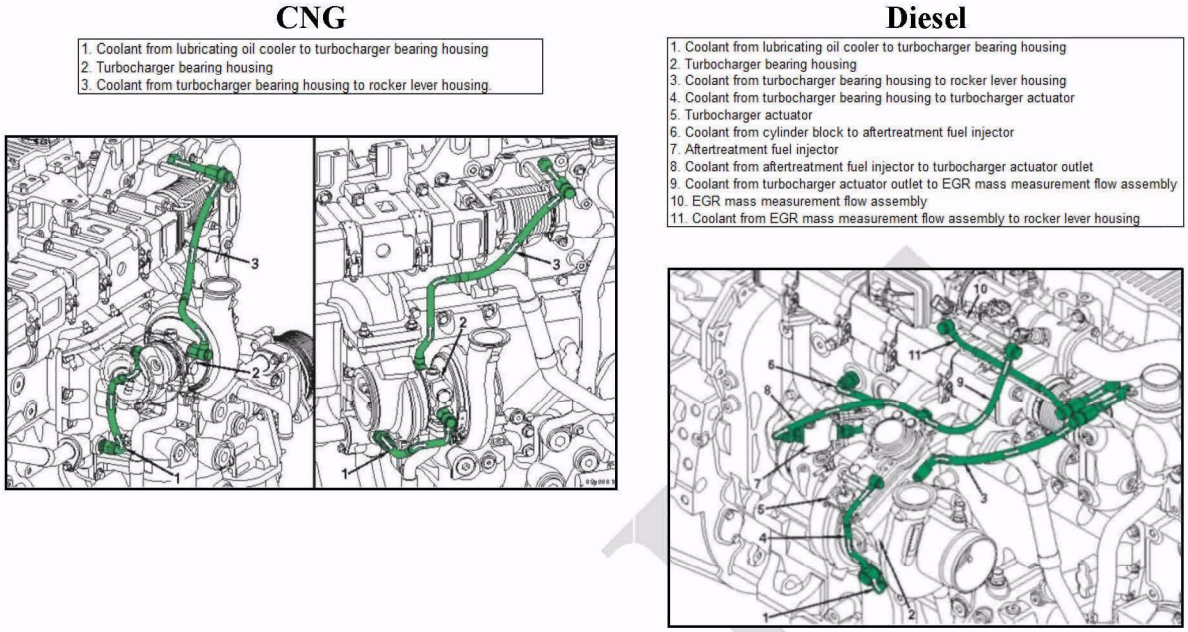


Figure 5-27: Coolant System Overview - 5
(Source: Cummins parts website https://quickserve.cummins.com)

5.8 Air Intake System

5.8.1 Diesel Air Intake System

With emission levels being of great concern, Cummins used a variable geometry turbocharger to cut emission levels and create more power.

The variable geometry turbocharger gives quicker engine response times along with better shifting time and engine deceleration than the fixed geometry turbochargers.

Active control on the variable geometry turbocharger can make the intake manifold pressure change. When this happens the Electronic Control Module (ECM) adjusts the flow of Exhaust Gas Recirculation (EGR) into the engine and the engine power is not affected.

The turbocharger may make a whistle sound during idle conditions. When this happens it's due to the engine control system making changes to the variable geometry turbocharger position. This allows for more heat to the SCR After-treatment system. This is a part of the normal engine operation.

The variable geometry turbocharger is protected from damage by a power decrease for high altitudes. The Turbo unit is also electronically controlled by the ECM by way of the variable geometry actuator which is mounted on the top of the turbocharger as shown in Figure 5-28.

Diesel Only

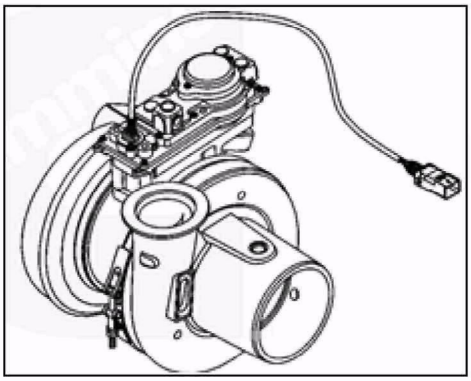


Figure 5-28: ISX Turbocharger
(Source: Cummins parts website https://quickserve.cummins.com)

The air from the intake is compressed by the turbocharger and the temperature is increased, the heated air is then passed through a charge air cooler. The cooler air is denser which allows more air to be forced into the cylinder, giving the combustion more efficiency as shown in Figure 5-29.

Diesel Only

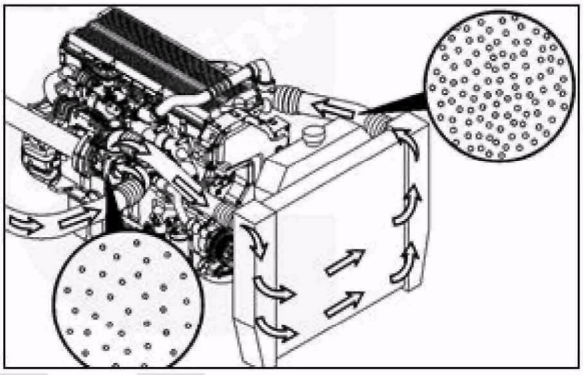


Figure 5-29: Compressed Turbocharger Air
(Source: Cummins parts website https://quickserve.cummins.com)

5.8.2 CNG Air Intake System

CNG engines do not use fuel injection like Diesel engines. They are throttled similar to a carbureted gasoline engine.

Fresh intake air, recirculated exhaust gas and fuel in its gaseous state are blended together. It sits physically in the same place as the diesel, at the end of the engine's intake manifold.
The throttle plate on the ISX12 G engine opens to allow air to pass into the cylinder so the engine brake will work.

The ISX12 G turbocharger has a waste gate. The boost and waste gate are controlled by the Electronic Control Module (ECM), and are connected to the fuel system. When the throttle is opened, the air intake is supplied with boost. When it's closed the boost is released through the waste gate. This release sounds like a puff and is called turbo chuff. This is normal and not an indication of an engine problem.

The CNG system also uses a fixed geometry waste gate style turbocharger.

Figure 5-30 lists the components of both systems and shows the differences between the Diesel and CNG air intake systems.

CNG

1. Intake air inlet to turbocharger elbow
2. Intake air combination sensor (pressure, temperature, and humidity)
3. Turbocharger air to charge-air cooler
4. Charge-air cooler
5. From charge-air cooler to air inlet adapter
6. Intake air throttle
7. Fuel control housing
8. Intake manifold
9. Intake valve port
10. Intake valve
11. Exhaust gas recirculation (EGR) cooler
12. EGR crossover tube
13. Exhaust gas to EGR valve
14. EGR valve
15. EGR mass measurement flow assembly
16. Exhaust gas to intake manifold connection.

Diesel

1. Intake air inlet to turbocharger
2. Turbocharger air to charge-air cooler
3. Charge-air cooler
4. From charge-air cooler to intake manifold
5. Intake air connection
6. Intake valve port
7. Intake valve
8. Exhaust gas recirculation (EGR) cooler
9. Exhaust gas to EGR valve
10. EGR valve
11. EGR mass measurement flow assembly
12. EGR crossover tube
13. Exhaust gas to intake manifold connection

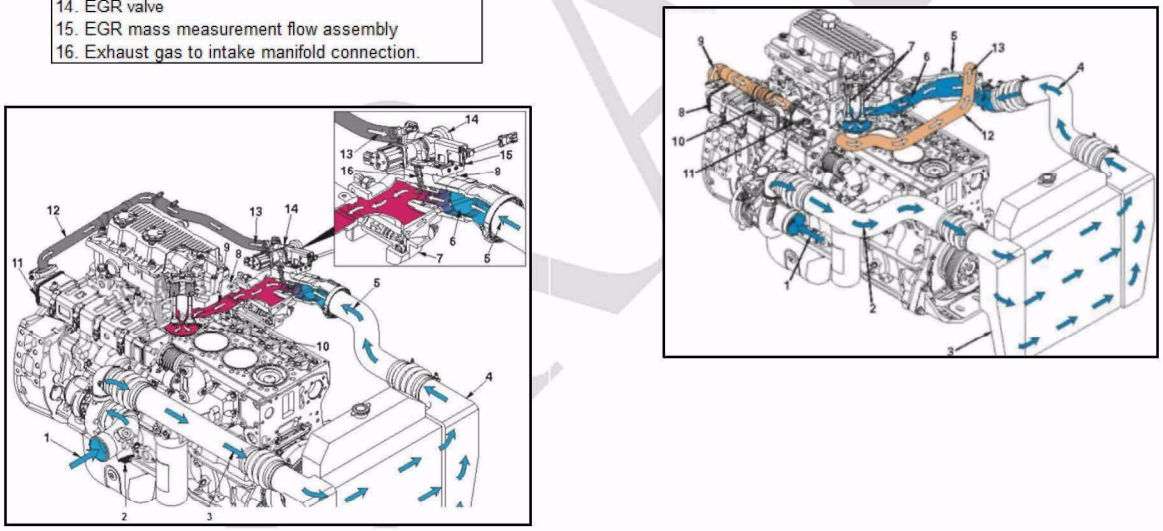


Figure 5-30: Air Flow Diagram for Air Intake System
(Source: Cummins parts website https://quickserve.cummins.com)

5.9 Exhaust System

This section includes the After-treatment system of the off-engine exhaust components.

Both the Diesel and the CNG have the same type of EGR cooling unit although the Diesel has 112 inner cooling tubes inside of the cooler as compared to 108 inner cooling tubes in the CNG.

Engines with an exhaust gas recirculation (EGR) unit will work together with the air intake system and exhaust system to provide intake charge-air in the right proportions to the engine.

Figure 5-31 is the EGR overview for both Diesel and CNG engines.

CNG

1. Exhaust port
2. Exhaust manifold
3. EGR cooler gas inlet
4. EGR cooler
5. EGR cooler gas outlet
6. EGR valve
7. Turbocharger
8. Turbocharger exhaust outlet connection

Diesel

1. Exhaust valve port
2. Exhaust gas to exhaust gas recirculation (EGR) cooler
3. EGR cooler
4. Cooled exhaust gas to rear EGR transfer tube
5. EGR hose
6. EGR valve
7. EGR orifice pressure
8. EGR mass measurement flow assembly
9. EGR differential pressure sensor
10. EGR temperature sensor
11. EGR crossover tube
12. Exhaust manifold
13. Exhaust gas to aftertreatment system

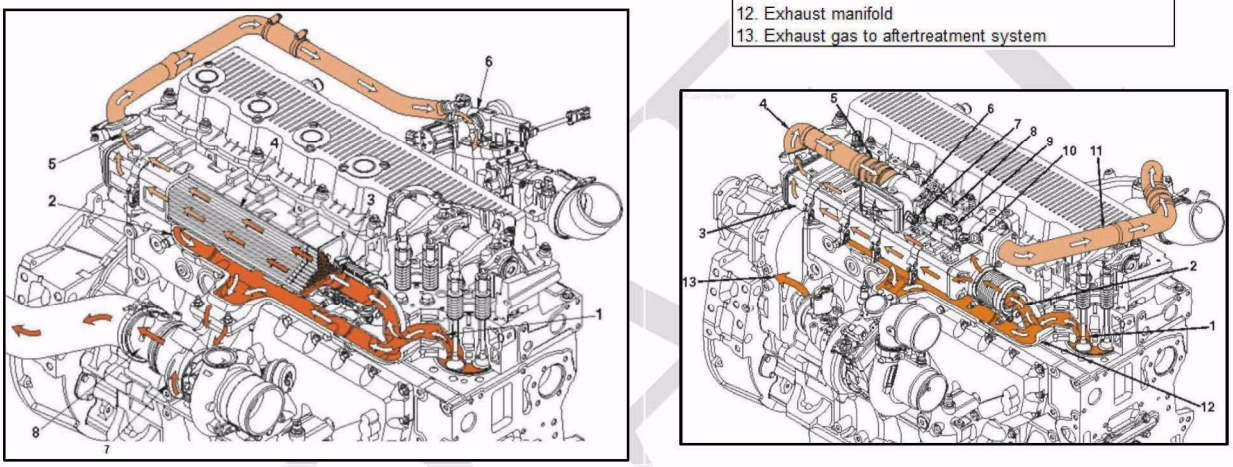


Figure 5-31: EGR Overview
(Source: Cummins parts website https://quickserve.cummins.com)

Figure 5-32 shows some of the differences in the EGR systems for both Diesel and CNG engines.

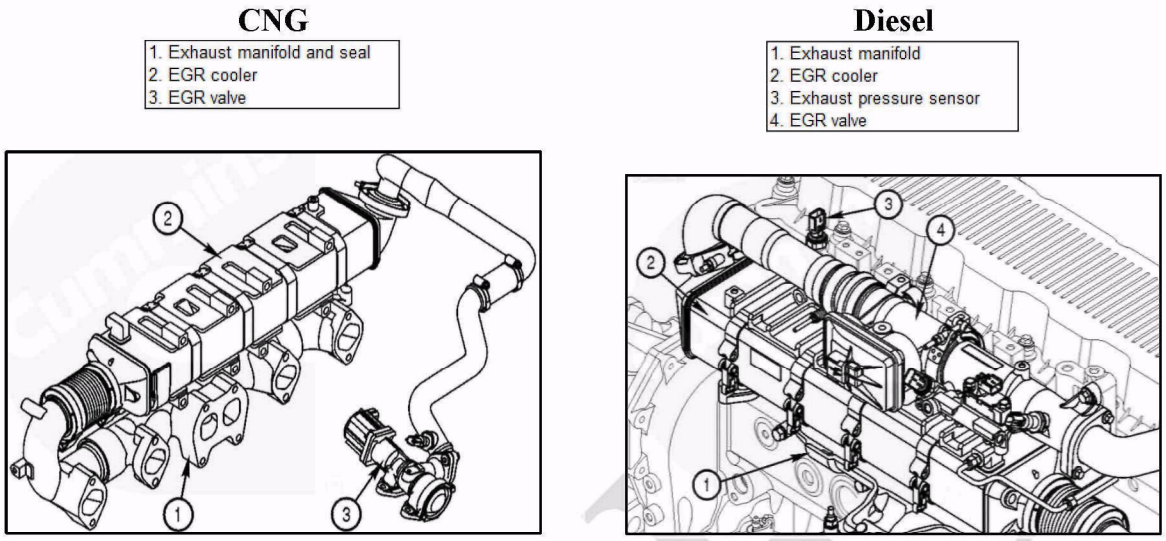


Figure 5-32: EGR Components

(Source: Cummins parts website https://quickserve.cummins.com)

The three-piece design of the exhaust manifold is a sealed slip-joint design that allows for thermal thermal expansion. Both Diesel and CNG are the same, as shown in Figure 5-33.

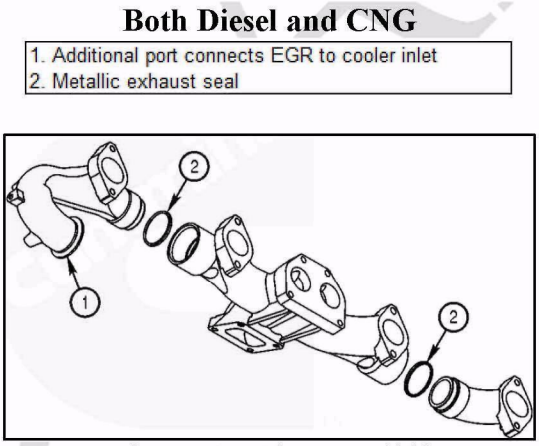


Figure 5-33: Exhaust Manifold

(Source: Cummins parts website https://quickserve.cummins.com)

Exhaust gas that flows to the EGR valve is cooled through the EGR cooler. With the EGR valve mounted after the EGR cooler, the cooler temperatures and pressures are the same as the exhaust manifold.

To prevent air from being trapped during coolant filling, a vent is located near the inlet of the EGR cooler as shown in Figure 5-34.

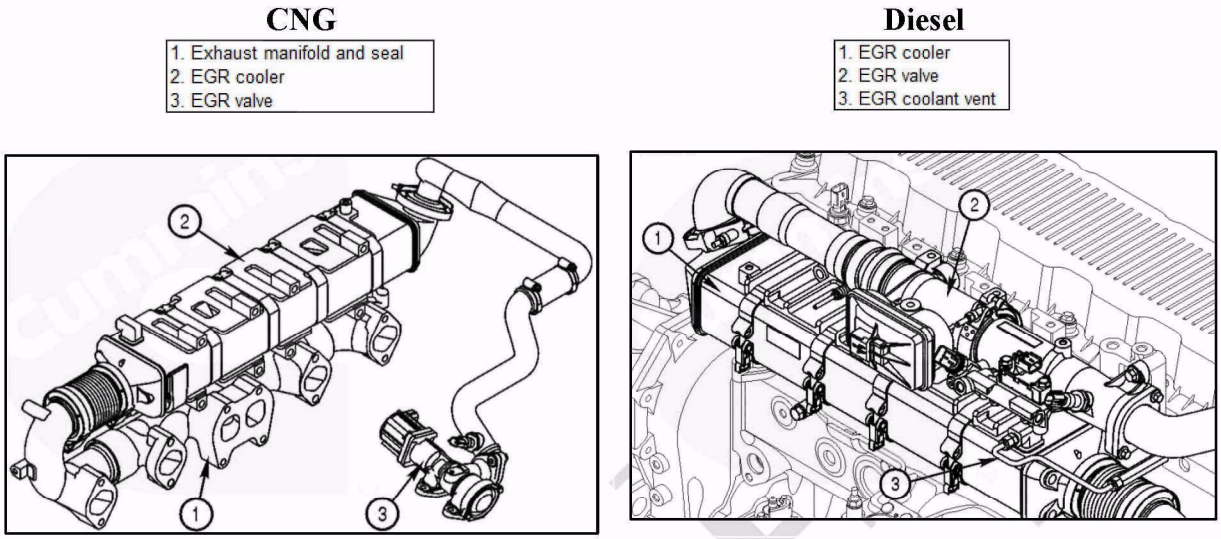


Figure 5-34: Exhaust Manifold

(Source: Cummins parts website https://quickserve.cummins.com)

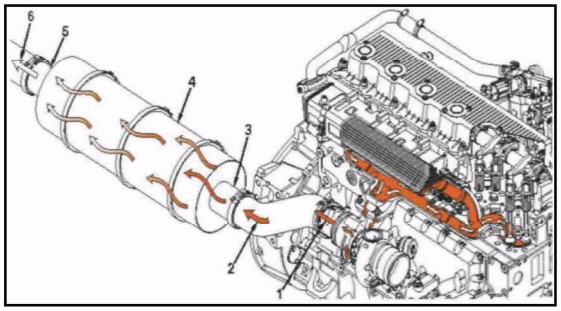
5.9.1 Off-Engine Exhaust System

Exhaust After-treatment system

As exhaust gas is expelled from the turbocharger it enters the off-engine exhaust system. Figure 5-35 shows the differences between the Diesel Selective catalytic reduction (SCR) system and the CNG Three-Way Catalytic Converters (TWC) exhaust systems. Refer to the Diesel exhaust section and the CNG exhaust section in beginning of this paper for in-depth explanations of each system.

CNG

1. Exhaust from turbocharger
2. Exhaust pipe with exhaust mixture
3. Catalyst inlet
4. Three way catalyst
5. Catalyst outlet
6. Exhaust flow exiting catalyst.



Diesel

1. Exhaust from turbocharger
2. Aftertreatment diesel oxidation catalyst (DOC) intake temperature sensor
3. Aftertreatment DOC
4. Aftertreatment diesel particulate filter (DPF) intake temperature sensor
5. Aftertreatment DPF combination pressure sensor (senses delta pressure across the filter and filter outlet pressure)
6. Aftertreatment DPF
7. Aftertreatment DPF outlet temperature sensor
8. Exhaust gas flow from the DPF
9. Diesel exhaust fluid (DEF) supply to aftertreatment DEF dosing valve
10. Aftertreatment DEF dosing valve
11. Decomposition reactor
12. Exhaust and DEF mixture
13. Aftertreatment selective catalyst reduction (SCR) intake temperature sensor
14. Aftertreatment SCR catalyst
15. Aftertreatment SCR outlet temperature sensor
16. Exhaust flow exiting aftertreatment system
17. Aftertreatment DEF dosing valve coolant fittings.

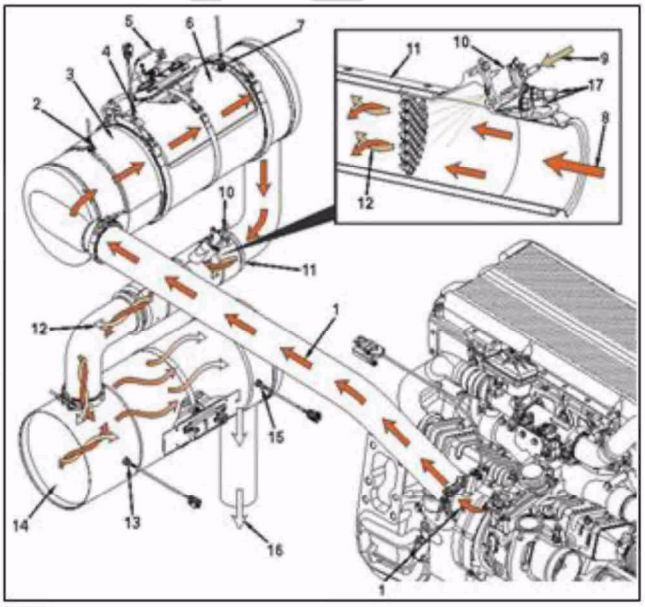


Figure 5-35: After-treatment Flow

(Source: Cummins parts website https://quickserve.cummins.com)

6. Direct Manufacturing Cost for the CNG/Diesel Study At Vehicle Level

As shown in the cost breakdown in Table 6-1, $10,964.42 is the cost of the base Diesel technology and $21,376.50 is the cost for the new CNG technology.

This is a cost differential total of $-10,412.08 "+" = cost decrease, "-" = cost increase

Additional details on the components are evaluated within each vehicle subsystem and their associated costs are provided in the following sections.

Table 6-1: Vehicle Level Direct Manufacturing Cost Of the CNG/Diesel Study

SYSTEM & SUBSYSTEM DESCRIPTION			DIESEL TECHNOLOGY GENERAL PART INFORMATION:										
			Manufacturing				Markup						
Item	System	Name/Description	Material	Labor	Burden	Total Manufacturing Cost (Component/ Assembly)	End Item Scrap	SG&A	Profit	ED&T-R&D	Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
			USD	USD	USD	USD	USD	USD	USD	USD	USD	USD	USD
1	01	Cyl Block System	-	-	-	-	-	-	-	-	-	-	-
2	02	Cyl Head System	0.20	0.38	0.25	0.83	0.00	0.03	0.02	0.01	0.06	-	0.89
3	03	Rocker Lever System	-	-	-	-	-	-	-	-	-	-	-
4	04	Cam Followers System	-	-	-	-	-	-	-	-	-	-	-
5	05	Fuel & Controls System	1,845.28	822.55	907.60	3,575.43	19.04	187.66	196.51	88.08	491.29	-	4,066.72
6	06	Injectors Plumbing & Filters System	197.62	207.97	200.56	606.15	3.40	42.20	40.39	14.90	100.89	-	707.05
7	07	Oil System	-	-	-	-	-	-	-	-	-	-	-
8	08	Fan & Water System	-	-	-	-	-	-	-	-	-	-	-
9	09	Accessory Drive provision System	-	-	-	-	-	-	-	-	-	-	-
10	10	Air Transfer System	313.99	146.34	220.33	680.66	8.37	45.78	46.52	18.37	119.03	-	799.69
11	11	Aftertreatment & Exhaust System	3,360.69	654.81	767.12	4,782.62	23.32	257.35	238.08	88.71	607.46	-	5,390.07
12	12	CPR Air System	-	-	-	-	-	-	-	-	-	-	-
13	13	Engine Voltage System	-	-	-	-	-	-	-	-	-	-	-
16	16	Flywheel & Flexplate System	-	-	-	-	-	-	-	-	-	-	-
17	17	Engine Gasket and Misc. System	-	-	-	-	-	-	-	-	-	-	-
21	21	Accessories Wiring System	-	-	-	-	-	-	-	-	-	-	-
			-	-	-	-	-	-	-	-	-	-	-
		SUBSYSTEM ROLL-UP	5,717.77	1,832.05	2,095.86	9,645.69	54.13	533.02	521.51	210.07	1,318.73	-	10,964.42

SYSTEM & SUBSYSTEM DESCRIPTION			CNG TECHNOLOGY GENERAL PART INFORMATION:										
Item	System	Name/Description	Manufacturing			Total Manufacturing Cost (Component/ Assembly)	Markup				Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
			Material	Labor	Burden		End Item Scrap	SG&A	Profit	ED&T-R&D			
			USD	USD	USD	USD	USD	USD	USD	USD	USD	USD	USD
1	01	Cyl Block System	0.90	0.34	0.16	1.40	0.00	0.01	0.01	-	0.02	-	1.41
2	02	Cyl Head System	-	-	-	-	-	-	-	-	-	-	-
3	03	Rocker Lever System	-	-	-	-	-	-	-	-	-	-	-
			-	-	-	-	-	-	-	-	-	-	-
4	04	Cam Followers System	-	-	-	-	-	-	-	-	-	-	-
5	05	Fuel & Controls System	12,761.48	831.80	1,615.77	15,209.05	65.69	703.71	742.40	346.33	1,858.13	-	17,067.19
6	06	Injectors Plumbing & Filters System	18.22	9.99	25.09	53.29	0.71	3.76	2.88	0.63	7.97	-	61.27
7	07	Oil System	-	-	-	-	-	-	-	-	-	-	-
8	08	Fan & Water System	-	-	-	-	-	-	-	-	-	-	-
9	09	Accessory Drive provision System	-	-	-	-	-	-	-	-	-	-	-
10	10	Air Transfer System	423.09	154.47	227.19	804.75	11.01	54.73	57.23	23.31	146.28	-	951.03
11	11	Aftertreatment & Exhaust System	1,763.84	279.82	309.73	2,353.39	12.59	122.30	136.21	64.07	335.17	-	2,688.56
12	12	CPR Air System	-	-	-	-	-	-	-	-	-	-	-
13	13	Engine Voltage System	289.39	115.85	127.97	533.21	2.72	27.05	29.87	14.20	73.84	-	607.04
16	16	Flywheel & Flexplate System	-	-	-	-	-	-	-	-	-	-	-
17	17	Engine Gasket and Misc. System	-	-	-	-	-	-	-	-	-	-	-
21	21	Accessories Wiring System	-	-	-	-	-	-	-	-	-	-	-
			-	-	-	-	-	-	-	-	-	-	-
		SUBSYSTEM ROLL-UP	15,256.92	1,392.26	2,305.91	18,955.09	92.71	911.56	968.59	448.55	2,421.40	-	21,376.50

SYSTEM & SUBSYSTEM DESCRIPTION			INCREMENTAL COST TO UPGRADE TO NEW TECHNOLOGY PACKAGE										
			Manufacturing				Markup						
Item	System	Name/Description	Material	Labor	Burden	Total Manufacturing Cost (Component/ Assembly)	End Item Scrap	SG&A	Profit	ED&T-R&D	Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
			USD	USD	USD	USD	USD	USD	USD	USD	USD	USD	USD
1	01	Cyl Block System	(0.90)	(0.34)	(0.16)	(1.40)	(0.00)	(0.01)	(0.01)	-	(0.02)	-	(1.41)
2	02	Cyl Head System	0.20	0.38	0.25	0.83	0.00	0.03	0.02	0.01	0.06	-	0.89
3	03	Rocker Lever System	-	-	-	-	-	-	-	-	-	-	-
			-	-	-	-	-	-	-	-	-	-	-
4	04	Cam Followers System	-	-	-	-	-	-	-	-	-	-	-
5	05	Fuel & Controls System	(10,916.21)	(9.25)	(708.17)	(11,633.62)	(46.65)	(516.05)	(545.90)	(258.25)	(1,366.85)	-	(13,000.47)
6	06	Injectors Plumbing & Filters System	179.40	197.98	175.48	552.86	2.69	38.45	37.52	14.27	92.92	-	645.78
7	07	Oil System	-	-	-	-	-	-	-	-	-	-	-
8	08	Fan & Water System	-	-	-	-	-	-	-	-	-	-	-
9	09	Accessory Drive provision System	-	-	-	-	-	-	-	-	-	-	-
10	10	Air Transfer System	(109.10)	(8.13)	(6.87)	(124.09)	(2.64)	(8.96)	(10.71)	(4.94)	(27.24)	-	(151.34)
11	11	Aftertreatment & Exhaust System	1,596.84	374.99	457.40	2,429.23	10.73	135.05	101.86	24.64	272.28	-	2,701.51
12	12	CPR Air System	-	-	-	-	-	-	-	-	-	-	-
13	13	Engine Voltage System	(289.39)	(115.85)	(127.97)	(533.21)	(2.72)	(27.05)	(29.87)	(14.20)	(73.84)	-	(607.04)
16	16	Flywheel & Flexplate System	-	-	-	-	-	-	-	-	-	-	-
17	17	Engine Gasket and Misc. System	-	-	-	-	-	-	-	-	-	-	-
21	21	Accessories Wiring System	-	-	-	-	-	-	-	-	-	-	-
			-	-	-	-	-	-	-	-	-	-	-
		SUBSYSTEM ROLL-UP	(9,539.15)	439.79	(210.05)	(9,309.40)	(38.59)	(378.54)	(447.07)	(238.48)	(1,102.68)	-	(10,412.08)

6.1 Cylinder Block Subsystem 01&02-01

The cylinder block 01 system is broken into 11 sub-subsystems & 1 assembly.

1. 01-01-01 Cylinder block
2. 01-01-02 Front gear housing
3. 01-01-03 Cylinder liner
4. 01-01-04 Crankshaft
5. 01-01-05 Cylinder block plumbing
    a. 01-01-05-01 Threaded plug (CNG Only)
6. 01-01-06 Piston cooling nozzle
7. 01-01-07 Vibration damper
8. 01-01-08 Conrods/parts & performance
9. 01-01-10 Front cover
10. 01-01-11 Camshaft
11. 01-01-12 Rear gear housing

6.2 Cylinder Block Sub-Subsystem 01-01-01 Overview

The Cummins ISXG11.9 liter CNG engine and the ISX11.9 liter Diesel engine blocks are identical (Figure 6-1) and therefore the two blocks were treated as the same and not quoted.

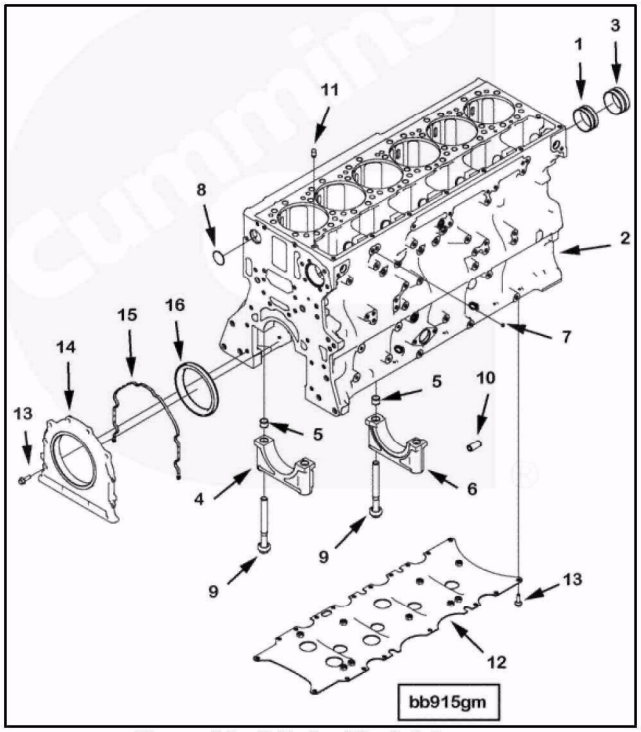


Figure 6-1: Cylinder Block Subsystem
(Source: Cummins parts website https://quickserve.cummins.com)

6.3 Front Gear Housing Sub-Subsystem 01-01-02 Overview

The Cummins ISXG11.9 liter CNG engine and the ISX11.9 liter Diesel engine front gear housings are identical (Figure 6-2) and were treated as the same and not quoted.

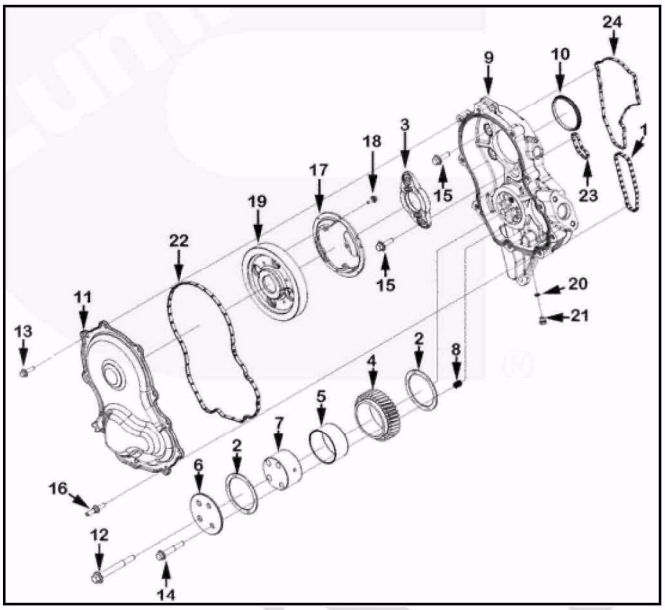


Figure 6-2: Front Gear Housing Subsystem
(Source: Cummins parts website https://quickserve.cummins.com)

6.4 Cylinder Block Liners Sub-Subsystem 01-01-03 Overview

The Cummins ISXG11.9 liter CNG engine and the ISX11.9 liter Diesel engine blocks cylinder liners are identical (Figure 6-3) and therefore were treated as the same and not quoted.

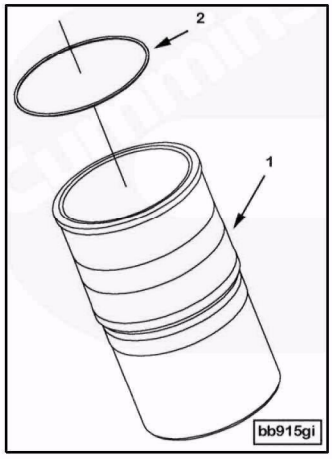


Figure 6-3: Cylinder Block Liners Subsystem
(Source: Cummins parts website https://quickserve.cummins.com)

6.5 Crankshaft Sub-Subsystem 01-01-04 Overview

The Cummins ISXG11.9 liter CNG engine and the ISX11.9 liter Diesel engine blocks crankshafts are identical (Figure 6-4) and therefore were treated as the same and not quoted.

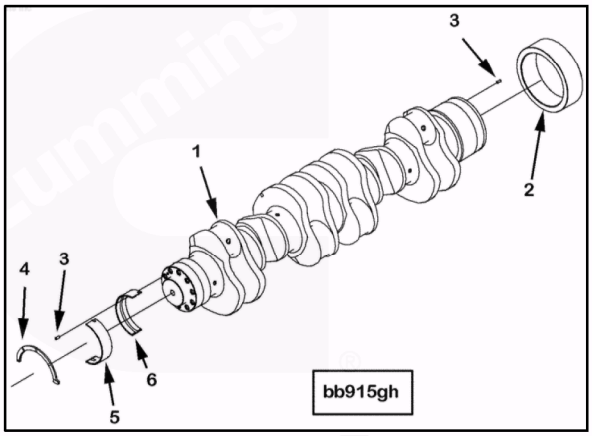


Figure 6-4: Cylinder Block Liners Subsystem
(Source: Cummins parts website https://quickserve.cummins.com)

6.6 Cylinder Block Plumbing Sub-Subsystem 01-01-05 Overview

The Cummins ISXG11.9 liter CNG engine has one more block plug then the Diesel due to the doser hole in the block being plugged. Figure 6-5 is a picture of the assembly 01-01-05-01 Threaded Plug.

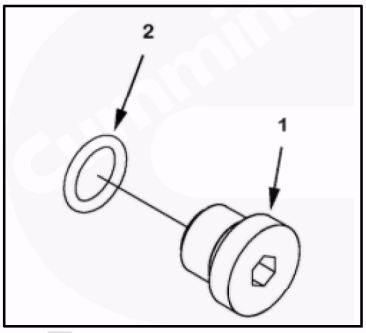


Figure 6-5: Cylinder Block Plumbing Plug
(Source: Cummins parts website https://quickserve.cummins.com)

6.7 Piston Cooling Nozzle Sub-Subsystem 01-01-06 Overview

The Cummins ISXG11.9 liter CNG engine and the ISX11.9 liter Diesel engine piston cooling nozzles are identical (Figure 6-6) and therefore were treated as the same and not quoted.

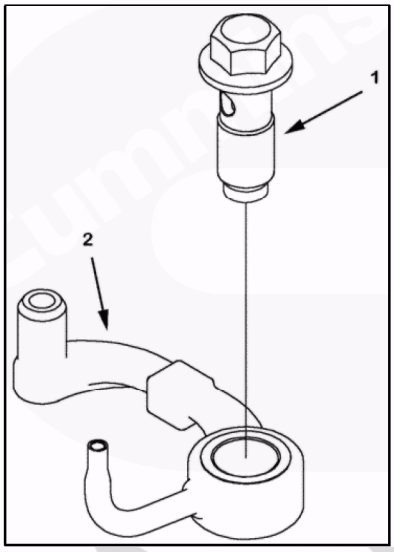


Figure 6-6: Piston Cooling Nozzle Subsystem
(Source: Cummins parts website https://quickserve.cummins.com)

6.8 Vibration Damper Sub-Subsystem 01-01-07 Overview

The Cummins ISXG11.9 liter CNG engine and the ISX11.9 liter Diesel engine vibration damper have a slight difference in the front adaptor coupling on the diesel. It was determined that this was for an attachment not related to this study and treated as the same and not quoted (Figure 6-7).

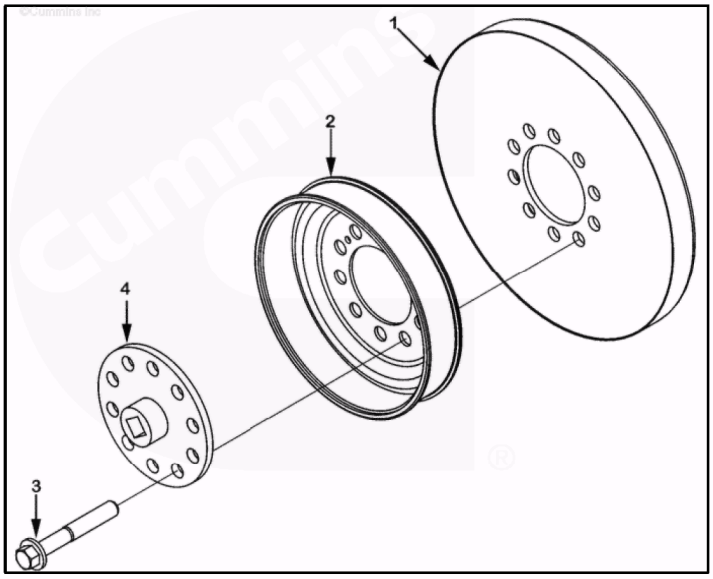


Figure 6-7: Vibration Damper Subsystem
(Source: Cummins parts website https://quickserve.cummins.com)

6.9 Conrods/Parts & Performance Sub-Subsystem 01-01-08 Overview

The Cummins ISXG11.9 liter CNG engine and the ISX11.9 liter Diesel engine Conrods/Parts & Performance subsystem have a slight difference in the design, but the manufacturing process and costs would not have any significance or relation to this study and treated as the same and not quoted (Figure 6-8).

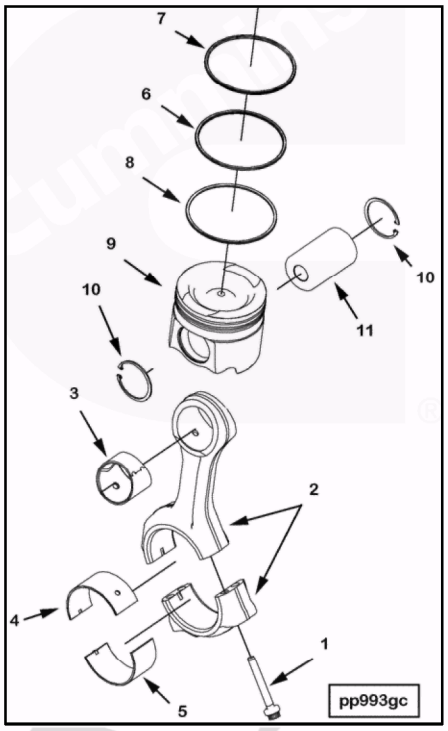


Figure 6-8: Conrods/Parts & Performance Subsystem
(Source: Cummins parts website https://quickserve.cummins.com)

6.10 Front Cover Sub-Subsystem 01-01-10 Overview

The Cummins ISXG11.9 liter CNG engine and the ISX11.9 liter Diesel engine front cover are identical (Figure 6-9) and therefore were treated as the same and not quoted.

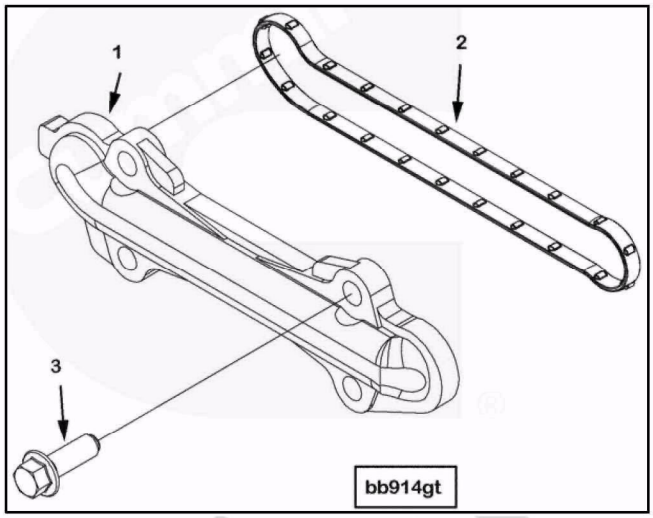


Figure 6-9: Front Cover Subsystem
(Source: Cummins parts website https://quickserve.cummins.com)

6.11 Camshaft Sub-Subsystem 01-01-11 Overview

The Cummins ISXG11.9 liter CNG engine and the ISX11.9 liter Diesel engine camshafts have slight machining differences that would not affect price and therefore were treated as the same and not quoted (Figure 6-10).

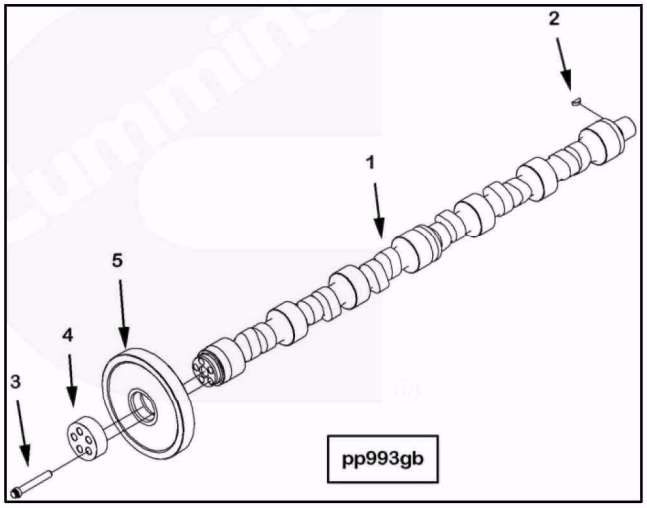


Figure 6-10: Camshaft Subsystem
(Source: Cummins parts website https://quickserve.cummins.com)

6.12 Rear Gear Housing Sub-Subsystem 01-01-12 Overview

The Cummins ISXG11.9 liter CNG engine and the ISX11.9 liter Diesel engine rear gear housing are identical (Figure 6-11) and there for were treated as the same and not quoted.

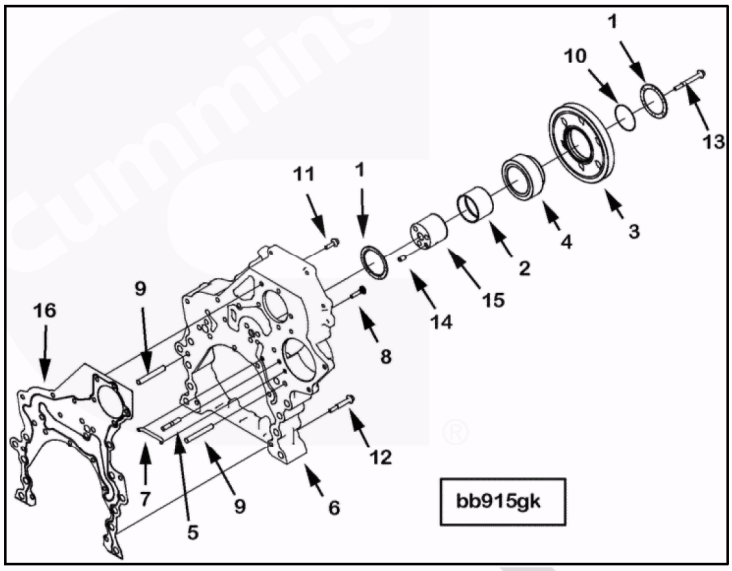


Figure 6-11: Rear Gear Housing Subsystem
(Source: Cummins parts website https://quickserve.cummins.com)

6.13 Direct Manufacturing Cost For Cylinder Block Subsystem 01-01

The cost breakdown below shows that the CNG system had an increase total of $1.41 due to added block pluming requirements. "+" = cost decrease, "-" = cost increase

Table 6-2: Direct Manufacturing Cost Of the Cylinder Block Subsystem 01-01

SYSTEM & SUBSYSTEM DESCRIPTION					DIESEL TECHNOLOGY GENERAL PART INFORMATION:										
Item	System	Subsystem	Sub-Subsystem	Name/Description	Manufacturing			Total Manufacturing Cost (Component/ Assembly)	Markup				Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
					Material	Labor	Burden		End Item Scrap	SG&A	Profit	ED&T-R&D			
					USD	USD	USD	USD	USD	USD	USD	USD	USD	USD	USD
	CNG / Diesel														
	01 Cylinder Block														
1		01 Cyl Block			-	-	-	-	-	-	-	-	-	-	-
2		02 Front Gear Housing			-	-	-	-	-	-	-	-	-	-	-
3		03 Cyl Liner			-	-	-	-	-	-	-	-	-	-	-
4		04 Crankshaft			-	-	-	-	-	-	-	-	-	-	-
5		05 Cyl Block Plumbing			-	-	-	-	-	-	-	-	-	-	-
6		06 Piston Colling Nozzle			-	-	-	-	-	-	-	-	-	-	-
7		07 Vibration Damper			-	-	-	-	-	-	-	-	-	-	-
8		08 Conrods/Parts & Performance			-	-	-	-	-	-	-	-	-	-	-
9		09 NA			-	-	-	-	-	-	-	-	-	-	-
10		10 Front Cover			-	-	-	-	-	-	-	-	-	-	-
11		11 Cam Shaft			-	-	-	-	-	-	-	-	-	-	-
12		12 Rear Gear Housing			-	-	-	-	-	-	-	-	-	-	-
				SUBSYSTEM ROLL-UP	-	-	-	-	-	-	-	-	-	-	-

SYSTEM & SUBSYSTEM DESCRIPTION					CNG TECHNOLOGY GENERAL PART INFORMATION:										
Item	System	Subsystem	Sub-Subsystem	Name/Description	Manufacturing			Total Manufacturing Cost (Component/ Assembly)	Markup				Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
					Material	Labor	Burden		End Item Scrap	SG&A	Profit	ED&T-R&D			
					USD	USD	USD	USD	USD	USD	USD	USD	USD	USD	USD
	CNG / Diesel														
		01 Cylinder Block													
1			01 Cyl Block		-	-	-	-	-	-	-	-	-	-	-
2			02 Front Gear Housing		-	-	-	-	-	-	-	-	-	-	-
3			03 Cyl Liner		-	-	-	-	-	-	-	-	-	-	-
4			04 Crankshaft		-	-	-	-	-	-	-	-	-	-	-
5			05 Cyl Block Plumbing		0.90	0.34	0.16	1.40	0.00	0.01	0.01	-	0.02	-	1.41
6			06 Piston Colling Nozzle		-	-	-	-	-	-	-	-	-	-	-
7			07 Vibration Damper		-	-	-	-	-	-	-	-	-	-	-
8			08 Conrods/Parts & Performance		-	-	-	-	-	-	-	-	-	-	-
9			09 NA		-	-	-	-	-	-	-	-	-	-	-
10			10 Front Cover		-	-	-	-	-	-	-	-	-	-	-
11			11 Cam Shaft		-	-	-	-	-	-	-	-	-	-	-
12			12 Rear Gear Housing		-	-	-	-	-	-	-	-	-	-	-
				SUBSYSTEM ROLL-UP	0.90	0.34	0.16	1.40	0.00	0.01	0.01	-	0.02	-	1.41

SYSTEM & SUBSYSTEM DESCRIPTION					INCREMENTAL COST TO UPGRADE TO NEW TECHNOLOGY PACKAGE										
					Manufacturing				Markup						
Item	System	Subsystem	Sub-Subsystem	Name/Description	Material	Labor	Burden	Total Manufacturing Cost (Component/ Assembly)	End Item Scrap	SG&A	Profit	ED&T-R&D	Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
					USD	USD	USD	USD	USD	USD	USD	USD	USD	USD	USD
	CNG / Diesel														
		01 Cylinder Block													
1			01 Cyl Block		-	-	-	-	-	-	-	-	-	-	-
2			02 Front Gear Housing		-	-	-	-	-	-	-	-	-	-	-
3			03 Cyl Liner		-	-	-	-	-	-	-	-	-	-	-
4			04 Crankshaft		-	-	-	-	-	-	-	-	-	-	-
5			05 Cyl Block Plumbing		(0.90)	(0.34)	(0.16)	(1.40)	(0.00)	(0.01)	(0.01)	-	(0.02)	-	(1.41)
6			06 Piston Colling Nozzle		-	-	-	-	-	-	-	-	-	-	-
7			07 Vibration Damper		-	-	-	-	-	-	-	-	-	-	-
8			08 Conrods/Parts & Performance		-	-	-	-	-	-	-	-	-	-	-
9			09 NA		-	-	-	-	-	-	-	-	-	-	-
10			10 Front Cover		-	-	-	-	-	-	-	-	-	-	-
11			11 Cam Shaft		-	-	-	-	-	-	-	-	-	-	-
12			12 Rear Gear Housing		-	-	-	-	-	-	-	-	-	-	-
			SUBSYSTEM ROLL-UP		(0.90)	(0.34)	(0.16)	(1.40)	(0.00)	(0.01)	(0.01)	-	(0.02)	-	(1.41)

7. Cylinder Head Subsystem 01-02

The cylinder head 02 subsystem is broken into 1 sub-subsystem & 1 assembly.

01-02-01 Cylinder head

01-02-01-01 Cylinder head (Diesel Only)

7.1 Cylinder Head Sub-Subsystem 01-02-01 Overview

The Cummins ISXG11.9 liter CNG engine and the ISX11.9 liter Diesel engine Cylinder Heads are identical, except the Diesel head has two more expansion plugs callout #7 than the CNG cylinder head (Figure 7-1).

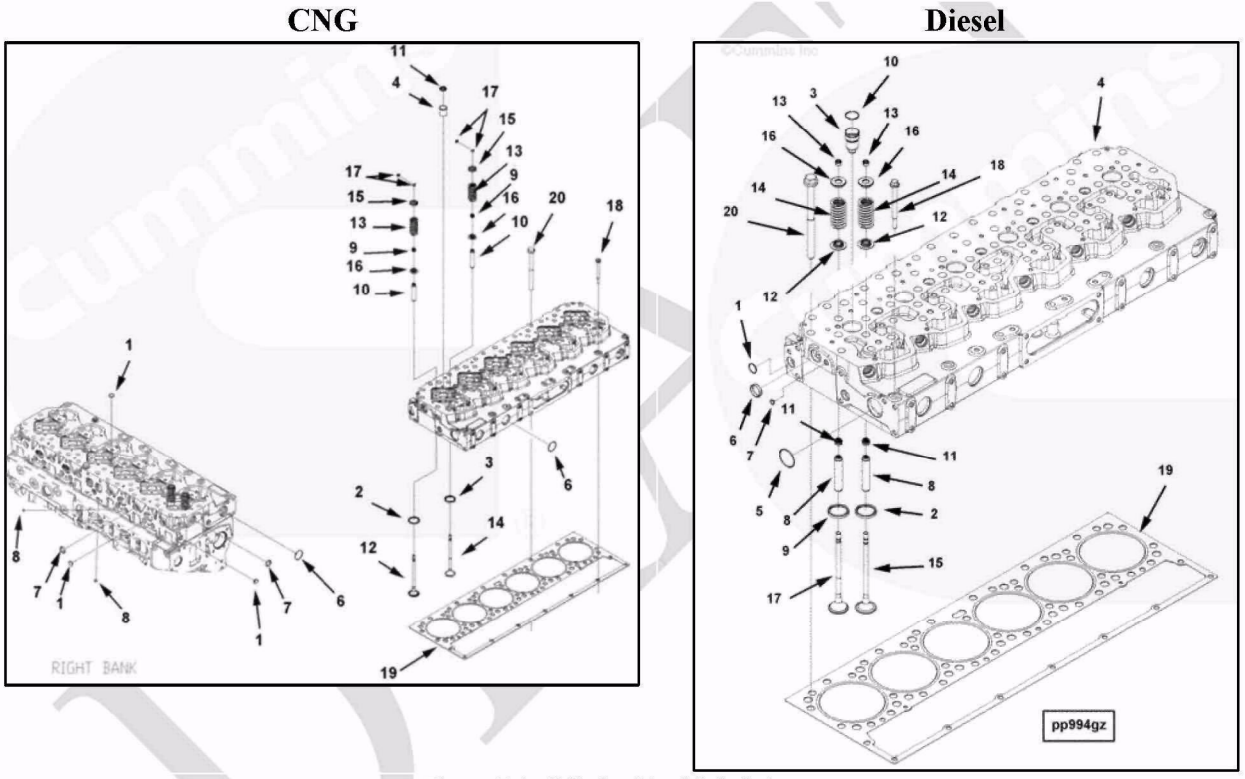


Figure 7-1: Cylinder Head Sub-Subsystem
(Source: Cummins parts website https://quickserve.cummins.com)

7.2 Direct Manufacturing Cost for Cylinder Head Subsystem 01-02

The cost breakdown below shows that the Diesel system had an increase total of $.89 due to added Expansion Plug requirements. "+" = cost decrease, "-" = cost increase

Table 7-1: Direct Manufacturing Cost Of the Cylinder Head Subsystem 01-02

SYSTEM & SUBSYSTEM DESCRIPTION					DIESEL TECHNOLOGY GENERAL PART INFORMATION:										
					Manufacturing				Markup						
Item	System	Subsystem	Sub-Subsystem	Name/Description	Material	Labor	Burden	Total Manufacturing Cost (Component/ Assembly)	End Item Scrap	SG&A	Profit	ED&T-R&D	Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
					USD	USD	USD	USD	USD	USD	USD	USD	USD	USD	USD
	CNG / Diesel														
	02 Cylinder Head System														
1		01 Cyl Head			0.20	0.38	0.25	0.83	0.00	0.03	0.02	0.01	0.06	-	0.89
2		02			-	-	-	-	-	-	-	-	-	-	-
3		03			-	-	-	-	-	-	-	-	-	-	-
4		04			-	-	-	-	-	-	-	-	-	-	-
5		05			-	-	-	-	-	-	-	-	-	-	-
6		06			-	-	-	-	-	-	-	-	-	-	-
7		07			-	-	-	-	-	-	-	-	-	-	-
8		08			-	-	-	-	-	-	-	-	-	-	-
9		09			-	-	-	-	-	-	-	-	-	-	-
10		10			-	-	-	-	-	-	-	-	-	-	-
				SUBSYSTEM ROLLUP	0.20	0.38	0.25	0.83	0.00	0.03	0.02	0.01	0.06	-	0.89

SYSTEM & SUBSYSTEM DESCRIPTION					CNG TECHNOLOGY GENERAL PART INFORMATION:										
Item	System	Subsystem	Sub-Subsystem	Name/Description	Manufacturing			Total Manufacturing Cost (Component/ Assembly)	Markup				Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
					Material	Labor	Burden		End Item Scrap	SG&A	Profit	ED&T-R&D			
					USD	USD	USD	USD	USD	USD	USD	USD	USD	USD	USD
	CNG / Diesel														
		02 Cylinder Head System													
1			01 Cyl Head		-	-	-	-	-	-	-	-	-	-	-
2			02		-	-	-	-	-	-	-	-	-	-	-
3			03		-	-	-	-	-	-	-	-	-	-	-
4			04		-	-	-	-	-	-	-	-	-	-	-
5			05		-	-	-	-	-	-	-	-	-	-	-
6			06		-	-	-	-	-	-	-	-	-	-	-
7			07		-	-	-	-	-	-	-	-	-	-	-
8			08		-	-	-	-	-	-	-	-	-	-	-
9			09		-	-	-	-	-	-	-	-	-	-	-
10			10		-	-	-	-	-	-	-	-	-	-	-
				SUBSYSTEM ROLL-UP	-	-	-	-	-	-	-	-	-	-	-

SYSTEM & SUBSYSTEM DESCRIPTION					INCREMENTAL COST TO UPGRADE TO NEW TECHNOLOGY PACKAGE										
					Manufacturing				Markup						
Item	System	Subsystem	Sub-Subsystem	Name/Description	Material	Labor	Burden	Total Manufacturing Cost (Component/ Assembly)	End Item Scrap	SG&A	Profit	ED&T-R&D	Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
					USD	USD	USD	USD	USD	USD	USD	USD	USD	USD	USD
	CNG / Diesel														
	02 Cylinder Head System														
1			01 Cyl Head		0.20	0.38	0.25	0.83	0.00	0.03	0.02	0.01	0.06	-	0.89
2			02		-	-	-	-	-	-	-	-	-	-	-
3			03		-	-	-	-	-	-	-	-	-	-	-
4			04		-	-	-	-	-	-	-	-	-	-	-
5			05		-	-	-	-	-	-	-	-	-	-	-
6			06		-	-	-	-	-	-	-	-	-	-	-
7			07		-	-	-	-	-	-	-	-	-	-	-
8			08		-	-	-	-	-	-	-	-	-	-	-
9			09		-	-	-	-	-	-	-	-	-	-	-
10			10		-	-	-	-	-	-	-	-	-	-	-
				SUBSYSTEM ROLL-UP	0.20	0.38	0.25	0.83	0.00	0.03	0.02	0.01	0.06	-	0.89

8. Rocker Lever Subsystem 01-03

The rocker lever 03 subsystem is broken into 5 sub-subsystems & 7 assemblies.

01-03-01 Rocker lever
01-03-02 Paint
01-03-03 Valve cover
    01-03-03-01 Valve cover
01-03-04 Crankcase breather
    01-03-04-01 Crankcase breather
    01-03-04-02 Molded hose
    01-03-04-03 Molded hose
    01-03-04-04 Breather support
    01-03-04-05 Lube oil drain tube (All wash not quoted)
    01-03-04-06 Breather adapter (CNG Only)
01-03-05 Engine Brake

8.1 Rocker Lever Sub-Subsystem 01-03-01 Overview

The Cummins ISXG11.9 liter CNG engine and the ISX11.9 liter Diesel engine Rocker lever assemblies are the same and not quoted. See Figure 8-1.

CNG **Diesel**

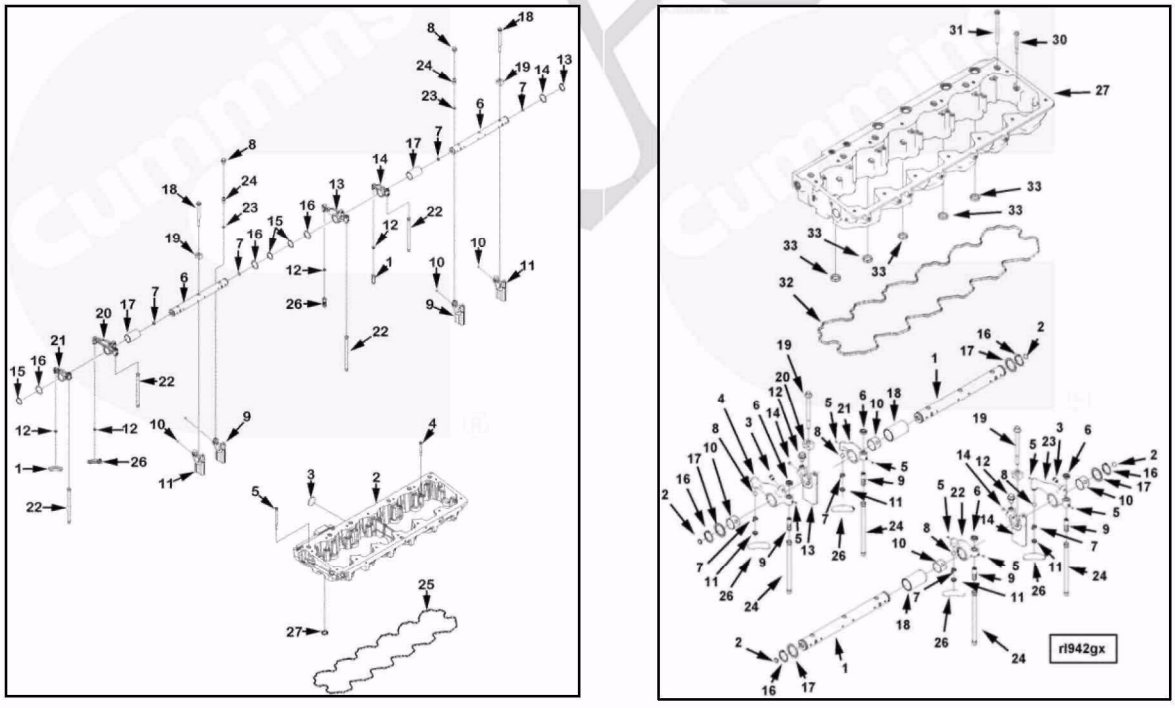


Figure 8-1: Rocker Lever Sub-Subsystem
(Source: Cummins parts website https://quickserve.cummins.com)

8.2 Paint Sub-Subsystem 01-03-02 Overview

The Cummins ISXG11.9 liter CNG engine and the ISX11.9 liter Diesel engine paint are identical for the two engines and were treated as the same and not quoted.

8.3 Valve Cover Sub-Subsystem 01-03-03 Overview

The Cummins ISXG11.9 liter CNG engine and the ISX11.9 liter Diesel engine valve cover assemblies 01-03-03-01 are different configurations due to the CNG spark ignited engine technology relative to conventional compression ignition Diesel (Figure 8-2). Only parts with different numbers will be quoted.

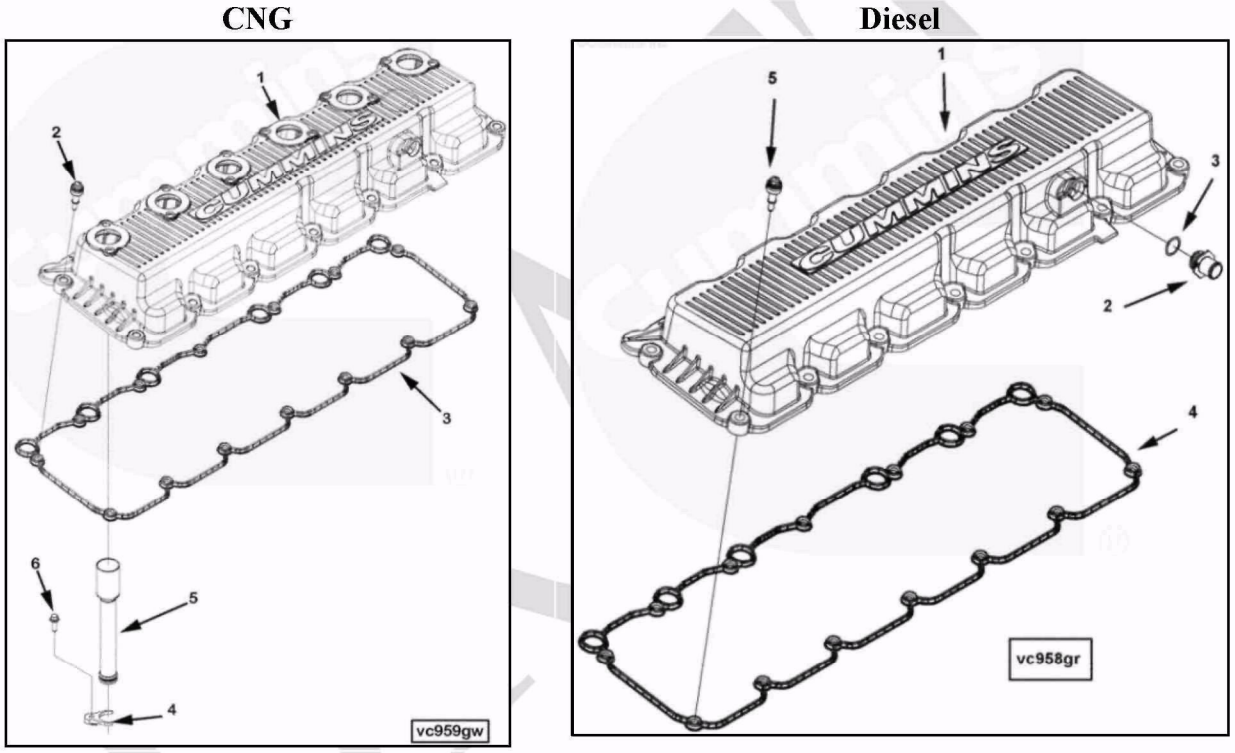


Figure 8-2: Valve Covers Sub-Subsystem
(Source: Cummins parts website https://quickserve.cummins.com)

8.4 Crankcase Breather Sub-Subsystem 01-03-04 Overview

The Cummins ISXG11.9 liter CNG engine and the ISX11.9 liter Diesel engine crankcase breather sub-subsystems are shown in Figure 8-3.

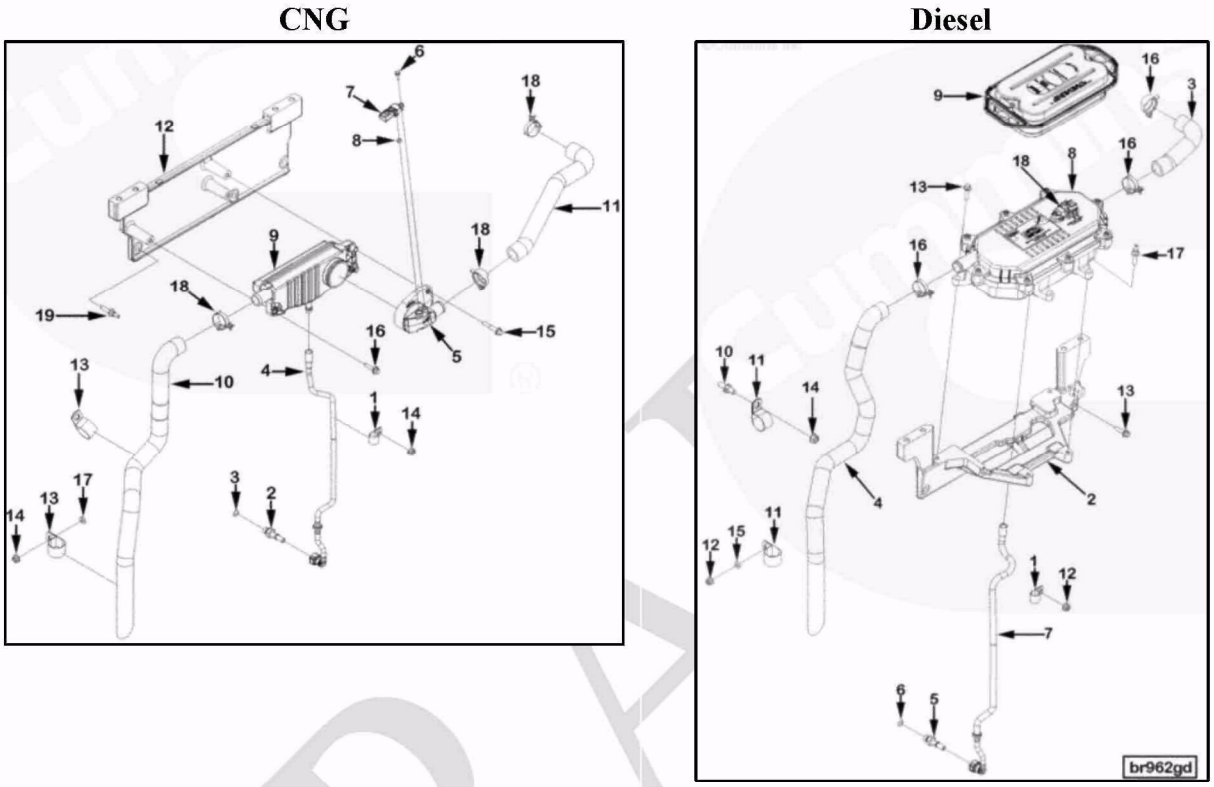


Figure 8-3: Crankcase Breather Sub-Subsystem
(Source: Cummins parts website https://quickserve.cummins.com)

The breather 04 sub-subsystem was broken down 6 into assemblies.

01-03-04-01 Crankcase breather
01-03-04-02 Molded hose
01-03-04-03 Molded hose
01-03-04-04 Breather support
01-03-04-05 Lube oil drain tube (All wash and not quoted)
01-03-04-06 Breather adapter (CNG Only)

The following sections show each assembly and what was quoted.

8.4.1 Crankcase Breather

Figure 8-4 illustrates the 01-03-04-01 Crankcase breather assembly; only parts with different numbers will be quoted.

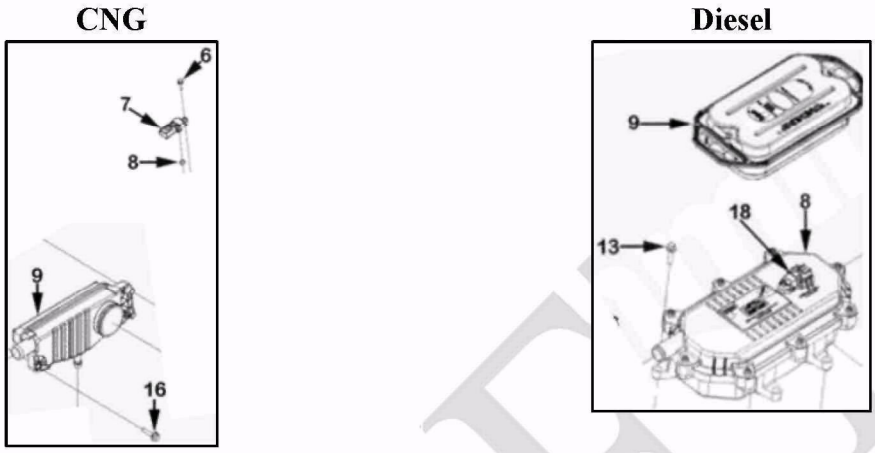


Figure 8-4: Crankcase Breather Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

8.4.2 Molded Hose

Figure 8-5 shows the 01-03-04-02 molded hose assembly. Only parts with different numbers will be quoted.

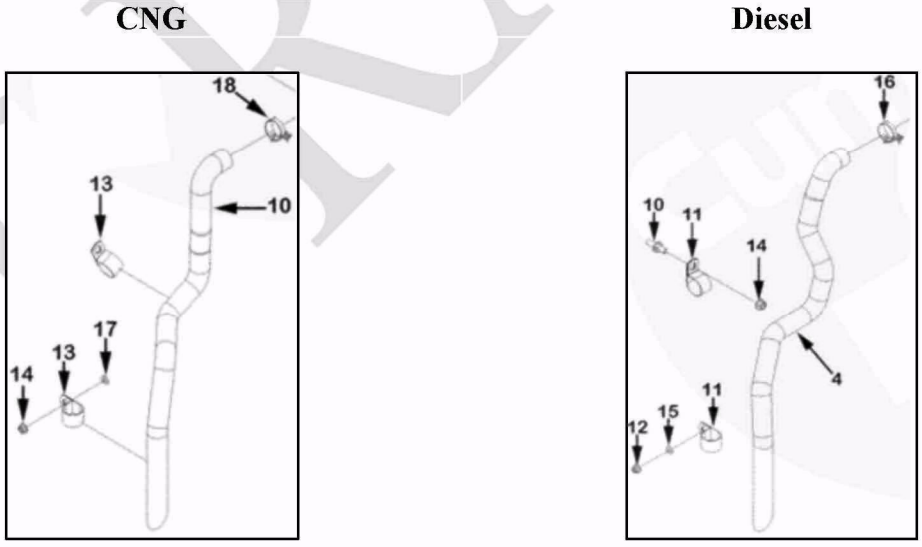


Figure 8-5: Molded Hose Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

8.4.3 Molded Hose

Figure 8-6 illustrates the 01-03-04-03 molded hose assembly; only parts with different numbers will be quoted.

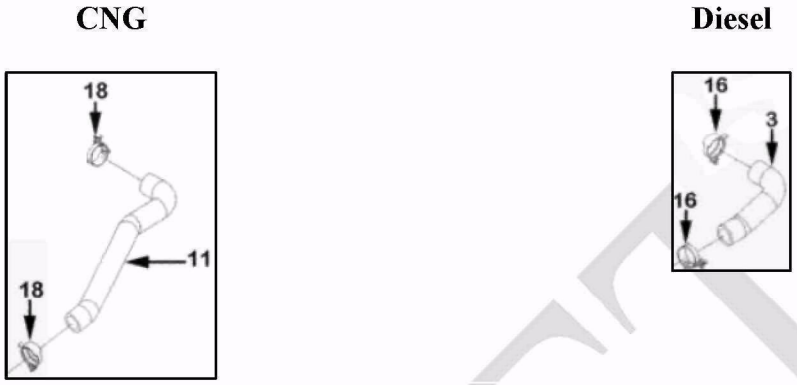


Figure 8-6: Molded Hose Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

8.4.4 Breather Support

Figure 8-7 shows the 01-03-04-04 Breather support assembly; only parts with different numbers will be quoted.

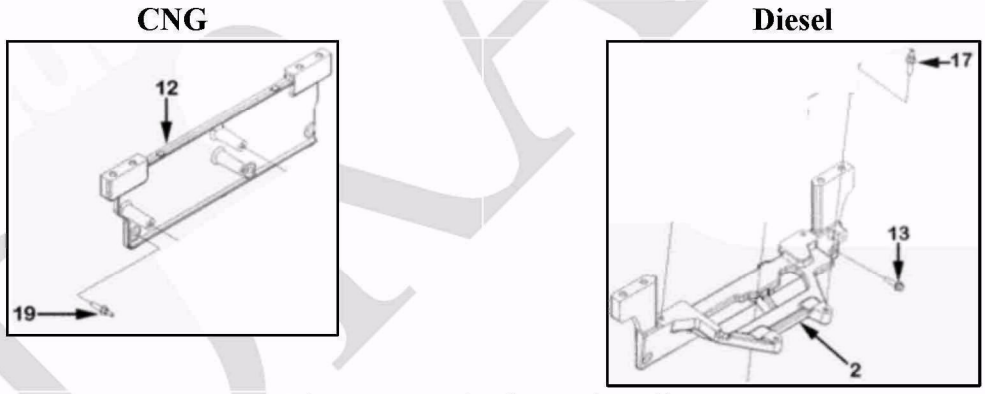


Figure 8-7: Breather Support Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

8.4.5 Lube Oil Drain Tube Assembly

Figure 8-8 illustrates the 01-03-04-05 Lube oil drain tube assemblies are identical and not quoted.

Figure 8-8: Lube Oil Drain Tube Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

8.4.6 Breather Adapter Assembly

Figure 8-9 shows the 01-03-04-06 Breather adapter assembly is unique to CNG and will be quoted.

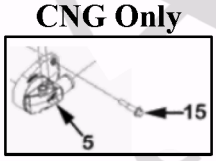


Figure 8-9: Breather Adapter Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

8.5 Engine Brake Sub-Subsystem 01-03-05 Overview

The Cummins ISXG11.9 liter CNG engine brake system and the ISX11.9 liter Diesel engine brake system were treated as the same and not quoted.

8.6 Direct Manufacturing Cost For Rocker Lever Subsystem 01-03

The cost breakdown below shows that the CNG system had an increase total of -$11.32 due to valve cover and crankcase breather changes. "+" = cost decrease, "-" = cost increase.

Table 8-1: Direct Manufacturing Cost Of the Rocker Lever Subsystem 01-03

SYSTEM & SUBSYSTEM DESCRIPTION					DIESEL TECHNOLOGY GENERAL PART INFORMATION:										
					Manufacturing				Markup						
Item	System	Subsystem	Sub-Subsystem	Name/Description	Material	Labor	Burden	Total Manufacturing Cost (Component/ Assembly)	End Item Scrap	SG&A	Profit	ED&T-R&D	Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
					USD	USD	USD	USD	USD	USD	USD	USD	USD	USD	USD
	CNG / Diesel														
	03 Rocker Lever														
1			01 Rocker Lever		-	-	-	-	-	-	-	-	-	-	-
2			02 Paint		-	-	-	-	-	-	-	-	-	-	-
3			03 Valve Cover		12.67	0.57	1.46	14.70	0.03	0.58	0.39	0.10	1.10	-	15.79
4			04 Crankcase Breather		43.94	10.82	21.77	76.53	0.22	3.21	2.72	1.02	7.17	-	83.70
5			05 Engine Brake		-	-	-	-	-	-	-	-	-	-	-
6			06		-	-	-	-	-	-	-	-	-	-	-
7			07		-	-	-	-	-	-	-	-	-	-	-
8			08		-	-	-	-	-	-	-	-	-	-	-
9			09		-	-	-	-	-	-	-	-	-	-	-
10			10		-	-	-	-	-	-	-	-	-	-	-
				SUBSYSTEM ROLL-UP	56.61	11.39	23.23	91.23	0.25	3.79	3.10	1.12	8.27	-	99.50

SYSTEM & SUBSYSTEM DESCRIPTION					CNG TECHNOLOGY GENERAL PART INFORMATION:										
Item	System	Subsystem	Sub-Subsystem	Name/Description	Manufacturing			Total Manufacturing Cost (Component/ Assembly)	Markup				Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
					Material	Labor	Burden		End Item Scrap	SG&A	Profit	ED&T-R&D			
					USD	USD	USD	USD	USD	USD	USD	USD	USD	USD	USD
	CNG / Diesel														
	03 Rocker Lever														
1		01 Rocker Lever			-	-	-	-	-	-	-	-	-	-	-
2		02 Paint			-	-	-	-	-	-	-	-	-	-	-
3		03 Valve Cover			26.53	14.46	24.76	65.75	0.24	4.34	3.13	0.60	8.31	-	74.06
4		04 Crankcase Breather			14.84	4.72	14.64	34.20	0.07	1.36	0.91	0.23	2.57	-	36.76
5		05 Engine Brake			-	-	-	-	-	-	-	-	-	-	-
6		06			-	-	-	-	-	-	-	-	-	-	-
7		07			-	-	-	-	-	-	-	-	-	-	-
8		08			-	-	-	-	-	-	-	-	-	-	-
9		09			-	-	-	-	-	-	-	-	-	-	-
10		10			-	-	-	-	-	-	-	-	-	-	-
				SUBSYSTEM ROLL-UP	41.37	19.17	39.40	99.94	0.31	5.70	4.04	0.83	10.88	-	110.82

SYSTEM & SUBSYSTEM DESCRIPTION					INCREMENTAL COST TO UPGRADE TO NEW TECHNOLOGY PACKAGE										
					Manufacturing				Markup						
Item	System	Subsystem	Sub-Subsystem	Name/Description	Material	Labor	Burden	Total Manufacturing Cost (Component/ Assembly)	End Item Scrap	SG&A	Profit	ED&T-R&D	Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
					USD	USD	USD	USD	USD	USD	USD	USD	USD	USD	USD
	CNG / Diesel														
		03 Rocker Lever													
1			01 Rocker Lever		-	-	-	-	-	-	-	-	-	-	-
2			02 Paint		-	-	-	-	-	-	-	-	-	-	-
3			03 Valve Cover		(13.86)	(13.89)	(23.30)	(51.05)	(0.21)	(3.76)	(2.74)	(0.50)	(7.22)	-	(58.27)
4			04 Crankcase Breather		29.10	6.10	7.13	42.34	0.15	1.85	1.81	0.80	4.60	-	46.94
5			05 Engine Brake		-	-	-	-	-	-	-	-	-	-	-
6			06		-	-	-	-	-	-	-	-	-	-	-
7			07		-	-	-	-	-	-	-	-	-	-	-
8			08		-	-	-	-	-	-	-	-	-	-	-
9			09		-	-	-	-	-	-	-	-	-	-	-
10			10		-	-	-	-	-	-	-	-	-	-	-
				SUBSYSTEM ROLL-UP	15.24	(7.79)	(16.17)	(8.71)	(0.06)	(1.91)	(0.94)	0.30	(2.61)	-	(11.32)

9. Cam Follower Lever Subsystem 01-04

9.1 Cam Follower Lever Subsystem 01-04 Overview

The Cummins ISXG11.9 liter CNG engine and the ISX11.9 liter Diesel engine Cam Follower Subsystem were treated as the same and not quoted (Figure 9-1).

Both CNG and Diesel

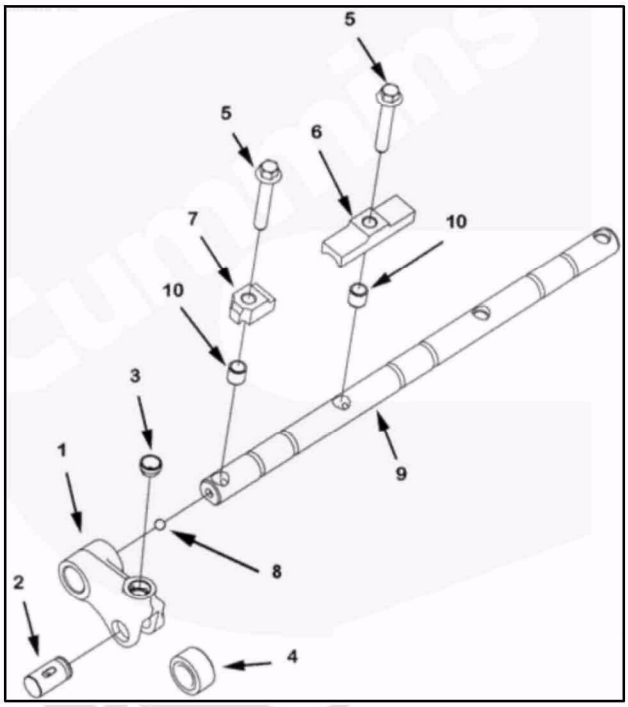


Figure 9-1: Cam Follower Lever Subsystem
(Source: Cummins parts website https://quickserve.cummins.com)

10. Fuel & Controls Subsystem 01-05

The fuel & controls 05 subsystem is broken into 6 sub-subsystems and 41 Assemblies.

- 01-05-01 Fuel pump – Diesel only
  - 01-05-01-01 Fuel pump body
  - 01-05-01-02 Fuel pump support
  - 01-05-01-03 Fuel pump
  - 01-05-01-04 Fuel pump support
  - 01-05-01-05 Fuel pump head
  - 01-05-01-06 Fuel control actuator
  - 01-05-01-07 Fuel pump gear
- 01-05-02 Engine control module (ECM)
  - 01-05-02-01 Electronic control module

01-05-02-02 Position sensor
01-05-02-03 Temperature sensor
01-05-02-04 Oxygen sensor
01-05-02-05 Humidity sensor – CNG only
01-05-02-06 Temperature sensor
01-05-02-07 Spring washer
01-05-02-08 Pressure sensor
01-05-02-09 Relay – Diesel only
01-05-02-10 Pressure sensor – Diesel only
01-05-02-11 Nitrogen Oxide Sensor – Diesel only
01-05-02-12 Knock sensor – CNG only

- 01-05-03 Engine control module (ECM) Wiring harness
  - 01-05-03-01 Wiring retainer bracket –CNG only
  - 01-05-03-02 Wiring harness
- 01-05-04 Fuel control module – CNG only
  - 01-05-04-01 Intake manifold cover
  - 01-05-04-02 Fuel control housing
  - 01-05-04-03 Fuel control module
  - 01-05-04-04 Mass flow sensor
  - 01-05-04-05 Fuel transfer connection
  - 01-05-04-06 Pressure sensor
  - 01-05-04-07 Actuator
  - 01-05-04-08 Module support
  - 01-05-04-09 Plain hose
- 01-05-05 Fuel pressure regulator – CNG only
  - 01-05-05-01 Fuel control housing
  - 01-05-05-02 Fuel shutoff valve
  - 01-05-05-03 Air control valve
  - 01-05-05-04 Coupling nipple
  - 01-05-05-05 Threaded plug
  - 01-05-05-06 Pressure regulator valve
  - 01-05-05-07 Plain hose coupling
  - 01-05-05-08 Pressure sensor
- 01-05-06 Fuel tank
  - 01-05-06-01 Fuel tanks
  - 01-05-06-02 Tank plumbing & electrical
  - 01-05-06-03 Fuel tank bracket system

10.1 Fuel Pump Sub-Subsystem 01-05-01 Overview – Diesel Only

The fuel pump 01 Sub-subsystem is a Diesel fuel part only. The Cummins ISXG11.9 liter CNG engine does not require a fuel pump for CNG. Figure 10-1 shows the fuel pump and all parts will be quoted.

Diesel Only

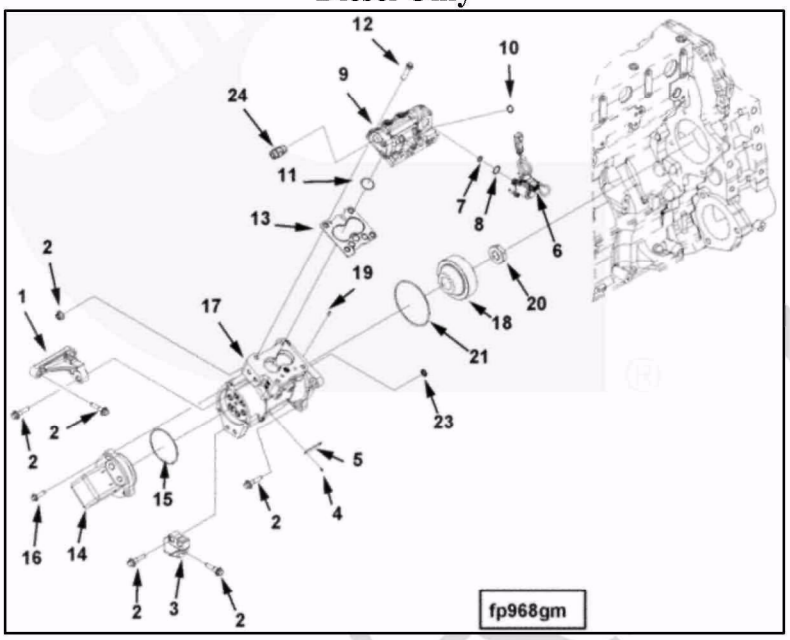


Figure 10-1: Fuel Pump Sub-Subsystem
(Source: Cummins parts website https://quickserve.cummins.com)

The Fuel Pump 01 sub-subsystem is broken down into 7 assemblies.

01-05-01-01 Fuel pump body
01-05-01-02 Fuel pump support
01-05-01-03 Fuel pump
01-05-01-04 Fuel pump support
01-05-01-05 Fuel pump head
01-05-01-06 Fuel control actuator
01-05-01-07 Fuel pump gear

10.1.1 Fuel Pump Body

Figure 10-2 illustrates the 01-05-01-01 Fuel pump body assembly which is a Diesel part only and all parts will be quoted.

Diesel Only

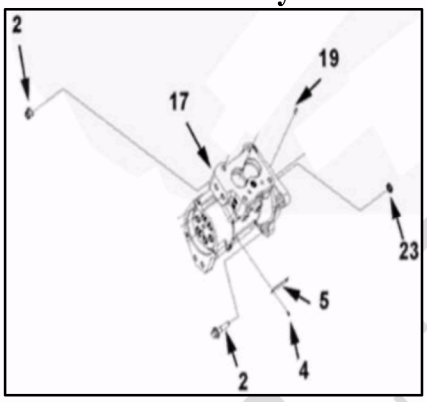


Figure 10-2: Fuel Pump Body Assembly

(Source: Cummins parts website https://quickserve.cummins.com)

10.1.2 Fuel Pump Support

Figure 10-3 shows the 01-05-01-02 Fuel pump support assembly which is a Diesel part only and all parts will be quoted.

Diesel Only

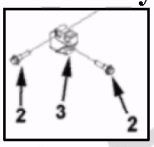


Figure 10-3: Fuel Pump Support Assembly

(Source: Cummins parts website https://quickserve.cummins.com)

Figure 10-4 illustrates the 01-05-01-03 Fuel pump assembly which is a Diesel part only and all parts will be quoted.

Diesel Only

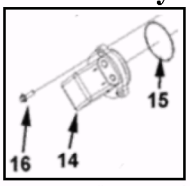


Figure 10-4: Fuel Pump Assembly

(Source: Cummins parts website https://quickserve.cummins.com)

10.1.3 Fuel Pump Support

Figure 10-5 illustrates the 01-05-01-04 Fuel pump support assembly which is a Diesel part only and all parts will be quoted.

Diesel Only

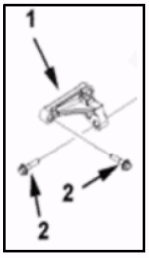


Figure 10-5: Fuel Pump Support Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

10.1.4 Fuel Pump Head

Figure 10-6 shows the 01-05-01-05 Fuel pump head assembly which is a Diesel part only and all parts will be quoted.

Diesel Only

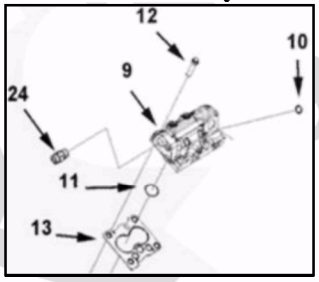


Figure 10-6: Fuel Pump Head Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

10.1.5 Fuel Control Actuator

Figure 10-7 illustrates the 01-05-01-06 Fuel control actuator assembly which is a Diesel part only and all parts will be quoted.

Diesel Only

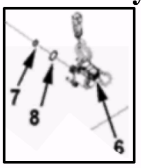


Figure 10-7: Fuel Control Actuator Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

10.1.6 Fuel Pump Gear

Figure 10-8 shows the 01-05-01-07 Fuel pump gear assembly which is a Diesel part only and all parts will be quoted.

Diesel Only

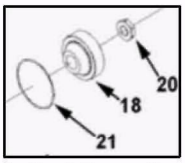


Figure 10-8: Fuel Pump Gear Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

10.2 Engine Control Module (ECM) Sub-Subsystem 01-05-02 Overview

The Engine control module (ECM) 02 Sub-subsystem for the Cummins ISXG11.9 liter CNG engine and the ISX11.9 liter Diesel engine are different. Any parts that have the same part numbers will not be quoted. All other parts will be quoted, including the ECM electronic board differences. See Figure 10-9.

CNG **Diesel**

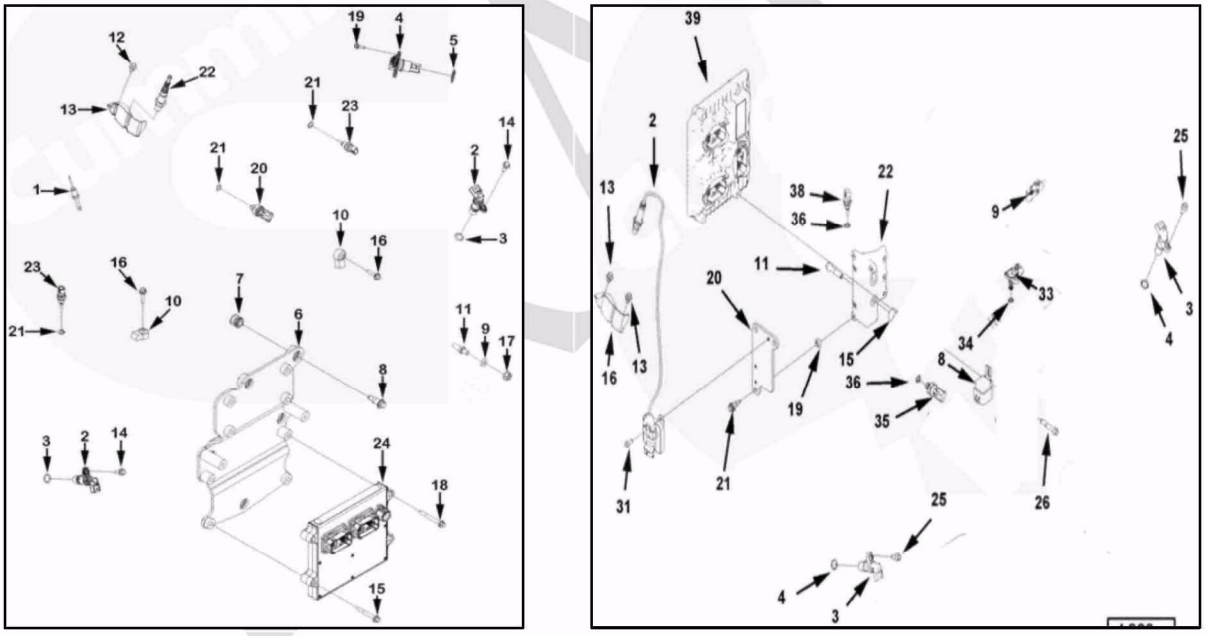


Figure 10-9: Engine Control Module (ECM) Subsystem
(Source: Cummins parts website https://quickserve.cummins.com)

The Engine control module 02 sub-subsystem is broken down into 12 assemblies.

01-05-02-01 Electronic control module
01-05-02-02 Position sensor
01-05-02-03 Temperature sensor
01-05-02-04 Oxygen sensor
01-05-02-05 Humidity sensor – CNG only
01-05-02-06 Temperature sensor
01-05-02-07 Spring washer
01-05-02-08 Pressure sensor
01-05-02-09 Relay – Diesel only
01-05-02-10 Pressure sensor – Diesel only
01-05-02-11 Nitrogen Oxide sensor – Diesel only
01-05-02-12 Knock sensor – CNG only

The following sections show each assembly and what was quoted.

10.2.1 Electronic Control Module (ECM)

Figure 10-10 the 01-05-02-01 ECM assembly, any identical parts in the board are not quoted.

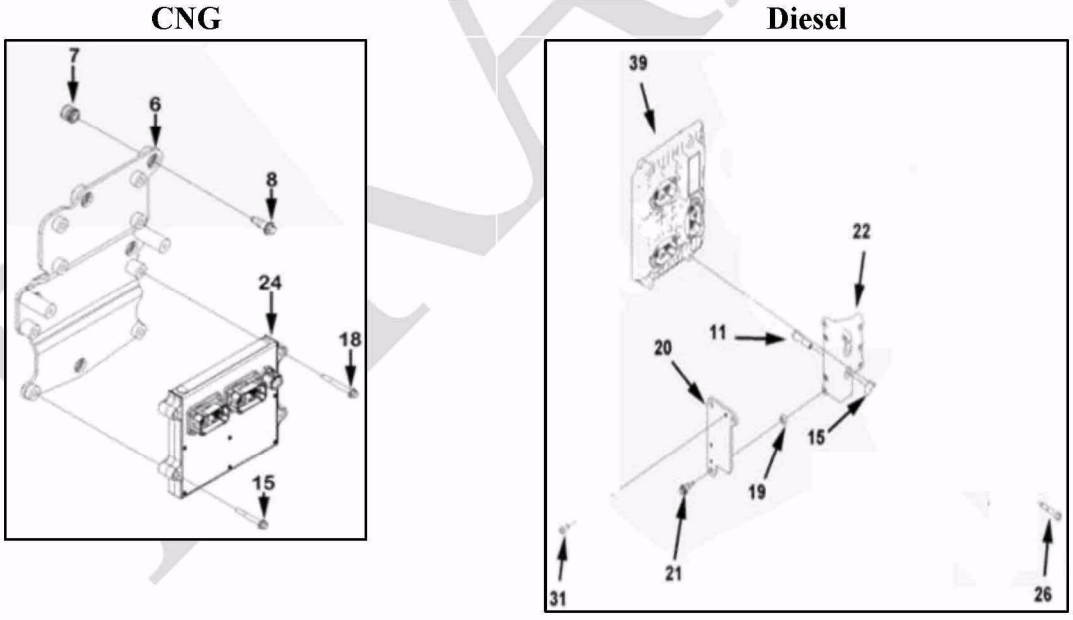


Figure 10-10: Electronic Control Module Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

10.2.2 Position Sensor

Figure 10-11 illustrates the 01-05-02-02 Position sensor. There are two position sensor assemblies; one used on the cam shaft and one on the crank shaft of the Cummins ISXG11.9 liter CNG engine and the ISX11.9 liter Diesel engine. Both assemblies are identical and not quoted.

CNG **Diesel**

Figure 10-11: Position Sensor Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

10.2.3 Temperature Sensor

Figure 10-12 illustrates the 01-05-02-03 Temperature sensor assembly. The Cummins ISXG11.9 liter CNG engine and the ISX11.9 liter Diesel engine have unique temperature sensors and both will be quoted.

CNG **Diesel**

Figure 10-12: Temperature Sensor Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

10.2.4 Oxygen Sensor

Figure 10-13 shows the 01-05-02-04 Oxygen sensor assembly. The Cummins ISXG11.9 liter CNG engine contains the Oxygen sensor assembly (#22) while the ISX11.9 liter Diesel engine does not have the Oxygen sensor. Only parts with different numbers will be quoted.

CNG **Diesel**

Figure 10-13: Oxygen Sensor Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

10.2.5 Humidity Sensor

Figure 10-14 illustrates the 01-05-02-05 Humidity sensor assembly is for the Cummins ISXG11.9 liter CNG engine only. This assembly will be quoted.

CNG Only

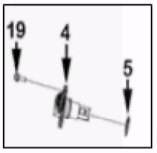


Figure 10-14: Humidity Sensor Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

10.2.6 Temperature Sensor

Figure 10-15 illustrates the 01-05-02-06 Temperature sensor assembly. The Cummins ISXG11.9 liter CNG engine and the ISX11.9 liter Diesel engine are identical and not quoted.

CNG **Diesel**

Figure 10-15: Temperature Sensor Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

10.2.7 Spring Washer

Figure 10-16 shows the 01-05-02-07 Spring washer assembly. The Cummins ISXG11.9 liter CNG engine and the ISX11.9 liter Diesel engine are identical and not quoted.

Figure 10-16: Spring Washer Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

10.2.8 Pressure Sensor

Figure 10-17 illustrates the 01-05-02-08 Pressure sensor assembly. The Cummins ISXG11.9 liter CNG engine and the ISX11.9 liter Diesel engine are identical and not quoted.

Figure 10-17: Pressure Sensor Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

10.2.9 Relay

Figure 10-18 shows the 01-05-02-09 Relay assembly for only the Cummins ISX11.9 liter Diesel engine. This assembly will be quoted.

Diesel Only

Figure 10-18: Relay Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

10.2.10 Pressure Sensor

Figure 10-19 illustrates the 01-05-02-10 Pressure sensor assembly for only the Cummins ISX11.9 liter Diesel engine. This assembly will be quoted.

Diesel Only

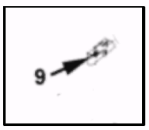


Figure 10-19: Pressure Sensor Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

10.2.11 Nitrogen Oxide Sensor

Figure 10-20 shows the 01-05-02-11 Nitrogen oxide sensor assembly for only the Cummins ISX11.9 liter Diesel engine. This assembly will be quoted.

Diesel Only

Figure 10-20: Nitrogen Oxide Sensor Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

10.2.12 Knock Sensor

Figure 10-21 illustrates the 01-05-02-12 Knock sensor assembly for only the Cummins ISXG11.9 liter CNG engine. This assembly will be quoted.

CNG Only

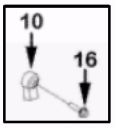


Figure 10-21: Knock Sensor Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

10.3 Engine Control Module (ECM) Wiring Harness Sub-Subsystem 01-05-03 Overview

The Cummins ISXG11.9 liter CNG engine and the ISX11.9 liter Diesel engine ECM wire harnesses are different configurations due to the CNG spark ignited engine technology relative to conventional compression ignition Diesel as shown in Figure 10-22.

CNG **Diesel**

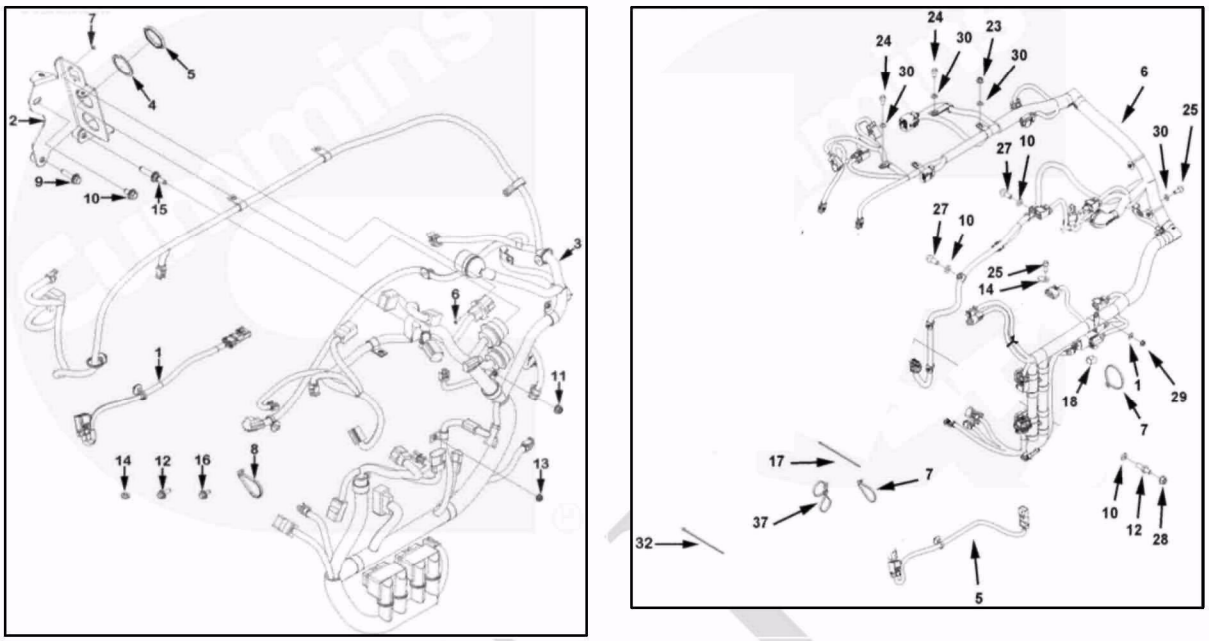


Figure 10-22: ECM Wire Harness Sub-Subsystem
(Source: Cummins parts website https://quickserve.cummins.com)

Engine control module (ECM) wiring harness 03 sub-subsystem is broken down into 2 assemblies.

01-05-03-01 ECM wiring harness mounting bracket
01-05-03-02 ECM wiring harness

The following sections show each assembly and what was quoted.

10.3.1 ECM Wiring Harness Mounting Bracket

Figure 10-23 shows the 01-05-03-01 ECM wiring harness mounting bracket which is a Cummins ISXG11.9 liter CNG engine part only and will be quoted complete.

CNG Only

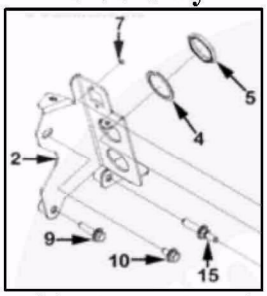


Figure 10-23: ECM Wiring Harness Mounting Bracket Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

10.3.2 ECM Wiring Harness

Figure 10-24 illustrates the 01-05-03-02 ECM wiring harness assembly. The Cummins ISXG11.9 liter CNG engine and the ISX11.9 liter Diesel engine has slightly different wiring harnesses so only parts with different numbers will be quoted.

CNG **Diesel**

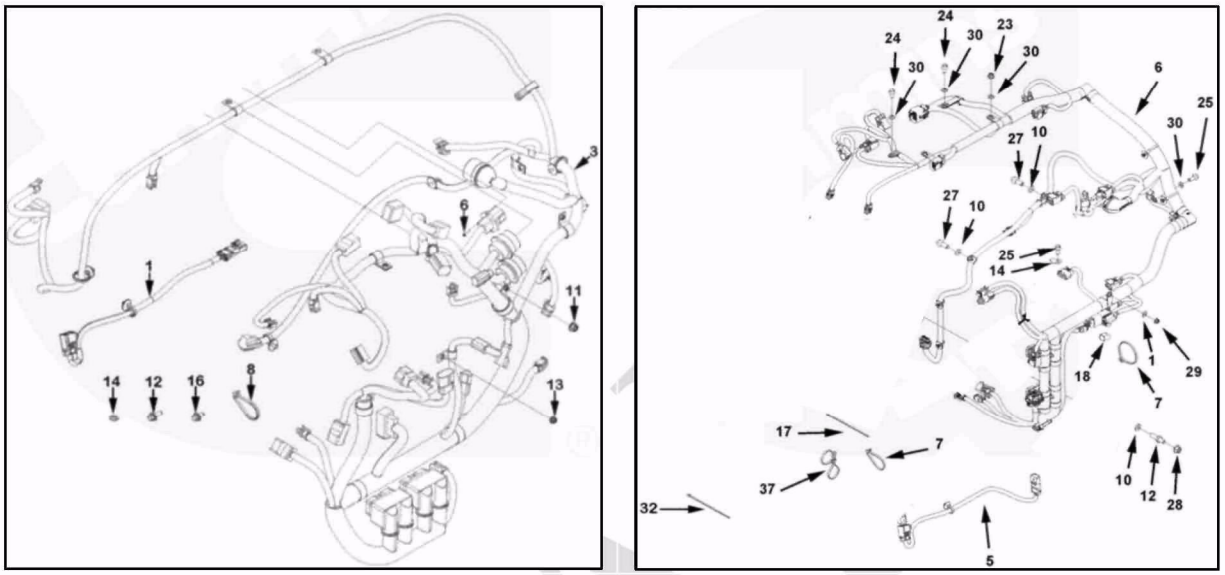


Figure 10-24: ECM Wiring Harness Assembly

(Source: Cummins parts website https://quickserve.cummins.com)

10.4 Fuel Control Module Sub-Subsystem 01-05-04 Overview – CNG Only

The fuel control module is a Cummins ISXG11.9 liter CNG engine part only and will be quoted complete as shown in Figure 10-25.

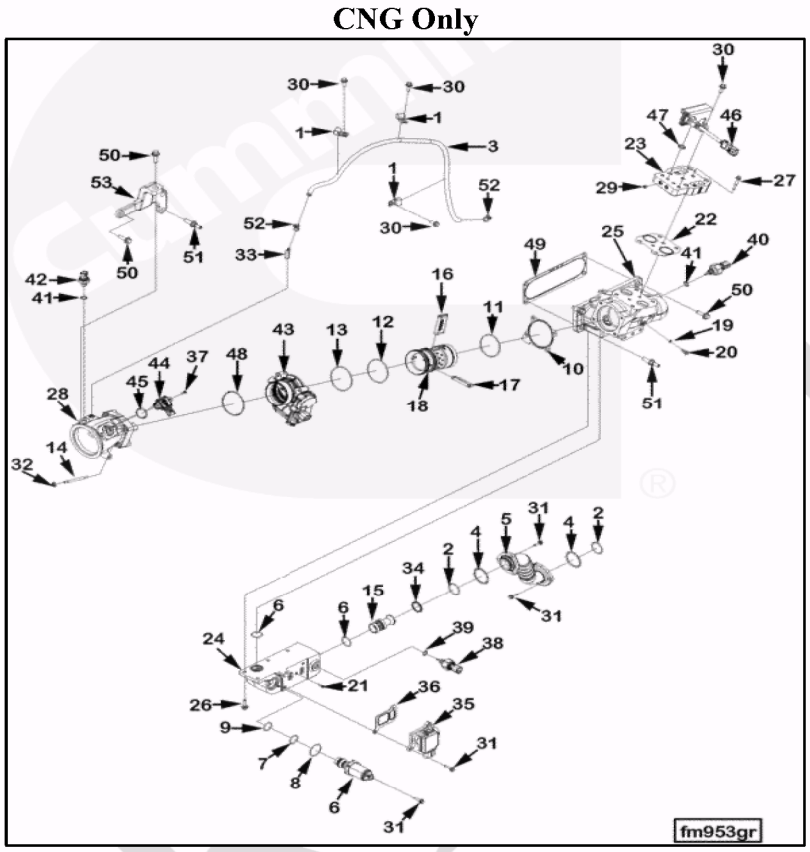


Figure 10-25: Fuel Control Module – CNG Only Sub-Subsystem
(Source: Cummins parts website https://quickserve.cummins.com)

The fuel control module 04 sub-subsystem is broken down into 9 assemblies.

01-05-04-01 Intake manifold cover
01-05-04-02 Fuel control housing
01-05-04-03 Fuel control module
01-05-04-04 Mass flow sensor
01-05-04-05 Fuel transfer connection
01-05-04-06 Pressure sensor
01-05-04-07 Actuator
01-05-04-08 Module support
01-05-04-09 Plain hose

The following sections show each assembly and what was quoted.

10.4.1 Intake Manifold Cover

Figure 10-26 illustrates the 01-05-04-01 Intake manifold cover assembly which is a Cummins ISXG11.9 liter CNG engine part only and will be quoted complete.

CNG Only

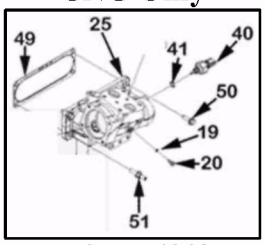


Figure 10-26: Intake Manifold Cover Assembly

(Source: Cummins parts website https://quickserve.cummins.com)

10.4.2 Fuel Control Housing

Figure 10-27 shows the 01-05-04-02 Fuel control housing assembly which is a Cummins ISXG11.9 liter CNG engine part only and will be quoted complete.

CNG Only

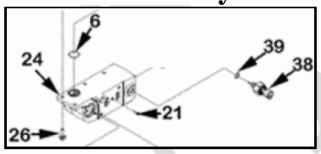


Figure 10-27: Fuel Control Housing Assembly

(Source: Cummins parts website https://quickserve.cummins.com)

10.4.3 Fuel Control Module

Figure 10-28 illustrates the 01-05-04-03 Fuel control module assembly which is a Cummins ISXG11.9 liter CNG engine part only and will be quoted complete.

CNG Only

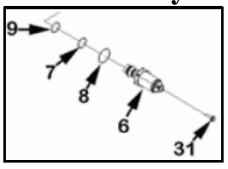


Figure 10-28: Fuel Control Module Assembly

(Source: Cummins parts website https://quickserve.cummins.com)

10.4.4 Mass Flow Sensor

Figure 10-29 shows the 01-05-04-04 Mass flow sensor assembly which is a Cummins ISXG11.9 liter CNG engine part only and will be quoted complete.

CNG Only

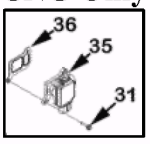


Figure 10-29: Mass Flow Sensor Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

10.4.5 Fuel Transfer Connection

Figure 10-30 illustrates the 01-05-04-05 Fuel transfer connection assembly which is a Cummins ISXG11.9 liter CNG engine part only and will be quoted complete.

CNG Only

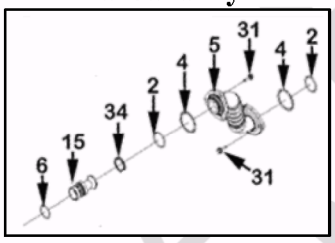


Figure 10-30: Fuel Transfer Connection Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

10.4.6 Pressure Sensor

Figure 10-31 shows the 01-05-04-06 Pressure sensor assembly which is a Cummins ISXG11.9 liter CNG engine part only and will be quoted complete.

CNG Only

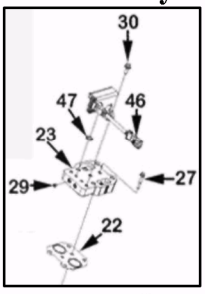


Figure 10-31: Pressure Sensor Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

10.4.7 Actuator

Figure 10-32 illustrates the 01-05-04-07 Actuator assembly which is a Cummins ISXG11.9 liter CNG engine part only and will be quoted complete.

CNG Only

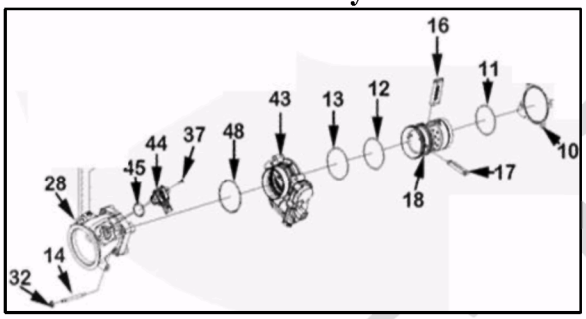


Figure 10-32: Actuator Assembly

(Source: Cummins parts website https://quickserve.cummins.com)

10.4.8 Module Support

Figure 10-33 shows the 01-05-04-08 Module support assembly which is a Cummins ISXG11.9 liter CNG engine part only and will be quoted complete.

CNG Only

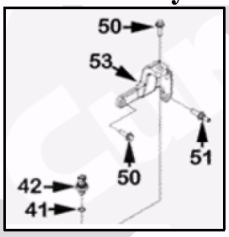


Figure 10-33: Module Support Assembly

(Source: Cummins parts website https://quickserve.cummins.com)

10.4.9 Plain Hose

Figure 10-34 illustrates the 01-05-04-09 Plain hose assembly which is a Cummins ISXG11.9 liter CNG engine part only and will be quoted complete.

CNG Only

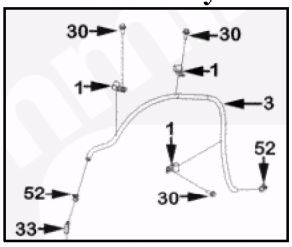


Figure 10-34: Plain Hose Assembly

(Source: Cummins parts website https://quickserve.cummins.com)

10.5 Fuel Pressure Regulator Sub-Subsystem 01-05-05 Overview

The fuel pressure regulator is a Cummins ISXG11.9 liter CNG engine part only and will be quoted complete as shown in Figure 10-35.

CNG Only

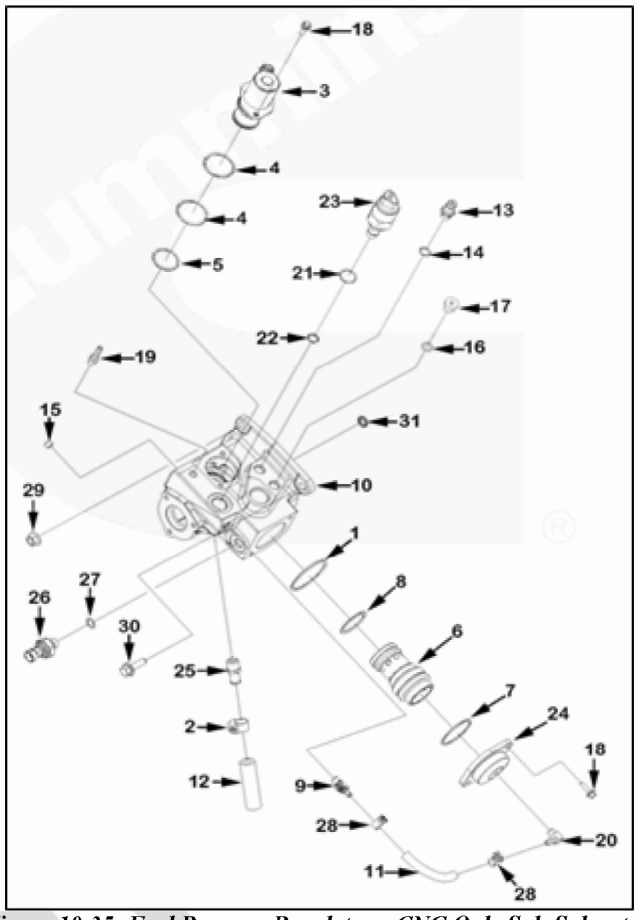


Figure 10-35: Fuel Pressure Regulator – CNG Only Sub-Subsystem
(Source: Cummins parts website https://quickserve.cummins.com)

The Fuel Pressure Regulator 05 Sub-subsystem is broken down into 8 assemblies.

01-05-05-01 Fuel pressure reg. housing
01-05-05-02 Fuel shutoff valve
01-05-05-03 Air control valve
01-05-05-04 Coupling nipple
01-05-05-05 Threaded plug
01-05-05-06 Pressure regulator valve
01-05-05-07 Plain hose coupling
01-05-05-08 Pressure sensor

The following sections show each assembly and what was quoted.

10.5.1 Fuel Pressure Reg. Housing

Figure 10-36 shows the 01-05-05-01 Fuel pressure reg. housing assembly which is a Cummins ISXG11.9 liter CNG engine part only and will be quoted complete.

CNG Only

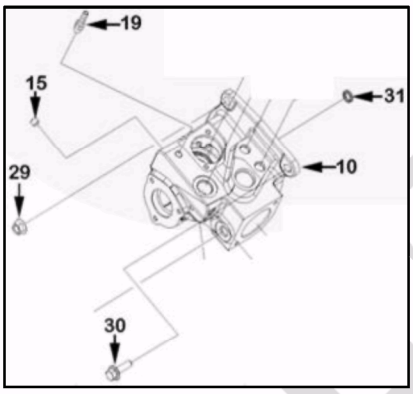


Figure 10-36: Fuel Pressure Reg. Housing Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

10.5.2 Fuel Shutoff Valve

Figure 10-37 illustrates the 01-05-05-02 Fuel shutoff valve assembly which is a Cummins ISXG11.9 liter CNG engine part only and will be quoted complete.

CNG Only

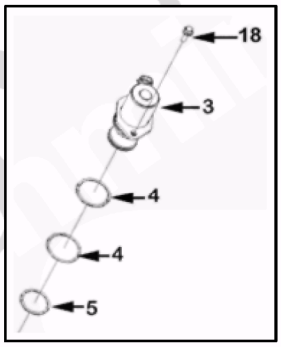


Figure 10-37: Fuel Shutoff Valve Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

10.5.3 Air Control Valve

Figure 10-38 shows the 01-05-05-03 Air control valve assembly which is a Cummins ISXG11.9 liter CNG engine part only and will be quoted complete.

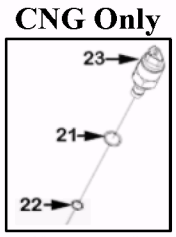


Figure 10-38: Air Control Valve Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

10.5.4 Coupling Nipple

Figure 10-39 illustrates the 01-05-05-04 Coupling nipple assembly which is a Cummins ISXG11.9 liter CNG engine part only and will be quoted complete.

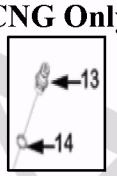


Figure 10-39: Coupling Nipple Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

10.5.5 Threaded Plug

Figure 10-40 shows the 01-05-05-05 Threaded plug assembly which is a Cummins ISXG11.9 liter CNG engine part only and will be quoted complete.

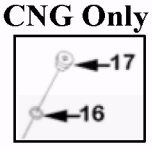


Figure 10-40: Threaded Plug Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

10.5.6 Pressure Regulator Valve

Figure 10-41 illustrates the 01-05-05-06 Pressure regulator valve assembly which is a Cummins ISXG11.9 liter CNG engine part only and will be quoted complete.

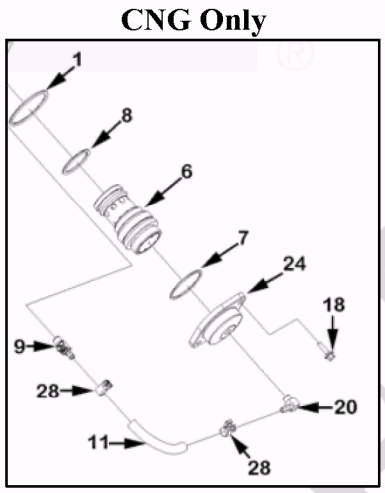


Figure 10-41: Pressure Regulator Valve Assembly

(Source: Cummins parts website https://quickserve.cummins.com)

10.5.7 Plain Hose Coupling

Figure 10-42 shows the 01-05-05-07 Plain hose coupling assembly which is a Cummins ISXG11.9 liter CNG engine part only and will be quoted complete.

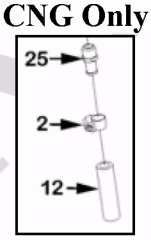


Figure 10-42: Plain Hose Coupling Assembly

(Source: Cummins parts website https://quickserve.cummins.com)

10.5.8 Pressure Sensor

Figure 10-43 illustrates the 01-05-05-08 Pressure sensor assembly which is a Cummins ISXG11.9 liter CNG engine part only and will be quoted complete.

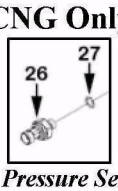


Figure 10-43: Pressure Sensor Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

10.6 Fuel Tank Sub-Subsystem 01-05-06 Overview

The Fuel Tank Sub-subsystem for the Cummins ISXG11.9 liter CNG engine and the ISX11.9 liter Diesel engine is different. Any parts that have the same part numbers will not be quoted; all other parts will be quoted. See Figure 10-44.

Figure 10-44: Fuel Tank Sub-Subsystem
(Source: Cummins parts website https://quickserve.cummins.com & www.southwestproducts.com & Cleveland Tank Supply http://www.clevelandtank.com/aluminum-fuel-tanks.html & valew.com)

The Fuel Tank 06 Sub-subsystem is broken down into 3 assemblies.

01-05-06-01 Fuel Tanks
01-05-06-02 Fuel Tank plumbing
01-05-06-03 Fuel Tank brackets

The following sections show each assembly and what was quoted.

10.6.1 Fuel Tank

Figure 10-45 shows the 01-05-06-01 Fuel Tank assembly. The Cummins ISXG11.9 liter CNG engine and the ISX11.9 liter Diesel engine are different. All parts will be quoted.

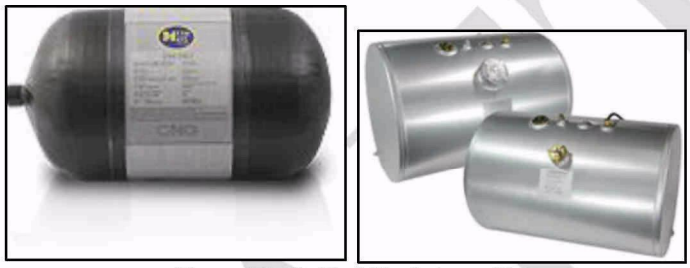


Figure 10-45: Fuel Tank Assembly
(Source: CNG tank- http://www.metal-mate.com/web/dinsorweb/en/product.php?name=ngv_cylinder
Diesel Tank pictures from Cleveland Tank & Supply http://www.clevelandtank.com/aluminum-fuel-tanks.html)

10.6.2 Fuel Tank Plumbing

The 01-05-06-02 Fuel Tank plumbing assembly for the Cummins ISXG11.9 liter CNG engine shown in Figure 10-46 and the ISX11.9 liter Diesel engine shown in Figure 10-47 are different. All parts will be quoted.

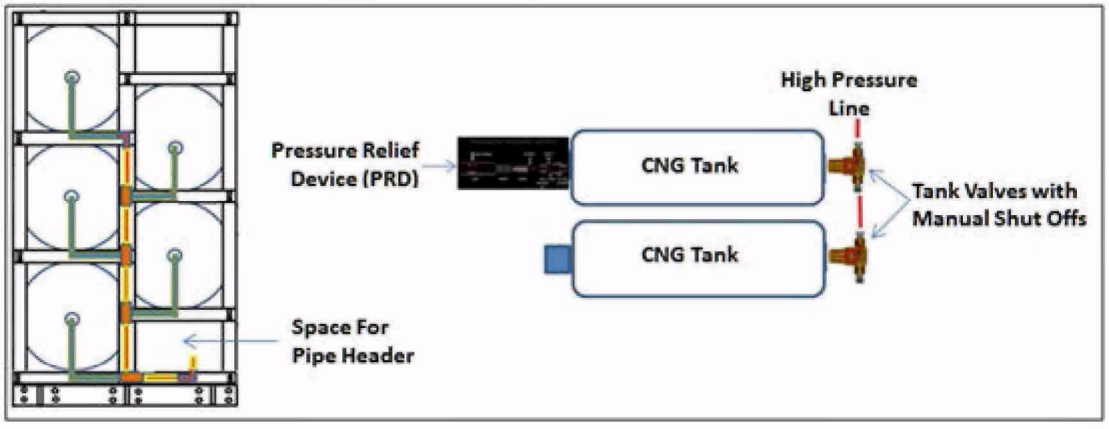


Figure 10-46: CNG Fuel Tank Plumbing Assembly
(Source: FEV)

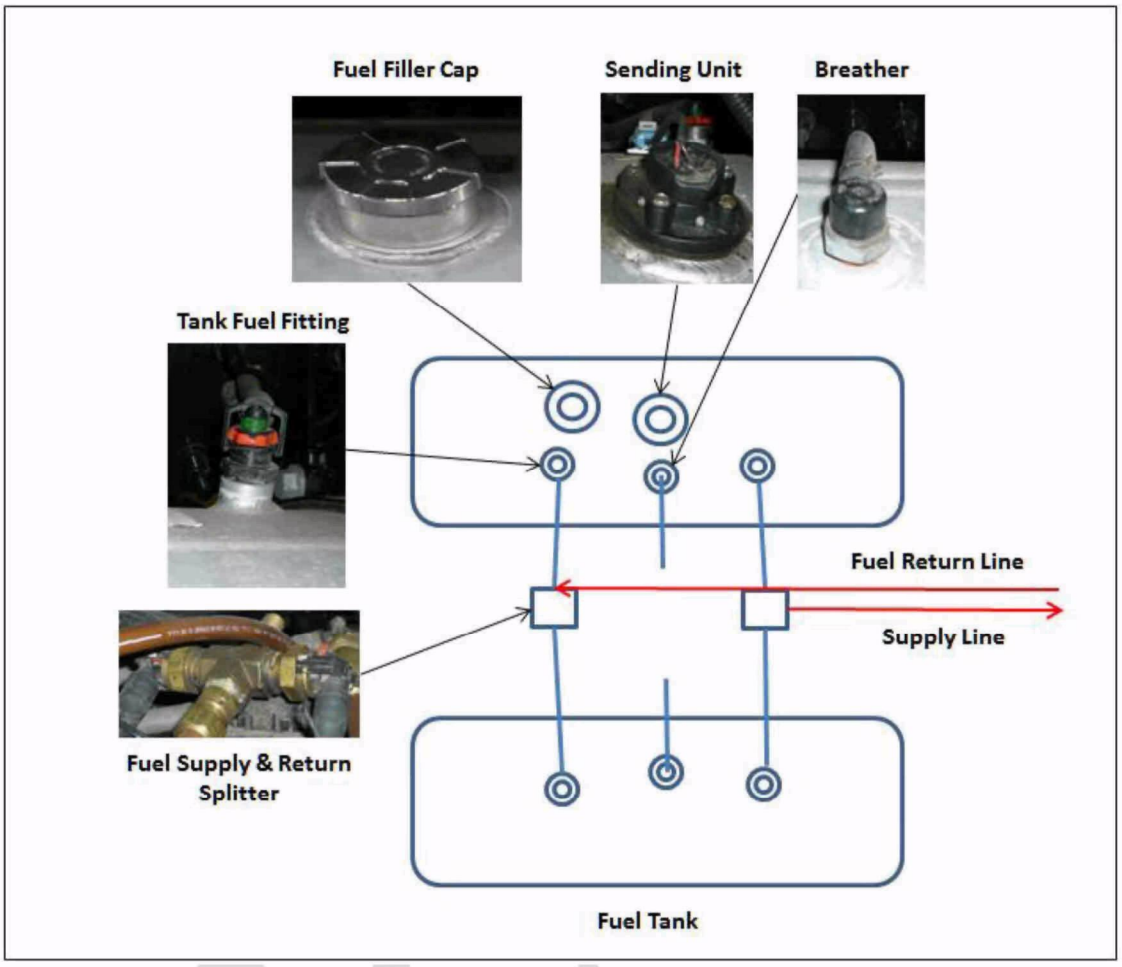


Figure 10-47: Diesel Fuel Tank Plumbing Assembly
(Source: FEV)

10.6.3 Fuel Tank Brackets

The 01-05-06-03 Fuel tank brackets assembly for the Cummins ISXG11.9 liter CNG engine shown in Figure 10-48 and the ISX11.9 liter Diesel engine shown in Figure 10-49 are different. All parts will be quoted.

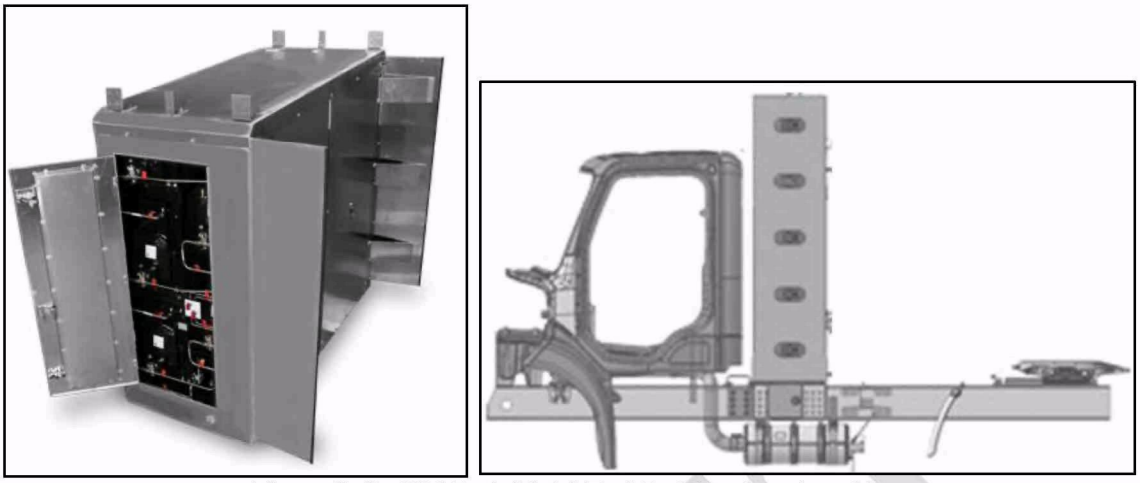


Figure 10-48: CNG Back Of Cab Fuel Tank Brackets Assembly
(Source: http://www.todaysmotorvehicles.com/cng-truck-mainstay-quantum-91014.aspx & http://www.freightlinertrucks.com/Trucks/Alternative-Power-Trucks/Natural-Gas/Natural-Gas-FAQ/)

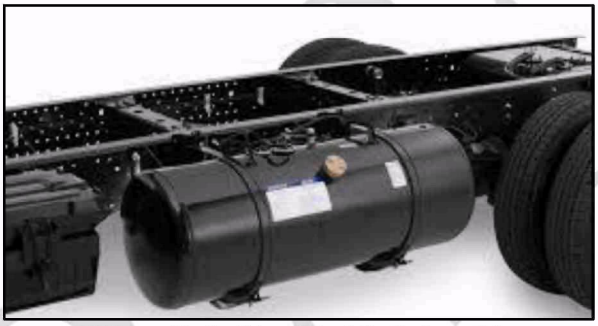


Figure 10-49: Diesel Fuel Tank Assembly
(Source: http://www.isuzucv.com/service/accessories)

10.7 Fuel & Controls 01-05 Subsystem Cost Impact

10.7.1 Direct Manufacturing Cost For Fuel & Controls 01-05 Subsystem

The cost breakdown below shows that the CNG system had an increase total of -$13,000.47 due to major differences between the CNG and the Diesel fuel systems. "+" = cost decrease, "-" = cost increase.

Table 10-1: Direct Manufacturing Cost of the Fuel & Controls 01-05 Subsystem

SYSTEM & SUBSYSTEM DESCRIPTION					DIESEL TECHNOLOGY GENERAL PART INFORMATION:										
					Manufacturing				Markup						
Item	System	Subsystem	Sub-Subsystem	Name/Description	Material	Labor	Burden	Total Manufacturing Cost (Component/ Assembly)	End Item Scrap	SG&A	Profit	ED&T-R&D	Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
					USD	USD	USD	USD	USD	USD	USD	USD	USD	USD	USD
	CNG / Diesel														
	05 Fuel & Controls														
1				01 Fuel Pump	427.49	155.36	233.71	816.56	6.35	59.80	58.34	22.18	146.66	-	963.22
2				02 Engine Control Module (ECM)	371.40	131.99	139.97	643.36	3.65	31.37	35.16	17.09	87.27	-	730.63
3				03 Engine Control Module (ECM) Wiring harness	31.11	13.71	11.38	56.20	0.22	3.07	2.67	0.95	6.91	-	63.10
4				04 Fuel Control Module	-	-	-	-	-	-	-	-	-	-	-
5				05 Fuel Pressure Reg.	-	-	-	-	-	-	-	-	-	-	-
6				06 Fuel Tank System	1,015.28	521.49	522.55	2,059.31	8.82	93.42	100.34	47.86	250.44	-	2,309.76
7				07	-	-	-	-	-	-	-	-	-	-	-
8				08	-	-	-	-	-	-	-	-	-	-	-
9				09	-	-	-	-	-	-	-	-	-	-	-
10				10	-	-	-	-	-	-	-	-	-	-	-
				SUBSYSTEM ROLL-UP	1,845.28	822.55	907.60	3,575.43	19.04	187.66	196.51	88.08	491.29	-	4,066.72

SYSTEM & SUBSYSTEM DESCRIPTION					CNG TECHNOLOGY GENERAL PART INFORMATION:										
Item	System	Subsystem	Sub-Subsystem	Name/Description	Manufacturing			Total Manufacturing Cost (Component/ Assembly)	Markup				Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
					Material	Labor	Burden		End Item Scrap	SG&A	Profit	ED&T-R&D			
					USD	USD	USD	USD	USD	USD	USD	USD	USD	USD	USD
	CNG / Diesel														
	05 Fuel & Controls														
1		01 Fuel Pump			-	-	-	-	-	-	-	-	-	-	-
2		02 Engine Control Module (ECM)			285.16	99.20	97.02	481.38	2.33	23.32	25.12	11.81	62.58	-	543.96
3		03 Engine Control Module (ECM) Wiring harness			43.60	14.71	12.65	70.96	0.31	4.53	3.79	1.17	9.80	-	80.76
4		04 Fuel Control Module			280.78	110.50	151.88	543.16	3.66	31.19	32.07	13.84	80.76	-	623.92
5		05 Fuel Pressure Reg.			108.11	42.07	50.07	200.25	1.22	11.41	11.69	5.03	29.35	-	229.60
6		06 Fuel Tank System			12,043.84	565.31	1,304.15	13,913.30	58.17	633.27	669.73	314.48	1,675.65	-	15,588.95
7		07			-	-	-	-	-	-	-	-	-	-	-
8		08			-	-	-	-	-	-	-	-	-	-	-
9		09			-	-	-	-	-	-	-	-	-	-	-
10		10			-	-	-	-	-	-	-	-	-	-	-
				SUBSYSTEM ROLL-UP	12,761.48	831.80	1,615.77	15,209.05	65.69	703.71	742.40	346.33	1,858.13	-	17,067.19

SYSTEM & SUBSYSTEM DESCRIPTION					INCREMENTAL COST TO UPGRADE TO NEW TECHNOLOGY PACKAGE										
					Manufacturing				Markup						
Item	System	Subsystem	Sub-Subsystem	Name/Description	Material	Labor	Burden	Total Manufacturing Cost (Component/ Assembly)	End Item Scrap	SG&A	Profit	ED&T-R&D	Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
					USD	USD	USD	USD	USD	USD	USD	USD	USD	USD	USD
	CNG / Diesel														
		05 Fuel & Controls													
1			01 Fuel Pump		427.49	155.36	233.71	816.56	6.35	59.80	58.34	22.18	146.66	-	963.22
2			02 Engine Control Module (ECM)		86.23	32.80	42.95	161.98	1.32	8.04	10.04	5.29	24.69	-	186.68
3			03 Engine Control Module (ECM) Wiring harness		(12.49)	(1.01)	(1.27)	(14.76)	(0.09)	(1.46)	(1.12)	(0.23)	(2.89)	-	(17.66)
4			04 Fuel Control Module		(280.78)	(110.50)	(151.88)	(543.16)	(3.66)	(31.19)	(32.07)	(13.84)	(80.76)	-	(623.92)
5			05 Fuel Pressure Reg.		(108.11)	(42.07)	(50.07)	(200.25)	(1.22)	(11.41)	(11.69)	(5.03)	(29.35)	-	(229.60)
6			06 Fuel Tank System		(11,028.55)	(43.83)	(781.61)	(11,853.99)	(49.35)	(539.84)	(569.40)	(266.62)	(1,425.20)	-	(13,279.19)
7			07		-	-	-	-	-	-	-	-	-	-	-
8			08		-	-	-	-	-	-	-	-	-	-	-
9			09		-	-	-	-	-	-	-	-	-	-	-
10			10		-	-	-	-	-	-	-	-	-	-	-
				SUBSYSTEM ROLL-UP	(10,916.21)	(9.25)	(708.17)	(11,633.62)	(46.65)	(516.05)	(545.90)	(258.25)	(1,366.85)	-	(13,000.47)

11. Injector Pluming & Filters Subsystem 01-06

The Injector Pluming & Filters 06 subsystem is broken into 3 sub-subsystems and 9 Assemblies.

01-06-01 Injector plumbing – Diesel only
- 01-06-01-01 Accumulator
- 01-06-01-02 Injector fuel supply connector
- 01-06-01-03 Injector fuel supply tube

01-06-02 Injectors – Diesel only
- 01-06-02-01 Injectors

01-06-03 Fuel Filter
- 01-06-03-01 Fuel filter head
- 01-06-03-02 Quick disconnect connector
- 01-06-03-03 Fuel transfer tube A
- 01-06-03-04 Fuel transfer tube B
- 01-06-03-05 Check valve

11.1 Injector Plumbing Sub-Subsystem 01-06-01 Overview – Diesel Only

The Injector plumbing 01 Sub-subsystem is a Diesel fuel part only. The Cummins ISXG11.9 liter CNG engine does not require injectors. Figure 11-1 shows the Injector plumbing and all parts will be quoted.

Diesel Only

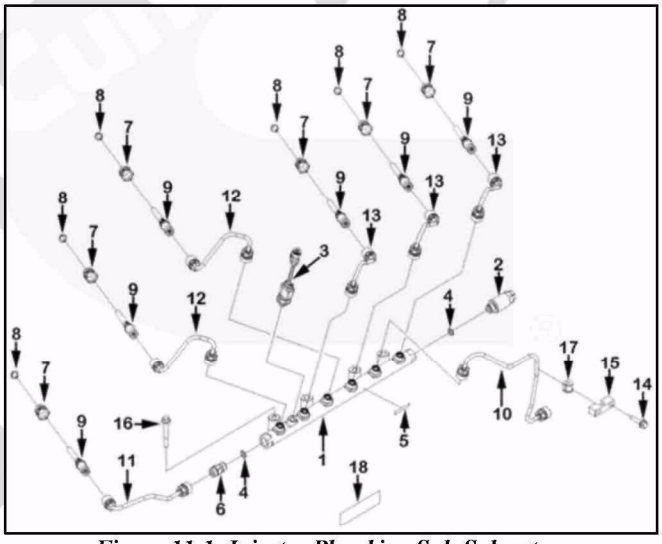


Figure 11-1: Injector Plumbing Sub-Subsystem

(Source: Cummins parts website https://quickserve.cummins.com)

The Injector plumbing 01 sub-subsystem is broken down into 3 assemblies.

01-06-01-01 Accumulator
01-06-01-02 Injector fuel supply connector
01-06-01-03 Injector fuel supply tube

The following sections show each assembly and what was quoted.

Figure 11-2 illustrates the 01-06-01-01 Accumulator assembly for the ISX11.9 liter Diesel engine only. All parts will be quoted.

Diesel Only

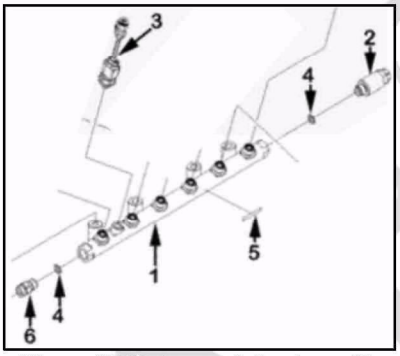


Figure 11-2: Accumulator Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

Figure 11-3 shows the 01-06-01-02 Injector fuel supply connector assembly for the ISX11.9 liter Diesel engine only. All parts will be quoted.

Diesel Only

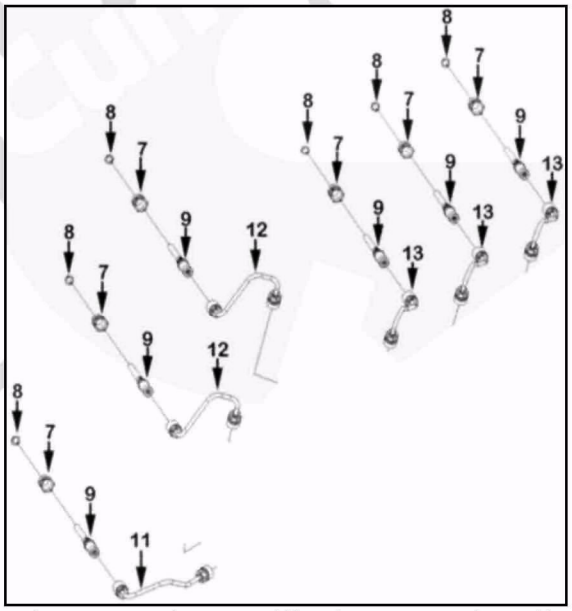


Figure 11-3: Injector Fuel Supply Connector Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

Figure 11-4 illustrates the 01-06-01-03 Injector fuel supply tube assembly for the ISX11.9 liter Diesel engine only. All parts will be quoted.

Diesel Only

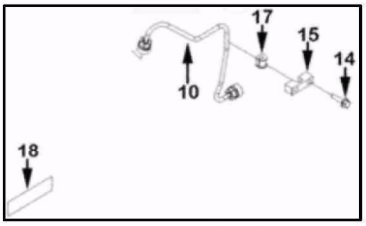


Figure 11-4: Injector Fuel Supply Tube Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

11.2 Injectors Sub-Subsystem 01-06-02 Overview – Diesel Only

The Injectors 02 Sub-subsystem is a Diesel fuel part only. The Cummins ISXG11.9 liter CNG engine does not require injectors for CNG. Figure 11-5 shows the Injectors and all parts will be quoted.

Diesel Only

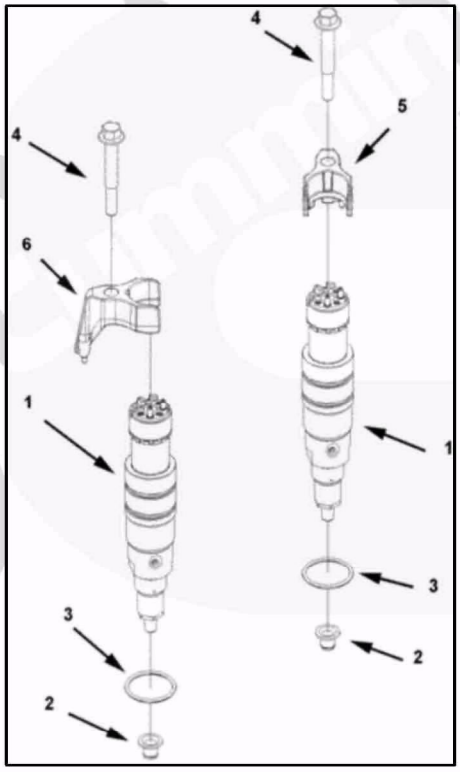


Figure 11-5: Injectors Sub-Subsystem
(Source: Cummins parts website https://quickserve.cummins.com)

The Injectors 02 Sub-subsystem is broken down into 1 assembly.

01-06-02-01 Injectors

The following sections show the assembly and what was quoted.

Figure 11-6 shows the 01-06-02-01 Injectors assembly for the ISX11.9 liter Diesel engine only. All parts will be quoted.

Diesel Only

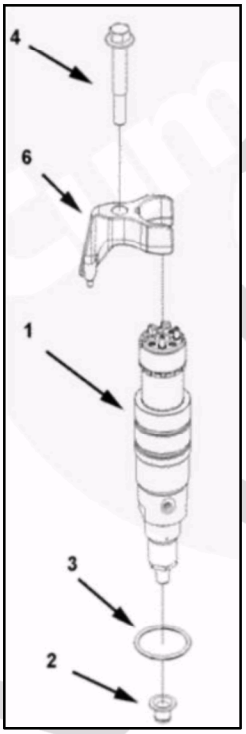


Figure 11-6: Injectors Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

11.3 Fuel Filter Sub-Subsystem 01-06-03 Overview

Figure 11-7 illustrates the Fuel filter 03 Sub-subsystem which is different for the Cummins ISXG11.9 liter CNG engine and the Cummins ISX11.9 liter Diesel engine. All parts will be quoted.

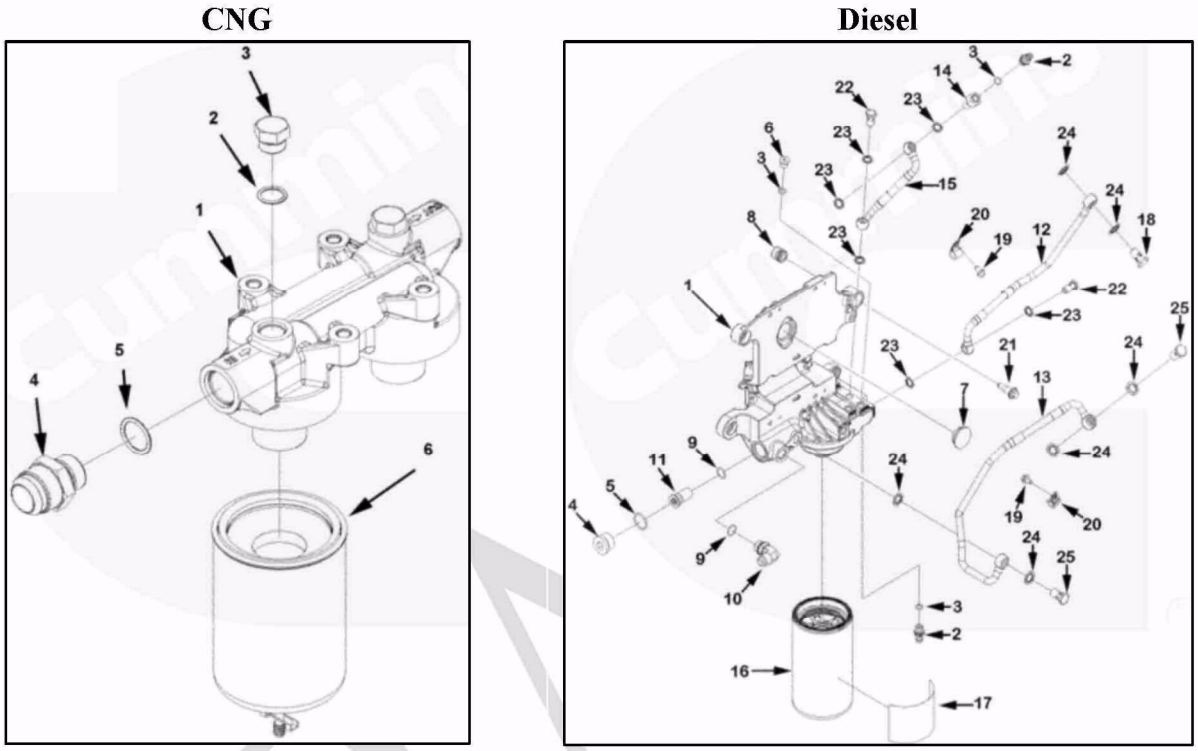


Figure 11-7: Fuel Filter Sub-Subsystem
(Source: Cummins parts website https://quickserve.cummins.com)

The Fuel filter 03 Sub-subsystem is broken down into 5 assemblies.

01-06-03-01 Fuel filter head
01-06-03-02 Quick disconnect connector
01-06-03-03 Fuel transfer tube A
01-06-03-04 Fuel transfer tube B
01-06-03-05 Check valve

The following sections show each assembly and what was quoted.

Figure 11-8 shows the 01-06-03-01 Fuel filter head assembly which is different for the Cummins ISXG11.9 liter CNG engine and the Cummins ISX11.9 liter Diesel engine. All parts will be quoted.

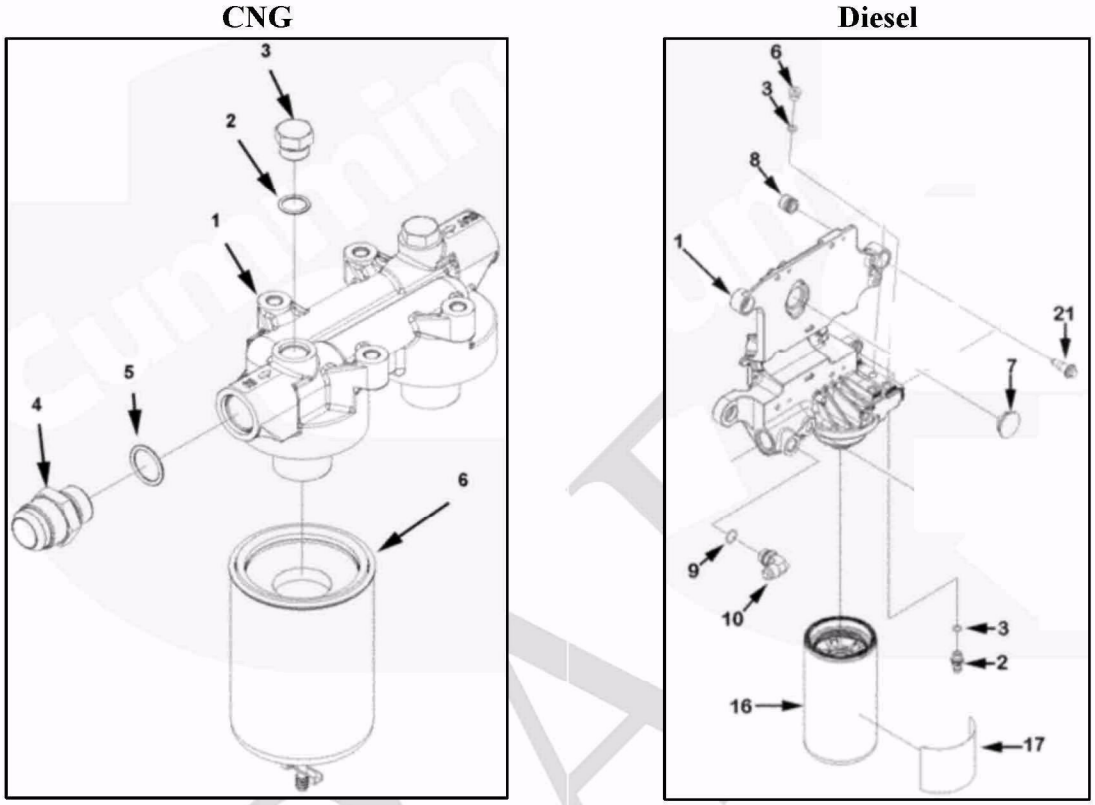


Figure 11-8: Fuel Filter Head Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

Figure 11-9 illustrates the 01-06-03-02 Quick disconnect connector assembly for the ISX11.9 liter Diesel engine only. All parts will be quoted.

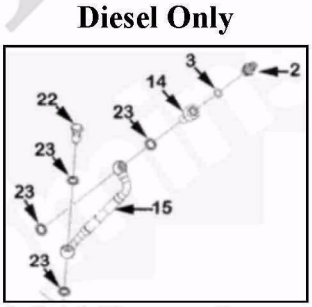


Figure 11-9: Quick Disconnect Connector Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

Figure 11-10 shows the 01-06-03-03 Fuel transfer tube assembly for the ISX11.9 liter Diesel engine only. All parts will be quoted.

Diesel Only

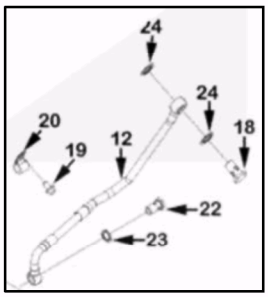


Figure 11-10: Fuel Transfer Tube Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

Figure 11-11 illustrates the 01-06-03-04 Fuel transfer tube B assembly for the ISX11.9 liter Diesel engine only. All parts will be quoted.

Diesel Only

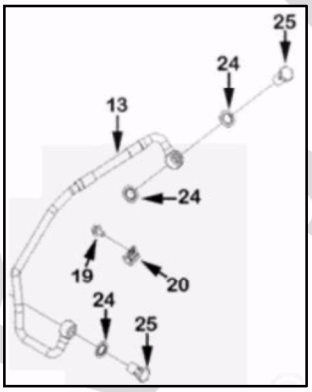


Figure 11-11: Fuel Transfer Tube B Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

Figure 11-12 shows the 01-06-03-05 Check valve assembly for the ISX11.9 liter Diesel engine only. All parts will be quoted.

Diesel Only

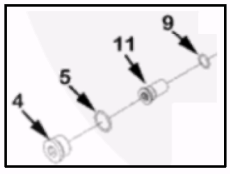


Figure 11-12: Check Valve Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

11.4 Direct Manufacturing Cost for Injector Plumbing & Filter 01-06 Subsystem

The cost breakdown below shows that the Diesel system had an increase total of $645.78 due to the Diesel fuel injectors and associated hardware. "+" = cost decrease, "-" = cost increase

Table 11-1: Direct Manufacturing Cost Of the Injector Plumbing & Filter 01-06 Subsystem

SYSTEM & SUBSYSTEM DESCRIPTION					DIESEL TECHNOLOGY GENERAL PART INFORMATION:										
Item	System	Subsystem	Sub-Subsystem	Name/Description	Manufacturing			Total Manufacturing Cost (Component/ Assembly)	Markup				Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
					Material	Labor	Burden		End Item Scrap	SG&A	Profit	ED&T-R&D			
					USD	USD	USD	USD	USD	USD	USD	USD	USD	USD	USD
	CNG / Diesel														
	06 Injector Pluming & Filters														
1			01 Injector plumbing		67.31	33.19	37.66	138.17	0.81	8.98	9.44	3.96	23.19	-	161.36
2			02 Injectors		66.99	146.02	134.64	347.65	2.31	27.68	27.26	10.14	67.39	-	415.04
3			03 Fuel Filter		63.32	28.76	28.26	120.33	0.28	5.54	3.70	0.80	10.32	-	130.65
4			04		-	-	-	-	-	-	-	-	-	-	-
5			05		-	-	-	-	-	-	-	-	-	-	-
6			06		-	-	-	-	-	-	-	-	-	-	-
7			07		-	-	-	-	-	-	-	-	-	-	-
8			08		-	-	-	-	-	-	-	-	-	-	-
9			09		-	-	-	-	-	-	-	-	-	-	-
10			10		-	-	-	-	-	-	-	-	-	-	-
				SUBSYSTEM ROLL-UP	197.62	207.97	200.56	606.15	3.40	42.20	40.39	14.90	100.89	-	707.05

SYSTEM & SUBSYSTEM DESCRIPTION					CNG TECHNOLOGY GENERAL PART INFORMATION:										
					Manufacturing				Markup						
Item	System	Subsystem	Sub-Subsystem	Name/Description	Material	Labor	Burden	Total Manufacturing Cost (Component/ Assembly)	End Item Scrap	SG&A	Profit	ED&T-R&D	Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
					USD	USD	USD	USD	USD	USD	USD	USD	USD	USD	USD
	CNG / Diesel														
		06 Injector Pluming & Filters													
1			01 Injector plumbing		-	-	-	-	-	-	-	-	-	-	-
2			02 Injectors		-	-	-	-	-	-	-	-	-	-	-
3			03 Fuel Filter		18.22	9.99	25.09	53.29	0.71	3.76	2.88	0.63	7.97	-	61.27
4			04		-	-	-	-	-	-	-	-	-	-	-
5			05		-	-	-	-	-	-	-	-	-	-	-
6			06		-	-	-	-	-	-	-	-	-	-	-
7			07		-	-	-	-	-	-	-	-	-	-	-
8			08		-	-	-	-	-	-	-	-	-	-	-
9			09		-	-	-	-	-	-	-	-	-	-	-
10			10		-	-	-	-	-	-	-	-	-	-	-
				SUBSYSTEM ROLL-UP	18.22	9.99	25.09	53.29	0.71	3.76	2.88	0.63	7.97	-	61.27

SYSTEM & SUBSYSTEM DESCRIPTION					INCREMENTAL COST TO UPGRADE TO NEW TECHNOLOGY PACKAGE										
					Manufacturing				Markup						
Item	System	Subsystem	Sub-Subsystem	Name/Description	Material	Labor	Burden	Total Manufacturing Cost (Component/ Assembly)	End Item Scrap	SG&A	Profit	ED&T-R&D	Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
					USD	USD	USD	USD	USD	USD	USD	USD	USD	USD	USD
	CNG / Diesel														
		06 Injector Pluming & Filters													
1			01 Injector plumbing		67.31	33.19	37.66	138.17	0.81	8.98	9.44	3.96	23.19	-	161.36
2			02 Injectors		66.99	146.02	134.64	347.65	2.31	27.68	27.26	10.14	67.39	-	415.04
3			03 Fuel Filter		45.10	18.77	3.17	67.04	(0.43)	1.78	0.82	0.17	2.35	-	69.39
4			04		-	-	-	-	-	-	-	-	-	-	-
5			05		-	-	-	-	-	-	-	-	-	-	-
6			06		-	-	-	-	-	-	-	-	-	-	-
7			07		-	-	-	-	-	-	-	-	-	-	-
8			08		-	-	-	-	-	-	-	-	-	-	-
9			09		-	-	-	-	-	-	-	-	-	-	-
10			10		-	-	-	-	-	-	-	-	-	-	-
				SUBSYSTEM ROLL-UP	179.40	197.98	175.48	552.86	2.69	38.45	37.52	14.27	92.92	-	645.78

12. Oil Subsystem 01-07

The Oil subsystems are Identical for both CNG and Diesel and will not be quoted.

01-07-01 Oil pan – No Costing/Identical
01-07-02 Oil fill arrangement – No Costing/Identical
01-07-03 Oil level gauge – No Costing/Identical
01-07-04 Full flow oil filter – No Costing/Identical
01-07-05 Engine oil cooler – Parts are very similar/No Costing
01-07-06 Lubricating oil pump – No Costing/Identical

13. Fan & Water Subsystem 01-08

The Fan & Water subsystems are Identical for both CNG and Diesel and will not be quoted.

01-08-01 Water pump – No Costing/Identical
01-08-02 Drive fan – Parts are very similar/No Costing
01-08-03 Thermostat – Parts are very similar/No Costing
01-08-04 Water inlet connection – Parts are very similar/No Costing
01-08-05 Water outlet connection – Parts are very similar/No Costing
01-08-06 Corrosion resistor – No Costing/Identical
01-08-07 Cabin heater plumbing – No Costing/Identical

14. Accessory Drive Provision Subsystem 01-09

The Accessory drive provision subsystems are Identical for both CNG and Diesel and will not be quoted.

01-09-01 Accessory drive – No Costing/Identical

15. Air Transfer Subsystem 01-10

The Air Transfer 10 subsystem is broken into 7 sub-subsystems and 5 assemblies.

01-10-01 Air transfer connection – Parts are very similar/No Costing
01-10-02 Air intake connection – Parts are very similar/No Costing
01-10-03 Air inlet connection (Diesel Only)
    01-10-03-01 Air inlet connection
01-10-04 Coolant heater starter aid – No Costing/Identical
01-10-05 Turbocharger
    01-10-05-01 Turbocharger
01-10-06 Turbocharger arrangement
    01-10-06-01 Air inlet pipe
01-10-07 Turbocharger plumbing
    01-10-07-01 Turbocharger oil drain tube
    01-10-07-02 Air fuel control tube

15.1 Air Inlet Connection Sub-Subsystem 01-10-03 Overview

The Air inlet connection 03 Sub-subsystem is a Diesel part only. The Cummins ISXG11.9 liter CNG engine does not have an air inlet connection. Figure 15-1 shows the air inlet connection and all parts will be quoted.

Diesel Only

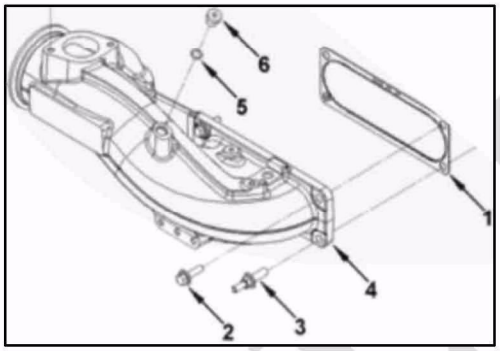


Figure 15-1: Air Inlet Connection Sub-Subsystem
(Source: Cummins parts website https://quickserve.cummins.com)

The Air inlet connection 03 Sub-subsystem is broken down into 1 assembly.

01-10-03-01 Air inlet connection

The following sections show the assembly and what was quoted.

Figure 15-2 illustrates the 01-10-03-01 Air inlet connection assembly is for the ISX11.9 liter Diesel engine only. All parts will be quoted.

Diesel Only

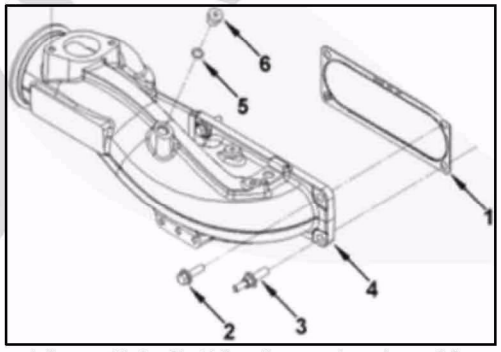


Figure 15-2: Air Inlet Connection Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

15.2 Turbocharger Sub-Subsystem 01-10-05 Overview

Figure 15-3 shows the Turbocharger 05 Sub-subsystem which is different for the Cummins ISXG11.9 liter CNG engine and the Cummins ISX11.9 liter Diesel engine. All parts will be quoted.

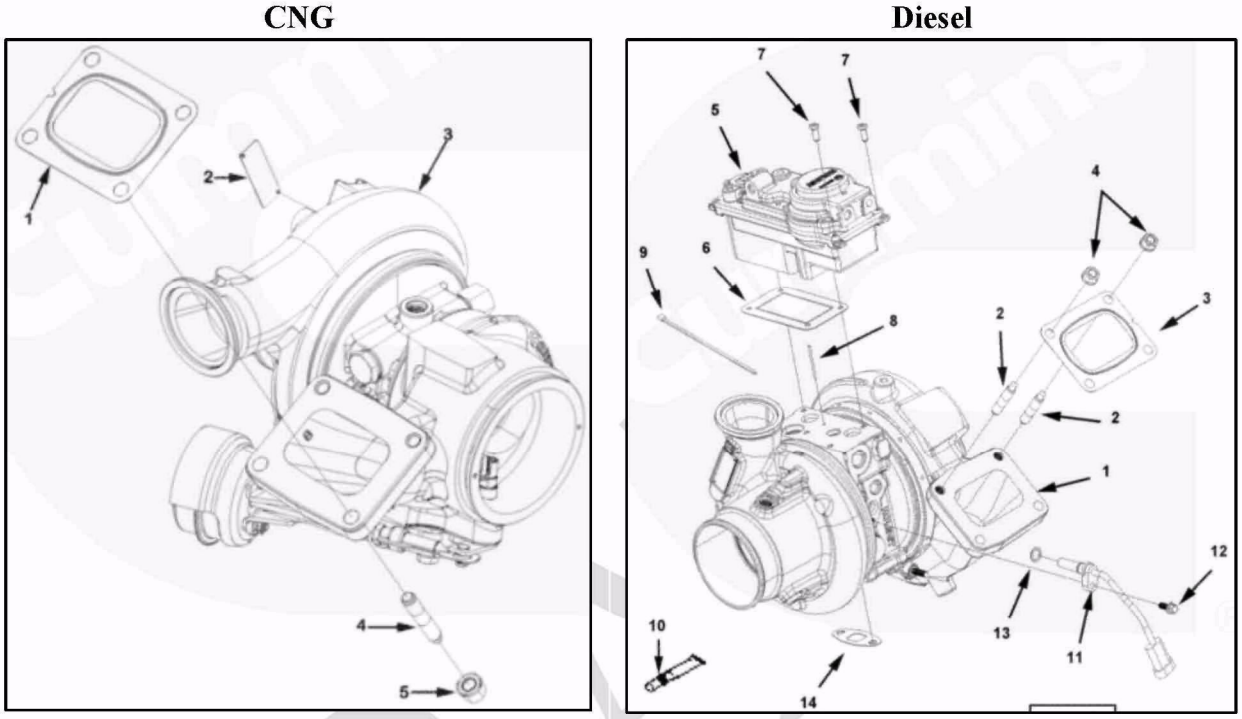


Figure 15-3: Turbocharger Sub-Subsystem
(Source: Cummins parts website https://quickserve.cummins.com)

The Turbocharger 05 Sub-subsystem is broken down into 1 assembly.

01-10-05-01 Turbocharger

The following sections show each assembly and what was quoted.

Figure 15-4 illustrates the 01-10-05-01 Turbocharger assemblies which are different for the Cummins ISXG11.9 liter CNG engine and the Cummins ISX11.9 liter Diesel engine. All parts will be quoted.

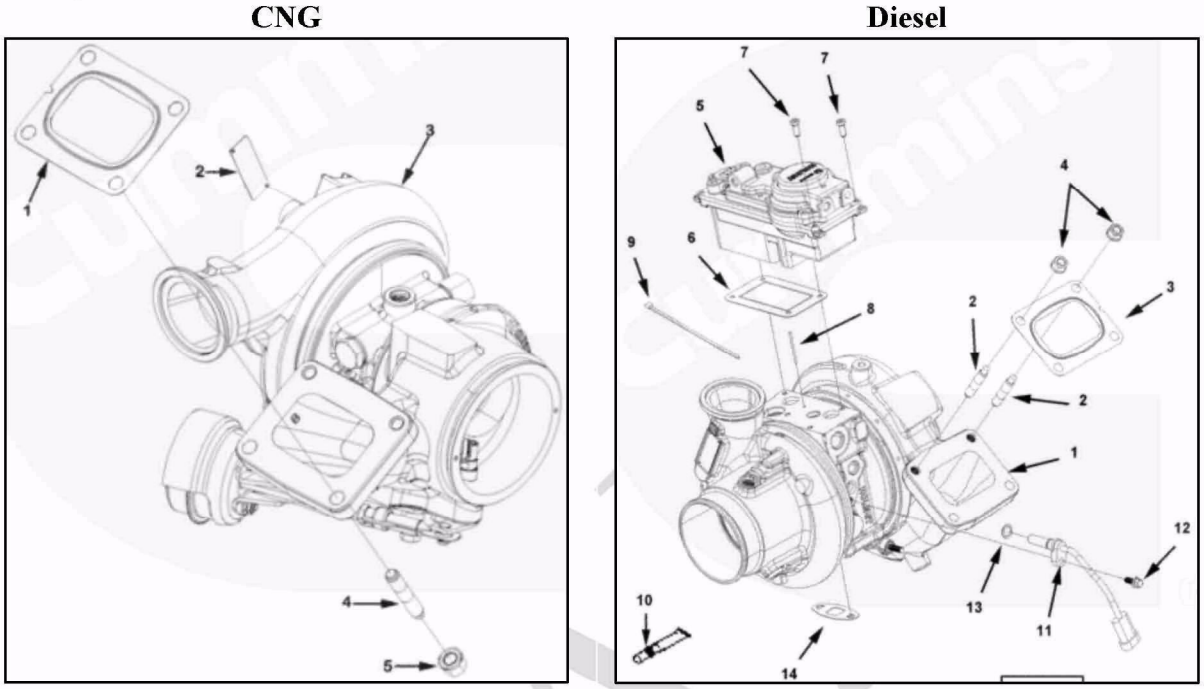


Figure 15-4: Turbocharger Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

15.3 Turbocharger Arrangement Sub-Subsystem 01-10-06 Overview

Figure 15-5 shows the Turbocharger arrangement 06 Sub-subsystem which is different for the Cummins ISXG11.9 liter CNG engine and the Cummins ISX11.9 liter Diesel engine. All parts with the same numbers will be disregarded and only parts different numbers will be quoted.

CNG **Diesel**

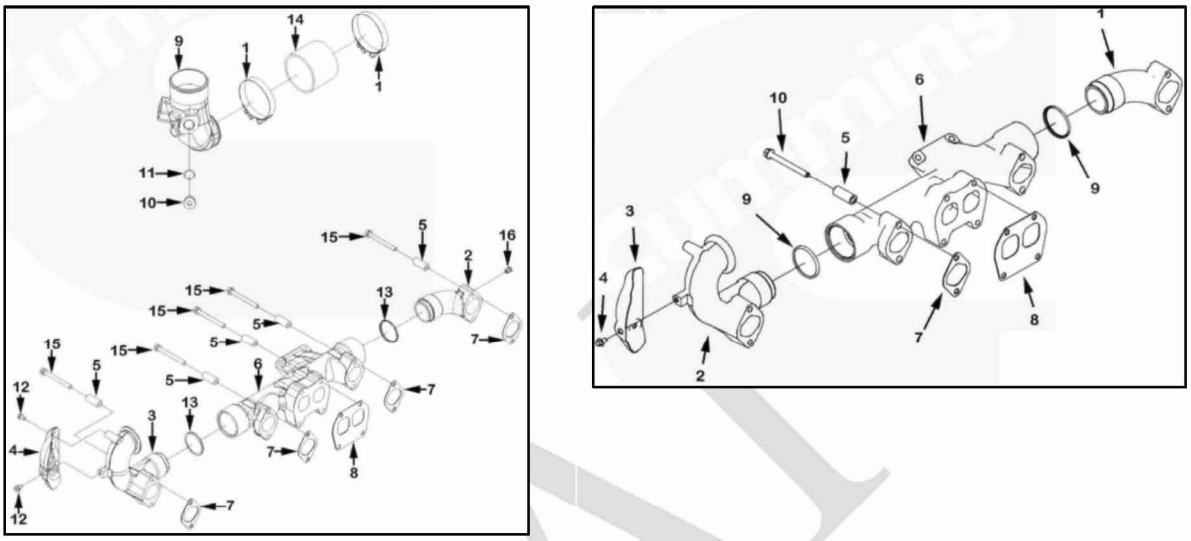


Figure 15-5: Turbocharger Arrangement Sub-Subsystem
(Source: Cummins parts website https://quickserve.cummins.com)

The Turbocharger Arrangement 06 Sub-subsystem is broken down into 1 assembly.

01-10-06-01 Air inlet pipe

The following sections show the assembly and what was quoted.
Figure 15-6 illustrates the 01-10-06-01 Air inlet pipe assemblies which are different for the Cummins ISXG11.9 liter CNG engine and the Cummins ISX11.9 liter Diesel engine. All parts with the same numbers will be disregarded and only parts different numbers will be quoted.

CNG Only

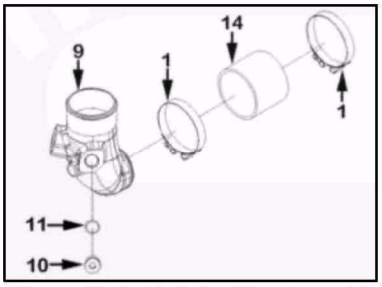


Figure 15-6: Air Inlet Pipe Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

15.4 Turbo Charger Plumbing Sub-Subsystem 01-10-07 Overview

Figure 15-7 shows the Turbocharger plumbing 07 Sub-subsystem which is different for the Cummins ISXG11.9 liter CNG engine and the Cummins ISX11.9 liter Diesel engine. Only parts with different numbers will be quoted.

CNG **Diesel**

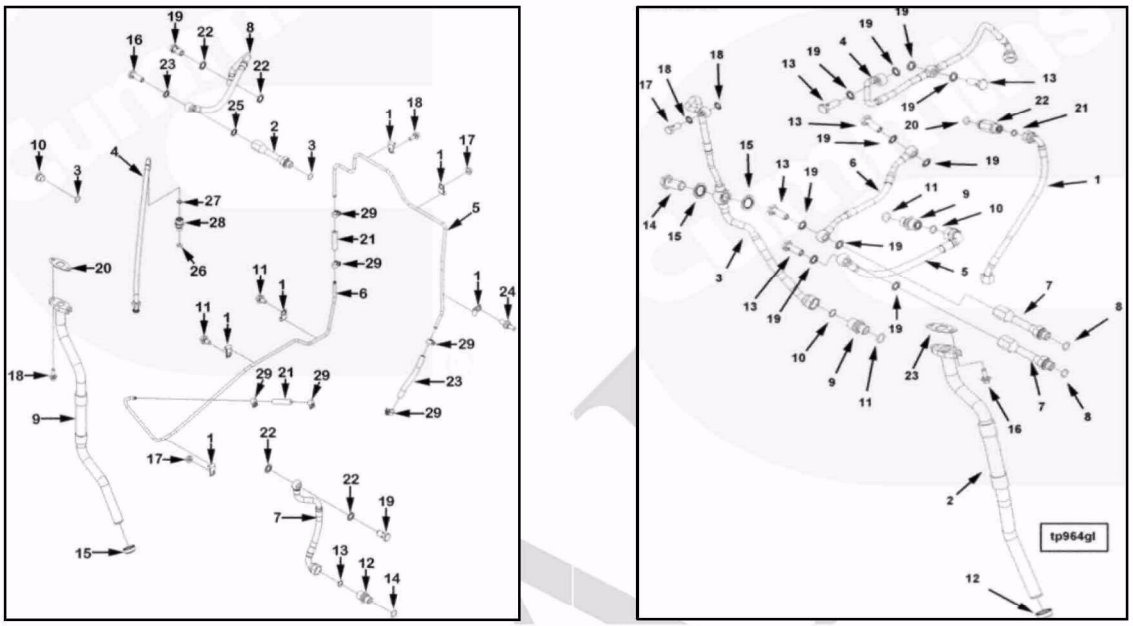


Figure 15-7: Turbocharger Plumbing Sub-Subsystem

(Source: Cummins parts website https://quickserve.cummins.com)

The Turbocharger plumbing 07 Sub-subsystem is broken down into 2 assemblies.

01-10-07-01 Turbocharger oil drain tube
01-10-07-02 Air fuel control tube

The following sections show each assembly and what was quoted.

Figure 15-8 illustrates the 01-10-07-01 Turbocharger oil drain tube assembly which is different for the Cummins ISXG11.9 liter CNG engine and the Cummins ISX11.9 liter Diesel engine. Only parts different numbers will be quoted.

Figure 15-8: Turbocharger Plumbing Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

Figure 15-9 the 01-10-07-02 Air fuel control tube assembly is different for the Cummins ISXG11.9 liter CNG engine and the Cummins ISX11.9 liter Diesel engine. Only parts different numbers will be quoted.

CNG **Diesel**

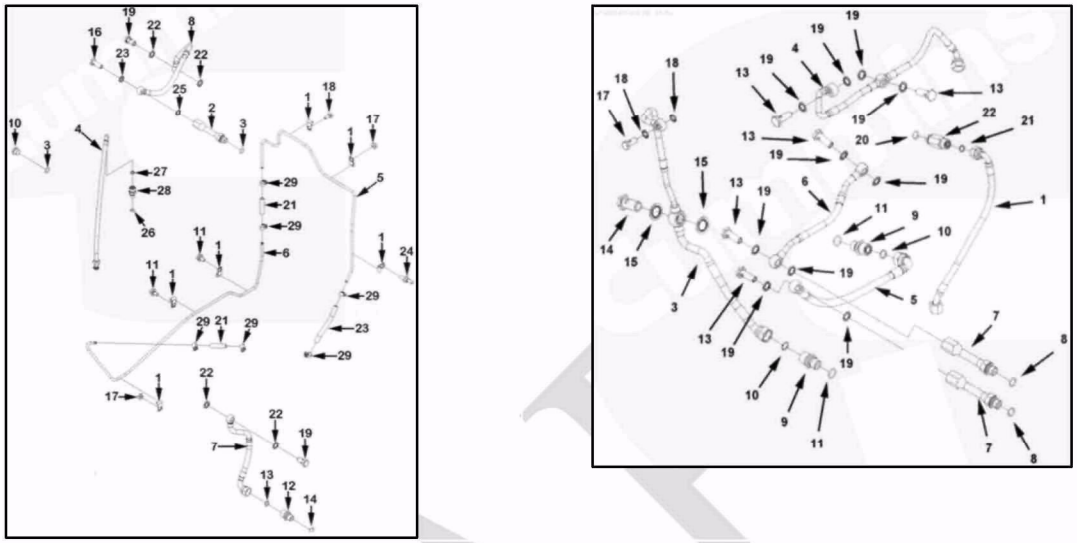


Figure 15-9: Air Fuel Control Tube Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

15.5 Direct Manufacturing Cost For Air Transfer 01-10 Subsystem

The cost breakdown below shows that the CNG system had an increase total of -$151.34 due to the differences in the turbo charger and associated hardware. "+" = cost decrease, "-" = cost increase.

Table 15-1: Direct Manufacturing Cost of the Air Transfer 01-10 Subsystem

SYSTEM & SUBSYSTEM DESCRIPTION					DIESEL TECHNOLOGY GENERAL PART INFORMATION:										
					Manufacturing				Markup						
Item	System	Subsystem	Sub-Subsystem	Name/Description	Material	Labor	Burden	Total Manufacturing Cost (Component/ Assembly)	End Item Scrap	SG&A	Profit	ED&T-R&D	Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
					USD	USD	USD	USD	USD	USD	USD	USD	USD	USD	USD
	CNG / Diesel														
	10 Air Transfer														
1			01 Air Transfer Connection		-	-	-	-	-	-	-	-	-	-	-
2			02 Air Intake Connection		-	-	-	-	-	-	-	-	-	-	-
3			03 Air Inlet Connection		17.38	4.62	14.86	36.87	0.90	3.10	2.60	0.59	7.19	-	44.05
4			04 Coolant Heater Starter Aid		-	-	-	-	-	-	-	-	-	-	-
5			05 Turbocharger		267.76	126.84	191.96	586.56	7.33	39.90	42.07	17.39	106.69	-	693.25
6			06 Turbocharger Arrangement		-	-	-	-	-	-	-	-	-	-	-
7			07 Turbocharger Plumbing		28.85	14.88	13.50	57.23	0.14	2.78	1.85	0.38	5.16	-	62.39
8			08		-	-	-	-	-	-	-	-	-	-	-
9			09		-	-	-	-	-	-	-	-	-	-	-
10			10		-	-	-	-	-	-	-	-	-	-	-
				SUBSYSTEM ROLL-UP	313.99	146.34	220.33	680.66	8.37	45.78	46.52	18.37	119.03	-	799.69

SYSTEM & SUBSYSTEM DESCRIPTION					CNG TECHNOLOGY GENERAL PART INFORMATION:										
Item	System	Subsystem	Sub-Subsystem	Name/Description	Manufacturing			Total Manufacturing Cost (Component/ Assembly)	Markup				Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
					Material	Labor	Burden		End Item Scrap	SG&A	Profit	ED&T-R&D			
					USD	USD	USD	USD	USD	USD	USD	USD	USD	USD	USD
	CNG / Diesel														
		10 Air Transfer													
1			01 Air Transfer Connection		-	-	-	-	-	-	-	-	-	-	-
2			02 Air Intake Connection		-	-	-	-	-	-	-	-	-	-	-
3			03 Air Inlet Connection		-	-	-	-	-	-	-	-	-	-	-
4			04 Coolant Heater Starter Aid		-	-	-	-	-	-	-	-	-	-	-
5			05 Turbocharger		391.43	140.76	205.88	738.07	10.38	50.88	53.84	22.19	137.29	-	875.36
6			06 Turbocharger Arrangement		6.54	3.74	12.44	22.72	0.53	1.96	2.13	0.82	5.45	-	28.17
7			07 Turbocharger Plumbing		25.13	9.97	8.87	43.96	0.09	1.89	1.26	0.29	3.54	-	47.51
8			08		-	-	-	-	-	-	-	-	-	-	-
9			09		-	-	-	-	-	-	-	-	-	-	-
10			10		-	-	-	-	-	-	-	-	-	-	-
				SUBSYSTEM ROLL-UP	423.09	154.47	227.19	804.75	11.01	54.73	57.23	23.31	146.28	-	951.03

SYSTEM & SUBSYSTEM DESCRIPTION					INCREMENTAL COST TO UPGRADE TO NEW TECHNOLOGY PACKAGE									
					Manufacturing				Markup						
Item	System	Subsystem	Sub-Subsystem	Name/Description	Material	Labor	Burden	Total Manufacturing Cost (Component/ Assembly)	End Item Scrap	SG&A	Profit	ED&T-R&D	Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
					USD	USD	USD	USD	USD	USD	USD	USD	USD	USD	USD
	CNG / Diesel														
		10 Air Transfer													
1			01 Air Transfer Connection		-	-	-	-	-	-	-	-	-	-	-
2			02 Air Intake Connection		-	-	-	-	-	-	-	-	-	-	-
3			03 Air Inlet Connection		17.38	4.62	14.86	36.87	0.90	3.10	2.60	0.59	7.19	-	44.05
4			04 Coolant Heater Starter Aid		-	-	-	-	-	-	-	-	-	-	-
5			05 Turbocharger		(123.66)	(13.92)	(13.92)	(151.50)	(3.05)	(10.98)	(11.77)	(4.80)	(30.60)	-	(182.11)
6			06 Turbocharger Arrangement		(6.54)	(3.74)	(12.44)	(22.72)	(0.53)	(1.96)	(2.13)	(0.82)	(5.45)	-	(28.17)
7			07 Turbocharger Plumbing		3.72	4.91	4.63	13.27	0.04	0.89	0.59	0.09	1.62	-	14.88
8			08		-	-	-	-	-	-	-	-	-	-	-
9			09		-	-	-	-	-	-	-	-	-	-	-
10			10		-	-	-	-	-	-	-	-	-	-	-
				SUBSYSTEM ROLL-UP	(109.10)	(8.13)	(6.87)	(124.09)	(2.64)	(8.96)	(10.71)	(4.94)	(27.24)	-	(151.34)

16. After-treatment and Exhaust Subsystem 01-11 – Diesel Only

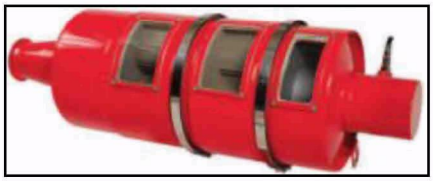
The After-treatment and Exhaust 11 subsystem is broken into 3 sub-subsystems and 24 assemblies.

- 01-11-01 After-treatment device
  - 01-11-01-01 Exhaust After-treatment device
  - 01-11-01-02 After-treatment frame brackets
  - 01-11-01-03 After-treatment urea tank – Diesel only
  - 01-11-01-04 After-treatment urea tank brackets– Diesel only
- 01-11-02 Engine fluid doser components
  - 01-11-02-01 Flexible hose – Diesel only
  - 01-11-02-02 Exhaust outlet connection - No Costing/Identical
  - 01-11-02-03 Doser injector – Diesel only
  - 01-11-02-04 Fuel supply tube A – Diesel only
  - 01-11-02-05 Fuel manifold – Diesel only
  - 01-11-02-06 Fuel supply tube B – Diesel only
  - 01-11-02-07 Air inlet tube – Diesel only
- 01-11-03 Exhaust recirculation
  - 01-11-03-01 Exhaust recirculation
  - 01-11-03-02 Air transfer tube A
  - 01-11-03-03 Air transfer tube B
  - 01-11-03-04 Exhaust gas recirculation cooler
  - 01-11-03-05 Exhaust gas recirculation valve
  - 01-11-03-06 Exhaust recirculation valve support - No Costing/Identical
  - 01-11-03-07 Bellows - No Costing/Identical
  - 01-11-03-08 Exhaust cooler water inlet tube - No Costing/Identical
  - 01-11-03-09 Exhaust cooler water outlet tube - No Costing/Identical
  - 01-11-03-10 Air flow metering orifice – Diesel only
  - 01-11-03-11 Pressure sensing tube – Diesel only
  - 01-11-03-12 Exhaust transfer tube – Diesel only
  - 01-11-03-13 Miscellaneous – Diesel only

16.1 After-treatment Device Sub-Subsystem 01-11-01 Overview

Figure 16-1 shows the After-treatment device 01 Sub-subsystem which is different for the Cummins ISXG11.9 liter CNG engine and the Cummins ISX11.9 liter Diesel engine. Only parts with different numbers will be quoted.

CNG **Diesel**



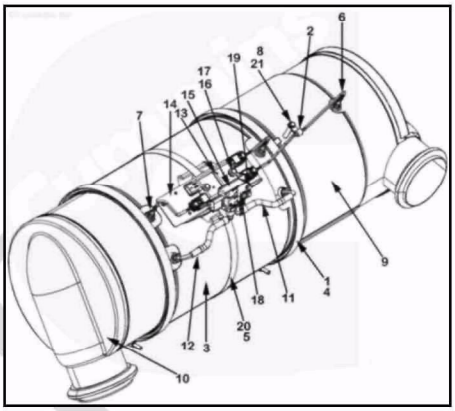


Figure 16-1: After-treatment Device Sub-Subsystem
(Source: Cummins parts website https://quickserve.cummins.com & FEV)

The After-treatment device 01 Sub-subsystem is broken down into 3 assemblies.

01-11-01-01 Exhaust After-treatment device
- 01-11-01-02 After-treatment frame brackets
- 01-11-01-03 After-treatment urea tank – Diesel only
- 01-11-01-04 After-treatment urea tank brackets – Diesel only

The following sections show each assembly and what was quoted.

Figure 16-2 illustrates the 01-11-01-01 Exhaust After-treatment device assembly which is different for the Cummins ISXG11.9 liter CNG engine and the Cummins ISX11.9 liter Diesel engine. Only parts with different numbers will be quoted.

CNG **Diesel**

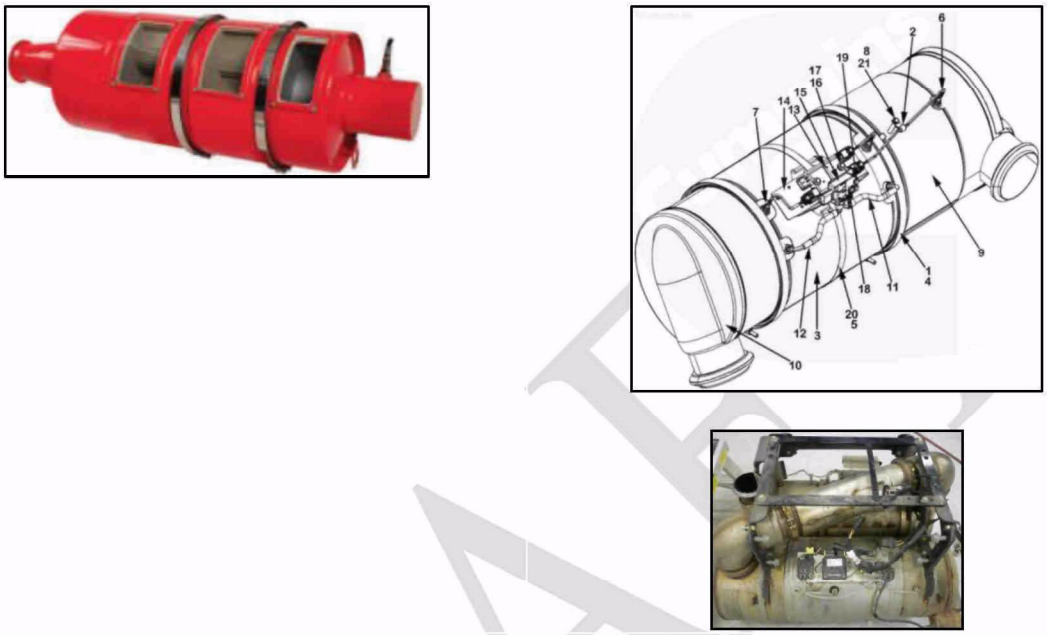


Figure 16-2: After-treatment Device Assembly
(Source: Cummins parts website https://quickserve.cummins.com & FEV)

Figure 16-3 shows the 01-11-01-02 After-treatment frame brackets assembly which is different for the Cummins ISXG11.9 liter CNG engine and the Cummins ISX11.9 liter Diesel engine. Only parts with different numbers will be quoted.

CNG **Diesel**

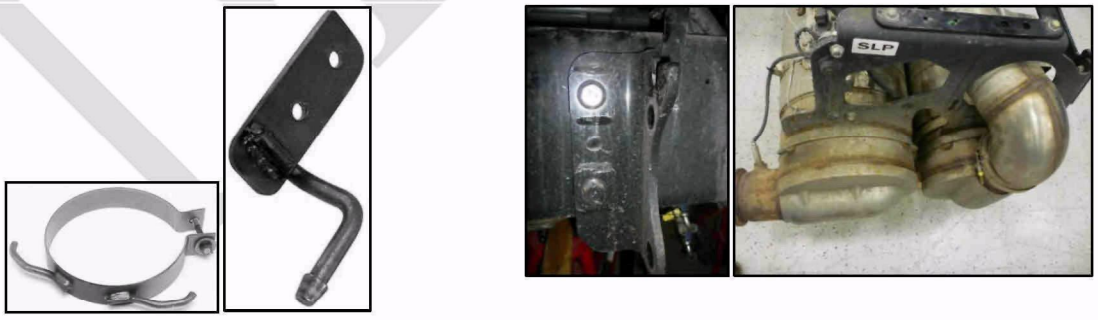


Figure 16-3: After-treatment Frame Brackets Assembly
(Source: http://www.autozone.com & FEV)

Figure 16-4 illustrates the 01-11-01-03 After-treatment urea tank assembly is for the ISX11.9 liter Diesel engine only. All parts will be quoted.

Diesel Only

Figure 16-4: After-treatment Urea Tank Assembly
(Source: FEV)

Figure 16-5 shows the 01-11-01-04 After-treatment urea tank brackets assembly which is for the ISX11.9 liter Diesel engine only. All parts will be quoted.

Diesel Only

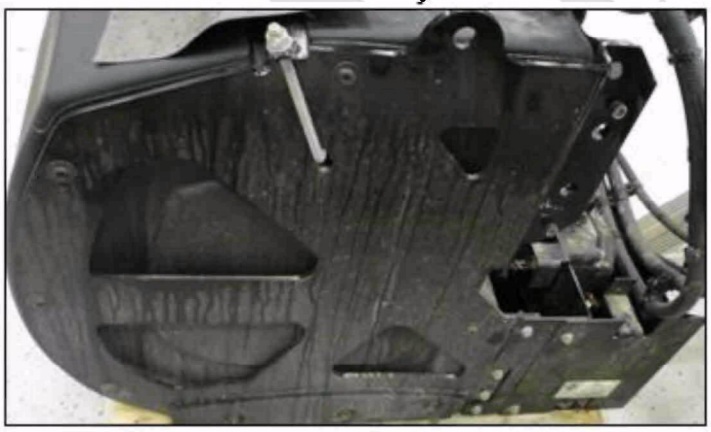


Figure 16-5: After-treatment Urea Tank Brackets Assembly
(Source: FEV)

16.2 Engine Fluid Doser Components Sub-Subsystem 01-11-02 Overview

Figure 16-6 illustrates the Engine Fluid Doser components 02 Sub-subsystem for the ISX11.9 liter Diesel engine only. All parts will be quoted.

Diesel Only

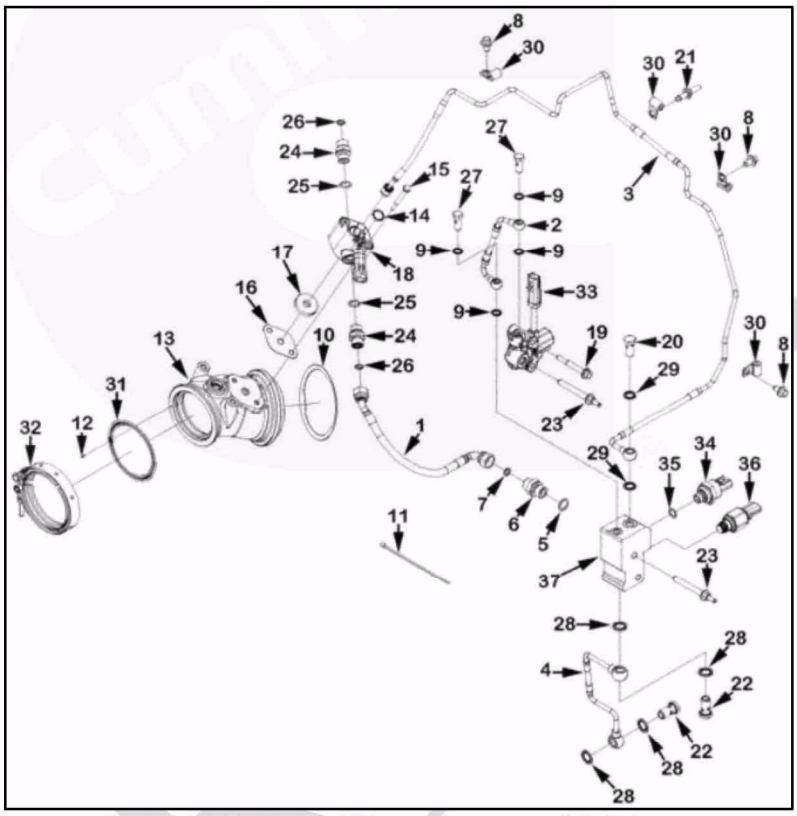


Figure 16-6: Engine Fluid Doser Components Sub-Subsystem

(Source: Cummins parts website https://quickserve.cummins.com & FEV)

The Engine Fluid Doser components 02 Sub-subsystem is broken down into 7 assemblies.

01-11-02-01 Flexible hose – Diesel only
01-11-02-02 Exhaust outlet connection - No Costing/Identical
01-11-02-03 Doser injector – Diesel only
01-11-02-04 Fuel supply tube A – Diesel only
01-11-02-05 Fuel manifold – Diesel only
01-11-02-06 Fuel supply tube B – Diesel only
01-11-02-07 Air inlet tube – Diesel only

The following sections show each assembly and what was quoted.

Figure 16-7 shows the 01-11-02-01 Flexible hose assembly for the ISX11.9 liter Diesel engine only. All parts will be quoted.

Diesel Only

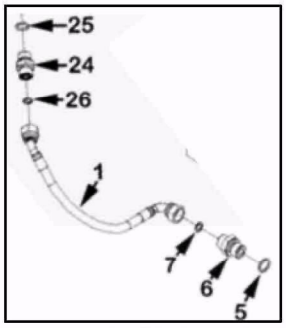
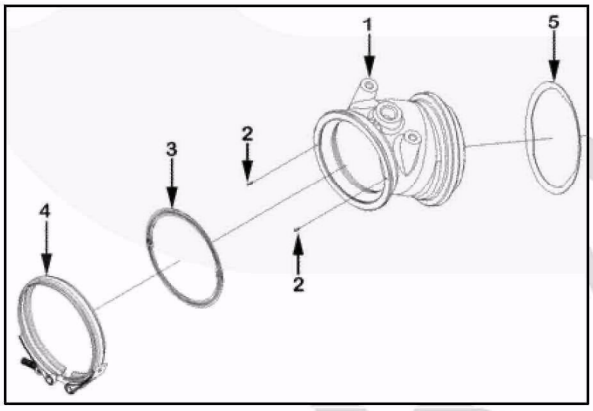


Figure 16-7: Flexible Hose Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

Figure 16-8 illustrates the 01-11-02-02 Exhaust outlet connection assembly which is identical for both the ISXG11.9 CNG engine and for the ISX11.9 liter Diesel engine. This part will not be quoted.

CNG



Diesel

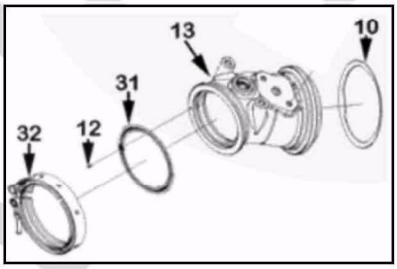


Figure 16-8: Exhaust Outlet Connection Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

Figure 16-9 shows the 01-11-02-03 Doser injector assembly for the ISX11.9 liter Diesel engine only. All parts will be quoted.

Diesel Only

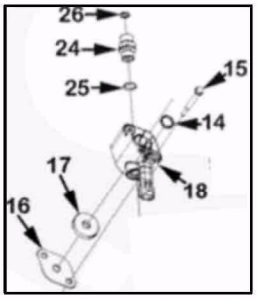


Figure 16-9: Doser Injector Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

Figure 16-10 illustrates the 01-11-02-04 Fuel supply tube assembly for the ISX11.9 liter Diesel engine only. All parts will be quoted.

Diesel Only

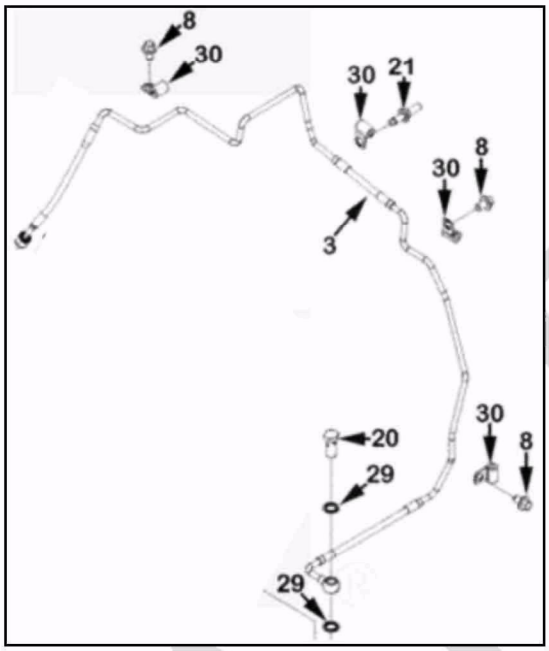


Figure 16-10: Fuel Supply Tube Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

Figure 16-11 shows the 01-11-02-05 Fuel manifold assembly for the ISX11.9 liter Diesel engine only. All parts will be quoted.

Diesel Only

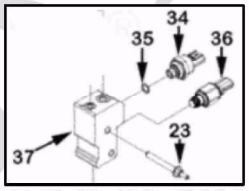


Figure 16-11: Fuel Manifold Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

Figure 16-12 illustrates the 01-11-02-06 Fuel supply tube B assembly for the ISX11.9 liter Diesel engine only. All parts will be quoted.

Diesel Only

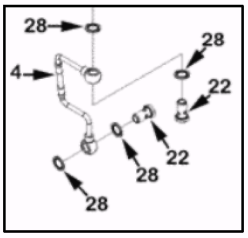


Figure 16-12: Fuel Supply Tube B Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

Figure 16-13 illustrates the 01-11-02-07 Air Inlet Tube assembly for the ISX11.9 liter Diesel engine only. All parts will be quoted.

Diesel Only

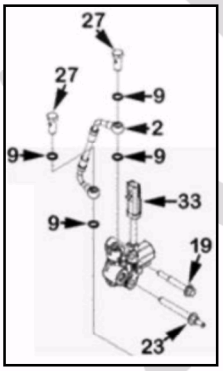


Figure 16-13: Air Inlet Tube Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

16.3 Exhaust Recirculation Sub-Subsystem 01-11-03 Overview

Figure 16-14 shows the Exhaust recirculation 03 Sub-subsystem which is different for the Cummins ISXG11.9 liter CNG engine and the Cummins ISX11.9 liter Diesel engine. Only parts with different numbers will be quoted.

CNG **Diesel**

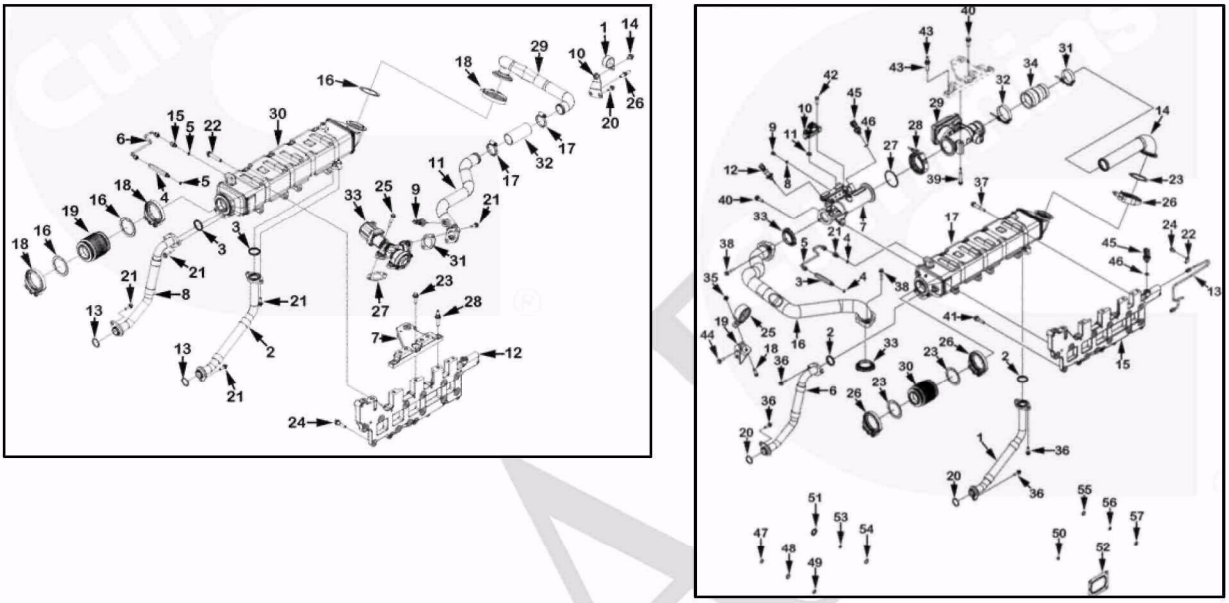


Figure 16-14: Exhaust Recirculation Sub-Subsystem
(Source: Cummins parts website https://quickserve.cummins.com)

The Exhaust recirculation 03 Sub-subsystem is broken down into 12 assemblies.

01-11-03-01 Exhaust recirculation
01-11-03-02 Air transfer tube A
01-11-03-03 Air transfer tube B
01-11-03-04 Exhaust gas recirculation cooler
01-11-03-05 Exhaust gas recirculation valve
01-11-03-06 Exhaust recirculation valve support - No Costing/Identical
01-11-03-07 Bellows - No Costing/Identical
01-11-03-08 Exhaust cooler water inlet tube - No Costing/Identical
01-11-03-09 Exhaust cooler water outlet tube - No Costing/Identical
01-11-03-10 Air flow metering orifice – Diesel only
01-11-03-11 Pressure sensing tube – Diesel only
01-11-03-12 Exhaust transfer tube – Diesel only

The following sections show each assembly and what was quoted.
Figure 16-15 illustrates the 01-11-03-01 Exhaust recirculation assembly which is different for the Cummins ISXG11.9 liter CNG engine and the Cummins ISX11.9 liter Diesel engine. Only parts

with different numbers will be quoted.

CNG **Diesel**

Figure 16-15: Exhaust Recirculation Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

Figure 16-16 shows the 01-11-03-02 Air transfer tube assembly which is different for the Cummins ISXG11.9 liter CNG engine and the Cummins ISX11.9 liter Diesel engine. Only parts with different numbers will be quoted.

CNG **Diesel**

Figure 16-16: Air Transfer Tube Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

Figure 16-17 illustrates the 01-11-03-03 Air transfer tube B assembly which is different for the Cummins ISXG11.9 liter CNG engine and the Cummins ISX11.9 liter Diesel engine. Only parts with different numbers will be quoted.

CNG **Diesel**

Figure 16-17: Air Transfer Tube B Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

Figure 16-18 shows the 01-11-03-04 Exhaust gas recirculation cooler assembly which is different for the Cummins ISXG11.9 liter CNG engine and the Cummins ISX11.9 liter Diesel engine. Only parts with different numbers will be quoted.

CNG **Diesel**

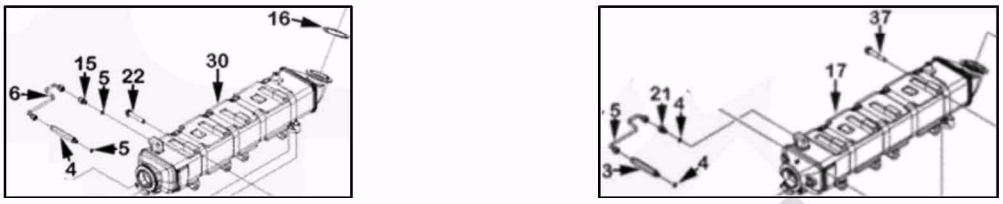


Figure 16-18: Exhaust Gas Recirculation Cooler Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

Figure 16-19 illustrates the 01-11-03-05 Exhaust gas recirculation valve assembly which is different for the Cummins ISXG11.9 liter CNG engine and the Cummins ISX11.9 liter Diesel engine. Only parts with different numbers will be quoted.

CNG **Diesel**

Figure 16-19: Exhaust Gas Recirculation Valve Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

Figure 16-20 shows the 01-11-03-06 Exhaust gas recirculation valve support assembly which is identical for the Cummins ISXG11.9 liter CNG engine and the Cummins ISX11.9 liter Diesel engine. Items will not be quoted.

CNG **Diesel**

Figure 16-20: Exhaust Gas Recirculation Valve Support Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

Figure 16-21 illustrates the 01-11-03-07 Bellows assembly which is identical for the Cummins ISXG11.9 liter CNG engine and the Cummins ISX11.9 liter Diesel engine. Items will not be quoted.

CNG **Diesel**

Figure 16-21: Bellows Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

Figure 16-22 shows the 01-11-03-08 Exhaust cooler water inlet tube assembly which is identical for the Cummins ISXG11.9 liter CNG engine and the Cummins ISX11.9 liter Diesel engine. No items will be quoted.

CNG **Diesel**

Figure 16-22: Exhaust Cooler Water Inlet Tube Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

Figure 16-23 illustrates the 01-11-03-09 Exhaust cooler water outlet tube assembly which is identical for the Cummins ISXG11.9 liter CNG engine and the Cummins ISX11.9 liter Diesel engine. No items will be quoted.

CNG **Diesel**

Figure 16-23: Exhaust Cooler Water Outlet Tube Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

Figure 16-24 shows the 01-11-03-10 Air flow metering orifice assembly for the ISX11.9 liter Diesel engine only. All parts will be quoted.

Diesel Only

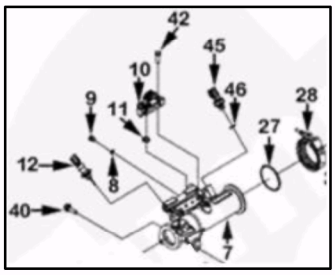


Figure 16-24: Air Flow Metering Orifice Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

Figure 16-25 illustrated the 01-11-03-11 Pressure sensing tube assembly for the ISX11.9 liter Diesel engine only. All parts will be quoted.

Diesel Only

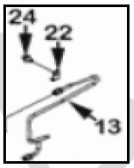


Figure 16-25: Pressure Sensing Tube Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

Figure 16-26 illustrates the 01-11-03-12 Exhaust transfer tube assembly for the ISX11.9 liter Diesel engine only. All parts will be quoted.

Diesel Only

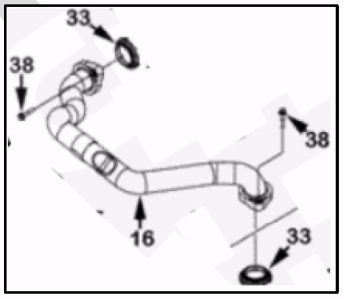


Figure 16-26: Exhaust Transfer Tube Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

16.4 Direct Manufacturing Cost For After-treatment and Exhaust 01-11 Subsystem

The cost breakdown below shows that the Diesel system had an increase total of $2,701.51 due to the Diesel requirements for exhaust After-treatment. "+" = cost decrease, "-" = cost increase

Table 16-1: Direct Manufacturing Cost Of the After-treatment and Exhaust 01-11 Subsystem

SYSTEM & SUBSYSTEM DESCRIPTION					DIESEL TECHNOLOGY GENERAL PART INFORMATION:										
					Manufacturing				Markup						
Item	System	Subsystem	Sub-Subsystem	Name/Description	Material	Labor	Burden	Total Manufacturing Cost (Component/ Assembly)	End Item Scrap	SG&A	Profit	ED&T-R&D	Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
					USD	USD	USD	USD	USD	USD	USD	USD	USD	USD	USD
	CNG / Diesel														
	11 Aftertreatment and Exhaust														
1		01 Aftertreatment Divice			3,081.86	562.43	650.60	4,294.88	18.52	227.58	207.96	76.66	530.72	-	4,825.60
2		02 Fluid Doser			85.57	45.78	50.98	182.33	0.96	9.87	9.21	3.57	23.61	-	205.94
3		03 Catalytic Converter			193.27	46.60	65.54	305.40	3.84	19.90	20.90	8.49	53.13	-	358.54
4		04 Exhaust Recirculation			-	-	-	-	-	-	-	-	-	-	-
5		05			-	-	-	-	-	-	-	-	-	-	-
6		06			-	-	-	-	-	-	-	-	-	-	-
7		07			-	-	-	-	-	-	-	-	-	-	-
8		08			-	-	-	-	-	-	-	-	-	-	-
9		09			-	-	-	-	-	-	-	-	-	-	-
10		10			-	-	-	-	-	-	-	-	-	-	-
				SUBSYSTEM ROLL-UP	3,360.69	654.81	767.12	4,782.62	23.32	257.35	238.08	88.71	607.46	-	5,390.07

SYSTEM & SUBSYSTEM DESCRIPTION					CNG TECHNOLOGY GENERAL PART INFORMATION:										
Item	System	Subsystem	Sub-Subsystem	Name/Description	Manufacturing			Total Manufacturing Cost (Component/ Assembly)	Markup				Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
					Material	Labor	Burden		End Item Scrap	SG&A	Profit	ED&T-R&D			
					USD	USD	USD	USD	USD	USD	USD	USD	USD	USD	USD
	CNG / Diesel														
	11 Aftertreatment and Exhaust														
1		01 Aftertreatment Divice			1,661.75	248.36	261.38	2,171.49	10.75	109.65	123.28	59.06	302.74	-	2,474.23
2		02 Fluid Doser			-	-	-	-	-	-	-	-	-	-	-
3		03 Catalytic Converter			102.10	31.45	48.35	181.90	1.84	12.65	12.93	5.01	32.43	-	214.33
4		04 Exhaust Recirculation			-	-	-	-	-	-	-	-	-	-	-
5		05			-	-	-	-	-	-	-	-	-	-	-
6		06			-	-	-	-	-	-	-	-	-	-	-
7		07			-	-	-	-	-	-	-	-	-	-	-
8		08			-	-	-	-	-	-	-	-	-	-	-
9		09			-	-	-	-	-	-	-	-	-	-	-
10		10			-	-	-	-	-	-	-	-	-	-	-
				SUBSYSTEM ROLL-UP	1,763.84	279.82	309.73	2,353.39	12.59	122.30	136.21	64.07	335.17	-	2,688.56

SYSTEM & SUBSYSTEM DESCRIPTION					INCREMENTAL COST TO UPGRADE TO NEW TECHNOLOGY PACKAGE										
					Manufacturing				Markup						
Item	System	Subsystem	Sub-Subsystem	Name/Description	Material	Labor	Burden	Total Manufacturing Cost (Component/ Assembly)	End Item Scrap	SG&A	Profit	ED&T-R&D	Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
					USD	USD	USD	USD	USD	USD	USD	USD	USD	USD	USD
	CNG / Diesel														
		11 Aftertreatment and Exhaust													
1			01 Aftertreatment Divice		1,420.11	314.07	389.22	2,123.39	7.77	117.93	84.68	17.60	227.97	-	2,351.36
2			02 Fluid Doser		85.57	45.78	50.98	182.33	0.96	9.87	9.21	3.57	23.61	-	205.94
3			03 Catalytic Converter		91.17	15.14	17.19	123.51	2.00	7.25	7.97	3.48	20.70	-	144.21
4			04 Exhaust Recirculation		-	-	-	-	-	-	-	-	-	-	-
5			05		-	-	-	-	-	-	-	-	-	-	-
6			06		-	-	-	-	-	-	-	-	-	-	-
7			07		-	-	-	-	-	-	-	-	-	-	-
8			08		-	-	-	-	-	-	-	-	-	-	-
9			09		-	-	-	-	-	-	-	-	-	-	-
10			10		-	-	-	-	-	-	-	-	-	-	-
				SUBSYSTEM ROLL-UP	1,596.84	374.99	457.40	2,429.23	10.73	135.05	101.86	24.64	272.28	-	2,701.51

17. Flywheel/Flex Plate Subsystem 01-16

The Flywheel/Flex plate 16 subsystem for both the Cummins ISXG11.9 liter CNG engine and the Cummins ISX11.9 liter Diesel engine will be treated as the same and will not be quoted.

18. Compressed Air Subsystem 01-12

The Compressed Air 12 subsystem is an accessory item for both the Cummins ISXG11.9 liter CNG engine and the Cummins ISX11.9 liter Diesel engine and will not be quoted.

19. Engine Voltage Subsystem 01-13

The Engine Voltage 13 subsystem is broken into 4 sub-subsystems and 3 assemblies.

01-13-01 Engine operating voltage - No Costing/Identical
01-13-02 Ignition
- 01-13-02-01 Ignition coil – CNG only
- 01-13-02-02 Ignition control module – CNG only
- 01-13-02-03 Ignition control module wiring harness – CNG only

01-13-03 Alternator mounting - No Costing/Identical
01-13-04 Starter motor mounting - No Costing/Identical

20. Ignition Sub-Subsystem 01-13-02 Overview

Figure 20-1 shows the Ignition 02 Sub-subsystem which is a Cummins ISXG11.9 liter CNG engine part only. All parts will be quoted.

CNG Only

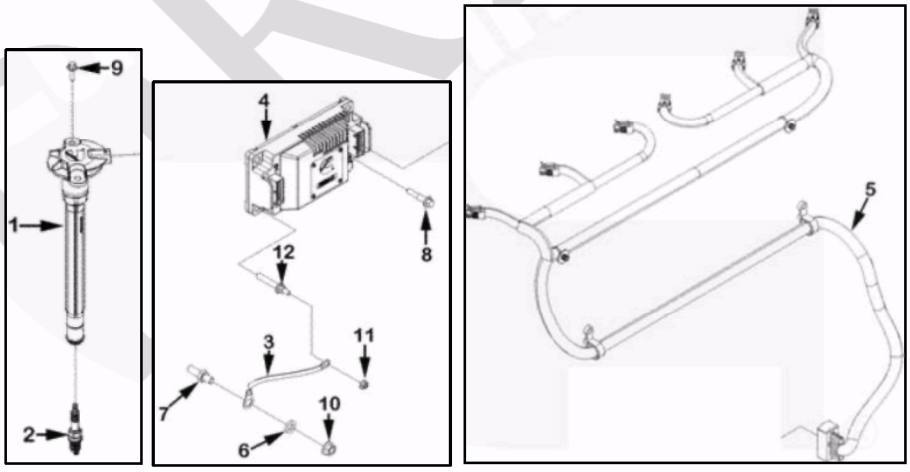


Figure 20-1: Ignition Sub-Subsystem
(Source: Cummins parts website https://quickserve.cummins.com)

The Ignition 02 Sub-subsystem is broken down into 3 assemblies.

01-13-02-01 Ignition coil – CNG only
01-13-02-02 Ignition control module – CNG only
01-13-02-03 Ignition control module wiring harness – CNG only

The following sections show each assembly and what was quoted.

Figure 20-2 illustrates the 01-13-02-01 Ignition coil assembly which is a Cummins ISXG11.9 liter CNG engine part only. All parts will be quoted.

CNG Only

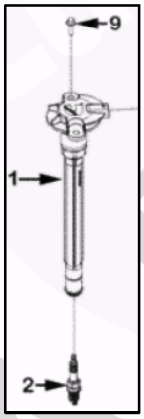


Figure 20-2: Ignition Coil Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

Figure 20-3 shows the 01-13-02-02 Ignition control module assembly which is a Cummins ISXG11.9 liter CNG engine part only. All parts will be quoted.

CNG Only

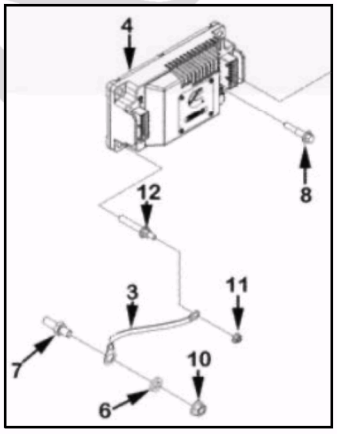


Figure 20-3: Ignition Control Module Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

Figure 20-4 illustrates the 01-13-02-03 Ignition control module wiring harness assembly which is a Cummins ISXG11.9 liter CNG engine part only. All parts will be quoted.

CNG Only

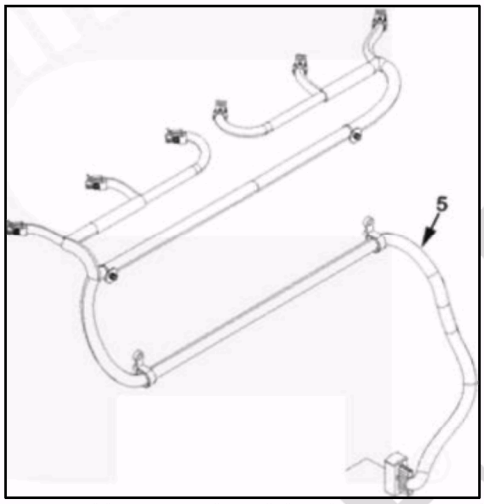


Figure 20-4: Ignition Control Module Wiring Harness Assembly
(Source: Cummins parts website https://quickserve.cummins.com)

21. Direct Manufacturing Cost For Engine Voltage 01-13 Subsystem

The cost breakdown below shows that the CNG system had an increase total of $-607.04 due to the CNG requiring an Ignition system as the Diesel does not. "+" = cost decrease, "-" = cost increase

Table 21-1: Direct Manufacturing Cost Of the Engine Voltage 01-13 Subsystem

SYSTEM & SUBSYSTEM DESCRIPTION					DIESEL TECHNOLOGY GENERAL PART INFORMATION:										
					Manufacturing				Markup						
Item	System	Subsystem	Sub-Subsystem	Name/Description	Material	Labor	Burden	Total Manufacturing Cost (Component/ Assembly)	End Item Scrap	SG&A	Profit	ED&T-R&D	Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
					USD	USD	USD	USD	USD	USD	USD	USD	USD	USD	USD
	CNG / Diesel														
	13 Engine Voltage System														
1		01 Engine Operating Voltage			-	-	-	-	-	-	-	-	-	-	-
2		02 Ignition System			-	-	-	-	-	-	-	-	-	-	-
3		03 Alternator Mounting			-	-	-	-	-	-	-	-	-	-	-
4		04 Starter Motor Mounting			-	-	-	-	-	-	-	-	-	-	-
5		05			-	-	-	-	-	-	-	-	-	-	-
6		06			-	-	-	-	-	-	-	-	-	-	-
7		07			-	-	-	-	-	-	-	-	-	-	-
8		08			-	-	-	-	-	-	-	-	-	-	-
9		09			-	-	-	-	-	-	-	-	-	-	-
10		10			-	-	-	-	-	-	-	-	-	-	-
				SUBSYSTEM ROLL-UP	-	-	-	-	-	-	-	-	-	-	-

SYSTEM & SUBSYSTEM DESCRIPTION					CNG TECHNOLOGY GENERAL PART INFORMATION:										
Item	System	Subsystem	Sub-Subsystem	Name/Description	Manufacturing			Total Manufacturing Cost (Component/ Assembly)	Markup				Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
					Material	Labor	Burden		End Item Scrap	SG&A	Profit	ED&T-R&D			
					USD	USD	USD	USD	USD	USD	USD	USD	USD	USD	USD
	CNG / Diesel														
		13 Engine Voltage System													
1			01 Engine Operating Voltage		-	-	-	-	-	-	-	-	-	-	-
2			02 Ignition System		289.39	115.85	127.97	533.21	2.72	27.05	29.87	14.20	73.84	-	607.04
3			03 Alternator Mounting		-	-	-	-	-	-	-	-	-	-	-
4			04 Starter Motor Mounting		-	-	-	-	-	-	-	-	-	-	-
5			05		-	-	-	-	-	-	-	-	-	-	-
6			06		-	-	-	-	-	-	-	-	-	-	-
7			07		-	-	-	-	-	-	-	-	-	-	-
8			08		-	-	-	-	-	-	-	-	-	-	-
9			09		-	-	-	-	-	-	-	-	-	-	-
10			10		-	-	-	-	-	-	-	-	-	-	-
				SUBSYSTEM ROLL-UP	289.39	115.85	127.97	533.21	2.72	27.05	29.87	14.20	73.84	-	607.04

SYSTEM & SUBSYSTEM DESCRIPTION					INCREMENTAL COST TO UPGRADE TO NEW TECHNOLOGY PACKAGE										
					Manufacturing				Markup						
Item	System	Subsystem	Sub-Subsystem	Name/Description	Material	Labor	Burden	Total Manufacturing Cost (Component/ Assembly)	End Item Scrap	SG&A	Profit	ED&T-R&D	Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
					USD	USD	USD	USD	USD	USD	USD	USD	USD	USD	USD
	CNG / Diesel														
	13 Engine Voltage System														
1			01 Engine Operating Voltage		-	-	-	-	-	-	-	-	-	-	-
2			02 Ignition System		(289.39)	(115.85)	(127.97)	(533.21)	(2.72)	(27.05)	(29.87)	(14.20)	(73.84)	-	(607.04)
3			03 Alternator Mounting		-	-	-	-	-	-	-	-	-	-	-
4			04 Starter Motor Mounting		-	-	-	-	-	-	-	-	-	-	-
5			05		-	-	-	-	-	-	-	-	-	-	-
6			06		-	-	-	-	-	-	-	-	-	-	-
7			07		-	-	-	-	-	-	-	-	-	-	-
8			08		-	-	-	-	-	-	-	-	-	-	-
9			09		-	-	-	-	-	-	-	-	-	-	-
10			10		-	-	-	-	-	-	-	-	-	-	-
				SUBSYSTEM ROLL-UP	(289.39)	(115.85)	(127.97)	(533.21)	(2.72)	(27.05)	(29.87)	(14.20)	(73.84)	-	(607.04)

Conclusion Summary

The primary project objective was to determine the incremental direct manufacturing costs and weight for the Class 8 systems. Specifically, this included the Cummins ISX12-Diesel and the ISX12G-CNG engines, including fuel and exhaust systems for both.

The cost analysis is inclusive of all associated assembly costs from component to vehicle level. Calculations were performed to determine equipment sizing, cycle times and material usage requirements. FEV has utilized its extensive database of rates for equipment, labor, material, end item scrap, selling, general and administrative (SG&A), profit, and engineering, design and testing (ED&T) to develop costs representative of what an OEM would incur for such a system at a volume of 50,000 units per year.

Cost and Weight Differences

The overall cost differences of CNG as compared to the Diesel at a system level are shown in Table 0-1.

Table 0-1: CNG vs. Diesel Cost & Weight Differences

EPA Class 8 Diesel vs CNG Study

	Diesel Base Technology		CNG New Technology		Delta Difference	
	Cost	Weight KG	Cost	Weight KG	Cost	Weight KG
Engine	$1,508	102.74	$1,621	82.96	-$113	19.79
Exhaust	$5,390	400.41	$2,689	69.08	$2,702	331.34
Fuel	$4,067	275.24	$17,067	1460.11	-$13,000	-1184.88
Total	$10,964	778.39	$21,376	1612.15	-$10,412	-833.75

(1) "+" = mass decrease, "-" = mass increase
(2) "+" = cost decrease, "-" = cost increase

Note: 1) Fuel and exhaust components that are attached to the engine are considered engine components.
2) Fuel systems weight does not include the fuel.

As shown in the above table, the weight differences in the engine are minimal as compared to the fuel and exhaust systems.

The weight of the fuel system for the CNG is considerably more due to the weight of the additional high pressure CNG tanks and enclosures required to maintain the same mileage as the Diesel fuel system.

The CNG exhaust system weight is less when compared to the Diesel SCR system, urea tank and associated equipment.

Engine

The ISX12-Diesel and the ISX12G-CNG engine blocks and heads are from the same family of engines but have slight machining differences. However, those differences were absorbed in the machining process without additional cost.

The Diesel engine is a compression fuel ignited system with fuel injectors, a common fuel rail, and an electric actuated turbo system.

The CNG engine has a high energy Coil-On-Plug Ignition and a fixed geometry with a waste gate and a water-cooled bearing housing. The CNG engines low emissions are due to the Stoichiometric cooled Exhaust Gas Recirculation (SEGR), which uses almost all of the available oxygen in the fuel/air mixture. That enables the use of a Three-Way Catalyst (TWC) in the exhaust system to achieve the global emissions standards.

Fuel System

The Diesel fuel system is a standard side mounted system.

The CNG is a rear mounted enclosure with five high pressure CNG tanks to achieve the same approximate mileage of the Diesel system.

Exhaust System

The Diesel exhaust system is a standard SCR system with a urea After-treatment.

The CNG system is a more typical style gas fuel system which only requires a Three-Way Catalyst (TWC) exhaust.

End of Document