Z factor Consultation, LLC

Vehicle Power Comparison

A white paper comparing the current technologies of Battery Electric, Compressed Natural Gas and Diesel Vehicles in 2023 Trucking Operations

PURPOSE

This document serves as a guide for providing considerations and directing customers toward a proper vehicle specification for the stated application.

Any questions should be clarified with the author/s or an independent expert, prior to making a purchase.

The expert advice contained within this document is derived from author/s experience and communication with current industry suppliers. Any vendor products noted are referenced for purpose of example and are not presented as the sole solution.

Authors: Cindi Vangel, Brian Lindgren & Gary Hey
Date: August 2023

Which energy source is best for your organization and application?

Given today's EPA/GHG regulations, it's important to determine what energy source and company statement is best for a given application.

Since Battery Electric Vehicle, BEV, is in its relative infancy, this won't be an apples for apples comparison, but is as close as we can get today.

This document compares an Over-The-Road Class 8 aerodynamic chassis. All example chassis utilize the same model.

1. BEV - 400 KWH (536 HP – 1623 lb. ft. torque) continuous battery system/500 KWH (670 HP) peak
   Advertised range of 150 – 200 miles.
   Should pull a 6% continuous grade in the 28mph range at 80,000 lbs. GCWR

2. CNG ISX 12 N (400 HP 1450 lb. ft. torque)
   Range of 150 – 200 miles
   Should pull a 6% continuous grade in the 25mph range at 80,000 lbs. GCWR

3. Diesel X15 (450 HP 1650 lb. ft. torque).
   Range of 400+ miles
   Should pull a 6% continuous grade in the 26mph range at 80,000 lbs. GCWR

Chassis Packaging

The BEV specification utilizes twin saddle mounted battery packs.

The CNG is a single saddle mounted 40 Diesel Gallon Equivalent, DGE, tank (33 gallons useable fuel).

The diesel in the comparison has a 50 usable gallon tank plus 14-gallon DEF tank (both smallest available).

Given the differences in HP/toque and gearing, all will have different levels of performance, but the intent is to compare general price, weight, maintenance, and other considerations, while using the 200-mile BEV range as benchmark.

NOTE: Some BEV systems operate at 600 V DC, others at 1000 V DC, so range and battery weight/size/design will be affected as technology evolves.

Battery Electric Cell Life

200/miles a day
5 days/ week
50 weeks a year
250,000 miles over 5 years

Most Lithium-Iron-Phosphate (LFP) or Nickel-Manganese-Cobalt (NMC) batteries are good for around 3,000 full charge cycles.

A full charge cycle is defined as taking the State Of Charge, SOC, from 90% to 10% depletion. Most users won't run the batteries all the way down every day. Regardless, using 3000 cycles, battery life is:

1 charging cycle/day
250 days /year
12 years/life (3000 cycles/250 days)
250,000 mi/year = 3,000,000 battery life miles

Compare to Internal Combustion Engines touting a B10 or B50 life in the range of 1 million to 1.2 million miles.

Internal Combustion Engine Life

Diesel engine manufacturers generate a statistical value for how long their engine is expected to live before a major overhaul is anticipated. This is stated as either B10 or B50 life.

B50 at 1 million miles, represents that 50% of the engines will survive for that mileage term without a major overhaul.

1 to 1.2 million miles is the common operating time frame used to create the predictive life of the engine. This term varies by manufacturer and engine size.

Cummins advertises B50 at 1 million miles for their X15 engine.

Volvo’s D11 and D13 B50 life is advertised at 1.2 million.

Daimler DD15/DD16 both have a B50 rating of 1.2 million miles, while the DD13 has a B50 life of 1 million miles.

Navistar’s A26 is 1.2 million B10, meaning that only 10% of the engines will require a major overhaul within the mileage.

PACCAR's MX engine has a B10 design life of one million miles in linehaul applications.

NOTES: Proper maintenance and driver skill (or automation) are variables in longevity.

Application is also key. Better fuel economy (less fuel through the engine) usually decreases engine wear and increases life expectancy.

Speed can be a factor, especially when coupled with incorrect gearing.

EV Battery Considerations

Batteries are presently an enormous part of the total cost of an electric vehicle. Fleets will eventually be confronted with what to do with worn-out or expired batteries that have diminished capacity to hold a charge

As battery technology evolves the prices could be coming down, so most likely the future replacement batteries will be lighter, more powerful, and less expensive.

This is off-set by potential for low trade-in value on the existing vehicle batteries due to obsolescence at market time.

On the up-side, experts believe there will be a market for those batteries in a secondary application as stationary energy storage. Additionally, due to the module/pack configuration, the cells can be downsized to operate in smaller devices as well.

It’s still too far off to clearly define what uses your present batteries will come to, but fleets will eventually have to make cradle-to-grave decisions about their battery specifications.

There are a variety of battery chemistries currently in service. They are all under the Lithium-Ion umbrella. Each chemistry shines in it's own way and there is no silver bullet.

Some technologies have been around a while and are undergoing continuous improvement, while others are new and cutting edge. Yet another group are hybrids of two or more different chemistries.

You can be certain that you'll be seeing more of these chemical acronyms going forward.

- LI – Lithium Ion
- LFP – Lithium Iron Phosphate
- NMC - Nickle Manganese Cobalt
- NMCA – Nickle Manganese Cobalt Aluminum
- NCA – Nickle Cobalt Aluminum
- LTO – Lithium Titanate Oxide

Power Efficiency Engines v Motors

When operating at 65 MPH pulling 80,000 lbs down the level interstate, indicative of normal linehaul operation, approximately 40% of the fuel burned in an Internal Combustion Engine is converted to power output.

This lack of efficiency is due to Diesel engine losses encountered to sustain the vehicle operation. The influencing factors are: aerodynamics, rolling resistance, and accessory powered options.

These accessories include the coolant pump, cooling fan, alternator, power steering pump, brake air compressor and air conditioning compressor. When climbing a grade on a hot day, these items can pull as much as 80 or 90 HP, reducing the power available from a diesel engine for climbing. All systems generally require the same HP given the same aerodynamics.

Compare that performance to CNG engines which convert 25-30% of the energy in the natural gas into power output. This fuel source is less efficient than diesel, and is taxed with the same accessory power losses.

In contrast, BEVs experience much lower energy losses. The accessory drives are powered by separate motors that do not influence wheel end power.

Given similar aerodynamics, this results in about 85% of the energy out of the charging cable being turned into driving motor power.

Additionally the BEV incorporates regenerative braking, so when the vehicle slows, the drive motors revert into generators that replenish the electrical supply to the battery pack, thus increasing range.

Start/stop in-city driving, as well as hills, provide energy and increase the distance range for BEV systems.

Comparison Chassis Specification

Cab to Axle (CA or in this instance CT Cab to Tandem)

The BEV and CNG chassis have the same steer axle to back of cab dimension thus in this example measures 122”. The Diesel has the X15, resulting in a 6” shorter dimension at 116”.

All three chassis are set back steer axles, same truck model for the best maneuverability and aerodynamics.

Frame Rails

Both the CNG and Diesel have the 10 5/8”.

NOTE: Some OEMs have applied significantly larger frames for the BEV chassis due to placement and weight of battery packs. 11 5/8” inserted rail will add approximately 1,200 lbs for 216” wheelbase.

Transmission and drivetrain

BEV has a 2-speed rear axle (2.67:1 and 1:1) resulting in a 2:1 reduction and no transmission.

The CNG and Diesel are equipped with an Eaton 12-speed automated transmission with single axle ratio. The axle ratios vary, due to the engine size and sweet spot variance.

Steer Axle

All have the 13,200 lb. capacity steer axles to helps slide the trailer closer to the cab for better aerodynamics.

PTO’s

ePTO 650 VDC (180) amps. 58KW (78HP)
CNG and Diesel have the usual PTO provisions on the transmissions.

Drive Axles and Driveline

All axles are 40,000 lb. rated tandem configurations with disc brakes.

BEV has a 3.91 gear ratio
12-liter CNG a 3.55
15-liter Diesel a 2.64

All are designed for the best energy efficiency at 65 MPH.

Both CNG and Diesel have RPL 25 maintenance free drivelines.

Tires

All comparison chassis utilize the same tires and size. Rolling resistance contributes to 13 percent of the energy used by the vehicle.

Co-efficient of Rolling Resistance (CRR) values are assigned to tires by the manufacturers. Lower CRR equates to reduced loss and increased efficiency. Suppliers have developed new compounds with improved rolling resistance, aiding in improvement efforts.

It is worth noting that lower CRR values can equate to decreased tire life, one of many trade-offs in todays environment. Current tire offerings all help with fuel economy over previous products.

Specify 16 ply tires on the steer axle.

Serviceability

Diesel facilities are the standard shop environment that we have all become familiar with. Some additions over the past 10+ years have included the servicing of the aftertreatment components.

Technician training has ramped up since the introduction of common rail fuel systems and highly programable powertrain solutions.

Multiplexing is now common on all chassis and requires a higher degree of skill to diagnose corrosion and increased resistance on all chassis. As the chassis ages, wiring issues increase as well.

CNG facilities must be approved by the state regulatory authority, thus requirements vary by state. If facility approval is not sought, the vehicle must be maintained and fueled outdoors, in open air. CNG fuel systems also require yearly tank inspections.

CNG systems require specialty trained technicians, above and beyond diesel given the higher 3,600 psi gas pressures. There have been discussions about increasing pressures for improved operating range.

There are training organizations that help with this knowledge. Example NGV training at AFV International.

BEV shop bays will require chargers to address battery depletion, which is part of some maintenance procedures. Outside charging systems will also have to be installed, for customer quick charges.

Electrical Technicians also require specialized training. They must use insulated tools, wear PPE (Personal Protection Equipment), rubber gloves, and understand and respect the dangers of high DC Volts and Amperes.

BEVs and autonomous vehicles are even more concerning regarding electronics troubleshooting, given the higher technology. They may have to utilize oscilloscopes, thermal imaging cameras, infrared thermometers, etc., tools that diesel technicians may not be versed in.

Chasing wire ghosts is time consuming along with exchanging parts that are good (if not properly identified by trained Tech's), will add to the expense.

Technicians also require specialized training for high voltage batteries, software, computing systems, and regenerative braking.

Towing a BEV requires the High Voltage system to be shutdown according to OEM instructions. The driveline must be disconnected if a single drive motor is used to power the commonly used open design rear axles.

If the system doesn't have a driveline, then all axle shafts must be removed, and the hubs capped.

Some configurations use a heavy battery cable to transmit the power to the outer end drive motors, and use the air operated discs for emergency brakes. If equipped with a driveline emergency brake, ensure the wheels/tires are chalked when removing the axle shafts.

It should be noted that BEV's are still new enough that accurate average maintenance costs are not fully known.

Technology Required Deviations

Diesel: Since BEV and CNG are California compliant, we've added the extended 5-yr/350,000 mile CARB warranty into our pricing model. This is intended to make the price comparison more realistic.

Exhaust system is a vertical RH side of cab with vertical tailpipe.

CNG: We also added a 220-amp brushless alternator to the CNG chassis to remove a potential spark under the hood, in case of a gas leak.

The methane detector is an option for the CNG but was not added. If the driver has lost his/her sense of smell, it would be imperative to add this option.

Exhaust system horizonal with ground dump tailpipe.

BEV: Chassis has an on board 19.2 KW 240V AC battery charger (24 hours if drained to recharge) which allows the driver charging flexibility if a DC fast charge is not readily available.

The standard 11 KW takes 36 hours to charge. Both utilize the industry standard CCS1 connector. We included a stationary DC 180-amp fast charger in the initial quote for the BEV.

Warranty

CNG and Diesel

1 yr., 100K miles for components not covered under major components, frame, cab, etc.

See Owners Manuals

BEV

1 yr, 100K miles for components not covered under major components, frame, cab, etc.

3 yr., 300K miles ePowetrain, eAxle, eAccessory Systems, Controls and Hardware.

5 yr., 500K miles Battery Packs, Chiller

Registration

Some states are charging a fee for BEV vehicles since the road tax is derived from fuel tax.

Grants

Check with the OEM's, Federal, State, and Local grant awards for BEV and or CNG systems.

Licensing and Drivers

If you take the driving test with an Internal Combustion powered vehicle employing an Automated, Automatic transmission, or with a BEV powered vehicle, you will not be licensed to drive a Heavy-Duty vehicle with a manual transmission.

As of this writing, we are unaware of any special requirements for Electric Vehicles. Check with your local Department of Motor Vehicles (DMV) for BEV rules.

Also, class 6 restriction of 26,000 lbs. GVW remains. Today, there is no Class 6 or 7 added weight allowance for BEV or CNG on the Interstate, only for class 8 semi tractors. So, given the added battery vs. engine weight, payload will be sacrificed for vehicles operating in this realm.

Operator experience and motivation is one of the largest factors in the quest to squeeze the most miles out of the batteries or fuel systems.

Every good driver can understand the principles of operating the truck efficiently, but putting these principles into practice is under their control. Therefore, if you want peak performance you must employ the most conscientious drivers, or find a way to compensate them as an incentive, regardless of energy type.

Operation

A 12" sliding 5th wheel was specified. The placement of the wheel will need to be different for each power unit, with the diesel allowing furthest forward positioning, lessening cab to trailer gap and providing improved fuel economy.

For CNG we used saddle tanks. There are options for tanks in a cabinet back of cab, and if extended operating range is needed, these will be required. They will impact 5th wheel placement, so this is a consideration prior to build.

CNG system and BEV batteries are heavy, requiring the operational 5th wheel location to move rearward to avoid overloading the steer axle.

BEV and CNG chassis, are allowed an additional 2,000 lbs. for the tractor (not the trailer) potentially increasing gross up to 82,000 lbs. on the Interstate highways.

The trailer tandems are maxed at 34,000 lbs. per Federal Bridge. To account for the 2,000 lb. exception our distribution assumes 13,000 lbs. on the steer axle and 35,000 lbs. on the drive axles, and the 5th wheel position should reflect this.

The distribution accounts for the use of the heavier capacity steer axle in the over-the-road application, which is unavoidable here. It is also the reason 16-ply tires are required on the steer axle. The Front GAWR must not be lower than 13,000 lbs. to account for the added weight.

Energy Comparison Reports

COST COMPARISON			
VEHICLE TYPE	**Battery Electric Vehicle**	**Compressed Natural Gas X12N**	**Diesel 15-Liter X15**
BASE LIST PRICE	$696,082	$278,270	$249,003
NET PRICE	$420,000	$200,000	$180,000
UPGRADES/MODIFICATIONS	**180 KW DC Charger**	**40 Gallon CNG System**	
UP/MODS COST	$90,000 [1]	$21,540	
TOTAL COST	**$510,000**	**$221,540**	**$180,000**
[1] Check with the local power company for charges to install pads for stationary charger/s.			

WEIGHT COMPARISON			
VEHICLE TYPE	**Battery Electric Vehicle**	**Compressed Natural Gas X12N**	**Diesel 15-Liter X15**
CHASSIS WEIGHT	22,043 lbs.	14,799 lbs.	15,624 lbs.
ALT FUEL WEIGHT EXEMPTION	**(2000 lbs.)**	**(2000 lbs.)**	
UPGRADES/MODIFICATIONS	**Upgraded Rails**	**40 Gallon CNG System**	**50 Gallon Diesel**
UP/MODS WEIGHT	1,233 lbs. [1]	950 lbs.	461 lbs.
TOTAL WEIGHT	**21,276 lbs.** [1]	**13,749 lbs.**	**16,085 lbs.**
[1] BEV includes additional 1,233 lbs. for added frame strength required by some OEs. 20,043 lbs. w/o upgrade			

BEV, and CNG chassis, are allowed an additional 2,000 lbs. Federal Bridge Alternative Fuel Weight Exemption for the tractor, potentially increasing gross up to 82,000 lbs. on the Interstate highways. It is up to each individual state to allow the additional 2,000 lbs. on state and local roads.

FUELING COMPARISON			
VEHICLE TYPE	**Battery Electric Vehicle**	**Compressed Natural Gas X12N**	**Diesel 15-Liter X15**
FILL RATE	24 Hrs. AC - 19.2kw	5-10 Mins.	5 Mins.
UPGRADED FILL RATE	90-180 Mins. DC 180kw		
FUEL PRICE BASIS	**Dollars/KWH**	**Dollars/Gallon**	**Miles/Gallon**
UNIT PRICE [1]	0.125	2.000	4.500
[1] Energy unit pricing current as of Jan 2023			

ENERGY CONSUMPTION COMPARISON			
VEHICLE TYPE	**Battery Electric Vehicle**	**Compressed Natural Gas X12N**	**Diesel 15-Liter X15**
ENERGY UNIT	**kw/Mile**	**Gal./Mile**	**Gal./Mile**
CONSUMPTION RATE	2.50	5.50	9.00
ANNUAL MILEAGE	250,000	250,000	250,000
ANNUAL ADDITIVE COST [1]			$2,778
ANNUAL ENERGY COST	$78,125	$90,909	$127,778
[1] Diesel requires DEF ($2/Gal.) which is dosed at an average consumption rate of .05 Gal. DEF per diesel gallon			

Maintenance Comparison Reports

MAINTENANCE COMPARISON			
VEHICLE TYPE	Battery Electric Vehicle	Compressed Natural Gas X12N	Diesel 15-Liter X15
DAILY/WEEKLY			
Check	Software	Oil Level	Oil Level
Check	Hydraulic Fluid	Coolant Level	Coolant Level
Check		Transmission Fluid Level	Transmission Fluid Level
Check		Belts and Fan	Belts and Fan
Check		Vent Lines	
Drain		Low Pressure Filter	
Drain		High Pressure Filter	
25,000 - 30,000 Miles			
Check	HV Chiller		Exhaust System
Replace		High Pressure Filter Element	
36,000 Miles			
Replace		Coolant	
50.000 Miles/Annually			
Replace		Coolant Filter	Oil and Filter
Replace			Coolant Filter
Clean	HV Chiller Vent		
Inspect	HV Cables	Cyllinder	Air Leaks
Inspect		Full Leak	
Check	HV Bolt Torque	Fuel Filter	
Check	Gland Bolt Torque		
Check	HVAC Coolant Level		
60,000 - 75,000 Miles			
Replace		Sparkplugs	
Replace		Coil Extensions	
Replace		Oil and Filter	
Replace		Crankcase Breather	
Inspect		Overhead Valves	
100,000 Miles			
Replace	Powertrain Fuild	Coolant Filter	DEF Filter
Replace	HVAC Fluid		
Replace	HV Chiller Fluid		
Check			Aif Filter Gauge
125,000 Miles			
Check	HV Chiller Fluid		Exhaust System
150,000 Miles			
Replace		Sparkplugs	Engine Oil
Clean	HV Filler Vent		
Inspect	HV Cables		
Check	HV Bolt Torque		Air Filter/Gauge
Check	Motor Cab		
200,000 Miles			
Inspect		Overhead Valves	
300,000 Miles			
Replace		Coil Extensions	DEF Filter
Replace		Crankcase Breather Filter	
500,000 Miles			
Inspect			Overhead
Clean			DOC/DPF

Important Terms

AC: Alternating Current
BEV: Battery Electric Vehicle
CA: Cab to Axle
CARB: California Air Resources Board
Class 8: Vehicles with a weight rating in excess of 33,000 lbs.
CCS1: Combined Charging System (Combo 1)
CNG: Compressed Natural Gas
CRR: Co-efficient of Rolling Resistance
CT: Cab to Trunnion
DC: Direct Current
DEF: Diesel Exhaust Fluid
DGE: Diesel Gallon Equivalent
DMV: Department of Motor Vehicles
DOC: Diesel Oxidation Catalyst
DPF: Diesel Particulate Filter
EPA: Environmental Protection Agency
GAWR: Gross Axle Weight Rating
GCWR: Gross Combination Weight Rating
GHG: Green House Gas
GVW: Gross Vehicle Weight
HP: Horse Power
HV: High Voltage
HVAC: Heating Ventilation Air Conditioning
ICE: Internal Combustion Engine
KW: Kilo Watt
KWH: Kilo Watt Hour
LFP: Lithium Iron Phosphate
MPH: Miles Per Hour
NMC: Nickel Manganese Cobalt
NGV: Natural Gas Vehicle
OEM: Original Equipment Manufacturer
PPE: Personal Protection Equipment
PSI: Pounds per Square Inch
PTO: Power Take-Off
SOC: State Of Charge
SS: Solid State
V: Volt