APPLIED COMPRESSION SYSTEMS
"Complete Compressor Packaging Solutions"

TECHNICAL BULLETIN

SELECTING THE RIGHT COMPRESSOR, STORAGE SYSTEM AND COMPONENTS FOR YOUR CNG REFUELING STATION

COMPONENTS

One of the more difficult aspects of purchasing a CNG refueling system is determining what size of compressor is required and how much storage capacity is needed, since both of these factors will have a significant affect on the cost of the system.

In order to determine this, you must have a clear understanding of the components used in the system as well as some industry terminology.

So lets get started!

CNG COMPRESSOR

The gas compressor is the heart of the CNG fueling station.

Today all high-pressure CNG compressors are of the reciprocating type. That is, they compress gas through the action of a piston moving in a reciprocating (or backwards and forwards motion), within a cylinder.

The size of compressor will depend on the quantity of gas required each hour and the overall gas requirement each day. The filling pattern and operating hours of the site are also important factors to bear in mind. Essentially you need to make sure that at any given time a vehicle trying to fill should be able to get a full charge of gas normally 3,000 – 3,600 PSIG (207 to 248 Bar). This is a carefully worked out equation balanced between the size of the compressor and the capacity/number of storage cylinders.

The CNG compressor provides the means of moving gas from a base pressure (the **suction** or inlet pressure) to a higher pressure (the **discharge** pressure). To determine your compression requirements, you must consider the suction pressure and the discharge pressure as well as your desired flow of gas:

1. Suction pressure (PSIG, Bar, Kg/cm2)
2. Discharge pressure (PSIG, Bar, Kg/cm^2)
3. Desired flow gas (SCFM, MSCFD, M^3/Hr etc.)

It is important to understand that as suction (inlet) pressure increases, compressor capacity and the required horsepower also increase. This is particularly important if the compressor will be larger than 40-50 horsepower.

INLET PRESSURE CONTROLLER

If the suction pressure fluctuates, a pressure reducing regulator or control valve will need to be installed at the inlet of the compressor package to stabilize the inlet pressure to the compressor.

This control device will regulate the inlet pressure to ensure that the required power does not exceed the available electric motor power.

COMPRESSOR DRIVER

CNG compressors are most commonly driven by an electric motor, but can also be driven by a natural gas engine.

The motor shaft may be connected to the compressor shaft either directly through a drive coupling, or through the use of a v-belt drive system.

Smaller units will be v-belt driven while larger horizontally opposed compressors will be direct-coupled to the motor.

VENT GAS RECOVERY SYSTEM

While carbon dioxide is typically painted as the bad boy of greenhouse gases, methane is in fact 25-30 times more potent as a heat trapping gas.

As a result most environmental protection agencies have passed legislation which prohibits the venting of methane gas to the atmosphere.

CNG compressors require that gas which is trapped in the compressor cylinders and piping be vented to prevent the compressor from restarting under pressure.

The vent gas recovery system consists of a pressure vessel (recovery tank) and automated control valves.

This system is designed to capture the gas that is vented from the compressor on shut-down and recycle it into the inlet of the compressor when it restarts.

COMPRESSOR CONTROL PANEL

The compressor control panel is designed to allow the compressor to operate unattended and contains the intelligence to automatically start the compressor when the system pressure is too low and to stop it once the correct system pressure is reached.

It also watches for fault conditions and shuts down the compressor if an abnormal condition occurs.

These fault conditions will generally include the following:

- Low suction pressure
- High interstage pressures
- High discharge pressure
- High interstage temperature
- High discharge temperature
- Low oil
- High vibration

STORAGE CYLINDERS, SPHERES AND CASCADE SYSTEMS

Natural gas is stored in high-pressure cylinders or spheres, which can be manifolded together to form a cascade system. The gas is stored at pressure higher than the system pressure of the vehicles using either smaller cylinders or larger ASME code vessels, depending upon the storage capacity required. The cascade is often split into three banks: high, mid and low. The cylinders in each bank are interconnected with tubing looped for expansion and stress relief.

The amount of storage necessary will depend upon the compression capacity and/or the amount of gas to be dispensed in a certain time frame.

AUTOMATIC TEMPERATURE COMPENSATION SYSTEM

Unlike liquid fuel, which consistently holds about the same volume of fuel across a broad range of conditions, gas can expand and contract significantly depending on the gas pressure and the temperature. For example, under industry standard conditions, a tank on a vehicle may be able to hold 20 gasoline gallon equivalents, but on a hot day the gas will expand and the tank may only fill to 75% (or less) of its potential. The goal is to get as full of a fill as possible into the vehicle's tank.

The amount of CNG that can be stored varies based upon the pressure rating of the fuel system, the ambient temperature, and the fueling rate.

- **Pressure ratings:** The typical industry standard for CNG fueling system pressure is 3600 psi. Some systems in the U.S. and many systems overseas are rated at 3000 psi. This means that the fuel systems, including the tank and safety hardware, are capable of handling these pressures safely. When fueling, the dispenser is designed to fill the tank up until it achieves these pressures.
- **Ambient temperature:** The outside temperature affects the temperature of the CNG. At higher temperatures, CNG is less dense, and therefore does not contain as much energy per unit volume as it would at a lower temperature. When the CNG is stored in warm ambient temperatures, it expands and becomes less dense, so when the tank reaches the rated pressure, the CNG inside does not contain as much energy as it would at lower temperatures.
- **Fueling rate:** As the rate of fueling increases, the temperature of the fuel also increases – dramatically. Just like with ambient temperatures, as the fuel warms up it becomes less dense and therefore contains less energy by volume when the fuel system reaches the rated pressure. For this reason, you are usually able to get more CNG into a tank with a time-fill versus a fast-fill application.

Temperature compensation system uses an algorithm to adjust for ambient temperature and temperature of compression into the vehicle fuel storage system to ensure that vehicles receive a full fill.

PRIORITY PANEL

Used with fast fill systems, the primary function of a priority panel is to fill storage cylinders to ensure the fastest possible filling of the vehicles.

The priority panel decides if the incoming gas from the compressor is to be diverted to the cascade storage bottles or to the dispenser.

Once the pressure in the vehicle storage cylinders is at equilibrium with the ground storage cascade cylinders the gas will no longer flow.

If the pressure in the ground storage cylinders is too low to feed the vehicles, then the priority panel will divert the gas flow from the compressor directly to the dispenser.

The primary function of a priority panel is to fill storage banks to ensure the fastest possible filling of vehicles. The following functions are common to all models:

- Direct flow of CNG from a compressor to each of three storage banks
- Prioritize the filling of storage the ensure the third bank is maintained at the highest pressure (the reason for this is that the third bank is used to complete the fill and therefore requires the highest pressure)
- Prioritize the filling to ensure that, if the compressor is running, the flow of gas is directed to the third bank on the dispensers

Bearing in mind that a ground storage cascade system will generally be divided into three banks of cylinders

- When the compressor starts, the valve on bank three opens first
- When the pressure in bank three reaches the pressure setting for the bank two valve, the bank two valve opens
- At this point, both bank three and two are being filled
- When the pressure in banks three and two reach the pressure setting for the bank one valve, the bank one valve opens
- At this point, all three banks are being filled
- When the storage pressure reaches its maximum pressure, the compressor shuts off
- If a dispenser is drawing gas from bank three and the compressor is running, the gas will flow directly to the dispenser instead of storage, thereby assuring that vehicles are filled quickly and to the maximum allowable pressure.

Both mechanical and electronic panels are available.

SLOW FILL, FAST FILL SYSTEMS

Slow or Time Fill System

If vehicle-filling time is not critical and an overnight parking area is available a slow or time fill system can be very cost-effective option. Slow fill systems have no pressurized gas storage cylinders and generally use smaller (and less expensive) compressors than fast-fill systems. The compressor is used to directly fill the vehicle fuel tanks over a long period of time (typically 6 – 10 hours).

Fast Fill System

Fast fill systems provide fast and convenient fueling similar to that provided by conventional liquid fuel stations. CNG storage vessels arranged in cascades, or banks, are used to quickly fill vehicles during peak fueling times, when the compressors alone cannot meet demand. During off-peak times, the compressors refill the CNG storage cascade. These stations are suitable for fueling at public access stations where use patterns are random. They are also suitable for fueling fleets of light-duty vehicles, such as taxis and police cars that require a fast fill and have peak fueling periods. Most of the public access CNG stations worldwide use a cascade fast-fill system.

Combination System

Used when some vehicles return to a central location for fueling, while the balance of the fleet is not centrally garaged, and must be fueled in a short time period. This system combines both of the above features. The appropriate configuration is determined by the fueling characteristic of the fleet and customer requirements.

FILL POSTS

Used on slow fill systems, fill posts are simply the assembly that is used to transfer CNG from the piping system into the vehicle.

These are available in single, dual, and four hose versions and are normally unmetered.

FUEL DISPENSER

The CNG dispenser is a stand-alone unit that meters and dispenses the gas into the vehicle much like a conventional gasoline dispenser.

Dispensers can range from simple units with basic digital display to more sophisticated microprocessor based dispensing systems.

GAS DRYERS

ISO 15403:2000(E) states that “the single most important safety requirement of compressed natural gas (CNG) fuel is a very low water dew point temperature to preclude the formation of liquid water at any time.”

Gas utility companies generally deliver gas with a 7#MMSCF that means 7 pounds of water per million cubic feet of gas. This is sufficiently low to avoid condensation, hydrate formation and freeze-ups at normal pipeline operating pressures, however, Society of Automotive Engineers (SAE) specification SAE J1616 recommends drying CNG further to 10^{o} F (5 – 6^{o} C) at a pressure below the location’s low dry bulb temperature. Dew point is an important consideration because natural gas is generally stored and dispensed under pressure.

To eliminate any potential problems for your station or to your customer’s vehicles, the gas should be dried to a pressure dew point (PDP) that is well below the minimum ambient temperature that will occur at the highest storage pressure.

Several types of dryers are available depending on your requirements.

TERMINOLOGY

BRITISH THERMAL UNIT (BTU)

Is the basis for determining energy content of a fuel. It is helpful to understand exactly what a BTU (British Thermal Unit) is. A British Thermal Unit is the amount of heat (energy) required to raise the temperature of 1 pound of water by 1 degree Fahrenheit.

GASOLINE GALLON EQUIVALENT (GGE)

Compressed Natural Gas (CNG) is sold at the retail level either by mass, energy units or "gasoline gallon equivalents" (GGE).

The concept of gallon equivalents using a gallon of gasoline compared to another fuel is one that allows for a comparison of energy content based on British thermal units (BTUs). This comparison allows fleet operators to compare costs per "gallon" of many different kinds of fuel or to compare vehicle miles per "gallon" using the BTUs in a gallon of gasoline as the base gallon.

For example, if a gallon of gasoline has 114,063 BTUs and a gallon of propane has a 84,332 BTUs then the gasoline gallon equivalent (GGE) of propane is 1.35 gallons. Therefore, it can be determined that if a GGE of propane (1.35 gallons) costs more or less than a gallon of gasoline or if a GGE of propane will yield more or less miles per gallon for a particular vehicle than a gallon of gasoline for the same vehicle. This same concept can be used for many kinds of automotive fuels.

A "gasoline gallon equivalent (GGE)" is defined as 5.660 pounds of natural gas.

The table below summarizes the BTU content of different fuels and the number of units ne3ded to be equivalent to a gallon of regular unleaded gasoline as the base gallon (1 GGE). BTU values were rounded to nearest 100.

GASOLINE GALLON EQUIVALENTS			
Fuel Type	**Unit of Measure**	**BTUs/Unit**	**Gallon Equivalent**
Gasoline (Regular)	Gallon	114,100	1.00 Gallon
Diesel #2	Gallon	129,500	0.88 Gallon
Biodiesel (B100)	Gallon	118,300	0.96 Gallon
Biodiesel (B20)	Gallon	127,250	0.90 Gallon
Compressed Natural Gas (CNG)	Cubic Foot	900	126.67 Cu. Ft.
Liquid Natural Gas (LNG)	Gallon	75,000	1.52 Gallons
Propane (LPG	Gallon	84,300	1.35 Gallons
Ethanol (E100)	Gallon	76,100	1.50 Gallons
Ethanol (E85)	Gallon	81,800	1.39 Gallons
Methanol (M100)	Gallon	56,800	2.01 Gallons

DGE (Diesel Gallon Equivalent)

DGE corresponds to the amount of CNG containing the same energy content as one gallon of diesel. Ultra-low sulfer diesel has slightly less energy than traditional diesel, so 1.35 therms per DGE is commonly cited conversion rate.

GGE (Gasoline Gallon Equivalent)

GGE corresponds to the amount of CNG containing the same energy content as one gallon of gasoline. The typical conversion rate is 1.25 therms per GGE.

Inlet or Suction Pressure

Both inlet and suction pressure refer to the incoming pipeline gas pressure that supplies the CNG station. Inlet pressure is one of the main factors that determine the overall flow rate of a CNG station.

LNG (Liquefied Natural Gas)

LNG is natural gas that has been cooled to -259 degrees F (-191 degrees C) and then condensed into a colorless, odorless, non-corrosive, and non-toxic liquid. LNG is characterized as a cryogenic liquid.

Methane

Methane (CH4), commonly known as natural gas, is an abundant, colorless gas that burns efficiently without many byproducts. As methane is naturally odorless, it has a distinctive odor added as a safety measure.

MMBtu

One Million Btu.

PSI (Pounds per Square Inch)

PSI refers to pressure measured with respect to atmosphere pressure. Pressure gauges are adjusted to read zero at the surrounding atmospheric pressure.

SCF (Standard Cubic Foot)

Contains approximately 1,000 BTU.

SCFM (Standard Cubic Feet per Minute)

SCFM is the standard measurement for the flow rate of gas. A CNG station with a flow rate of 125 SCFM equates to 1 GGE per minute.

Therm

100,000 British thermal units (BTU). A common measure of gas as sold by utilities.

The following chart will provide a basic guideline as to the correct compressor size based on current gasoline or projected CNG usage.

TYPICAL CNG COMPRESSOR REQUIREMENTS

Gasoline Consumption Per Day (Gallon)	Required Natural Gas (GGE) (Note 1) (SCF)	Typical Compressor Capacity SCFM
5	635	1 – 2
10	1,270	3 – 4
15	1,905	4 – 5
20	2,540	5 – 6
25	3,175	6 – 7
50	6,350	12 – 14
75	9,525	20 – 25
100	12,700	25 – 30
125	15,875	30 – 35
150	19,050	35 – 40
175	22,225	45 – 50
200	24,500	50 – 55
300	38,100	75 – 100
400	50,800	100 – 125
500	63,500	125 – 150
600	76,200	155 – 160
700	88,900	180 – 210
800	101,600	210 – 235
900	114,300	235 – 260
1,000	127,000	260 – 280
1,500	190,500	350 – 400
2,000	254,000	500 – 550

NOTE 1: Gallons X 127 = GGE

SELECTING THE RIGHT COMPRESSOR AND CYLINDER SIZES

A good rule of thumb is 127 SCF (standard cubic feet) of natural gas equals 1 gallon of gasoline.

Therefore if you need 10 equivalent gallons of gasoline (GGE), you will need 1270 SCF of natural gas (10 X 127 = 1270).

If you need 40 equivalent gallons (GGE) you will need 5080 standard cubic feet of natural gas. (40 X 127 = 5080).

Balancing the right amount of storage with the correct compressor size that will satisfy the number of vehicles refueling in the time frame is a little more complicated and there are no simple rules of thumb that can be applied.

This is best done by means of our CNG fueling station computerized modeling program which allows us to evaluate a broad range of fueling station and vehicle factors, including: compressor size, cascade storage size and pressure, number of cascade banks, vehicle fuel storage capacity and operating pressure, etc.

We can also quickly and easily examine system-sizing trade-offs and optimize parameters such as compressor size and cascade storage sizing – resulting in potential capital and operating cost savings.

The following list will give an indication of some “typical” sizes of CNG fueling stations. Actual sizing MUST be reviewed on an application-by-application basis.

COMMON FUELING STATION SIZES

Package 1

Current Gasoline Consumption Rate:	25 – 30 gallons per day
Compressor Size:	7 ½ HP
Compressor Model:	Vector V19N307-5
Compressor Capacity:	9.2 SCFM @ 5000 PSIG
Gas Gallon Equivalent:	4.36 GGE
Maximum Discharge Pressure:	5000 PSIG (345 Bar G)
Storage Capacity:	2000 Cubic Feet (56 Cubic Meters)
Cylinder Configuration:	Multiple small cylinders
Application:	Generally suitable for 2 – 5 forklifts, cars or light trucks

Package 2

Current Gasoline Consumption Rate:	50 – 60 gallons per day
Compressor Size:	15 HP
Compressor Model:	Vector V19N515-6
Compressor Capacity:	19.5 SCFM
Gas Gallon Equivalent:	9.24 GGE
Maximum Discharge Pressure:	5000 PSIG (345 Bar G)
Storage Capacity:	3000 Cubic Feet (85 Cubic Meters)
Cylinder Configuration:	Multiple small cylinders
Application:	Generally suitable for 6 – 8 forklifts, company cars or light trucks

Package 3

Current Gasoline Consumption Rate:	75 – 100 gallons per day
Compressor Size:	30 HP
Compressor Model:	Vector V19N530-6
Compressor Capacity:	35 SCFM
Gas Gallon Equivalent:	16.58 GGE
Maximum Discharge Pressure:	5000 PSIG (345 Bar G)
Storage Capacity:	4,600 Cubic Feet (130 Cubic Meters)
Cylinder Configuration:	Multiple small cylinders
Application:	Generally suitable for approximately 10 - 12 forklifts, company cars or light trucks

Package 4

Current Gasoline Consumption Rate:	200 – 250 gallons per day
Compressor Size:	40 HP
Compressor Model:	Vector V19N440-5
Compressor Capacity:	62 SCFM
Gas Gallon Equivalent:	29.37 GGE
Maximum Discharge Pressure:	5000 PSIG (345 Bar G)
Storage Capacity:	8,500 Cubic Feet (240 Cubic Meters)
Cylinder Configuration:	Multiple small cylinders
Application:	Generally suitable for 20 – 30 forklifts, company cars or light trucks

Package 5

Current Gasoline Consumption Rate:	250 – 300 gallons per day
Compressor Size:	50 – 75 HP
Compressor Model:	Knox Western BF Series
Compressor Capacity:	80 – 125 SCFM
Gas Gallon Equivalent:	
Maximum Discharge Pressure:	5000 PSIG (345 Bar G)
Storage Capacity:	36,621 Cubic Feet (1,037 Cubic Meters)
Cylinder Configuration:	Three (3) 5000 PSIG ASME cylinders each 20” OD X 23 feet long
Application:	Generally suitable for 12 – 15 large delivery trucks, small bus fleets or small public fueling station

Package 6

Current Gasoline Consumption Rate:	600 – 700 gallons per day
Compressor Size:	100 – 125 HP
Compressor Model:	Knox Western TP-145 Series
Compressor Capacity:	150 – 200 SCFM
Gas Gallon Equivalent:	
Maximum Discharge Pressure:	5000 PSIG (345 Bar G)
Storage Capacity:	73,242 Cubic Feet (2,074 Cubic Meters) @ 5000 PSIG
Cylinder Configuration:	Six (6) 5000 PSIG ASME cylinders each 20” OD x 23 feet long
Application:	Generally suitable for medium bus fleets or medium sized public fueling station

Package 7

Current Gasoline Consumption Rate:	800 – 900 gallons per day
Compressor Size:	150 – 200 HP
Compressor Model:	Knox Western E-2245
Compressor Capacity:	
Gas Gallon Equivalent:	
Maximum Discharge Pressure:	5000 PSIG (345 Bar G)
Storage Capacity:	109,863 Cubic Feet (3,111 Cubic Meters)
Cylinder Configuration:	_____ 5000 PSIG ASME cylinders each 20” OD x 23 feet long
Application:	Generally suitable for larger bus fleets or large public fueling station

NOTE: The above packages are typical sizings only and will vary with specific customer requirements.