MODULE 11:

Glossary and Conversions

College of the Desert

Revision 0, December 2001


XCELLSiS
The Fuel Cell Engine Company


BALLARD


FTA
Federal Transit
Administration


COLLEGE OF THE DESERT
LUX ET VERITAS
1958


ATT
Advanced Transportation Technology


SunLine
TRANSIT AGENCY


AC
TRANSIT


VTA
SANTA CLARA
Valley Transportation Authority


NAC

MODULE 11: GLOSSARY AND CONVERSIONS

CONTENTS

MODULE 11: GLOSSARY AND CONVERSIONS

OBJECTIVES

This module is for reference only.

11.1 Glossary

This glossary covers words, phrases, and acronyms that are used with fuel cell engines and hydrogen fueled vehicles. Some words may have different meanings when used in other contexts.

There are variations in the use of periods and capitalization for abbreviations, acronyms and standard measures. The terms in this glossary are presented without periods.

ABNORMAL COMBUSTION – Combustion in which knock, pre-ignition, run-on or surface ignition occurs; combustion that does not proceed in the normal way (where the flame front is initiated by the spark and proceeds throughout the combustion chamber smoothly and without detonation).

ABSOLUTE PRESSURE – Pressure shown on the pressure gauge plus atmospheric pressure (psia). At sea level atmospheric pressure is 14.7 psia. Use absolute pressure in compressor calculations and when using the ideal gas law. See also psi and psig.

ABSOLUTE TEMPERATURE – Temperature scale with absolute zero as the zero of the scale. In standard, the absolute temperature is the temperature in °F plus 460, or in metric it is the temperature in °C plus 273. Absolute zero is referred to as Rankine or r, and in metric as Kelvin or K. Use absolute temperature in compressor calculations, and when using the ideal gas law.

ABSORPTION – To draw into the surface of. See also adsorption.

AC – Alternating Current.

AC GENERATOR (or ALTERNATOR) – An electric device that produces an electric current that reverses direction many times per second. Also called a synchronous generator.

ACTUAL CAPACITY – The quantity of gas actually compressed and delivered by a compressor cylinder. This is cylinder displacement (PD) times volumetric efficiency (VE). This is the capacity normally quoted on air compressors only, expressed in ACFM (actual cubic feet per minute).

ADP – Advanced Digital Processor

ADSORPTION – To stick to the surface of. See also absorption.

AIR-FUEL RATIO (A/F) – The proportions, by weight, of air and fuel supplied for combustion.

AIR POLLUTION – Any contamination of the air that is harmful to humans, animals or plants.

ALCOHOLS – A group of colorless organic compounds, each of which contains a hydroxyl (OH) group. The simplest alcohol is methanol CH_30H.

ALGORITHM – A process or procedure used to solve a problem. Generally synonymous with “programs” or “software” in a computer system.

ALTERNATING CURRENT (AC) – A type of current that flows from positive to negative and from negative to positive in the same conductor.

ALTERNATIVE FUEL – An alternative to gasoline or diesel fuel that is not produced in a conventional way from crude oil, for example CNG, LPG, LNG, ethanol, methanol and hydrogen.

AMPERES (Amps or A) – Unit of current flow. One Amp equals one coulomb of charge passing by a point per second.

ANALOG SIGNAL – An electrical signal that varies in voltage within a given parameter.

ANION – A negatively charged ion.

ANODE – The electrode at which oxidation (a loss of electrons) takes place. For fuel cells, the anode is electrically negative; for the opposite reaction of electrolysis, the anode is electrically positive.

ANSI – American National Standards Institute

AROMATICS – Chemical compounds added to natural gas in order to impart odor. Aromatics cannot be added to hydrogen for fuel cell use.

ASME CODE – The American Society of Mechanical Engineers’ Boiler and Pressure Vessel Code.

ASME CONTAINER – Any container/cylinder manufactured to the specifications of the American Society of Mechanical Engineers in effect at the time of fabrication.

ATMOSPHERIC PRESSURE – The absolute pressure above a perfect vacuum at any geographic location or temperature. The atmospheric pressure at sea level is 29.92 "Hg or 14.74 psi at 59 °F. Any change in altitude, temperature or movement of atmospheric air masses alters this figure.

AUTOIGNITION TEMPERATURE – The minimum temperature required to initiate self-sustained combustion in a combustible fuel mixture in the absence of a source of ignition. (Also known as self-ignition temperature.)

AUTOMOTIVE AIR POLLUTION – Evaporated and unburned fuel and other undesirable by-products of combustion that escape from a vehicle into the atmosphere, mainly carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx), sulfur oxides (SOx) and particulates.

BACKFIRE – The accidental explosion of an overly rich mixture in the exhaust manifold of a spark-ignition engine. Backfire conditions can also develop if the premature ignition occurs near the fuel intake valve and the resultant flame travels back into the induction system.

bar – Metric unit of pressure equal to one atmosphere. Bar is more correctly indicated as bara — pounds per square inch *absolute*, or the absolute pressure measured relative to a perfect vacuum. Related to this is barg – pounds per square inch *gauge* as measured relative to atmospheric pressure. 0 barg = 1 bara.

BASIC GAS LAWS – The relationships between pressure, temperature and volume/density of gas. See Boyle's Law, Charles' Law and Ideal Gas Law.

BATTERY – An energy storage device that produces electricity by means of chemical action. It consists of one or more electric cells. each of which has all the chemicals and parts needed to produce an electric current.

BENZENE – The simplest aromatic hydrocarbon, consisting of a single aromatic ring. A common constituent of gasoline and gasoline engine exhaust. It is a known carcinogen and is considered a toxic air contaminant.

BI-FUEL – A system that can operate on two fuels, one at a time and not simultaneously, such as gasoline and CNG.

BOILING POINT – The temperature at which a liquid becomes a gas or vice versa.

BOROSCOPE – Apparatus that enables detailed visual inspection of internal cylinder and tube surfaces, and allows for close up inspection of affected areas.

BOYLE'S LAW (First Gas Law) – If temperature remains constant, the volume occupied by a given weight of gas varies with its absolute pressure. As the volume of a gas is reduced, its pressure increases. Named for British physicist Robert Boyle (1627–1691). Also known as Mariotte's Law.

BRITISH THERMAL UNITS (Btu) – The quantity of heat required to raise the temperature of one pound of water 1 °F. Also Btuh: British thermal units per hour.

Btuh – British Thermal Units per Hour

BURST DISK – A safety device commonly used to relieve accidental high-pressure from a circuit. The burst disk is designed to rupture when subjected to a predetermined pressure level.

BURNING SPEED – The speed at which a flame travels through a combustible gas mixture (different from flame speed).

BUTANE – A type of petroleum gas that is liquid below 32 °F (0 °C) at atmospheric pressure.

BYPASS – A separate passage that permits a liquid, gas, or electric current to take a path other than that normally used.

CAA – Clean Air Act

CALIBRATE – To check or correct the initial setting of a test instrument.

CALIFORNIA AIR RESOURCES BOARD (CARB) – The California Air Resources Board certifies alternative fuel systems for adequate emissions performance. Any alternative fuel system conversions should employ only components approved by CARB, otherwise the EPA can require that the vehicle be returned to its original configuration.

CAPACITOR – An energy storage device that stores electrical energy in the form of an electrical charge. A capacitor consists of two metal plates with an insulating dielectric between them.

CAPACITY – The water volume of a container in standard cu ft (cf or ft^3) per gallon. (NFPA 52)

CARB – California Air Resources Board; see entry.

CARBON (C) – An atom and primary constituent of hydrocarbon fuels. Carbon is routinely left as a black deposit left on engine parts such as pistons, rings, and valves by the combustion of fuel.

CARBON DIOXIDE (CO_2) – A colorless, odorless gas that results from the complete combustion of carbon with oxygen. Carbon dioxide is a greenhouse gas and is a major contributor to the greenhouse effect.

CARBON MONOXIDE (CO) – A pollutant from engine exhaust that is a colorless, odorless, tasteless, poisonous gas that results from incomplete combustion of carbon with oxygen.

CARBURETION – The actions that take place in the carburetor: converting liquid fuel to vapor and mixing it with air to form a combustible mixture.

CARBURETOR – The device in an engine fuel system that mixes fuel with air and supplies the combustible mixture to the intake manifold for varied speed and load conditions of the engine.

CATALYST – A substance that can speed or slow a chemical reaction between substances, without itself being consumed by the reaction. Platinum is a typical catalyst.

CATALYTIC CONVERTER – A device in the exhaust system containing a catalyst so that reactions can occur that convert undesirable compounds in the exhaust gas into harmless gases.

CATHODE – The electrode at which reduction (a gain of electrons) takes place. For fuel cells, the cathode is electrically positive; for the opposite reaction of electrolysis, the cathode is electrically negative.

CATION – A positively charged ion.

cc – Cubic centimeter; see entry.

CELSIUS – Metric temperature scale and unit of temperature (ºC). Named for Swedish astronomer Anders Celsius (1701–1744) although the thermometer first advocated by him in 1743 had 100º as the freezing point of water, and 0º as the boiling point, the reverse of the modern Celsius scale. Also called the Centigrade scale, for the Latin for "hundred degrees."

CENTIMETER (cm) – A metric unit of linear measure. One centimeter equals about 0.4 inch, and one inch equals about 2.5 centimeters. One foot is equal to approximately 30 centimeters.

CENTRAL (FUEL) DELIVERY SYSTEM – This system forms the fuel-air mixture during the intake stroke. The injection is at the inlet of the air intake manifold. A carburetor is a central delivery system.

CETANE NUMBER – An indicator of the ignition quality of diesel fuel. A high-cetane fuel ignites more easily (at lower temperature) than a low-cetane fuel. Cetane numbers for diesel fuels range from 30 to 70 while 40 to 50 is typical.

cf (ft^3) – Cubic foot of gas determined at 14.7 psia and 70 ºF (100 kPa and 21 ºC).

CHARLES' LAW (Second Gas Law) – Named for French scientist Jacques A.C. Charles (1746–1823). Charles' law states that if pressure remains constant, the volume of a gas increases proportionately with any increase in temperature. Also known as the Gay-Lussac law for French chemist Joseph Louis Gay-Lussac (1778-1850) who published his work in 1802, whereas Charles claimed to have reached his conclusions in 1787 but never published them. Charles was the first to use hydrogen in a balloon, and his work on gas temperature led to the discovery of absolute zero.

CHECK – To verify that a component, system or measurement complies with specifications.

CHECK VALVE – A valve that opens to permit the passage of air or fluid in one direction only, or operates to prevent (check) some undesirable action.

CHEMICAL FORMULA – A chemical formula describes the chemical composition of a molecular compound or substance according to its constituent atoms. Hydrogen, methanol and ethanol are pure substances with a definite formula. Natural gas, commercial propane, gasoline and diesel fuel have variable compositions.

CHEMICAL REACTION – The formation of one or more new substances when two or more substances are brought together.

CLEAN AIR ACT (CAA) – Legislation enacted to regulate emissions and air pollution.

cm – Centimeter; see entry.

CNG – Compressed Natural Gas; see entry.

CNG CYLINDER – A cylinder or other container designed for use or used as part of a CNG system

CO – Carbon Monoxide; see entry.

CO_2 – Carbon Dioxide; see entry.

COALESCING FILTER – A filter designed to separate liquid from gas.

COMBUSTION – Burning, fire produced by the proper combination of fuel, heat, and oxygen. In the engine, the rapid burning of the air-fuel mixture that occurs in the combustion chamber.

COMBUSTION CHAMBER – The space between the top of the piston and the cylinder head, in which the air-fuel mixture is burned.

COMPOUND MOTOR – A type of DC electric motor in which two field magnets are connected to the armature, one in series and the other in parallel.

COMPRESSED HYDROGEN GAS (CHG) – Compressed hydrogen gas is hydrogen compressed to a high-pressure and stored at ambient temperature.

COMPRESSED NATURAL GAS (CNG) – Mixtures of hydrocarbon gases and vapors, consisting principally of methane in gaseous form that has been compressed for use as a vehicular fuel. (NFPA 52)

COMPRESSION – Reducing the volume of a gas by squeezing it into a smaller space. Increasing the pressure reduces the volume and increases the density and temperature of the gas.

COMPRESSION IGNITION (CI) ENGINE – An internal combustion engine in which air is admitted to the engine on the intake stroke and the rapid compression of the air raises the temperature to such a point that the fuel ignites. Typified by the diesel engine.

COMPRESSION RATIO (CR) – The volume of the cylinder when the piston is at BDC, divided by the volume of the cylinder when the piston is at TDC.

COMPRESSION RING – The upper ring or rings on a piston, designed to hold the compression in the combustion chamber and prevent blowby.

COMPRESSION STROKE – The piston movement from bottom dead center to top dead center immediately following the intake stroke, during which both the intake and exhaust valves are closed while the air fuel mixture in the cylinder is compressed.

COMPRESSOR – Equipment that pressurizes air, gas, etc. into a compressed state.

COMPUTER – A programmable electronic device that can store, retrieve and process data.

CONDENSATION – A change of state during which a gas turns to liquid, usually because of temperature or pressure changes.

CONDENSER – A device used to liquefy water from a moist gas stream.

CONSTANT VOLUME INJECTION (CVI) SYSTEM – A type of port injection fuel delivery system in which air is injected separately at the beginning of the intake stroke to dilute the hot residual gases and cool any hot spots.

COOLANT – A liquid used to transfer heat to or from engine components. In a fuel cell engine, the coolant consists of either pure de-ionized water, a mixture of de-ionized water with pure ethylene glycol, or standard antifreeze depending on the circuit.

COOLING SYSTEM – A system that removes heat from engine components by the forced circulation of coolant. Fuel cell engines typically have a *bus cooling system* and a *stack cooling system*.

CR – Compression Ratio; see entry.

CRANKCASE – The lower part of the engine in which the crankshaft rotates; includes the lower section of the cylinder block and the oil pan.

CRANKCASE VENTILATION – The circulation of air through the crankcase of a running engine to remove water, blowby and other vapors to prevent oil dilution, contamination, sludge formation and pressure buildup.

CRYOGENIC TEMPERATURES – Temperatures below –100 ºF (200 K; –73 ºC).

CTC – Canadian Transportation Commission.

CUBIC CENTIMETER – A volume of space equal to a cube that is one centimeter on each side. Abbreviated as cc or cm^3, and equivalent to a milliliter (mL) in capacity.

CYLINDER – A high pressure gas container (constructed, inspected, and maintained according to DOT or CTC regulations, ANSI/AGA NGV2, or CSA B51 standards. (NFPA 52)). Alternatively, a cylinder is also the circular tube-like opening in an engine block or casting in which a piston moves up and down.

DC – Direct Current; see entry.

DC GENERATOR – An electrical device that produces an electric current that always flows in the same direction.

DECELERATION – A decrease in velocity or speed with time; allowing the car or engine to coast to idle speed from a higher speed with the acceleration at or near the idle position.

DEFUELING – The terms depressurizing, venting and defueling all mean the release of gas from a vessel. The term defueling is used to mean the capture of released hydrogen for future use; the reverse of fueling.

DE-IONIZED WATER: Water with its ions removed to make it non-conductive. Also known as distilled water.

DE-IONIZING FILTER: A filter that removes ions from a liquid.

DENSITY – Density is measured as the amount of mass contained per unit volume. Density values only have meaning at a specified temperature and pressure since both of these parameters affect the compactness of the molecular arrangement, especially in a gas. The density of a gas is called its vapor density, and the density of a liquid is called its liquid density.

DETONATION – The very rapid burning of vapor resulting in a self-sustaining shock wave, the pressure behind which is several atmospheres. Detonation waves travel at speeds exceeding the speed of sound in air. In an internal combustion engine, detonation is commonly referred to as spark knock or ping. In the combustion chamber, an uncontrolled second flame front (after the spark occurs at the spark plug) with spontaneous combustion of the remaining compressed air-fuel mixture, resulting in a pinging noise. See pre-ignition and octane.

DEUTERIUM – Heavy hydrogen: containing a neutron in addition to a proton and electron.

DIAGNOSIS – A procedure followed in locating the cause of a malfunction.

DIAGNOSTIC CODE – A code obtained from a computerized diagnostic tool.

DIAPHRAGM – A thin dividing sheet or partition that separates an area into compartments; used in fuel pumps, modulator valves, vacuum advance units and other control devices.

DIELECTRIC – A nonconductive, insulating material.

DIESEL FUEL – Diesel fuel is the most common fuel for heavy-duty engines and is therefore a standard of comparison for other fuels.

DIESEL VOLUME EQUIVALENT (DVE) – The number of standard cubic meter of hydrogen equivalent to a liter of diesel (or, alternatively, scf of hydrogen equivalent to a gallon of diesel on an energy-equivalent basis).

DIPSTICK – An engine fluid level indicator.

DIRECT CURRENT (DC) – A current that flow through a circuit in one direction only. Direct current voltage is designated VDC.

DIRECT CYLINDER (FUEL) INJECTION SYSTEM – A sophisticated system that forms the fuel-air mixture inside the combustion cylinder after the air intake valve has closed.

DIFFUSIVITY – The ability of a gas to diffuse in air.

DISTRIBUTOR PILATE – The plate in the ignition distributor to which the coil switching device (points or pickup coil) is mounted and is usually moved by the vacuum advance.

DOT – US Department of Transportation.

DRY GAS – A gas that does not contain water vapor.

DUAL-FUEL – A system that operates on two fuels simultaneously, such as a fumigated diesel engine that runs on diesel and natural gas.

EFFICIENCY – The ratio between an actual result and the theoretically possible result.

EFFICIENCY, THERMAL – The ratio of the useable work that results from a thermodynamic process (such as a chemical reaction) to the total amount of energy released during the process.

EFFICIENCY, SYSTEM (OR OVERALL) – The ratio of the useable work that results from some series of processes to the total amount of energy used during those processes. System efficiency is only meaningful in relation to a defined series of processes; for example, the system efficiency for an engine at the flywheel is different (and necessarily higher than) the system efficiency at the wheels of a vehicle. The system efficiency for one system is often compared inappropriately to the system efficiency for another system that is defined differently.

EJECTOR – A device used to circulate gas: new gas enters the ejector where it mixes with and drives the recirculating flow by way of suction.

ELECTRONIC FUEL INJECTION (EFI) SYSTEM – A type of port injection fuel delivery system that meters the hydrogen fuel to each cylinder, using individual electronic fuel injectors for each cylinder and plumbed to a common fuel rail. The system uses variable injection timing and constant fuel rail pressure.

ELECTRODE – A conductor through which electricity enters or leaves an electrolyte. Batteries and fuel cells have a negative electrode (the anode) and a positive electrode (the cathode).

ELECTRONIC FUEL INJECTION SYSTEM (EFI) – A system that injects fuel into a spark ignition engine, and uses computer controls to meter and time fuel delivery. (see GFI)

ELECTROLYSIS – The decomposition water into its elemental components (hydrogen and oxygen) through the application of electrical energy.

EMISSION CONTROL – Any device or modification added onto or designed into a motor vehicle for the purpose of reducing air polluting emissions.

EMISSION STANDARDS – Allowable automobile emission levels, set by local, state and federal legislation.

ENCLOSURE – A structure whose purpose is to protect equipment from the environment or to provide noise attenuation. (NFPA 52)

ENDOTHERMIC – A chemical reaction that draws heat inward during the process of reaction.

ENERGY – The quantity of work a system or substance is capable of doing, usually measured in British thermal units (Btu) or Joules (J).

ENERGY CONTENT – Amount of energy for a given *weight* of fuel. Every fuel can liberate a fixed amount of energy when it reacts completely with oxygen to form water. This energy content is measured experimentally and is quantified by a fuel's higher heating value (HHV) and lower heating value (LHV). The difference between the HHV and the LHV is the "heat of vaporization" and represents the amount of energy required to vaporize a liquid fuel into a gaseous fuel, as well as the energy used to convert water to steam.

ENERGY DENSITY – Amount of energy for a given *volume* of fuel. Thus, energy density is the product of the energy content and the density of a given fuel.

ENGINE – A machine that converts heat energy into mechanical energy.

ENTHALPY – The thermodynamic measure of heat content. Enthalpy is used as a way to quantify the amount of energy released or absorbed when a system changes from one state to another.

ENTHALPY OF REACTION – The amount of energy released or absorbed during a chemical reaction. When water and oxygen combine to form water, the amount of energy released is equivalent to –230 BTU/$mole_{water}$ (–242 kJ/$mole_{water}$).

ENTROPY – The thermodynamic measure of the relative disorder or randomness of the universe. In any spontaneous process, entropy must always increase. It is this principle that makes perpetual motion machines impossible.

ENVIRONMENTAL PROTECTION AGENCY (EPA) – The independent agency of the United States government that sets standards and coordinates activities related to automotive and stationary emissions and the environment.

EQUIVALENCE RATIO – The actual A/F ratio divided by the stoichiometric A/F ratio. Lean mixtures are described as less than 1.0 and rich mixtures are greater than 1.0.

ETHANOL – An alcohol composed of carbon, hydrogen and oxygen. It is a clear colorless liquid and is the same alcohol found in beer, wine and whiskey. Ethanol is produced by fermenting a sugar solution with yeast.

EVAPORATION – The transforming of a liquid to the gaseous state.

EXHAUST EMISSIONS – Pollutants emitted into the atmosphere through any opening downstream of the exhaust ports of an engine.

EXHAUST GAS RECIRCULATION (EGR) – A thermal dilution and/or NOx control system that recirculates a portion of the exhaust gases back into the intake manifold.

EXHAUST STROKE – The piston stroke (from BDC to TDC) immediately following the power stroke, during which the exhaust valve opens so that the exhaust gases can escape from the cylinder to the exhaust manifold.

EXHAUST SYSTEM – The system through which exhaust gases leave the vehicle. Consists of the exhaust manifold, exhaust pipe, muffler, tail pipe and resonator.

EXOTHERMIC – A chemical reaction that expels heat outward during the process of reaction.

EXPANSION RATIO – The ratio of the volume at which a gas or liquid is stored compared to the volume of the gas or liquid at atmospheric pressure and temperature.

EXPANSION TANK (SURGE TANK) – A tank that provides room for fuel expansion or heated coolant, giving off any air that may be trapped in the system.

EXPLOSIVE LIMITS – The explosive range of a gas is defined in terms of its lower explosive limit (LEL) and its upper explosive limit (UEL). Between the two limits is the explosive range in which the gas and air are in the right proportions to burn when ignited. Below the LEL there is not enough fuel to burn. Above the UEL there is not enough air to support combustion. An explosion is different from a fire in that for an explosion, the combustion must be contained, allowing the pressure and temperature to rise to levels sufficient to violently destroy the containment.

FAHRENHEIT– Temperature scale and unit of temperature (°F). Named for German physicist Gabriel Daniel Fahrenheit (1686–1736) who was the first to use mercury as a thermometric fluid in 1714.

FAN – The bladed device on the front of the engine that rotates to draw cooling air through the radiator and around the engine.

FILTER – A device through which air, gases, or liquids are passed to remove impurities.

FLAME SPEED – The sum of burning speed and displacement velocity of the unburned gas mixture.

FLAME TEMPERATURE – The temperature of a flame burning a stoichiometric mixture of fuel and air (neither fuel nor air is in excess).

FLAMMABILITY LIMITS – The flammability range of a gas is defined in terms of its lower flammability limit (LFL) and its upper flammability limit (UFL). Between the two limits is the flammable range in which the gas and air are in the right proportions to burn when ignited. Below the lower flammability

limit there is not enough fuel to burn. Above the higher flammability limit there is not enough air to support combustion.

FLANGE – A rib or rim added for strength. Also used for guiding or attaching another object (component).

FLASHPOINT – The temperature at which the fuel produces enough vapors to form an ignitable mixture with air at its surface.

FLYWHEEL – An energy storage device in which a balanced mass spinning around a constant axis stores energy as rotational kinetic energy.

FOUR-STROKE CYCLE – The four piston strokes composed of intake, compression, power, and exhaust, that make up the complete cycle of piston movements in the four stroke engine.

FREEZING POINT – The temperature at which crystals of hydrocarbons formed on cooling disappear when the temperature of the fuel is allowed to rise.

FUEL – A substance that releases energy when reacted chemically with oxygen.

FUEL GAUGE – A gauge that indicates the amount of fuel in the fuel tank or cylinder.

FUEL INJECTION SYSTEM – A system (replacing the conventional carburetor) that delivers fuel under pressure into the combustion chamber, precombustion chamber, turbulence chamber, or into the airflow just as it enters each individual cylinder.

FUEL INJECTOR – A device for introducing fuel into a piston engine (replacing the carburetor).

FUEL STORAGE SYSTEM – One or more containers, including their interconnecting equipment designed for use in the mobile containment of fuel.

FUEL SYSTEM – The system (fuel cylinders and lines, gauge, fuel pump, carburetor, and intake manifold) that delivers the combustible mixture of vaporized fuel and air to the engine cylinders.

FUEL TANK – The storage tank for fuel on a vehicle.

FUELING FACILITY – A system of cylinders, pressure vessels, compression equipment, buildings, structures and associated equipment used for storage and dispensing of gaseous engine fuel in vehicle operations. Also known as a refueling facility.

GAS – A state of matter in which the matter has neither a definite shape nor a definite volume. Also an abbreviation for gasoline in North America.

GAS TURBINE ENGINE – A type of internal combustion engine in that the shaft is spun by the pressure of combustion gases flowing against curved turbine blades located around the shaft.

GASKET – A layer of material, usually made of cork or metal or both, that is placed between two machined surfaces to provide a tight seal between them.

GASOHOL – A blend of 90% gasoline and 10% ethanol used as an automotive fuel.

GASOLINE – A liquid blend of hydrocarbons obtained from crude oil, currently used as fuel in most automobile engines.

GAUGE PRESSURE – A pressure read on a scale that ignores atmospheric pressure. Thus, the atmospheric pressure of 14.7 psi absolute is equivalent to 0 psi gauge (PSIG) the pressure above atmospheric pressure — as shown on dial of a pressure gauge in pounds per square inch.

GENERATOR – An electrical device that converts mechanical power into electrical power.

GIBBS FREE ENERGY – The amount of energy available to do useful work resulting from a chemical reaction. When water and oxygen combine to form water, the useful energy is equivalent to –217 $BTU/mole_{water}$ (–229 $kJ/mole_{water}$).

gpm – gallons per minute, or grams per mile.

gps – gallons per second.

GRAMS PER MILE (gpm) – A mixed measure for the weight of pollutants emitted into the atmosphere with the vehicle exhaust gases. Anti-pollution laws set maximum limits for each exhaust pollutant in grams per mile.

GREENHOUSE EFFECT – The tendency for the atmosphere to hold in infrared radiation, or heat, because of increased levels of carbon dioxide (CO_2).

H_2 – Hydrogen; see entry.

H_20 – Water; see entry.

HAZARD – An existing or potential condition that can result in an accident.

HAZARDOUS – A substance or circumstance that may cause injury or damage by reason of being explosive, poisonous, corrosive, oxidizing, or otherwise harmful.

HC – Hydrocarbon; see entry. Also used to represent emissions from an internal combustion engine.

HEAT – A form of energy that is released by the burning of fuel. In an engine, heat energy is converted to mechanical energy.

HEAT OF COMPRESSION – An increase in temperature brought about by the compression of a gas.

HEV – Hybrid Electric Vehicle; see entry.

Hg – Chemical symbol for mercury.

HICE – Hydrogen internal combustion engines

HIGH PRESSURE CYLINDER – Cylinders used for storing high pressure gas with a service pressure of 1000 psig (68 barg) or greater.

HORSEPOWER (hp) – A standard measure of mechanical power, or the rate at which work is done. One hp equals 33,000 ft-lb of work per minute; it is the power necessary to raise 33,000 lb a height of 1 ft in 1 min. One horsepower equals 746 Watt, or 0.746 kW.

HYBRID ELECTRIC VEHICLE (HEV) – A vehicle that is powered by both an electric drive system and a second source of power, such as an internal combustion engine, referred to as the alternative power unit (APU).

HYDROCARBON (HC) – An organic compound containing only carbon and hydrogen, usually derived from fossil fuels such as petroleum, natural gas, and coal: an agent in the formation of photochemical smog.

HYDROGEN (H_2) – The simplest and lightest element in the universe, which exists as a gas except at low cryogenic temperatures. Hydrogen gas is colorless, odorless and highly flammable gas when mixed with oxygen over a wide range of concentrations. Hydrogen forms water when combusted, or when otherwise joined with air, as within a fuel cell. Hydrogen molecules in which both protons have the same spin are known as “orthohydrogen”. and those in which the protons have opposite spins are known as “parahydrogen”.

HYTHANE – A commercial gas product that contains 20% hydrogen and 80% natural gas.

IC Engine (ICE) – Internal Combustion Engine; see entry.

IDEAL GAS LAW (Third Gas Law) – Approximates the behavior of many gases under conditions close to ordinary atmospheric temperatures and pressures.

IDLE (IDLE SPEED) – Engine speed when the accelerator is fully released, and there is no load on the engine.

IGNITION – The action of the spark in starting the burning of the compressed air-fuel mixture in the combustion chamber.

IGNITION ENERGY – The amount of external energy that must be applied in order to ignite a combustible fuel mixture.

IGNITION SYSTEM – In the automobile, the system that furnishes high-voltage sparks to the engine cylinders to fire the compressed air-fuel mix-

ture. Consists of the battery, ignition coil, ignition distributor, ignition switch, wiring, and spark plugs.

INDUCTION MOTOR – A type of AC electric motor in which the rotor has no direct connection to an external source of electricity.

INERTIA – Property of an object that causes it to resist any change in its speed or direction of travel.

INJECTOR – The tube or nozzle through which fuel is introduced into the intake airstream or the combustion chamber.

INSPECT – To examine a component or system for surface condition, or function.

INSULATION – A material that prevents the transfer of electricity or heat.

INTEGRAL – Built into, as part of the whole.

INTERNAL COMBUSTION ENGINE (ICE) – An engine in which the fuel is burned inside the engine itself, rather than in a separate device, such as a boiler on a steam engine.

JOULE (J) – Metric unit of energy, work, heat or torque. Equal to the Newton-meter (Nm). Named for English physicist James Prescot Joule (1818–1889) who pioneered the measurement and understanding of heat.

KELVIN – Metric scale of absolute temperature (K). Named for Scottish physicist (1824–1907) who formulated the second law of thermodynamics in 1850 and introduced the absolute scale of temperature.

KILOGRAM (kg) – Metric unit of weight or mass, equal to approximately 2.2 lb. Related units are the milligram (mg) at 1000 per kg, and the metric tonne at 1000 kg.

KILOMETER (km) – Metric unit of length, equal to 0.62 miles (1.6 km per mile). Related units are the meter at 1000 per kilometer, the decimeter at 10 per meter, the centimeter at 100 per meter, and the millimeter at 1000 per meter.

KILOPASCALS (kPa) – Metric unit of pressure. One psi equals 6.9 kPa. One inch of mercury (HG) equals 3.38 kPa. Related units are the Pascal (Pa) at 1000 per kPa, the bar at 100 kPa and the megapascal at 1000 kPa. See also Pascal.

KILOWATT (kW) – A unit of power equal to about 1.34 hp, or 1000 watts. The Watt is named for James Watt, Scottish engineer (1736-1819), a pioneer in steam engine design.

km/h – Kilometer per hour. Note the use of the slash to indicate “per” instead of the abbreviation “p” as in mph or gps.

KNOCK – A common term that refers to the results of preignition or detonations sound caused by excessive clearance between moving parts in an engine. A knock can be overcome by increasing the octane number of the fuel, retarding ignition timing or by reducing engine load. In diesel engines, knock is caused by excessive pressure within the combustion chamber and abnormal fuel combustion. In diesel engines it is avoided by the use of higher cetane fuels.

kPa – Kilopascal; see entry. Note capitalization.

kW – Kilowatt; see entry. Note capitalization.

LABELED – Equipment or materials to which has been attached a label, symbol or other identifying mark of an organization acceptable to the "authority having jurisdiction" and concerned with product evaluation, that maintains periodic inspection of production of labeled equipment or materials and by whose labeling the manufacturer indicates compliance with appropriate standards or performance in a specified manner. (NFPA 52)

LAMBDA (λ) – Equal to the stoichiometric F/A ratio divided by the actual F/A ratio. Lambda is the inverse of PHI.

LEAK TESTING – Testing by use of a solution, such as a soap solution, to observe a leak under pressure by the formation of bubbles as gas escapes from the leak.

LEAN MIXTURE – An air-fuel mixture that has a relatively low proportion of fuel in relation to air. For example, an air-fuel ratio of 16:1 indicates a lean mixture, compared to an approximately normal air fuel ratio of 14.7:1 for gasoline.

LEV – Low Emission Vehicle; see entry.

LH2 (Liquefied Hydrogen) – Hydrogen cooled to 20.3 K (–423 ºF; –253 ºC) and ambient pressure becomes a liquid.

LIGHT-DUTY VEHICLE – A motor vehicle manufactured primarily for transporting persons or property and having a gross vehicle weight of 6000 lb (2720 kg) or less.

LIQUEFIED NATURAL GAS (LNG) – A motor fuel composed of natural gas that has been liquefied. Liquefied natural gas cooled to 111 K (–259 ºF; –162 ºC) and ambient pressure becomes a liquid.

LIQUEFIED PETROLEUM GAS (LPG) – Any material that is composed predominantly of any of the following hydrocarbons or mixtures of hydrocarbons: propane, propylene. normal butane, isobutylene and butylenes.

LITER (L) – Metric measure of capacity corresponding to a volume of 1000 cm^3 (or 1 dm^3). One liter is approximately equal to 34 fl oz, 0.26 gal (US) or 61 cubic inches. Related units are the milliliter (mL) at 1000 to the liter, and the kiloliter (kL) at 1000 L. Note use of capital L in abbreviations. Engine

displacement is often given in cubic centimeters (cc) for smaller engines, and in liters for larger engines.

LNG – Liquefied Natural Gas; see entry.

LPG – Liquefied Petroleum Gas; see entry.

LOW-PRESSURE CYLINDER – Those cylinders with a marked service pressure below 900 psi (6205 kPa).

LOWER EXPLOSIVE LIMIT (LEL) – The LEL is the lowest gas concentration that will support an explosion when mixed with air, contained and ignited. The LEL is always higher than the LFL.

LOWER FLAMMABLE LIMIT (LFL) – The LFL of a gas is the lowest gas concentration that will support a self-propagating flame when mixed with air and ignited.

MALFUNCTION – Improper or incorrect operation. See Check Engine light.

MANIFOLD – A device with several inlet or outlet passageways through which a gas or a liquid is gathered or distributed.

MANUAL SHUTOFF VALVE – A hand valve used to isolate a component or circuit.

MANUFACTURER – Any person, firm, or corporation engaged in the production or assembly of products, components, or systems.

MASS AIRFLOW SENSOR (MAF) – A sensor that measures the volume of air entering an engine, usually in grams per second (g/sec). Used in on-board computer systems.

MASS FLOW METER – A device for measuring the mass flow of gases.

MECHANICAL EFFICIENCY – In an engine, the ratio between brake horsepower and indicated horsepower.

MECHANICAL PROPERTIES – Properties of a material that pertain to its elastic and plastic behavior when force is applied: yield strength, ultimate strength, elongation, hardness, etc.

MELTING POINT – The temperature at which a solid becomes a liquid or vice versa.

METER (m) – Basic metric unit of length equal to 3.28 feet, 1.09 yards or 39.37 inches. Related units are the decimeter (dm) at 10 per meter, the centimeter (cm) at 100 per meter, the millimeter (mm) at 1000 per meter and the kilometer (km) at 1000 meters.

METHANE (CH_4) – See Natural Gas.

METHANOL (CH_30H) – Methyl alcohol, , is the simplest of the alcohols. It has been used, together with some of the higher alcohols, as a high-octane gasoline component and is a useful automotive fuel in its own right.

MILES PER HOUR (mph) – Standard measure of speed. Equal to 1.6 km/h.

MILLIGRAM (mg) – Metric unit of weight or mass equal to 1/1000 of a kilogram. The weight of 1 mL or 1 cc of water at atmosphere pressure.

MILLIMETER (mm) – Metric unit of length, equal to 0.04 inch, or 25 mm per inch. There are 1000 millimeters in a meter.

mm – Millimeter; see entry.

MODIFICATION – An alteration; a change from the original.

MOLECULAR WEIGHT – Sum of the weights of atoms making up a molecule.

MOLECULE – The smallest particle of a substance that retains all the properties of the substance; it is composed of atoms.

MOTIVE PRESSURE REGULATOR – A pressure regulator that reduces gas pressure from the high pressure conditions within the fuel storage system to an intermediate pressure, typically around 175 psig.

MOTOR – An electric motor. A motor converts electric energy to mechanical energy (motion).

mph – Miles per hour; see entry.

N_2 – Nitrogen; see entry.

NATURAL GAS – Mixtures of hydrocarbon gases and vapors consisting principally of methane in gaseous form. (NFPA 52)

NEWTON (N) – Metric unit of force that, acting on a mass of one kilogram, increases its velocity by one meter per second every second along the direction that it acts. Named for English mathematician Sir Isaac Newton (1642–1727) who had the greatest single influence on theoretical physics until Albert Einstein. He discovered the binomial theorem and differential calculus. In his major treatise *Principia Mathematica* (1687), generally considered the greatest scientific work ever written, he gave a mathematical description of the laws of mechanics and gravitation, and applied these to planetary and lunar motion. He also discovered that white light is made up of a mixture of colors, built the first reflecting telescope and revolutionized the minting of coins to prevent counterfeiting.

NITROGEN (N_2)– A colorless, tasteless, odorless gas that constitutes 78% of the atmosphere by volume and is a part of all living tissues.

NITROGEN OXIDES (NOx) – Any chemical compound of nitrogen and oxygen. Nitrogen oxides result from high temperature and pressure in the combustion chambers of automobile engines and other power plants during the

combustion process. When combined with hydrocarbons in the presence of sunlight, nitrogen oxides form smog. A basic air pollutant; automotive exhaust emission levels of nitrogen oxides are regulated by law.

NOBLE METALS – Metals (such as gold, silver, platinum, and palladium) that do not oxidize readily or enter into other chemical reactions. These metals will promote reactions between other substances. Platinum and palladium are used as the catalysts in catalytic converters.

NON-COMBUSTIBLE MATERIAL – A material that in the form in which it is used and under the conditions anticipated, will not ignite, burn, support combustion, or release flammable vapors when subjected to fire or heat. (NFPA 52)

NOx – See Nitrogen Oxides; see entry.

NOx CONTROL SYSTEM – A device or system used to reduce the amount of nitrogen oxides produced in an engine.

NUCLEUS – The positively charged particle that is the center of an atom.

O_2 – Oxygen; see entry.

OCTANE NUMBER – The number used to indicate the octane rating of a gasoline. The octane number describes the anti-knock properties of a fuel when used in an internal combustion engine. Knock is a secondary detonation that occurs after fuel ignition due to heat buildup in some other part of the combustion chamber. When the local temperature exceeds the autoignition temperature, knock occurs.

OCTANE RATING – A measure of the antiknock properties of a gasoline. The higher the octane rating, the more resistant the gasoline is to abnormal combustion.

ODORIZATION – A process of adding a distinctive odor to natural gas so that its presence can be easily detected.

OHM – A unit of electric resistance equal to the resistance of a circuit in which a potential difference of one volt produces a current of one ampere.

OEM – Original Equipment Manufacturer

OHM'S LAW – This law explains the relationship of voltage, current, and resistance in a circuit. One volt of electrical pressure is needed to push one ampere of electrical current through one ohm of resistance ($V = I \times R$).

OHMMETER – An instrument used to measure the amount of resistance (number of ohms) in an electric conductor or circuit.

OIL – A liquid lubricant; made from crude oil and used to provide lubrication between moving parts. In a diesel engine, oil is used for fuel.

OLEFIN – An unsaturated hydrocarbon containing one or more double bonds.

ORIFICE – A small opening, or hole, that controls the flow rate of a gas or liquid into a cavity.

O-RING – A type of sealing ring, made of a special rubber compound. The O-ring is placed into a groove to provide the sealing action.

OTTO CYCLE – The cycle of events in a four-stroke cycle engine. Named for the German inventor, Dr. Nikolaus Otto.

OVERHEAT – To become excessively hot. To operate above the manufacturer's recommended temperature range.

OXIDATION – Burning or combusting; the combining of material with oxygen. Rusting is slow oxidation, and combustion is rapid oxidation.

OXIDES OF NITROGEN (NOx) – See Nitrogen Oxides.

OXYGEN (O_2) – A colorless, tasteless, odorless, gaseous element that makes up about 21% of air. Oxygen is capable of combining rapidly with ALL elements (except inert gases) in the oxidation process called burning (combustion). Oxygen combines very slowly with many metals in the oxidizing process called rusting.

Pa – Pascal; see entry.

PARALLEL HYBRID – A type of hybrid electric vehicle in which the alternative power unit is capable of producing motive force and is mechanically linked to the drive train.

PARALLEL CIRCUIT – The electric circuit formed when two or more electrical devices have their terminals connected together, positive to positive and negative to negative, so that each may operate independently from the same power source.

PARTIAL PRESSURE – The amount of pressure contributed by an individual gas in a mixture of ideal gases toward the overall, total pressure.

PARTICLE – A very small piece of metal, dirt, or other impurity that may be contained in the air, fuel, or lubricating oil used in an engine.

PARTICULATES (PARTICULATE MATTER – PM) – Small particles (generally less than 30 microns) of carbon and other pollutants occurring as solid matter in the exhaust systems of vehicles. These particles generally remain suspended in the atmosphere, causing a major pollution problem in many U.S. cities. Current EPA regulations address only "respirable" or 'fine" particles that are less than 10 microns in diameter (PM 10).

PASCAL (Pa) – Metric unit of pressure. Related units are the kilopascal (kPa) at 1000 Pa, the bar at 100,000 Pa and the megapascal at 1,000,000 Pa. The Pascal is named for Blaise Pascal, French mathematician and physicist

(1623-1662) who discovered that air has weight, confirmed that a vacuum could exist and derived the principle that the pressure of fluid at rest is transmitted equally in all directions. He also founded the theory of probability, and developed a forerunner of integral calculus.

PASCAL'S LAW – The pressure of a gas is equal in all directions.

PASSIVATED ELEMENT – A substance that does not readily enter into chemical combination.

PETROLEUM – The crude oil from which gasoline, lubricating oil. and other such products are refined.

PHI (Φ) – Equal to the stoichiometric A/F ratio divided by the actual A/F ratio. Phi is the inverse of LAMBDA.

PHYSICAL PROPERTIES – Characteristics that pertain to the nature and composition of a material or object.

PISTON – A movable part, fitted into a cylinder, that can receive or transmit motion as a result of pressure changes in a fluid. In the engine, that cylindrical part which moves up and down within a cylinder as the crankshaft rotates.

PISTON DISPLACEMENT – The cylinder volume displaced by the piston as it moves from the bottom to the top of the cylinder during one complete stroke.

PISTON RINGS – Rings fitted into grooves in the piston to seal a cylinder assembly. There are two types: compression rings for sealing the compression in the combustion chamber, and oil rings to scrape excess oil off the cylinder wall.

POLARITY – The condition in an electric component or circuit that indicates the direction of current flow. The identification of one point as positive (+) and another point as negative (–) for a voltage.

POLLUTANT – Any substance that adds to the contamination or degrading of the environment. In a vehicle, any substance in the exhaust gas from the engine or evaporating from the fuel system.

POLLUTION – Any gas or substance that makes the environment less fit. Types of pollution include: air, ground water, ocean, noise, etc.

PORT (FUEL) DELIVERY SYSTEMS – This system forms the fuel-air mixture during the intake stroke. It is injected at the inlet port.

POWER OUTPUT – For an engine power output is based on the speed the engine is turning, multiplied by the torque produced.

ppb – Parts per billion

ppm – Parts per million

PREMATURE IGNITION or PRE-IGNITION – This occurs when the fuel mixture in the combustion chamber becomes ignited before ignition by the spark plug, and results in an inefficient, rough running engine.

PRESSURE – The exertion of continuous force on or against a body by another in contact with it, expressed as force per unit area.

PRESSURE DIFFERENTIAL (<P)– The difference between the pressure of the air/fuel mixture in the intake manifold and atmospheric pressure.

PRESSURE RELIEF DEVICE (PRD) – A safety device on a pressure vessel, actuated by either overpressure or overtemperature, that relieves the pressure by opening to vent some or all of the contents of the vessel.

PRESSURE TRANSDUCER – A sensor that converts pressure readings to electrical signals.

PRESSURE VESSEL – A container or other component designed in accordance with the ASME Code. (NFPA 52)

PRESSURIZE – To apply more than atmospheric pressure to gas or liquid.

PROCESS VARIABLE – A sensor used to set the setpoint of any PID control loop. In automotive fuel injection systems, the O_2 sensor is always the process variable.

PROPANE (C_3H_8)– A type of liquid petroleum gas (LPG) that is liquid below – 44 ºF (–42 ºC) at atmospheric pressure. Propane gas is heavier than air.

PROTON – A subatomic particle in the nucleus of an atom that carries a positive electric charge, and is not moveable by electrical means.

psi – Pounds per square inch; a unit of pressure. Psi is more correctly indicated as psia — pounds per square inch *absolute*, or the absolute pressure measured relative to a perfect vacuum. Related to this is psig – pounds per square inch *gauge* as measured relative to atmospheric pressure. 0 psig = 14.7 psia.

PULLEY – A metal wheel with a V-shaped groove around the rim that drives, or is driven by, a belt or rope.

PUMP – A device that develops pressure or transfers gas or liquid from one place to another.

PURGE – The use of a gas to flush residual gases and/or liquids from a container.

PYROLYSIS – The chemical decomposition brought about by heat.

QUENCH – During combustion, the removal of heat from the end gas or outside layers of air-fuel mixture by the cooler metallic surfaces of the combustion chamber, thus reducing the tendency for combustion to occur.

QUENCH AREA – The area of the combustion chamber near the cylinder walls that tends to cool (quench) combustion because of the nearby cool water jackets.

RADIATOR – A heat exchanger in the cooling system that removes heat from coolant passing through it, thus returning the coolant to the engine at a lower temperature.

RADIATOR PRESSURE CAP – A type of cap placed on the radiator filler tube that allows for the pressurization of the cooling system for more efficient operation.

RAFFINATE – The gas mixture that results when hydrogen is removed from reformate.

RATIO – Proportion; the relative amounts of two or more substances in a mixture. Usually expressed as a numerical relationship, as in 2:1.

REACTANT – A substance that enters into chemical combination with another substance.

REFORMING – A chemical process that reacts hydrogen-containing fuels in the presence of steam, oxygen, or both into a hydrogen-rich gas stream.

REFORMATE – The hydrogen-rich gas mixture that results from processing hydrogen containing fuels in a reformer.

REGENERATIVE (or DYNAMIC) BRAKING – A energy recovery system in which energy generated by vehicle braking is converting into electricity and stored.

REGULATOR – A device that controls generator output to prevent excessive voltage, excessive current output, or excessive air/gas pressure.

RELAY – An electrical device that opens or closes the high current portion of a circuit or circuits in response to a relatively low voltage signal. An electromagnetically operated switch.

RELIEF VALVE – A valve that opens when a preset pressure is reached. This relieves or prevents excessive pressures.

REMOVE AND REPLACE (R AND R) – To perform a series of servicing procedures on an original part or assembly; includes removal, inspection, lubrication, all necessary adjustments, and reinstallation.

REPLACE – To remove a used part or assembly and install a new or rebuilt part or assembly in its place; includes cleaning, lubricating, and adjusting as required.

RESISTANCE (R) – The characteristic of a device to oppose the passage of electrical current. The opposition to a flow of current through an electric circuit or device; measured in ohms. A voltage of 1 volt will cause 1 ampere to

flow through a resistance of 1 ohm. This is known as Ohm's law and can be written in three ways:

RESISTIVE TEMPERATURE DEVICE (RTD) – A device whose electrical resistance changes in proportion to its temperature.

REVOLUTIONS PER MINUTE (rpm) – A measure of rotational speed.

RICH MIXTURE – An air-fuel mixture that has a relatively high proportion of fuel and a relatively low proportion of air.

ROOM TEMPERATURE – A temperature from 68 to 72 °F (20 to 22 °C).

ROTARY – A circular motion of a moving part.

ROTOR – A revolving part of a machine, such as an alternator rotor, disk brake rotor, distributor rotor or Wankel-engine rotor.

rpm – Revolutions per minute; see entry.

SAE – Society of Automotive Engineers; used to indicate a grade or weight of oil measured according to the SAE.

SCAVENGING – The displacement of exhaust gas from the combustion chamber by fresh air.

scf – Standard cubic feet

scfd - Standard cubic feet per day

SCHEDULED DEFUELING/VENTING – The planned removal of hydrogen from a vehicle fuel storage system in order to make repairs or modifications to the bus equipment.

SEAL – A part or material that is used to close off the area of contact between two machine parts, usually to prevent fuel, gases, coolant or oil leakage.

SERIES CIRCUIT – An electric circuit in which the same current flows through all devices; positive terminals are connected to negative terminals.

SERIES HYBRID – A type of hybrid electric vehicle is which runs on battery power like a pure EV until the batteries discharge to a set level, then the alternative power unit turns on to recharge the battery.

SERIES MOTOR – A type of DC electric motor in which the armature and the field magnet are connected electrically in series.

SERVICE PRESSURE – The settled pressure at a uniform gas temperature of 70 °F (21 °C) and full gas content. It is the pressure for which the equipment has been constructed, under normal conditions. (NFPA 52)

SHORT CIRCUIT – A defect in an electric circuit that permits current to take a different path, instead of following the desired one.

SHUNT – A parallel connection or circuit.

SHUNT MOTOR – A type of DC electric motor that connects the magnet and armature in parallel.

SI SYSTEM – The metric system of measurement.

slpm – Standard liters per minute. Used to quantify the flow of gas adjusted to standard temperature and pressure.

SOLENOID – An electromechanical device (a coil of wire wound around a movable core) that, when connected to an electrical source such as a battery, produces a mechanical movement. This movement can be used to control a valve or to produce other movements.

SOLENOID SWITCH – A switch that is opened and closed electromagnetically by the movement of a solenoid core. The core also causes a mechanical action, such as the movement of a drive pinion into mesh with flywheel teeth for cranking. Also solenoid valve.

SOURCE(S) OF IGNITION – Devices or equipment that, because of their modes of use or operation, are capable of providing sufficient thermal energy to ignite flammable compressed natural gas-air mixtures when introduced into such a mixture or when such a mixture comes into contact with them and that will permit propagation of flame away from them. (NFPA 52)

SOx – Sulfur oxides; see entry.

SPARK PLUG – A device that screws into the cylinder head of an engine, provides a spark to ignite the compressed air-fuel mixture in the combustion chamber.

SPECIFIC GRAVITY – Ratio of the weight of the gas to the weight of air or the ratio of the weight of a liquid to an equal volume of pure water.

SPECIFIC HEAT – Ratio of the amount of heat required to raise the gas temperature one degree compared to the amount of heat required to raise an equal amount of water one degree.

SPECIFICATIONS – Information provided by the manufacturer, describing systems and their components, operations, and clearances. Also, the service procedures that must be followed for a system or component to operate properly.

SPEED – The rate of motion. For vehicles, speed is measured in miles per hour or kilometers per hour.

STANDARD CONDITIONS – Temperature and pressure conditions that correspond to 0 °C (32 °F) and 14.7 psig (1 barg) respectively. Sometimes, standard temperature is taken as room temperature.

STANDARD CUBIC FEET (SCF) – Cubic feet of gas determined at standard conditions.

STATOR – In the torque converter, a third member (in addition to turbine and pump) that changes the direction of a fluid under certain operating conditions (when stator is stationary).

STIRLING ENGINE – A type of internal combustion engine in which the piston is moved by changes in the pressure of a working gas that is alternately heated and cooled. It has two isothermal processes and two constant-volume processes.

STOICHIOMETRIC (STOICH) – A chemically perfect reaction of fuel and air in an engine (the only products of combustion are water and carbon dioxide).

STOICHIOMETRIC AIR-FUEL RATIO – The exact air-fuel ratio required to completely react a fuel into water and carbon dioxide.

STP – Standard temperature and pressure.

STROKE – In an engine cylinder, the distance that the piston moves in traveling from BDC to TDC or from TDC to BDC.

SULFUR OXIDES (SOx) – Acids that can form in small amounts as the result of a reaction between hot exhaust gas and the catalyst in a catalytic converter.

SWITCH – A device that opens and closes an electric circuit.

SYNCHRONOUS MOTOR – A type of AC electric motor in which the stator also produces a rotating magnetic field.

THERMAL – Of or pertaining to heat.

THERMAL EFFICIENCY – Ratio of the energy output of an engine to the energy in the fuel required to produce that output.

THERMOSTAT – A device for the automatic regulation of temperature: usually containing a temperature sensitive element that expands or contracts to open or close off the flow of a gas, liquid or electricity.

THREE-WAY CATALYTIC CONVERTER (TWC) – A catalytic converter that uses platinum, rhodium, and palladium to reduce vehicle emissions. Three-way catalysts require mixtures extremely close to stoichiometric for effective conversion of NOx.

TORQUE – The ability of a force to move a load or to do work. Turning or twisting motion; measured in standard in pound-feet (ft-lb), or in metric in the Newton-meter (Nm).

TORQUE WRENCH – A wrench that indicates the amount of twisting effort (rotary motion) being applied with the wrench.

TORRICELLI (torr) – Unit of pressure equal to 1 mm of mercury (1 mm Hg) or 1 atm = 760 torr. Named for the Italian physicist Evangelista Torricelli (1608–1647), who first measured the pressure of the atmosphere using a tube of mercury upended within a dish of mercury, coincidentally producing the first vacuum within the tube.

TRANSDUCER – Any device that converts an input signal of one form into an output signal of a different form.

TROUBLE DIAGNOSIS (TROUBLESHOOTING) – The detective work necessary to find the cause of a problem.

TURBOCHARGER – A supercharger driven by the engine exhaust gas pressure for pressurizing the intake air or air-fuel charge of an engine, so as to increase the mixture delivered to the cylinders thus increasing power output.

UPPER EXPLOSIVE LIMIT (UEL) – The UEL is the highest gas concentration that will support an explosion when mixed with air, contained and ignited. The UEL is always lower than the UFL.

UPPER FLAMMABLE LIMIT (UFL) – The UFL of a gas is the highest gas concentration that will support a self-propagating flame when mixed with air and ignited. Above the UFL, there is not enough oxygen present to support combustion; the fuel/air mixture is too rich.

VAC – Volts Alternating Current. See Alternating Current.

VACUUM – Negative gauge pressure, or a pressure less than atmospheric pressure. Vacuum can be measured in psi, but is usually measured in inches or millimeters of mercury (Hg); a reading of 30 in. Hg [762 mm Hg] would indicate a perfect vacuum.

VACUUM GAUGE – A device that measures pressures below atmospheric.

VALVE – A device that can be opened or closed to allow or to stop the flow of a liquid or gas.

VAN DER WAALS – Named after Dutch physicist Johannes Diderick van der Waals (1837–1923) who first worked out the adjustments to the ideal gas law in 1873. Van der Waals equation is $(P+a/V^2)(V-b) = \underline{R}T$. The feeble attractive forces between gas molecules that necessitate the probability adjustment (a/V^2) are called "van der Waals forces."

VANE – A flat, extended surface that is moved around an axis by or in a fluid: part of the internal revolving portion of a turbocharger.

VAPOR – A gas: any substance in the gaseous state, as distinguished from the liquid or solid state.

VAPORIZATION – A change of state from liquid to vapor by evaporation or boiling; a general term including both evaporation and boiling.

VDC – Volts Direct Current. See Direct Current.

VENT – An opening through which a gas can leave an enclosed chamber.

VENTILATION – The circulating of fresh air through any space to replace impure air.

VENTING – The discharge of hydrogen from a fuel storage system to the atmosphere.

VISCOSITY – A measure of the resistance to flow of a liquid. The lower the viscosity, the thinner the fluid is and the more easily it will flow. This is affected by temperature. At low temperatures, viscosity is high, while at high temperatures viscosity is low.

VISCOUS – Thick; tending to resist flowing.

VOC – Volatile Organic Compounds; see entry.

VOLTAGE (V) – The force that causes electrons to flow in a conductor. One Volt equals one Joule of work per Coulomb of electrons. The difference in electrical pressure (or potential) between two points in a circuit.

VOLTMETER – An electric meter for measuring the voltage or electrical pressure of an electric device, such as a battery or alternator, or for measuring the voltage between two points in an electric circuit.

VOLUME (V) – An area defined by measurement of length, width, and height, and expressed in cubic units such as the cubic feet, cubic centimeter, etc. Volume is constant, being a measurement of space rather than a condition of air or gas.

WANKEL (ROTARY) ENGINE – A rotary engine in which a three-lobe rotor turns eccentrically in an oval chamber to produce power.

WASTE SPARK SYSTEM – An ignition systems that energizes the spark each time the piston is at top dead center whether or not the piston is on the compression stroke or on its exhaust stroke. For hydrogen engines, the waste sparks are a source of pre-ignition.

WATER (H_2O) – A colorless, transparent, odorless, tasteless liquid compound of hydrogen and oxygen. The liquid form of steam and ice. Fresh water at atmospheric pressure is used as a standard for describing the relative density of liquids, the standard for liquid capacity, and the standard for fluid flow. The melting and boiling points of water are the basis for the Celsius temperature system. Water is the only byproduct of the combining of hydrogen and oxygen, and is produced during the burning of any hydrocarbon. Water is the only substance that expands on freezing as well as by heating, and has a maximum density at 4 °C.

WATER INJECTION – A technique for thermally diluting a fuel mixture by injecting water into the hydrogen fuel stream.

WEIGHT AND DENSITY OF AIR – Weight and density of a given volume of air vary proportionally with pressure. An air receiver tank filled with air at atmospheric pressure floats on water, whereas the same tank of air pressurized to 1000 psig contains a denser mass of air, and the increased weight causes it to sink.

WORKING PRESSURE – The pressure at which the equipment was designed to function, or if conditions have changed, the maximum pressure allowed at specified temperatures.

ZEV – Zero Emissions Vehicle

Z-FACTOR – Compressibility factor of a gas; a multiplier that accounts for its deviation from the ideal gas law.

11.2 Measurement Systems

Metric or SI System

The meter is the central unit of the metric system. Other measures, such as for area, volume, capacity, mass, energy, force, power, voltage and others are directly linked to the meter, greatly simplifying calculations. Orders of magnitude are in multiples of ten. The meter was first defined as 1.0×10^{-7} of the distance between the North Pole to the Equator as measured on a line through Paris. It is now defined as the length of the path traveled by light in a vacuum during 1/299,792,458th of a second.

The metric system was first introduced in France in 1793, but was not accepted until after 1837. Since then, the metric or "SI" system has become the official measurement system throughout most of the world.

Prefix	Symbol	Factor	Scientific Notation
exa	E	1,000,000,000,000,000,000	10^{18}
peta	P	1,000,000,000,000,000	10^{15}
tera	T	1,000,000,000,000	10^{12}
giga	G	1,000,000,000	10^{9}
mega	M	1,000,000	10^{6}
kilo	k	1,000	10^{3}
hecto	h	100	10^{2}
deca	da	10	10^{1}
		1	10^{0}
deci	d	0.1	10^{-1}
centi	c	0.01	10^{-2}
milli	m	0.001	10^{-3}
micro	③	0.000 001	10^{-6}
nano	n	0.000 000 001	10^{-9}
pico	p	0.000 000 000 001	10^{-12}
femto	f	0.000 000 000 000 001	10^{-15}
atto	a	0.000 000 000 000 000 001	10^{-18}
bold = commonly used			

Table 11-1 Metric Prefixes and Their Meaning

Standard, English or Imperial System

The standard/English/Imperial system does not have a central unit. The system grew out of various units that had been established ad hoc over centuries in many countries. Common units, such as the yard, foot and inch, were defined as the king's reach, the length of his foot and the width of his thumb, and therefore subject to continual change. The mile started as the distance an army could travel in an hour. Dimensions were eventually stan-

dardized by the English and the Imperial system spread throughout the British Empire.

In the US, the Imperial system was adapted in minor ways (as in liquid measure) and is known as the standard, English or US system. While mixed units and fractions are commonly used, it is the decimal measures (or "engineering units"), such as the decimal foot, that are used by scientists, engineers, etc. The foot is now officially defined as a portion of a meter.

Prefix	Symbol	Factor	Scientific Notation
millions	MM	1,000,000	10^6
thousands	M	1,000	10^3

Table 11-2 Standard Prefixes and Their Meaning

Engineering Units

Use engineering units without mixing units of different magnitude. For example, use 1.5' instead of 1'-6". The former can be multiplied with other numbers, while the latter cannot.

Use engineering units as decimals, not as fractions. For example, use 1.5 ft instead of 1½ ft. Fractions cannot be multiplied or otherwise manipulated mathematically in a practical way.

Prefixes to units should not be combined. For example, use billion instead of thousand-million, and giga instead of kilo-mega.

Periods, Commas and Plurals

In English-speaking countries, Asia and in many other countries, commas are used to separate thousands, while a period is used to indicate the decimal point. In France, Germany and many other European countries, the practice is the reverse; indicating the decimal point with a comma, and thousands by periods.

A zero should precede numbers that are less than zero, in order to draw attention to the decimal point. For example, write 0.24 rather than .24.

Periods should never be used with metric abbreviations. Standard units are often written with a period, but need not be.

Abbreviations for units should not be pluralized. For example, write 2 lb instead of 2 lbs.

11.3 Conversion Table

Unit	Accurately Multiply By	Roughly Multiply By	To Get
Length (Distance)			
ft or ' (feet)	12		in
yd (yards)	3		ft
mi (miles)	5280	5000	ft
in or " (inches)	1000		mill or thou (thousandths of an inch)
in	25.400	25	mm (millimeters)
in	2.540	2.5	cm (centimeters)
ft	0.304 80	0.3	m (meters)
m (meters)	3.280 84	3.3	ft
mi	1.609 344	1.6	km
km (kilometer)	1000		m
m	10		dm (decimeter)
m	100		cm
m	1000		mm
mm	1000		③m (micron)
light-years	9.46×10^{12}		km
light-years	5.88×10^{12}		mi
Speed (Velocity)			
mph (miles per hour)	1.609 344	1.6	km/h (kilometers per hour)
fps (feet per second)	0.304 80	0.3	m/s (meters per second)
fpm (feet per min)	0.304 80	0.3	m/min (meters per minute)
knots	1.151	1.2	mph
mach (speed of sound)	741.455	750	mph
c (speed of light)	186,281.7	1.86×10^{5}	mi/s (miles per second)
c	299,792,800	3×10^{8}	m/s (meters per second)

Unit	Accurately Multiply By	Roughly Multiply By	To Get
Acceleration			
mph/s (miles per hour per second)	0.026 823	0.027	km/h-s (kilometers per hour per sec)
ft/s^2 (feet per second per second)	0.304 80	0.3	m/s^2 (meters per second per second)
ft/s^2	1.097 28	1.1	km/h-s
gravity	32.174 05	32	ft/s^2
gravity	9.806 65	10	m/s^2
Area			
ft^2 *or* sq ft (square feet)	144	150	in^2 *or* sq in (square inch)
yd^2 *or* sq yd (square yards)	9	10	ft^2
in^2	6.45	6	cm^2 (square millimeters)
ft^2	0.093	0.1	m^2 (square meters)
mi^2 *or* sq mi (square miles)	2.590	2.6	km^2 (square kilometers)
acre	43,560	44,000	ft^2
acre	0.404 96	0.4	hectare
hectare	10,000		m^2
Volume, Capacity			
ft^3 *or* cu ft (cubic feet)	1728	1700	in^3 *or* cu in (cubic inches)
ft^3	7.480519	7.5	gal
gal	0.133 681	0.13	ft^3
yd^3 *or* cu yd (cubic yards)	27	30	ft^3
fl oz (fluid ounce)	2		Tb (tablespoon)
fl oz	1.804 688	2	in^3
in^3	0.554	0.5	fl oz
cup	8		fl oz
pt (pint)	2		cup
qt (quart)	2		pt
gal (gallon)	4		qt

Unit	Accurately Multiply By	Roughly Multiply By	To Get
gal	128	130	fl oz
US liquid barrel	31.5	30	gal
US liquid barrel	0.119 24	0.12	m^3
Imperial fl oz	0.960 76	1	fl oz
Imperial pt	2.5		cup
Imperial gal	153.721 7	150	fl oz
Imperial gal	160		Imperial fl oz
in^3	16.387 064	16	cm^3 (cubic centimeter) or mL (milliliter)
ft^3	28,316.85	30,000	cm^3 or mL
ft^3	28.316 85	30	L (liter) or dm^3 (cubic deci-meters)
ft^3	0.028 317	0.03	m^3 (cubic meter) or kL (kiloliter)
fl oz	29.573 53	30	cm^3 or mL
Imperial fl oz	28.413 07	30	cm^3 or mL
gal	3.785 412	4	L or dm^3
Imperial gal	4.546 092	4.5	L or dm^3
cm^3 or mL	0.061 024	0.06	in^3
cm^3 or mL	0.033 813	0.03	fl oz
m^3 or kL	35.314 475	35	ft^3
cm^3 or mL	1000		mm^3
L or dm^3	1000		cm^3 or mL
m^3 or kL	1000		L or dm^3
Mass			
lb (pound)	16		oz (ounce)
ton — short	2000		lb
ton — long	2240	2200	lb
ton — long	1.12	1.1	ton — short
oz	28.350	30	g (gram)
lb	453.592	500	g
lb	0.453 59	0.5	kg (kilogram)
ton — short	0.907 18	0.9	tonne
g	0.035 273	0.035	oz

kg	35.273 368	35	oz
Unit	**Accurately Multiply By**	**Roughly Multiply By**	**To Get**
kg	2.204 586	2.2	lb
tonne (metric)	2205	2200	lb
tonne	1.102 293	1.1	ton — short
tonne	1.016 064	1	ton — long
g	1000		mg
kg	1000		g
tonne	1000		kg
Mt (megatonne)	1,000,000		tonne
Mass Flow			
cfm (ft^3/min) (cubic feet per minute)	60		cfs (ft^3/s) (cubic feet per second)
cfh (ft^3/h)(cubic feet per hour)	24		cfm (ft^3/min)
gps (gallons per second)	60		gpm
gpm (gallons per minute)	8.020 833	8	cfh (ft^3/h)
cfs	28.317	30	slps (standard liters per sec.)
cfs	0.028 317	0.03	m^3/s (cubic meters per second)
cfm	28.316 85	30	slpm (standard liters per minute)
cfm	0.028 317	0.03	m^3/min (cubic meters per minute)
cfh	0.472	0.5	slpm
gpm	3.785 412	3.8	slpm
slpm	0.035 315	0.035	cfm
m^3/min	1000		slpm
slpm	60		slps
Force			
lb_F or lb (pound force)	4.448 222	4.5	N (Newtons) or J/m (Joules per meter)

N	0.224 809	0.22	lb_F
Unit	**Accurately Multiply By**	**Roughly Multiply By**	**To Get**
Pressure			
psi (pound-force per square inch)	16	15	oz per sq in (oz/in^2)
psf (pounds per square ft)	144	150	psi
psi	0.068 046	0.07	atm
psi	2.04	2	in Hg
psi	27.72	28	in of water
atm	14.696	15	psi
in Hg (inches of mercury)	0.491	0.5	psi
in Hg (or "Hg)	13.6	14	in of water
psi	6.894 757	7	kPa
psi	0.068 948	0.07	bar
psi	0.006 895	0.007	MPa
psi	51.715	50	Torr
in Hg	25.4	25	Torr
in Hg	3.386 39	3.4	kPa
in wg (inches of water)	248.84	250	kPa
atm	101.325	100	kPa
atm	1.013 25	1	bar
kPa (kilopascals)	0.145 038	0.15	psi
bar	14.503 77	15	psi
bar	0.986 923	1	atm
bar	0.1		MPa
bar	100		kPa
bar	1000		mbar (millibars)
kPa	1000		Pa
MPa (megapascals)	1000		kPa
GPa (gigapascals)	1000		MPa
Torr (millimeters of	0.133 322	0.13	kPa

mercury)			
Unit	**Accurately Multiply By**	**Roughly Multiply By**	**To Get**
Energy, Heat, Work, Torque			
ft-lb or ft-lb_F (foot-pounds)	16		in-lb (inch-pounds)
ft-lb	1.355 818	1.4	J (Joules) or Nm (Newton-meters)
Btu (British thermal units)	777.477	800	ft-lb
Btu or W-h (Watts per hour)	10,000		therm
Btu	1055.056	1000	J
Btu	1.055 056	1	kJ (kilojoules)
J	0.947 364	1	Btu
kW-h (kilowatt-hours)	3.6		MJ (megajoules)
kW-h	3600		kJ
Temperature			
ºF (degrees Fahrenheit)	–32; x 5/9	–30; x 0.5	ºC (degrees Celsius)
ºC	x 9/5 + 32	x 2 + 30	ºF
<ºF	x 5/9	x 0.5	<ºC
<ºC	x 1.8	x 2	<ºF
K	x 1.8		ºR
ºF	+459.67	+ 460	ºR (degrees Rankine)
ºC	+ 273.15	+ 273	K (degrees Kelvin)
Power, Heat Flow Rate			
Btuh (British thermal units per hour)	0.293 07	0.3	W (Watts) or J/s (Joules per second)
hp (horsepower)	0.000 393	0.0004	Btuh
hp – electric	0.746	0.7	kW (kilowatts)
Btuh	0.000 293	0.0003	kW
MBh (thou-sands of Btuh)	0.293	0.3	kW

Unit	Accurately Multiply By	Roughly Multiply By	To Get
Density			
oz/in^3 (ounces per cubic inch)	1730	1700	kg/m^3 (kilograms per cubic meter)
lb/ft^3 (pounds per cubic foot)	16.018	16	kg/m^3
kg/m^3	0.062 43	0.06	lb/ft^3
Specific Volume			
ft^3/lb (cubic feet per pound)	0.062 43	0.06	m^3/kg (cubic meters per kg)
m^3/kg	16.018	16	ft^3/lb
Energy Density or Heat Density			
Btu/ft^2 (British thermal units per sq. foot)	11.357	11	kJ/m^2 (kilojoules per square meter)
Btu/ft^3 (British thermal units per cubic foot)	37.297	37	kJ/m^3 (kilojoules per cubic meter)
Btu/gal (Btus per gallon)	1000.279	1000	kJ/L (kilo-joules per liter)
Power Density			
kW/ft^2 (kilowatts per square feet)	10.764	10	kW/m^2 (kilowatts per square meter)
$Btuh/ft^2$	3.1546	3	kW/m^2
Specific Heat			
Btu/lb (British thermal units per pound)	2.326	2.3	kJ/kg (kilojoules per kilogram) or J/g (Joules per gram)
Thermal Capacity			
Btu/lb-ºF (Btu per pound-ºF)	4.1868	4	kJ/kg-ºC (kilojoules per kilogram-ºC)

Unit	Accurately Multiply By	Roughly Multiply By	To Get
Fuel Consumption			
mpg (miles per gallon)	4.251 436	4	km/L (kilometers per liter)
mpg (miles per gallon)	0.235 21	0.25	L/100km (liters per 100 km)
gal/hp-hr (gallons per horsepower-hour)	0.079 317	0.08	L/kW-hr (liters per kilowatt-hour)
Humidity Ratio			
grain of moist-ure per pound of dry air	1/7000 or $1.428\ 57 \times 10^{-4}$		kg of moisture per kg of dry air
Pressure Drop (Water at 68 ºF; 20 ºC)			
ft/100ft (feet per 100 feet)	98	100	Pa/m (Pascals per meter)
ft/100ft	0.098	0.1	kPa/m (kilopascals per meter)
psi/100ft (psi per 100 feet)	226	230	Pa/m
kPa/m	10.2	10	ft/100ft