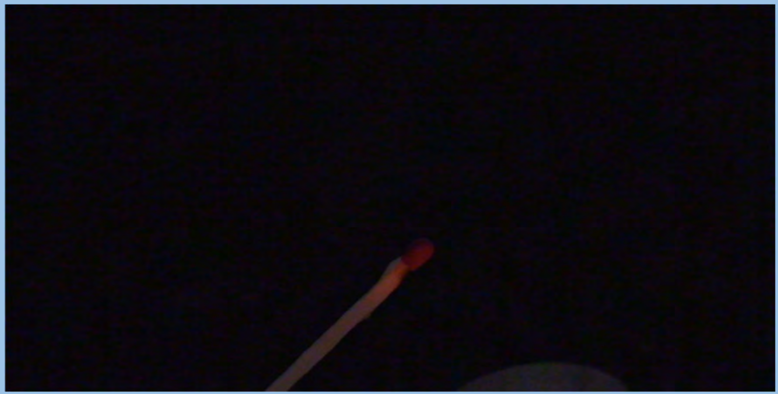
Understanding Internal Combustion

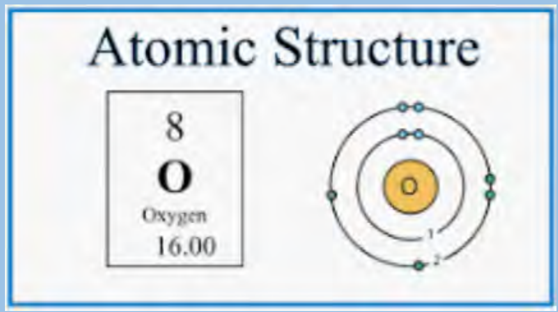
Instructor:Bernie C Thompson
Automotive Test Solutions

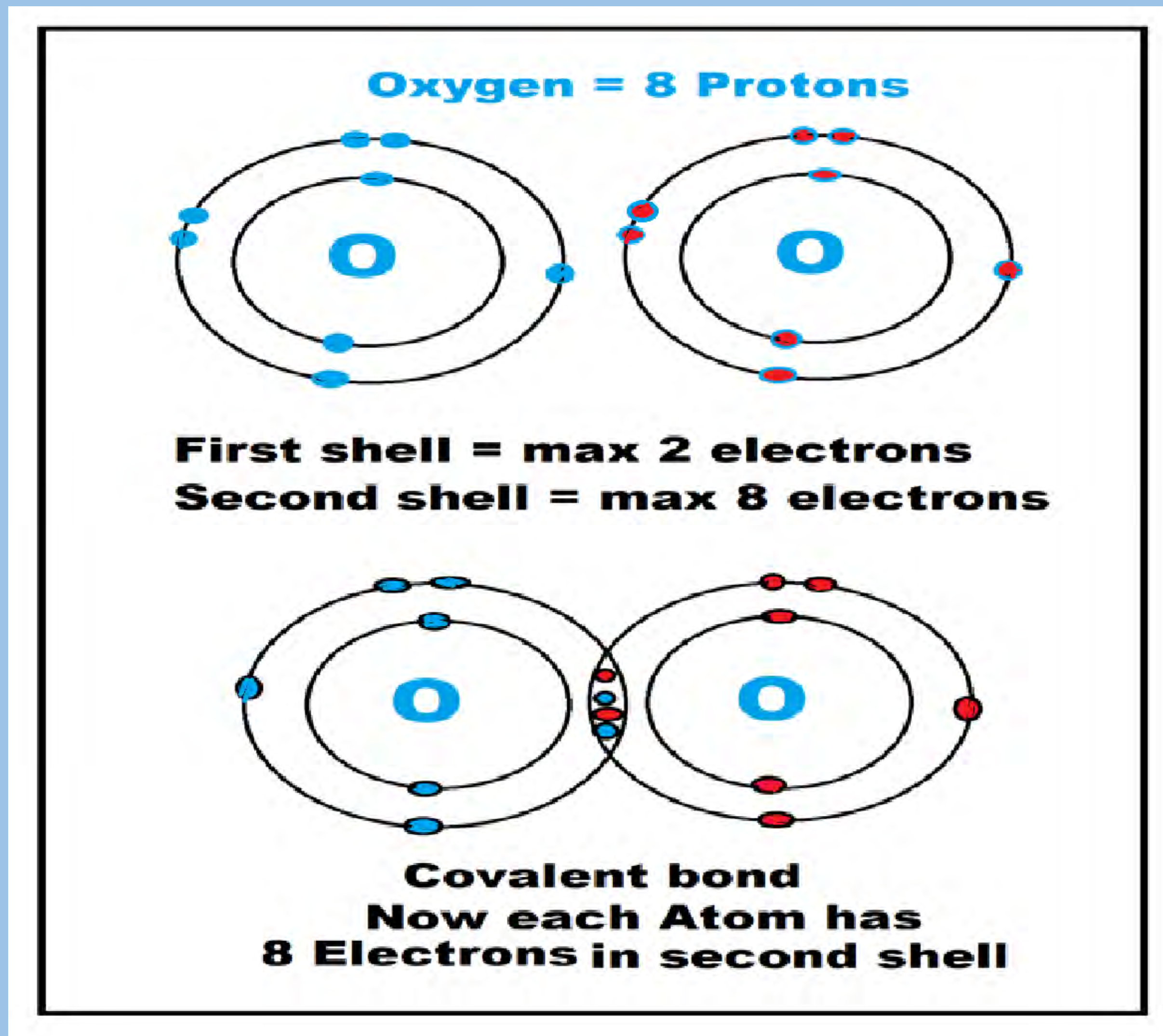
So what is Combustion



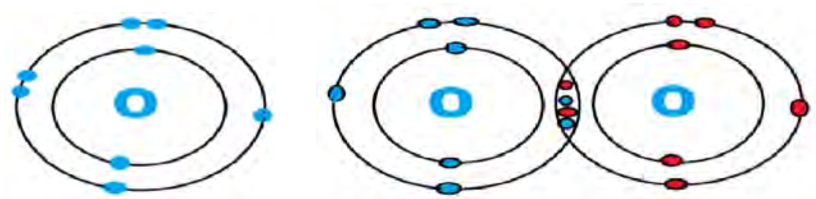
Combustion, or burning, is a high-temperature exothermic redox chemical reaction between a fuel and an oxidant, usually atmospheric oxygen, that produces oxidized gaseous products, in a mixture we will refer to as exhaust gas.

Oxygen is noncombustible, but will actively support the burning of combustible materials. The chemical formula of oxygen, also known as dioxygen, is O_2. This formula is given because oxygen usually combines with another oxygen by forming a covalent bond. Oxygen is a highly reactive element and is capable of combining with most other elements.



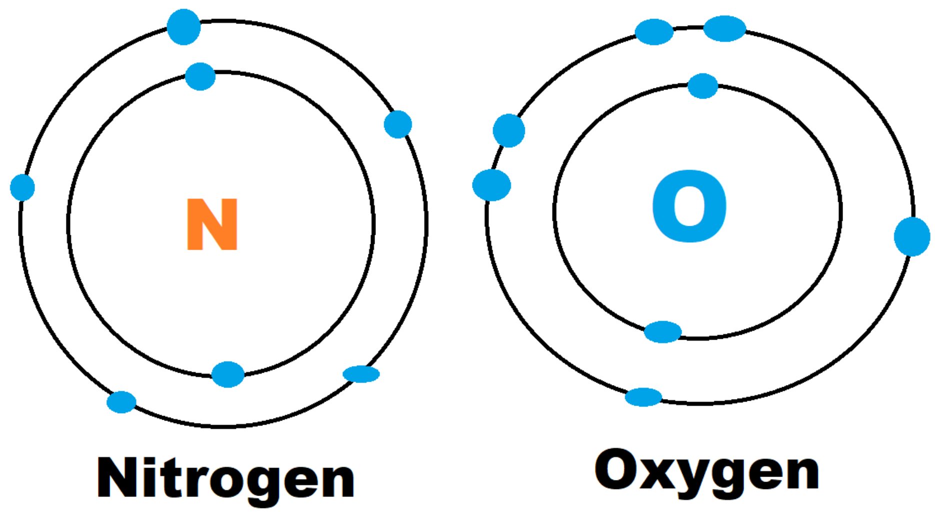

Oxygen = 8 Protons
O
O
First shell = max 2 electrons
Second shell = max 8 electrons
O
O
Covalent bond
Now each Atom has
8 Electrons in second shell

Oxygen's high reactivity is due to its biradical electron configuration. As shown in a valance electron drawing of O_2, the two unpaired electrons make the molecule highly susceptible to bond formation.



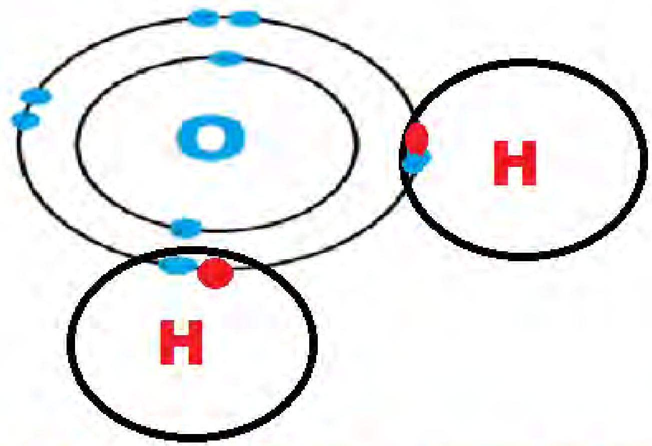
Oxygen Dioxygen

The main components of air, are comprised of approximately 79% nitrogen and 21% oxygen.



Combustion, a chemical reaction between substances. A combustion reaction is a reaction in which a substance reacts with oxygen gas, releasing energy in the form of light and heat. Combustion reactions must involve O2 as one reactant. The combustion of hydrogen gas produces water vapor.

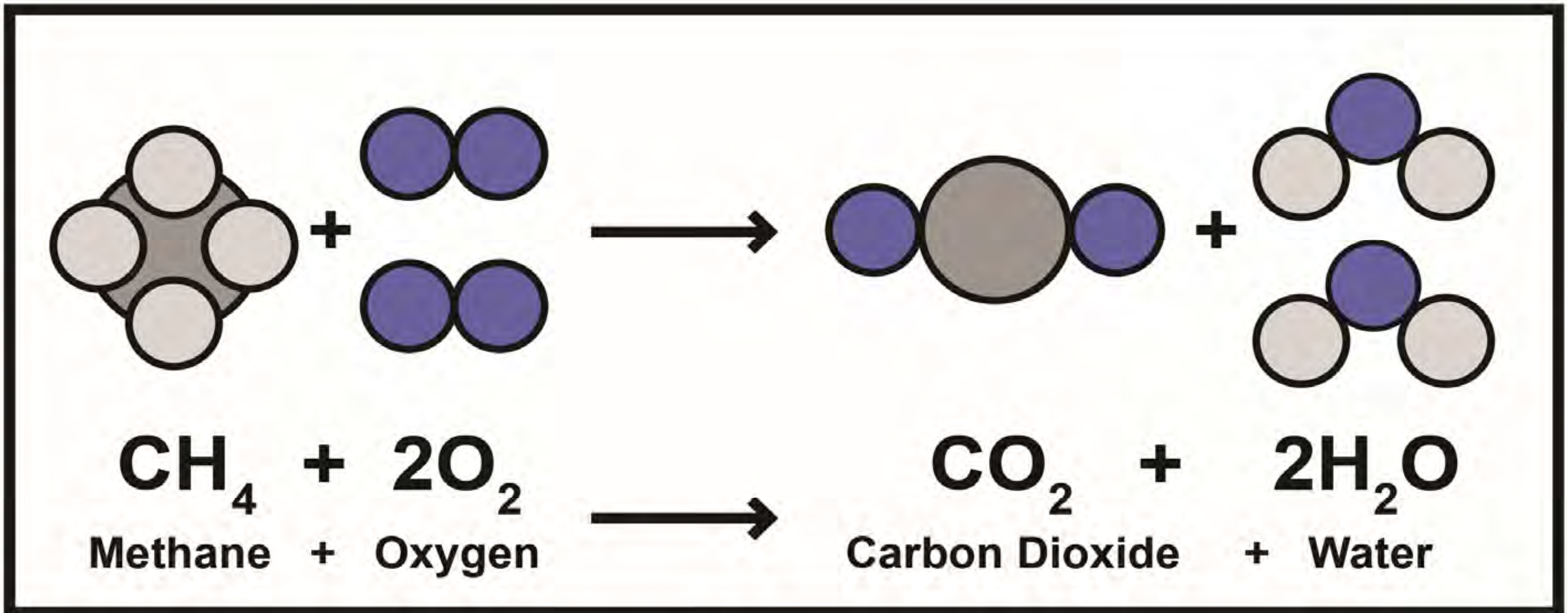
So, after combustion you have all the fuel hydrogen winding up as water molecules. 1 lb of hydrogen combines with 8 lbs of oxygen to form 9 pounds of water, or about 1.1 gallons, but there was only about 0.9 lbs in the original fuel gallon.



Dihydrogen monoxide

Water

Fuel to air ratio

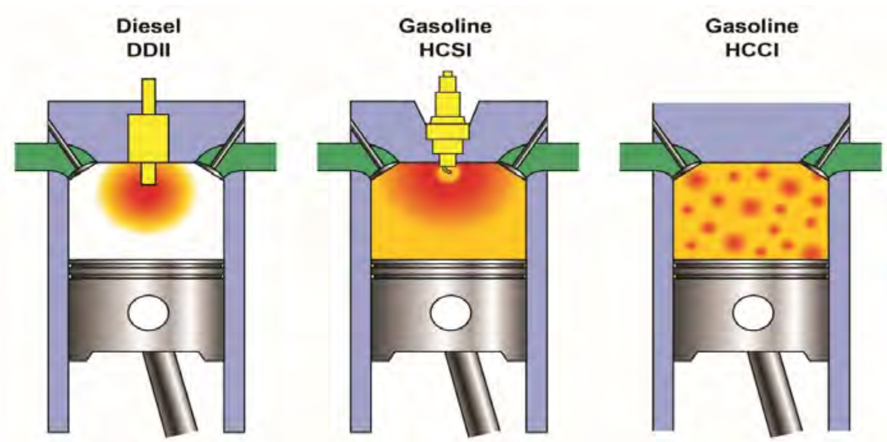


A stoichiometric diagram of the combustion reaction of methane

Internal Combustion Engine (ICE) refers to a heat engine that generates power by consuming fuel via combustion producing heat. ICE's are thermodynamic engines which use heat in a system that converts heat to usable energy, particularly mechanical energy, which can then be used to do mechanical work. Thermal efficiency is how efficiently the engine can transform the heat produced by the combustion into mechanical work.

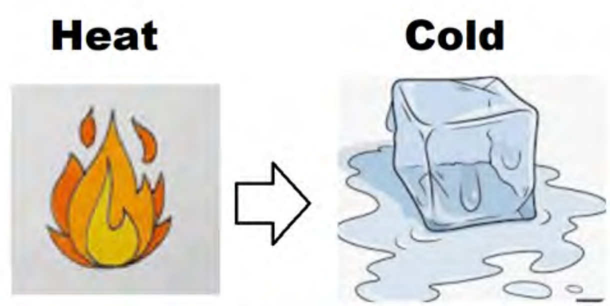
Thermodynamics deals with how work and energy (heat) are produced and consumed. It is used to model engines. Thermodynamics allows us to ignore the complexities of the mechanical system and concentrate on the engine's input and output instead.

The way in which the fuel air charge is set up and ignited is quite different and will change the thermodynamic efficiency of the engine. What is needed is a way to best extract the energy from the fuel stock.



First Law of Thermodynamics: Also known as the law of energy conservation, states that energy cannot be created or destroyed in an isolated system. Energy in a closed system is neither lost nor gained — it is only transformed.

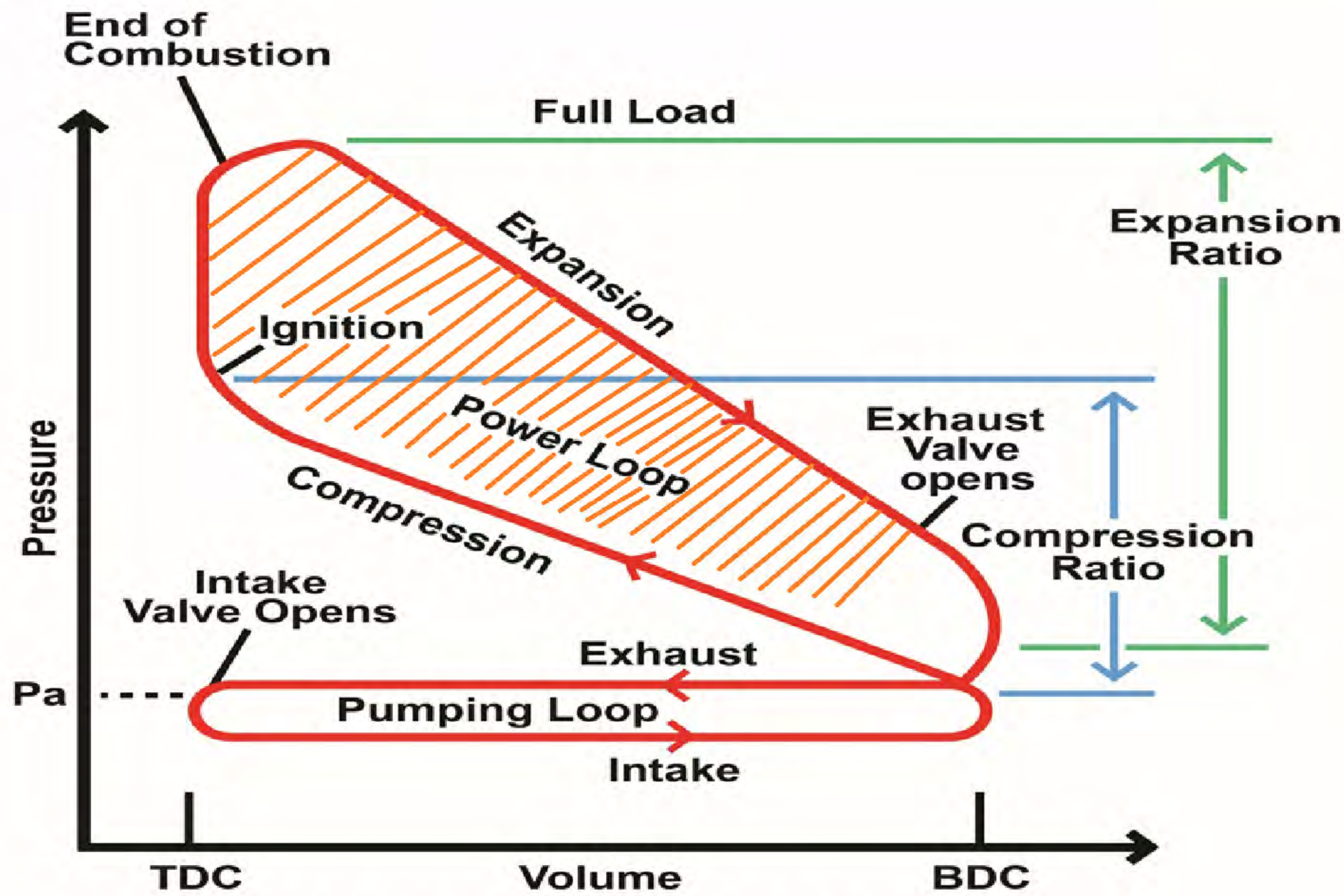
Second Law of Thermodynamics: states that any isolated system's entropy always increases.



Second Law of Thermodynamics:
means hot things always cool unless you do something to stop them. It expresses a fundamental and simple truth about the universe: that disorder, characterized as a quantity known as entropy, always increases.

So what does that mean for the ICE?

Second Law of Thermodynamics: is that *it is impossible for a heat engine to produce an amount of work equal to the amount of heat received from a thermal energy reservoir*. In other words, the second law states that it is impossible for a heat engine to convert all the heat it receives from a thermal energy reservoir to work.



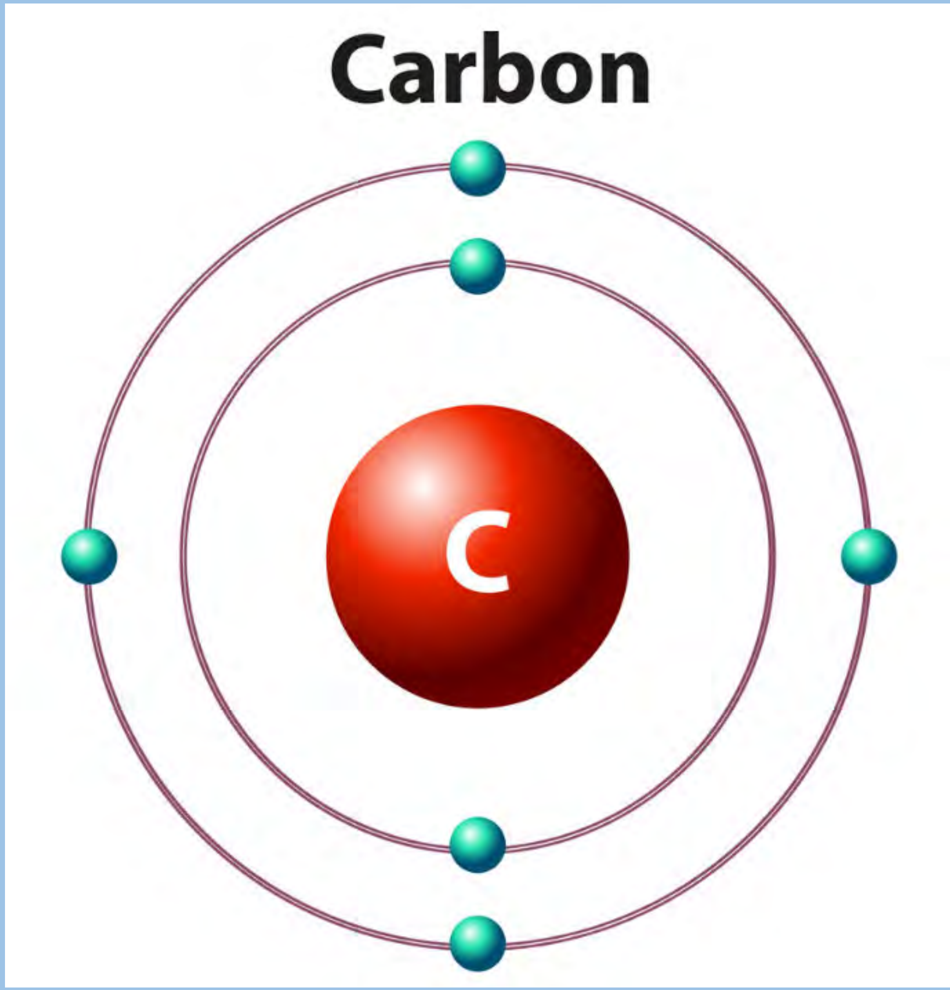
PV Otto Cycle Graph

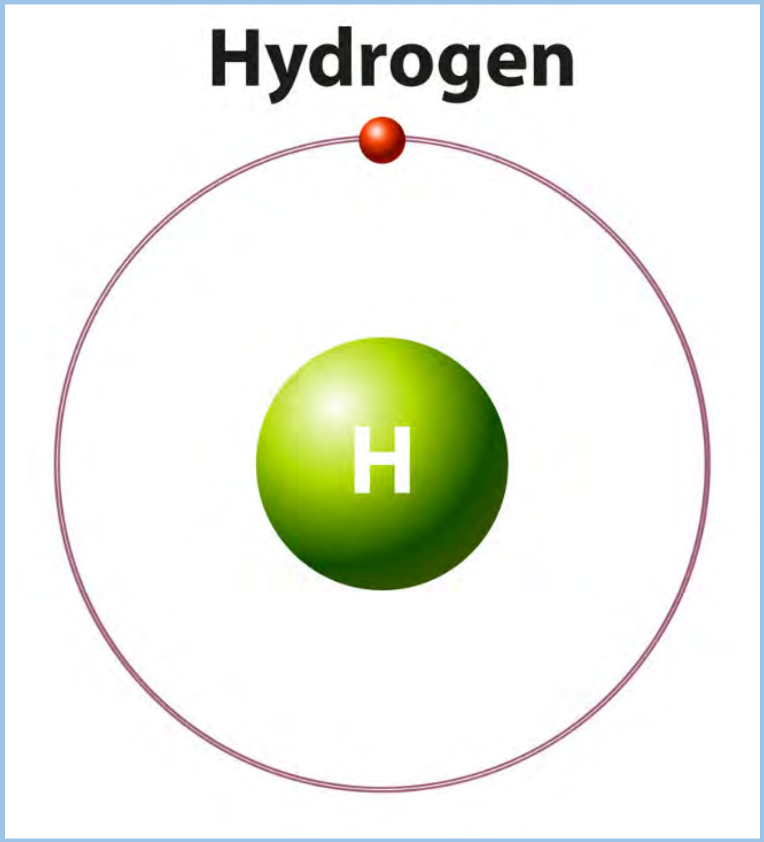
Modern gasoline engines have a maximum thermal efficiency of more than 50%, but most road legal cars are only about 20% to 40% when used to power a car. Many engines would be capable of running at higher thermal efficiency but at the cost of higher wear and emissions.

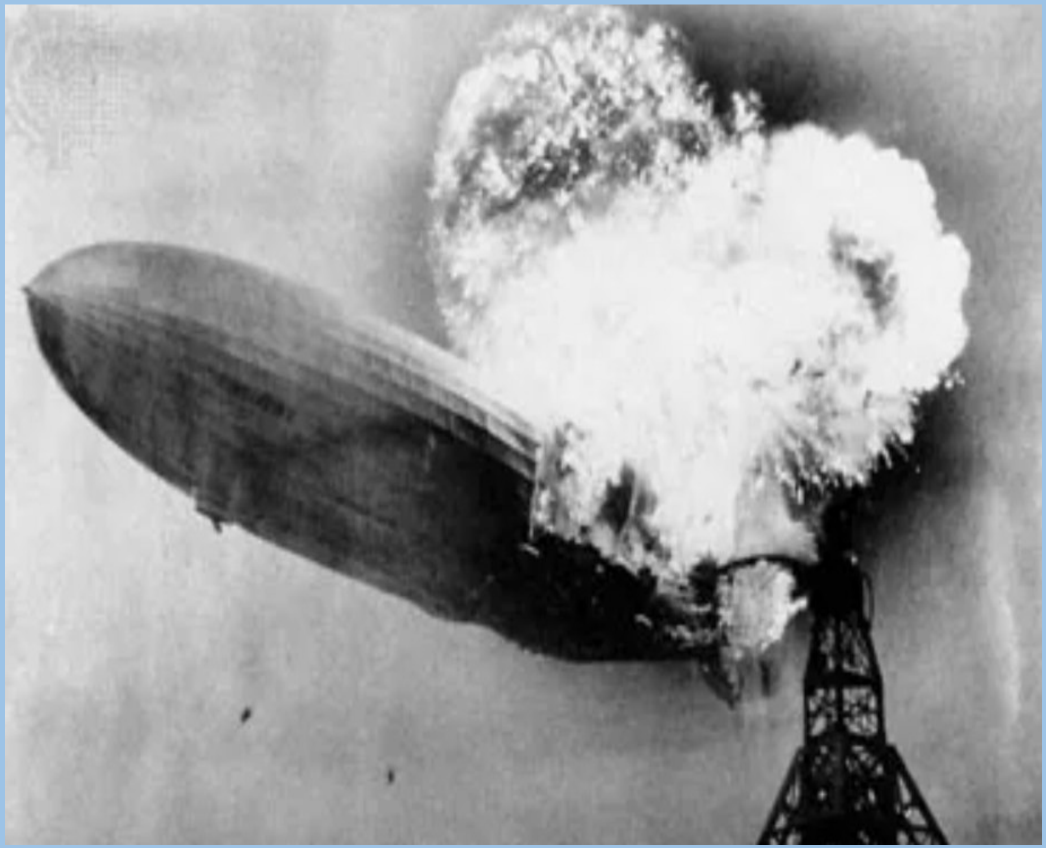
When an F1 car is at full throttle, about 54-56% of the fuel's chemical energy can be converted into mechanical energy to propel the car forward.

In order to produce the maximum thermodynamic efficiency, all of the fuel stock must burn quickly in the combustion process. This will produce the maximum heat from the fuel stock, which in turn produces the best thermal efficiency. Several things must happen for this to occur.

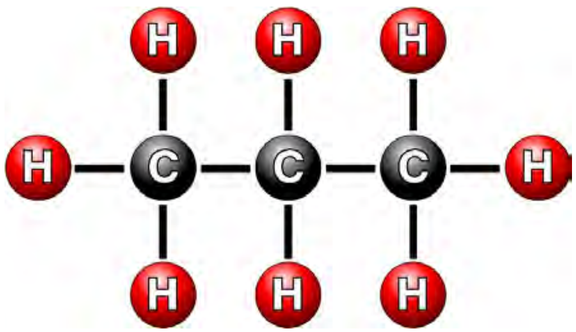
1. The correct air fuel ratio
2. In a spark ignition combustion process, it must have an homogeneous mixture or near complete uniformity of air and fuel mixture before ignition.
3. Heat provided from the compression stroke.
4. Point of ignition from Spark at the correct time.
5. Turning chemical potential into mechanical energy

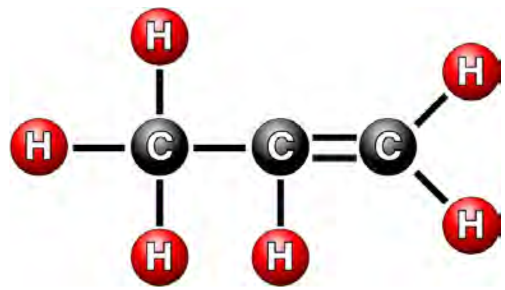

Carbon
C

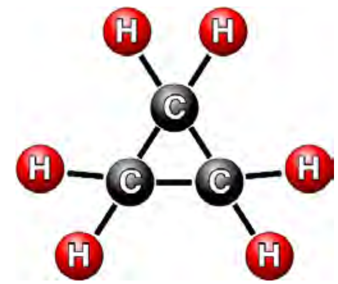

Hydrogen
H

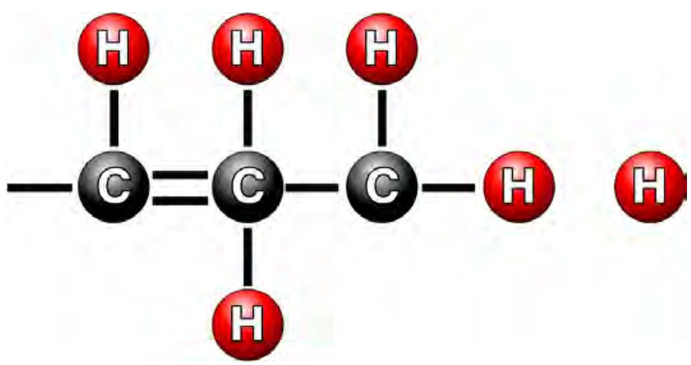


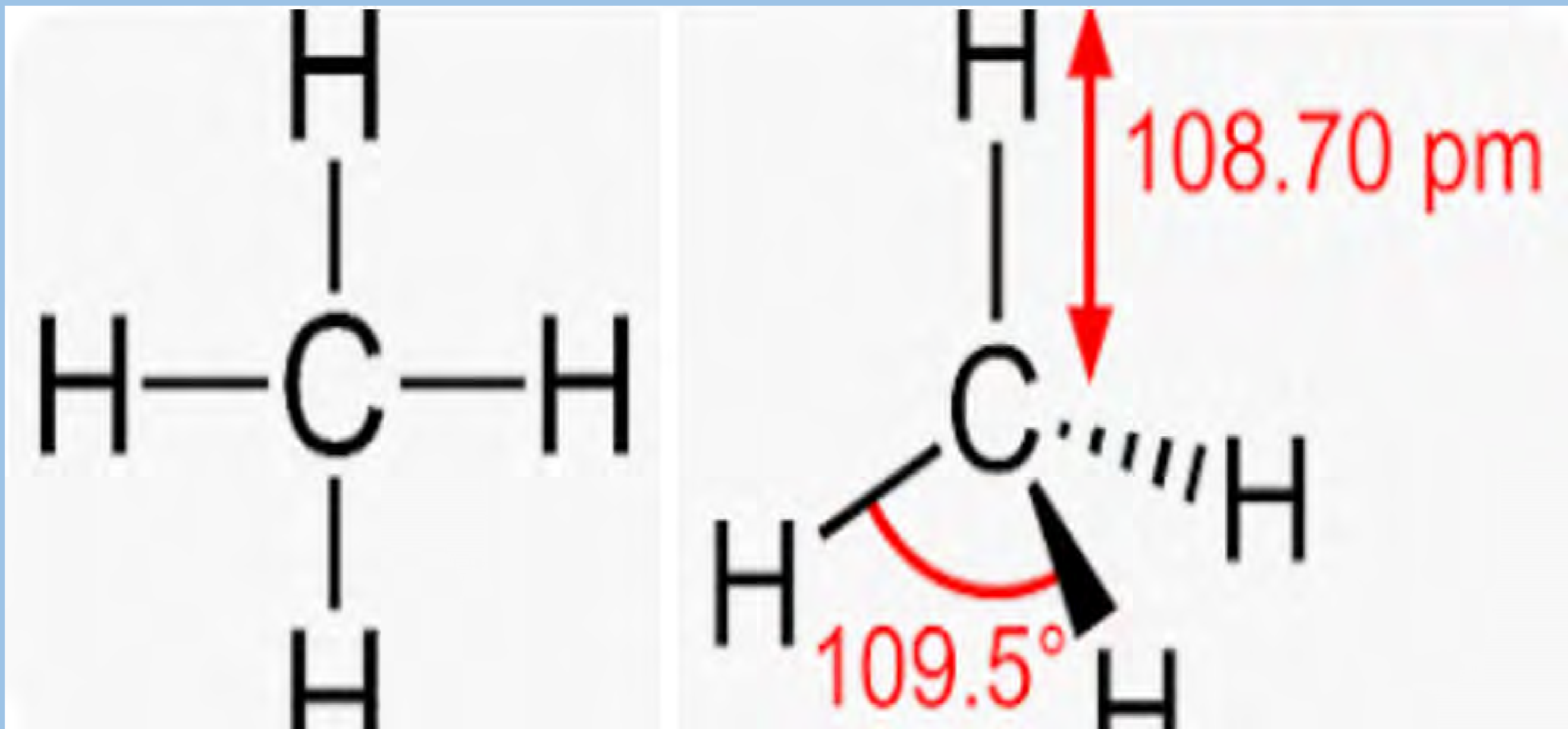
H_XC_X Can be chains, branches, or rings.



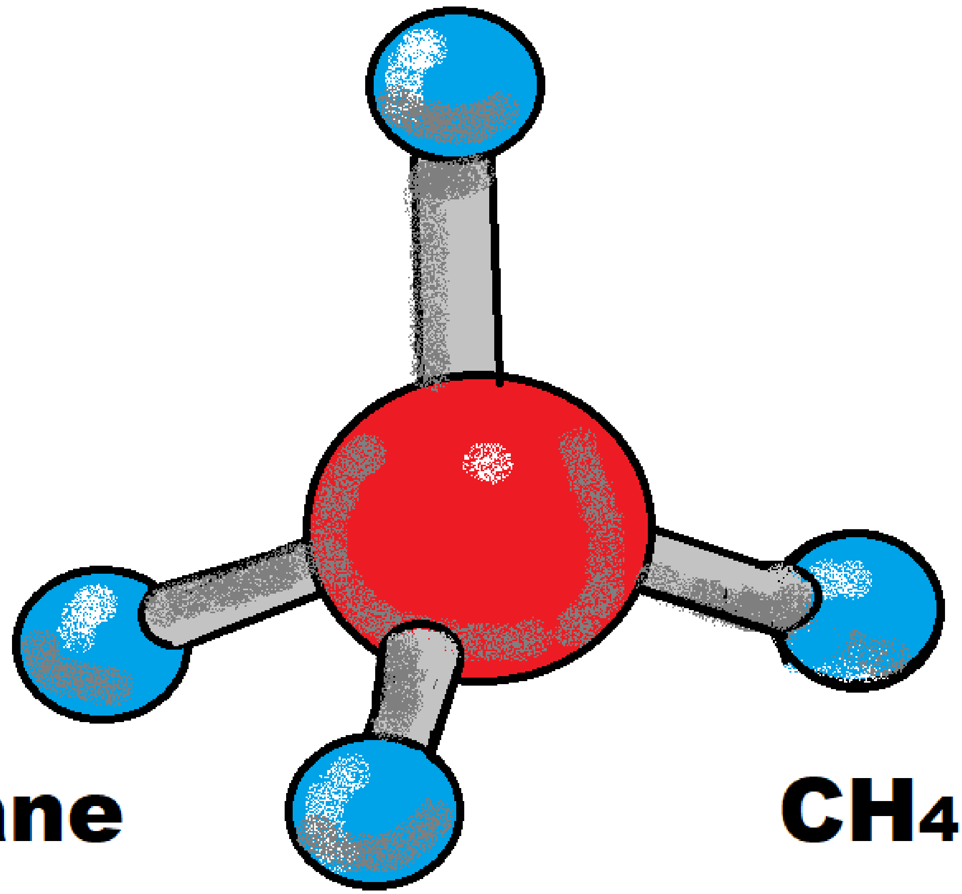








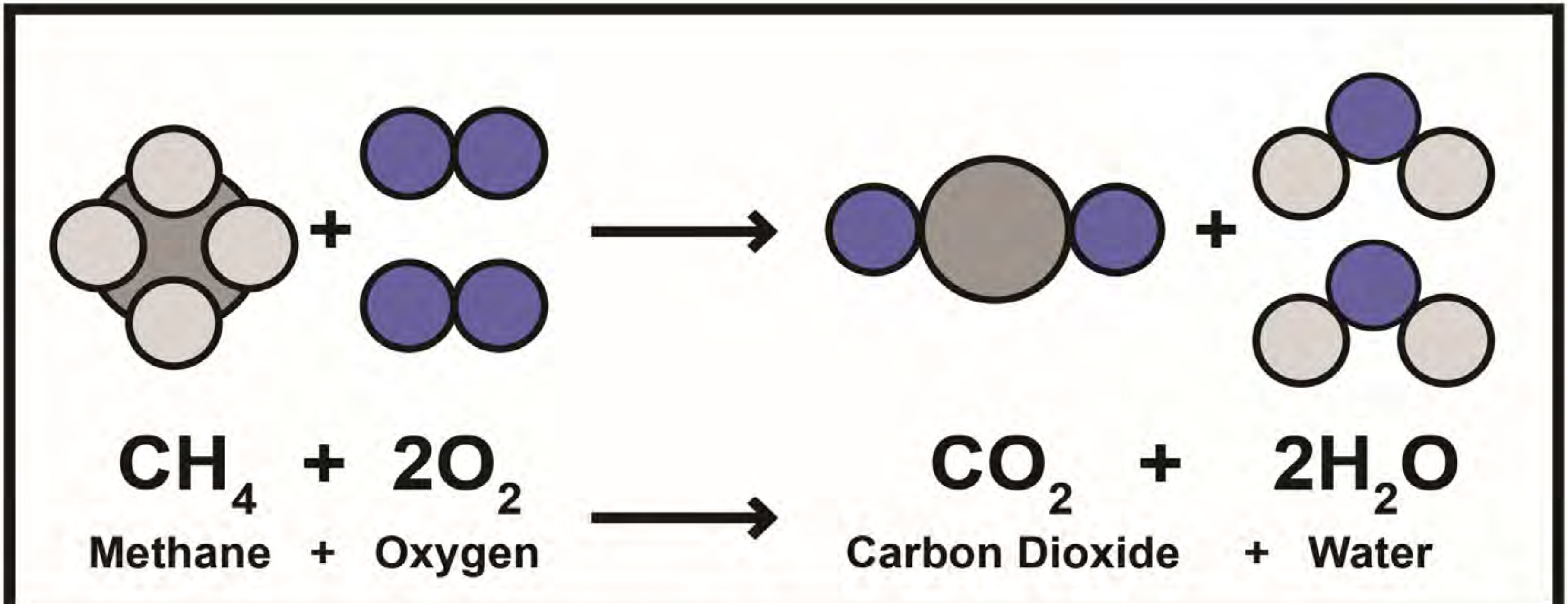
Methane CH_4



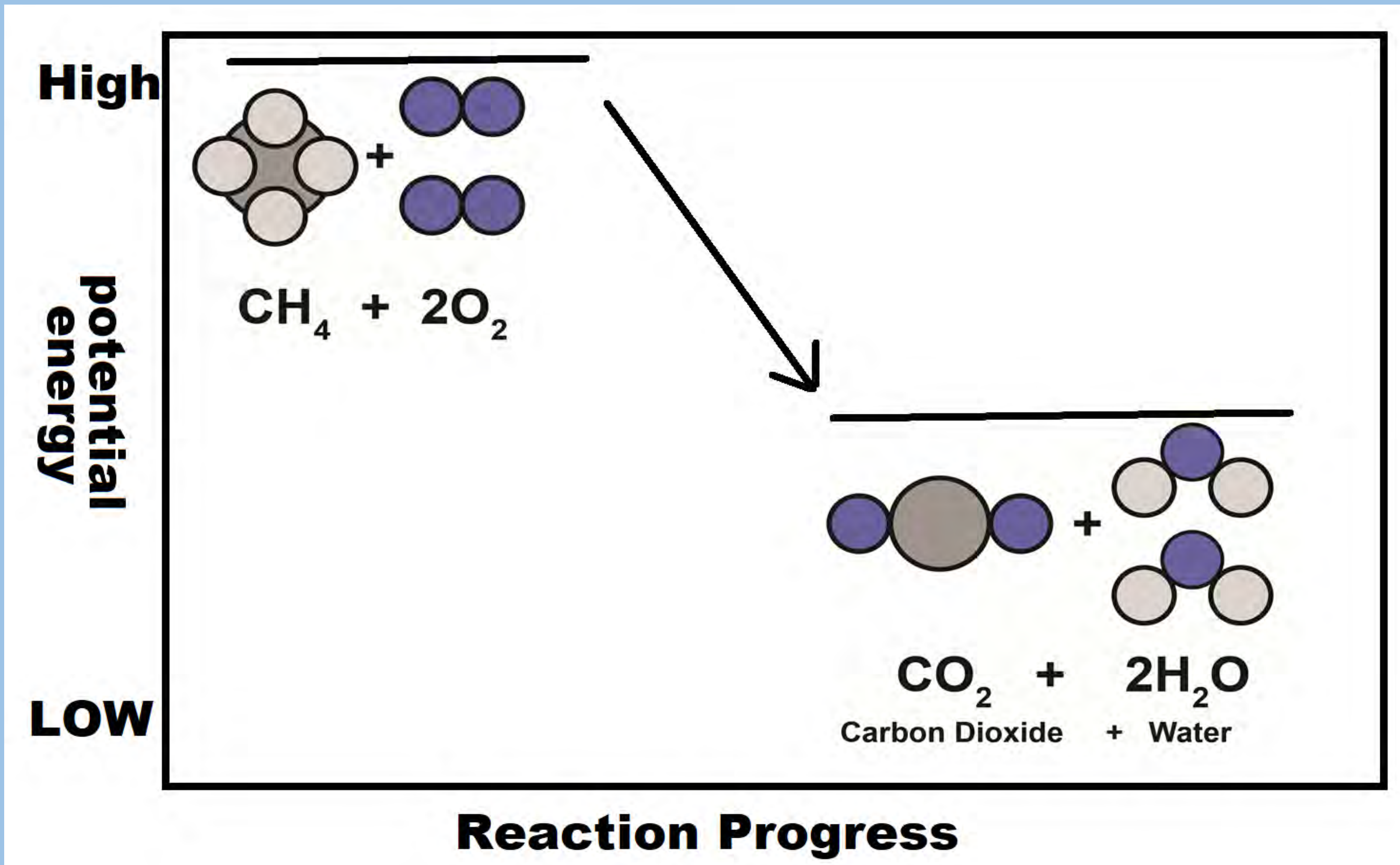
Methane

CH_4

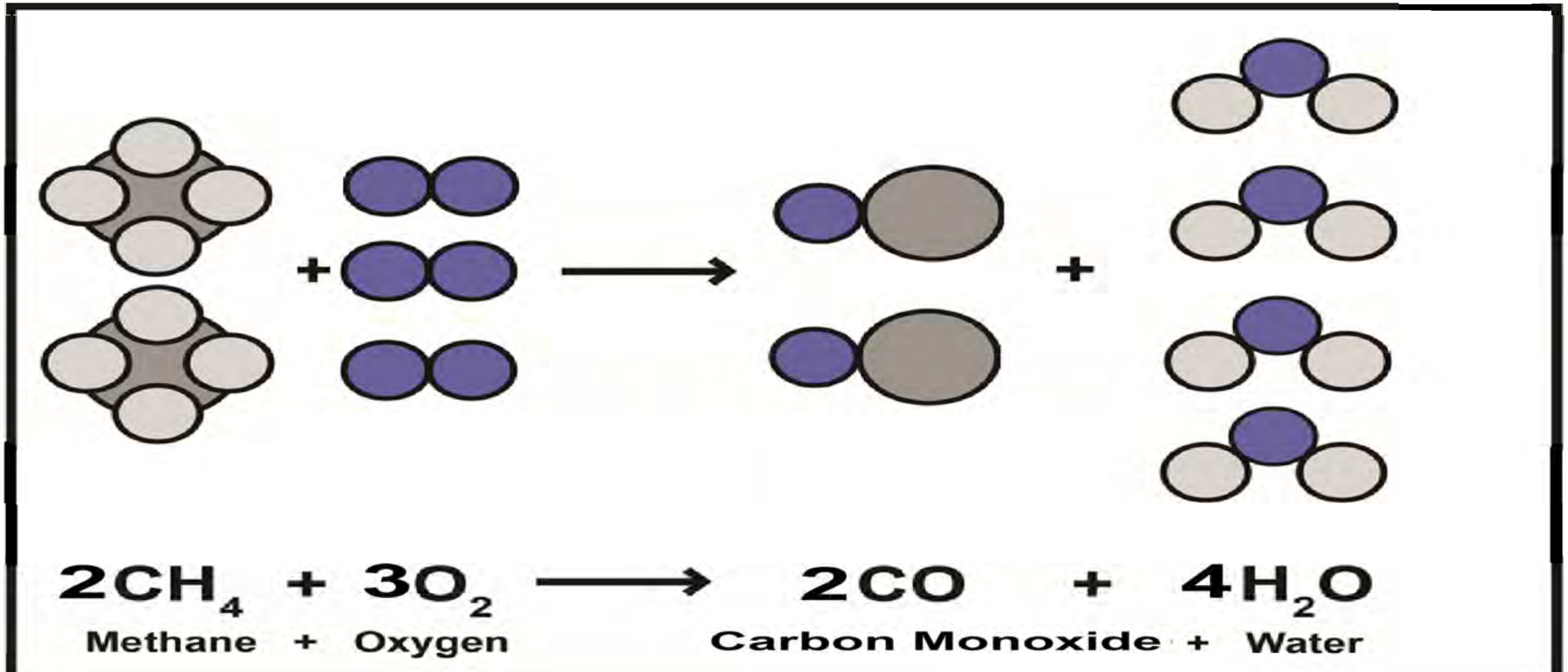
Fuel to air ratio



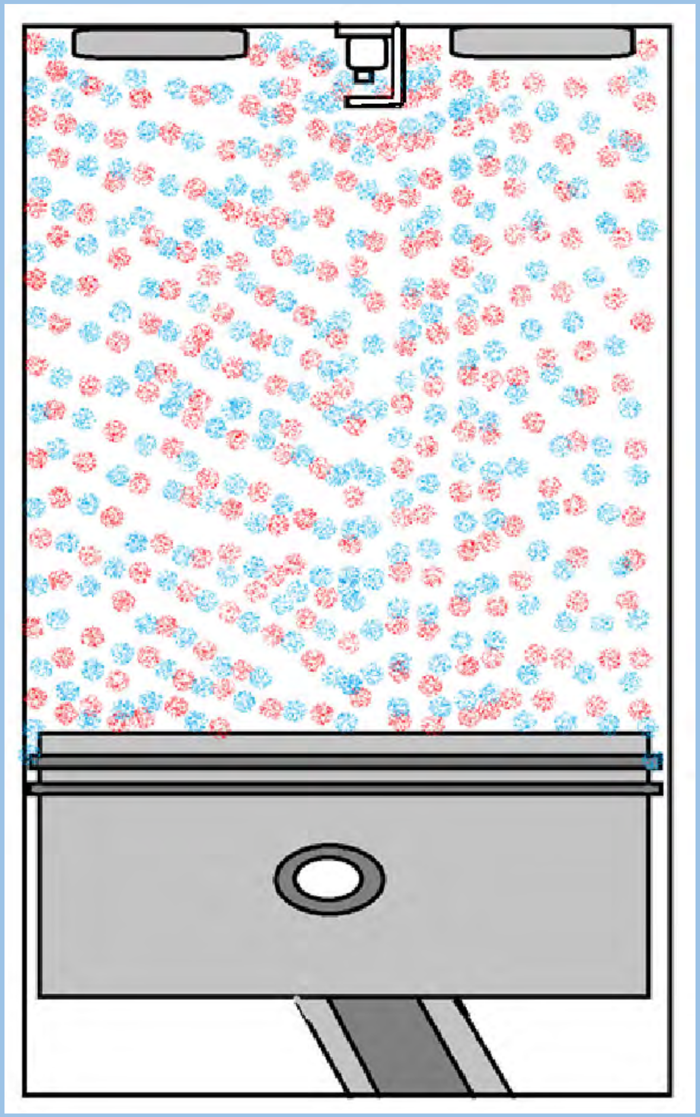
A stoichiometric diagram of the combustion reaction of methane


High
potential energy
LOW
CH_4 + $2O_2$
CO_2 + $2H_2O$
Carbon Dioxide + Water
Reaction Progress

Fuel to air ratio



A Rich mixture diagram of the combustion reaction of methane

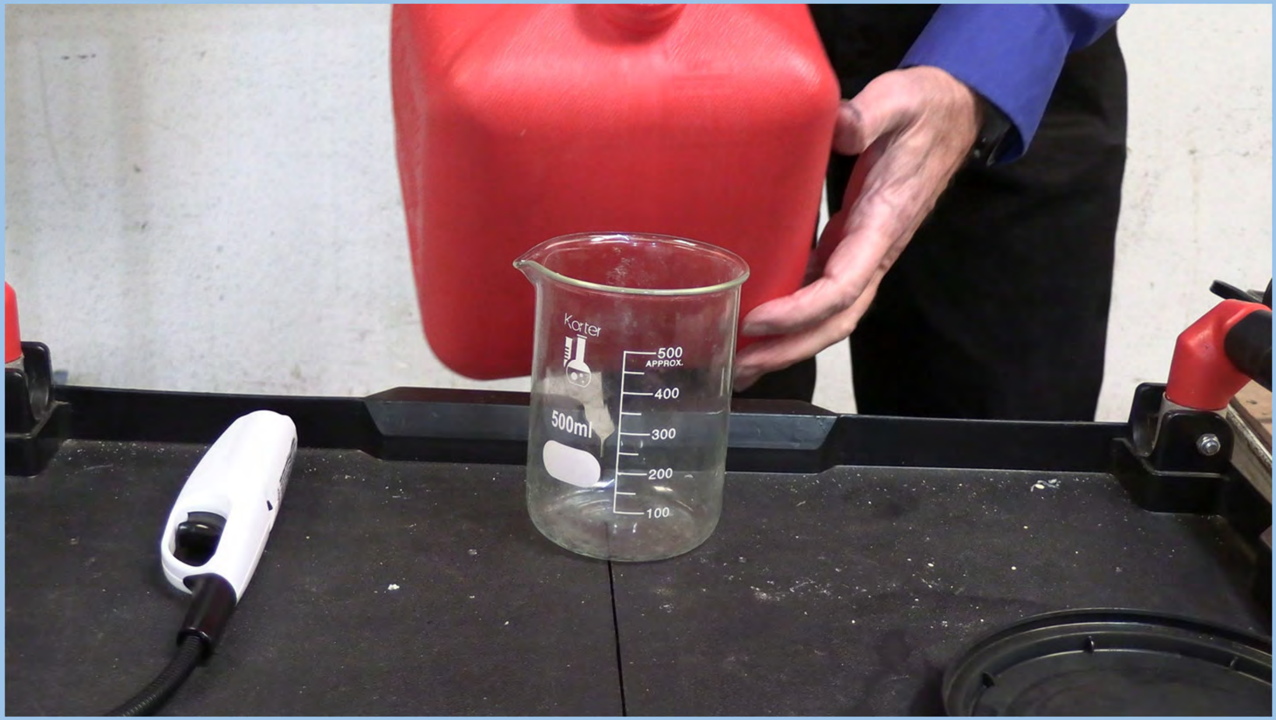


Homogeneous mixture or near complete uniformity of air and fuel mixture before ignition.

Why does it have to be an homogeneous mixture?

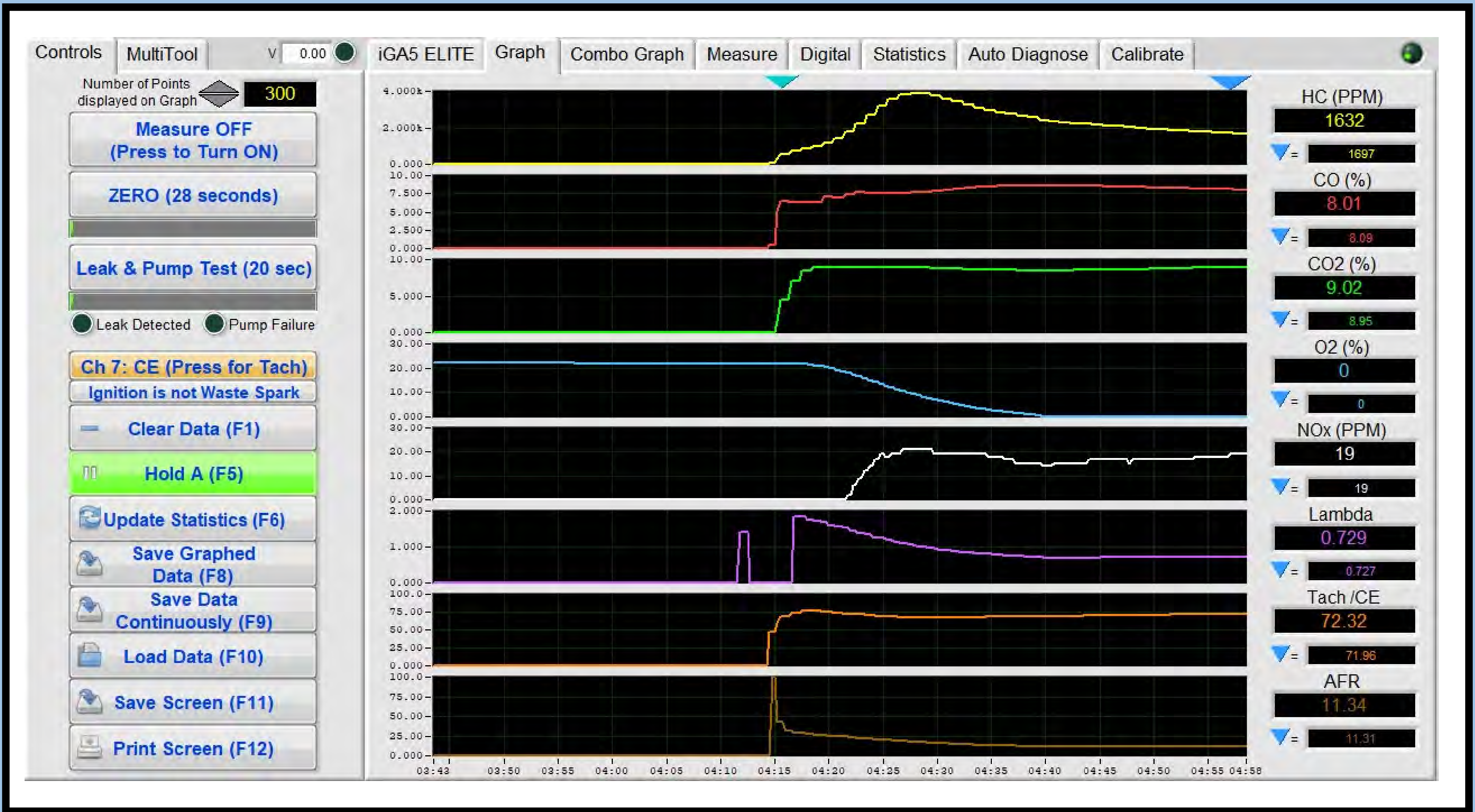
Why does it have to be an homogeneous mixture?

Fuel must be in a vapor format to burn. Liquids and solids do not burn.

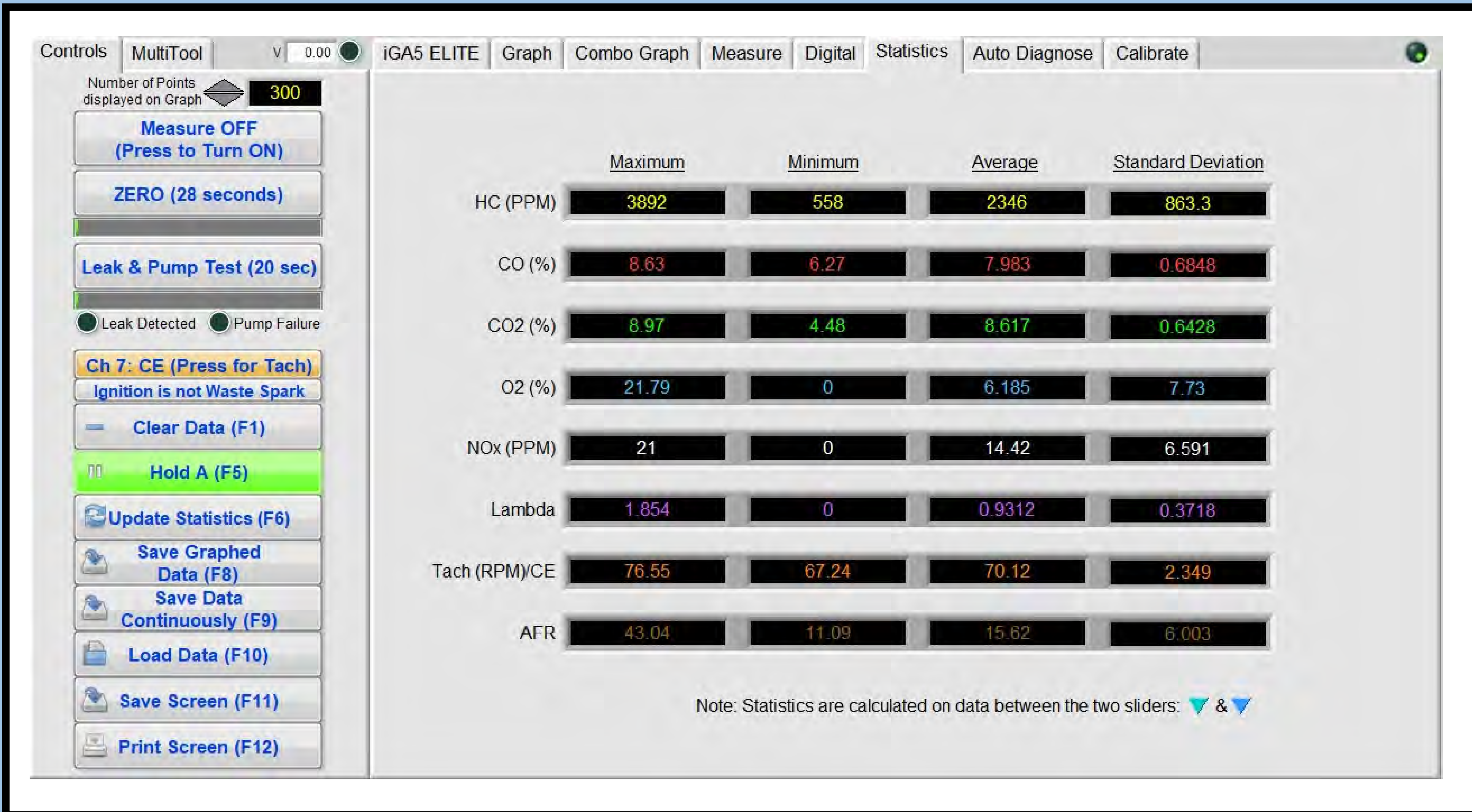


Port Fuel Injection (PFI)

2006 Hummer H3 19F start

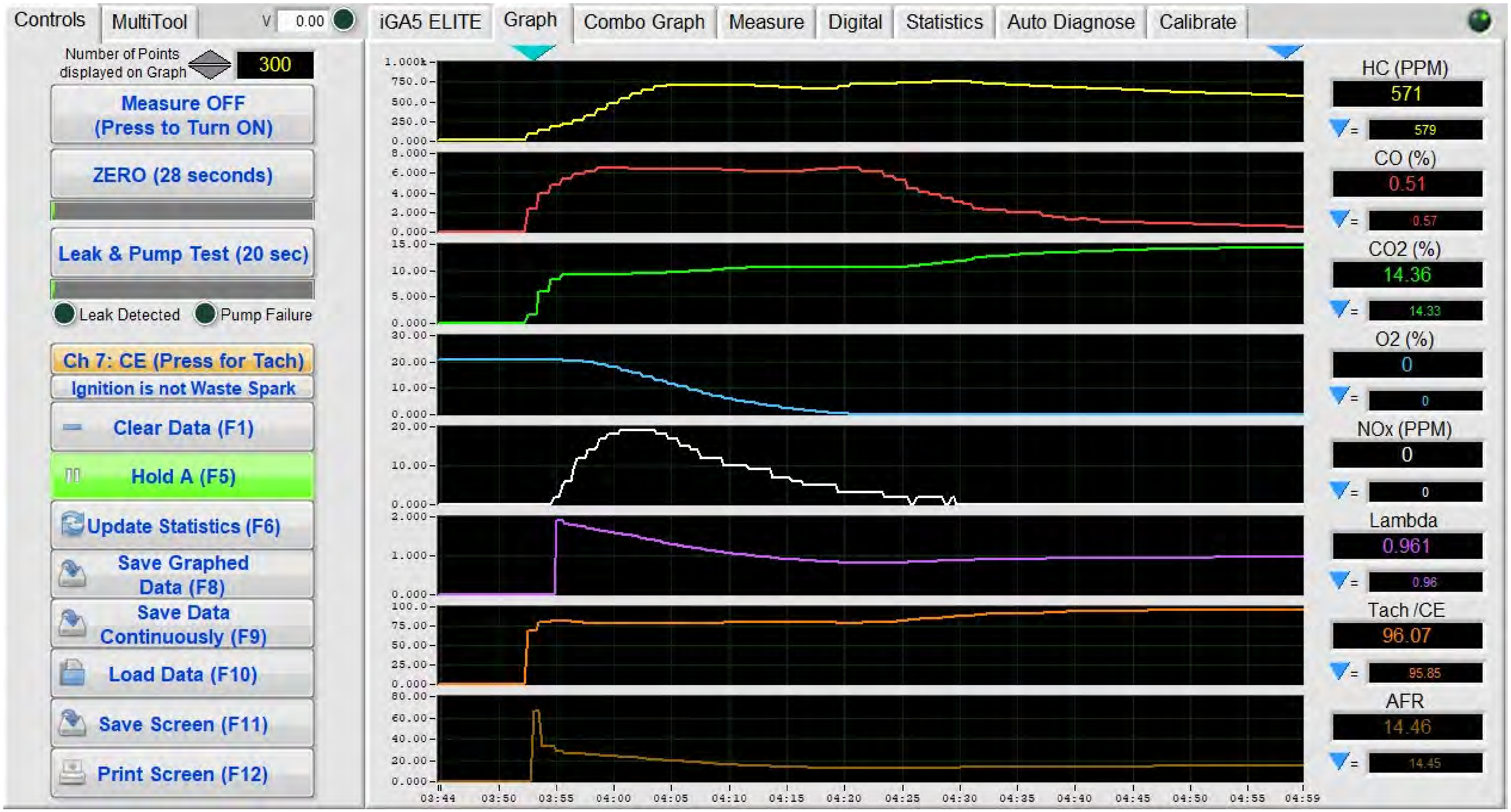


2006 Hummer H3 19F start

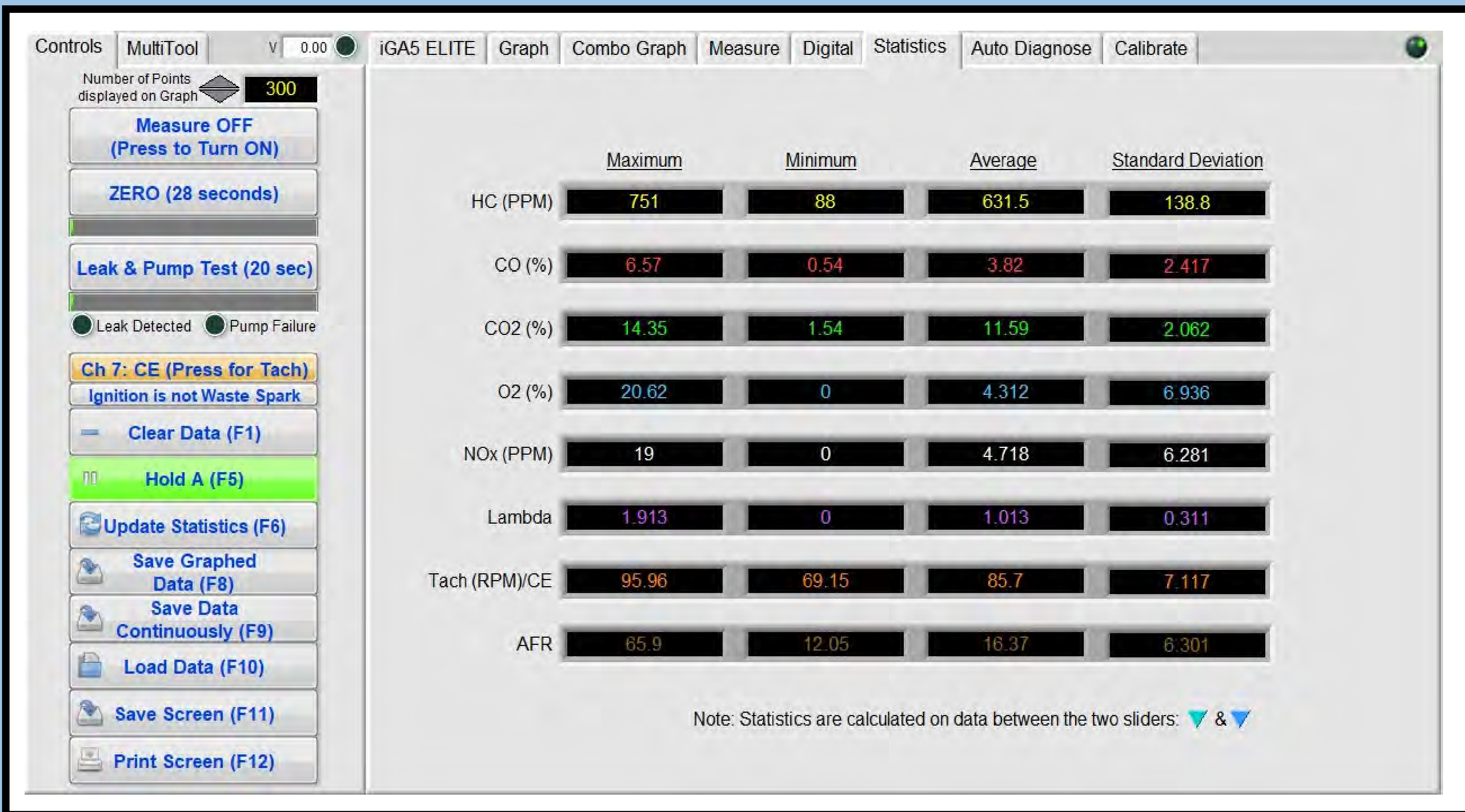


Gasoline Direct Injection (GDI)

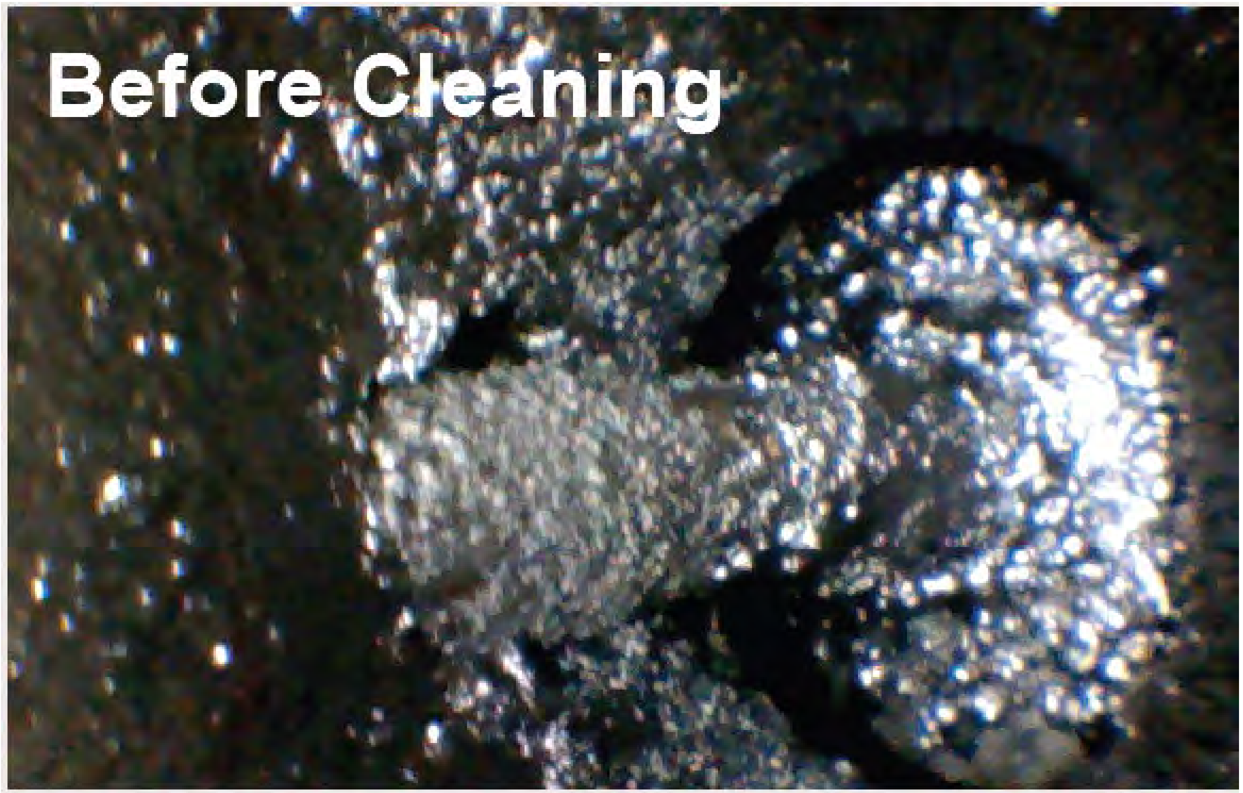
2024 Chevy Traverse 19F start

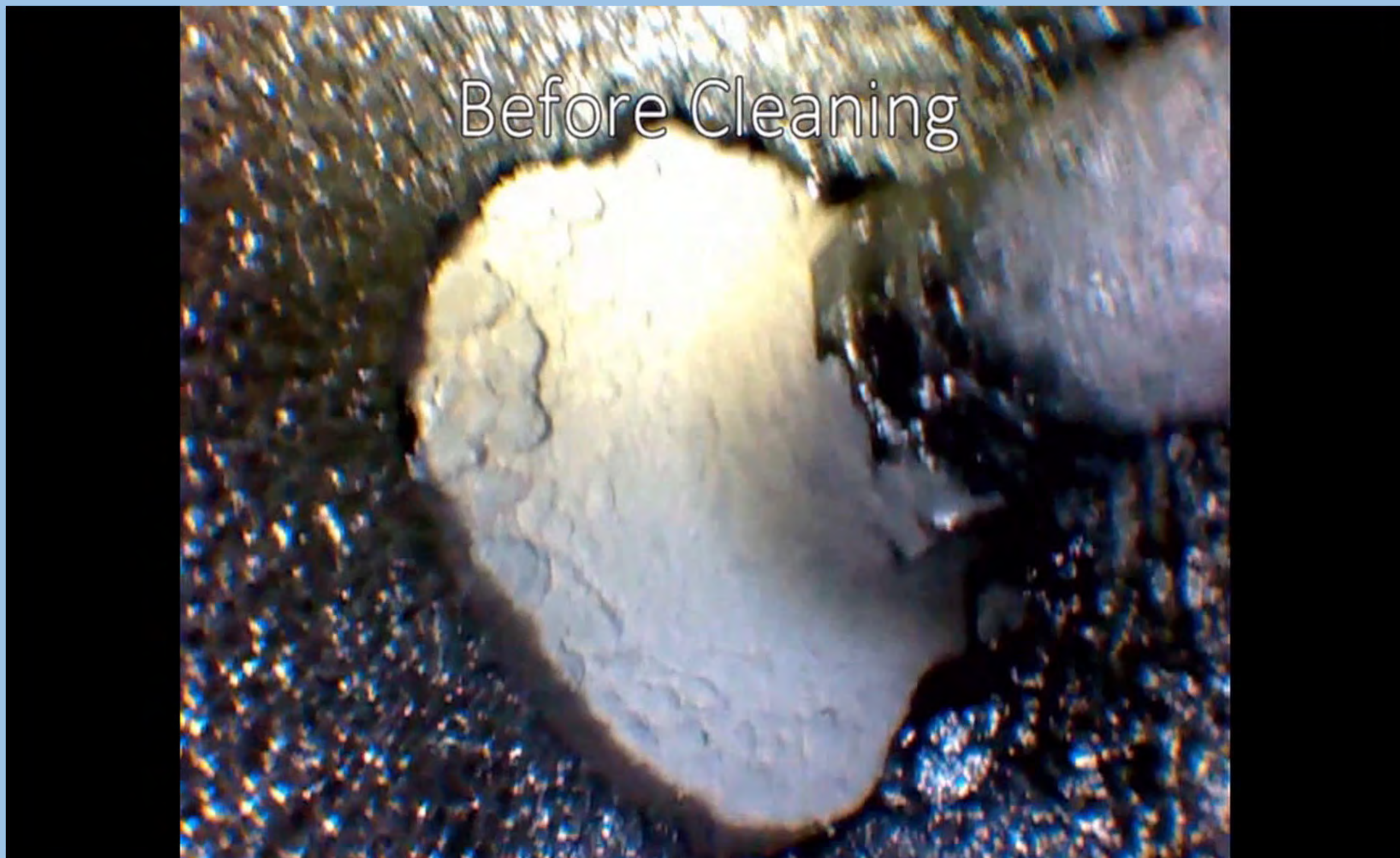


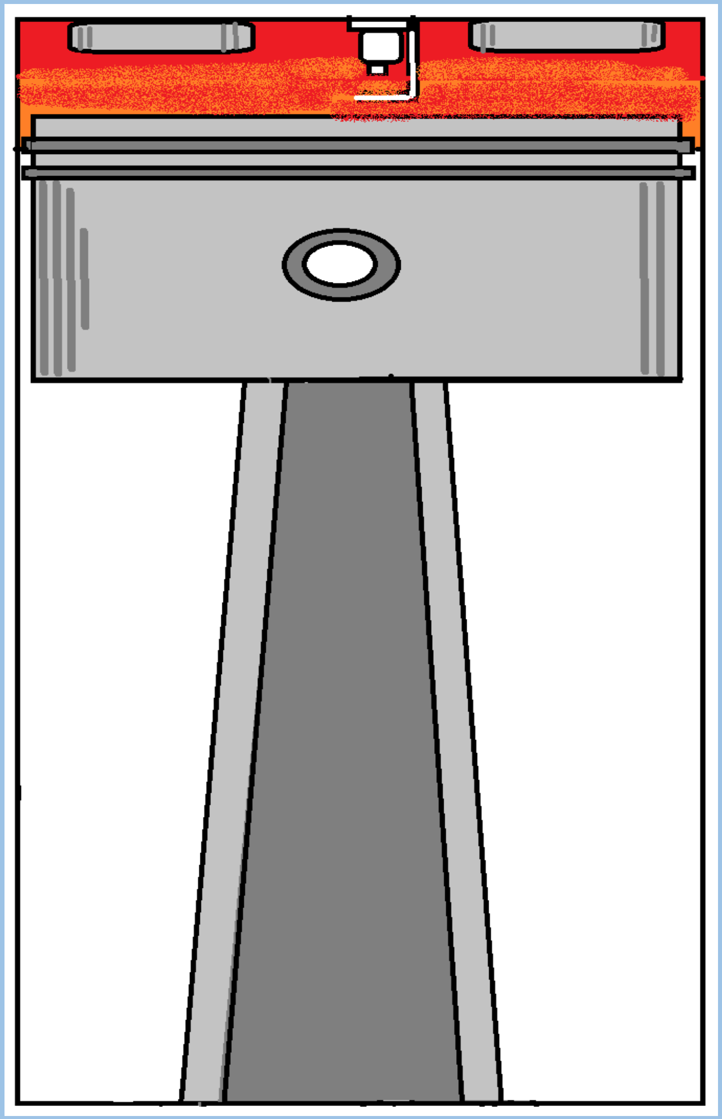
2024 Chevy Traverse 19F start



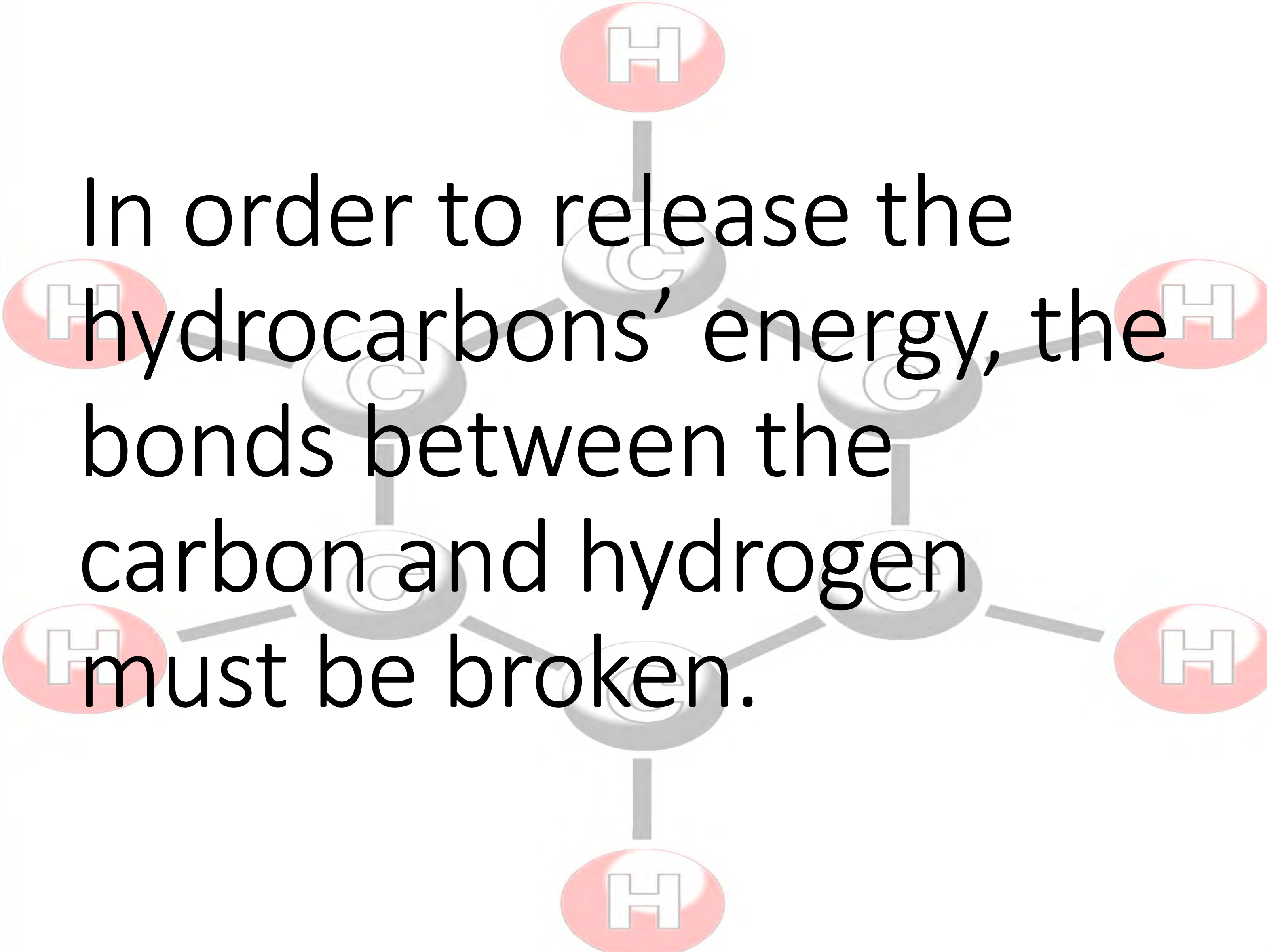
	Maximum	Minimum	Average	Standard Deviation
HC (PPM)	751	88	631.5	138.8
CO (%)	6.57	0.54	3.82	2.417
CO2 (%)	14.35	1.54	11.59	2.062
O2 (%)	20.62	0	4.312	6.936
NOx (PPM)	19	0	4.718	6.281
Lambda	1.913	0	1.013	0.311
Tach (RPM)/CE	95.96	69.15	85.7	7.117
AFR	65.9	12.05	16.37	6.301


Before Cleaning


Before Cleaning



Compression stroke heats air fuel charge
For an engine with 10:1 compression ratio and assuming 100% filling of the cylinder, with a 70°F outside air temperature, the compression temperature is a little under **900°F**.



In order to release the hydrocarbons' energy, the bonds between the carbon and hydrogen must be broken.

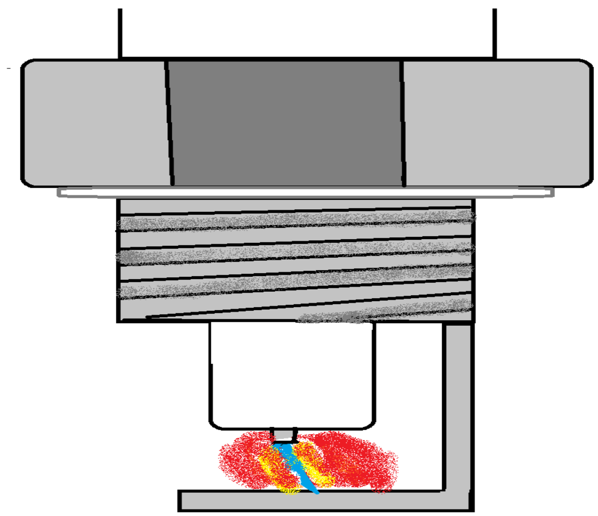
This is accomplished with high voltage that will ionize across the spark plug electrodes.

Spark Plugs
Use The Forth State of Matter
“Plasma”


So
What is
Plasma?


Plasma
IS A SUPER HEATED GAS WHICH IS IONIZED

Plasma Is Super heated gas which temperature ranges from 11,000° – 14,500° Fahrenheit, however spark plug plazma temperature is about 11,780° Fahrenheit



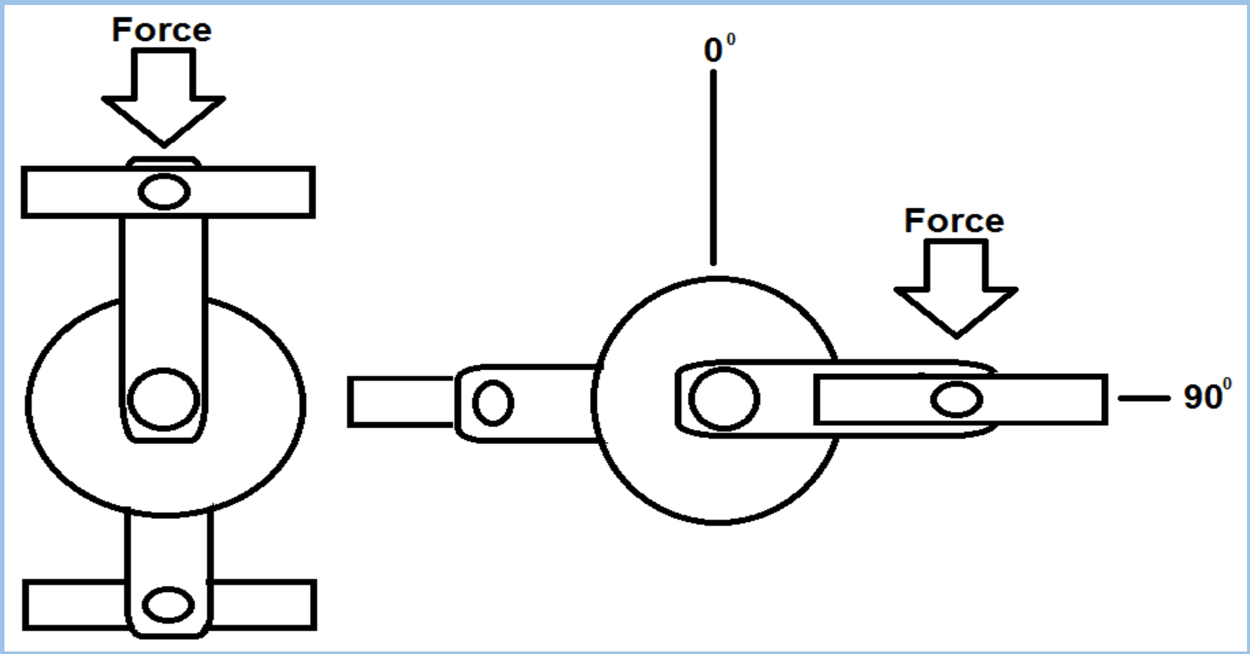
Localized super high temperature

This will take the fuel stock well past it's point of auto-ignition. Actually, the plasma temperatures are greatly important for the ignition processes as the plasma temperatures directly impact the chemical reaction rates.

Gasoline Auto-ignition temperature 536 ° F

Ignition Timing

The ignition coil will fire before the Top Dead Center (TDC) position. This is so the fuel can start its combustion process allowing enough time for the fuel to complete its burn before 90° After Bottom Dead Center (ABDC). The greatest mechanical advantage that can be produced from the fuel burning is at 90° ATDC crankshaft position.



Otto cycle 4 stroke engine

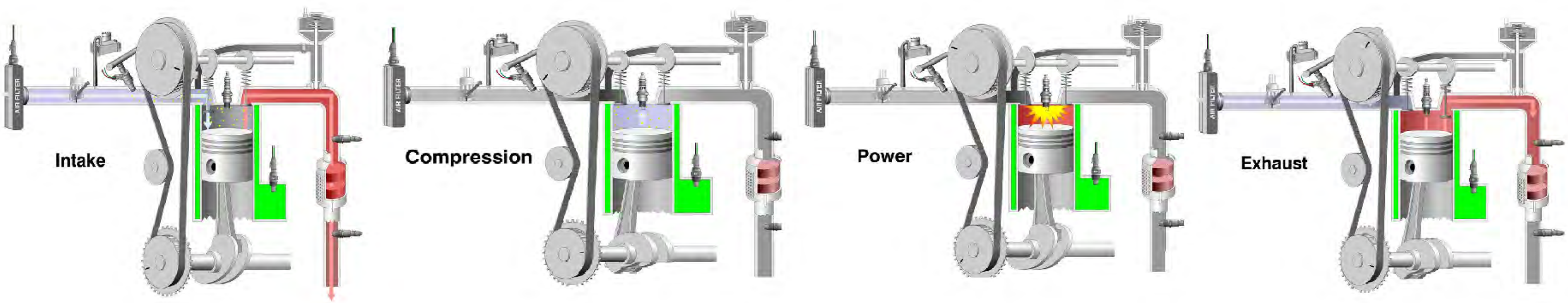
800 RPM = 150ms per fire cycle = 37.5 ms per stroke

2000 RPM = 60ms per fire cycle = 15 ms per stroke

3000 RPM = 40 ms per fire cycle = 10 ms per stroke

6000 RPM = 20 ms per fire cycle = 5 ms per stroke

So ignition timing must advance to keep up with RPM increase



Deflagration

is subsonic combustion in which a pre-mixed flame propagates through a mixture of fuel and oxidizer. Deflagrations in high and low fuel–oxidizer mixtures may transition to a detonation depending upon confinement.

Blue Flame vs Orange flame

In complete combustion with a blue-colored flame, the temperature of a propane flame is hotter. However, with a yellow or orange flame, the flame's temperature decreases.

3,596° F

1,832° F

Detonation

Combustion of a substance which is initiated suddenly and propagates extremely rapidly (supersonic), giving rise to a shock wave.

Supersonic shock wave

Knock

***spontaneous combustion*, also called *auto-ignition*, *detonation*, or *knock*, happens when rising temperature and pressure from the primary combustion causes unburned fuel to ignite. This uncontrolled secondary combustion causes pressure in the cylinder to spike and causes the knock to occur.**

The competition between the intended (controlled) and unintended (spontaneous) combustion causes the energy from the burning fuel to disperse unevenly, which can cause damage and place high pressure on the engine's piston. A similar undesirable condition is called pre-ignition, when the fuel ignites on its own before the spark ignites it.

Detonation is the supersonic shockwave that occurs throughout the combustion chamber creating a near stepwise change in pressure, this is where the charge is ignited instantly.

Detonation damage to Piston

In order to demonstrate the combustion reaction, I will use a combustion bottle.

A WHAT?

YEP

Combustion reaction bottle

400°F 100 grams gas

400°F 200 Grams gas

400°F 300 grams gas

300°F 100 grams gas

300°F 200 Grams gas

300°F 300 grams gas

400°F 50 grams gas

200°F 100 grams gas

Temp	Weight	HC	CO	CO_2	O2
400F	100gm	66	0.04	4.05	20.59
400F	200gm	261	.84	4.37	17.95
400F	300gm	1,564	1.6	4.95	17.18
300F	100gm	79	0.03	2.38	19.98
300F	200gm	410	.76	4.09	15.17
300F	300gm	4,349	1.51	3.27	15.01
200F	100gm	6,066	0	0	21.94
400F	50gm	4,138	0	0	21.63

Temp	Weight	HC	CO	CO_2	O2
400F	100gm	24	0.01	2.45	20.59
300F	100gm	79	0.03	2.39	19.9
400F	200gm	239	.83	4.28	17.95
300F	200gm	541	.72	3.89	15.17
400F	300gm	1,499	1.45	4.95	17.18
300F	300gm	4,631	1.43	3.15	15.01
200F	100gm	6,066	0	0	21.94
400F	50gm	4,138	0	0	21.63

Combustion gas review

HC = Hydrocarbon = raw fuel stock

CO = Carbon monoxide = not fully oxygenated Fuel stock

CO_2 = Carbon dioxide = Oxygenated fuel stock

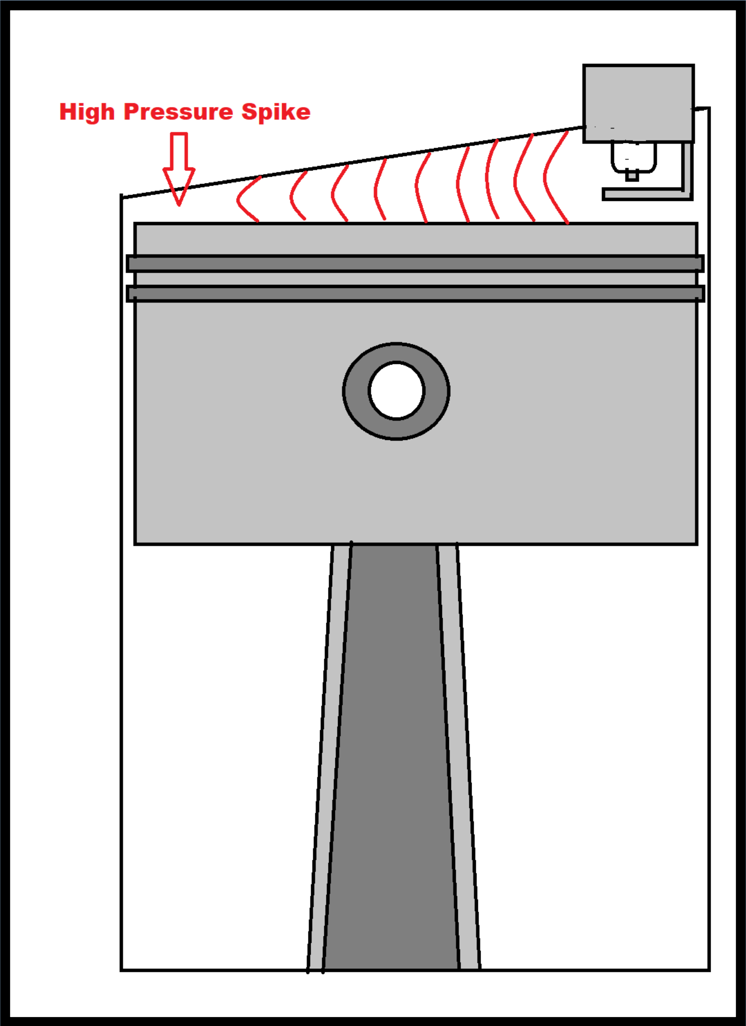
O_2 = Oxygen not converted during combustion

Other gases you will need to know

Nox Nitrogen Oxides

λ LAMBDA

Nox Nitrogen Oxides



Nox Nitrogen Oxides are produced by **high combustion temperatures and/or high pressures.** By redesigning the combustion chamber the Nox can be better controlled.

Lambda (λ) gas reading

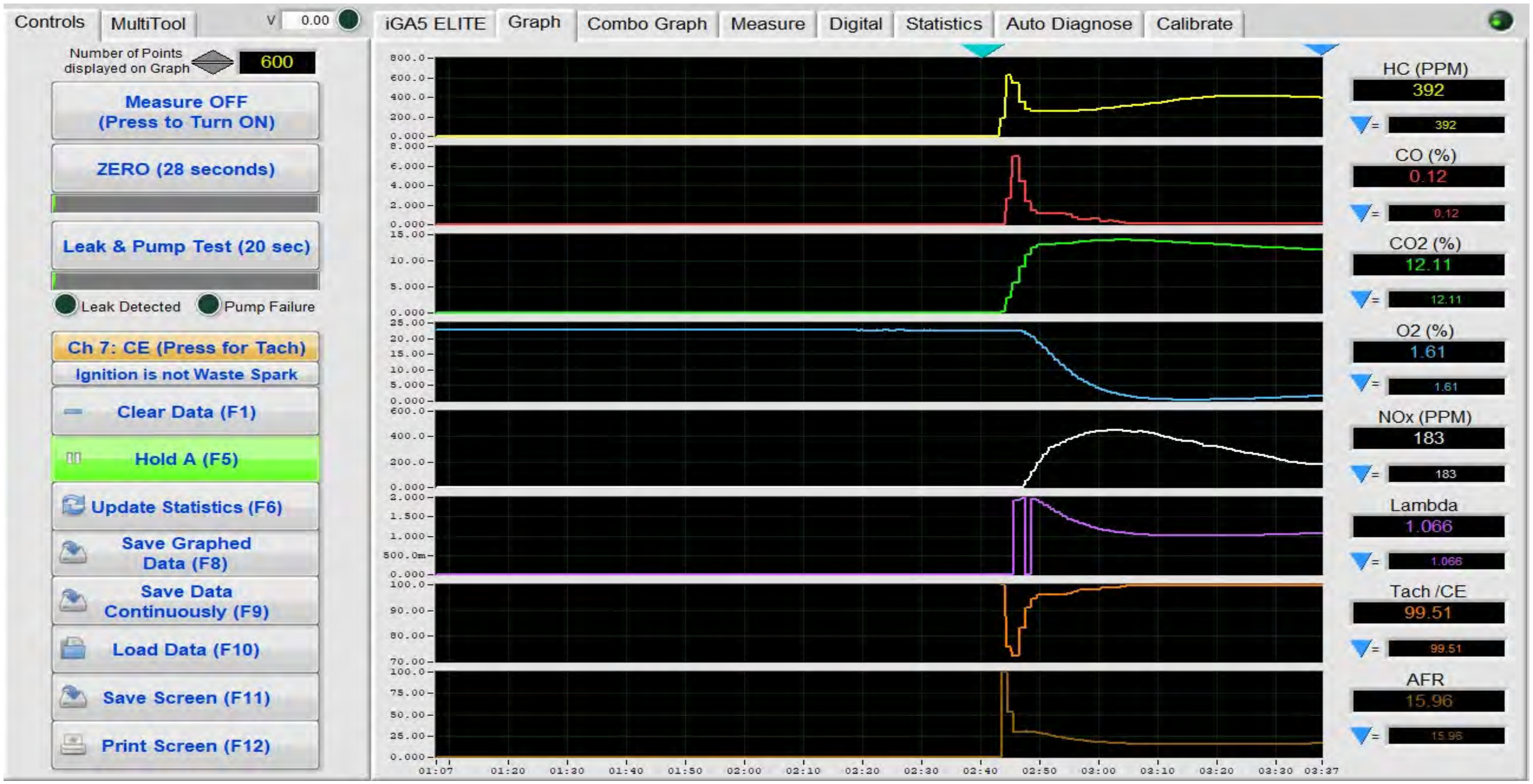
The lambda in the gas law reflects the difference between the actual quantity of oxygen in exhaust gases and the amount that should have been there in order to achieve complete ignition. The observed levels of Oxygen gas, Carbon dioxide, HC, and NOx in the exhaust gas are used to determine lambda. When a mixture contains exactly the amount of oxygen required to burn the amount of fuel present, the ratio will be one to one so lambda will equal 1.00. If the mixture is lean the lambda will be greater than one; .120 = 20% lean. If the mixture is rich it will be less than one; .80 = 20% rich.

Checking for exhaust leakage will be important

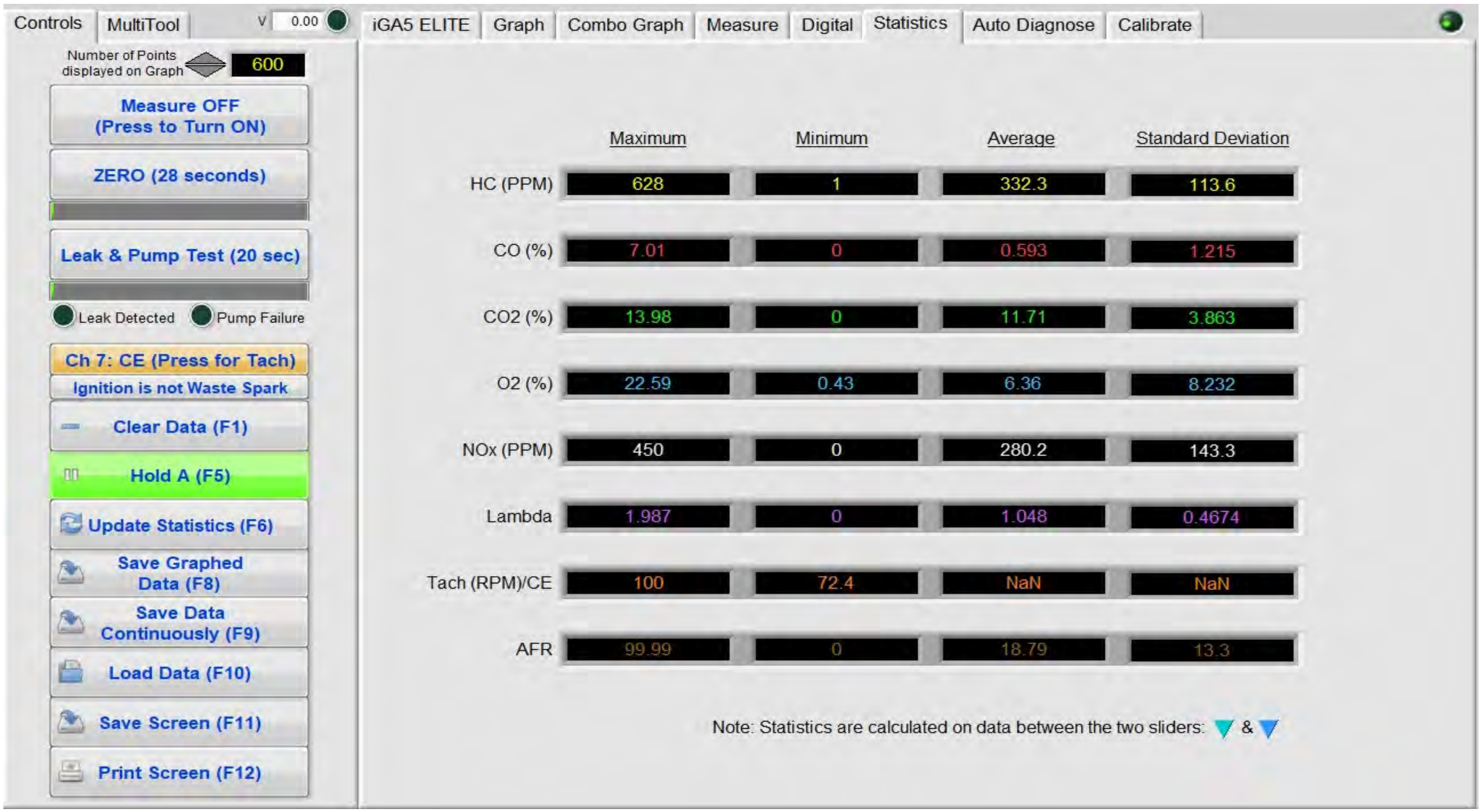
Exhaust must not have any leakage

Test Vehicle 1990 GMC 5.7L TBI

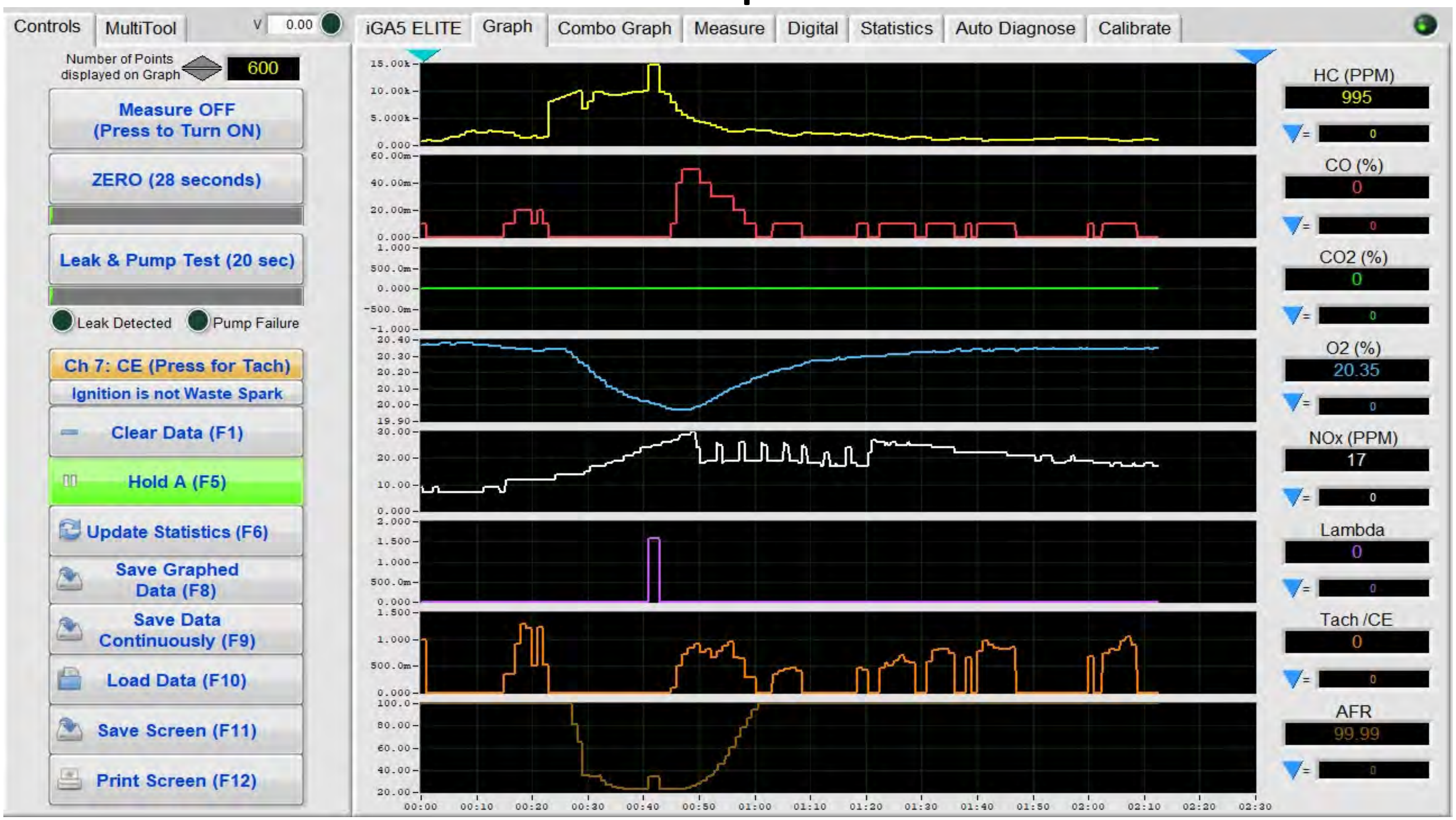
Test Vehicle 60°F start ok



Test Vehicle 60°F start ok



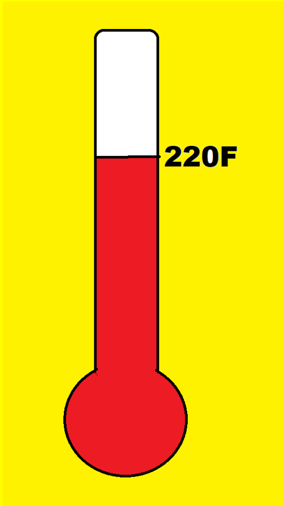
No Start No Spark



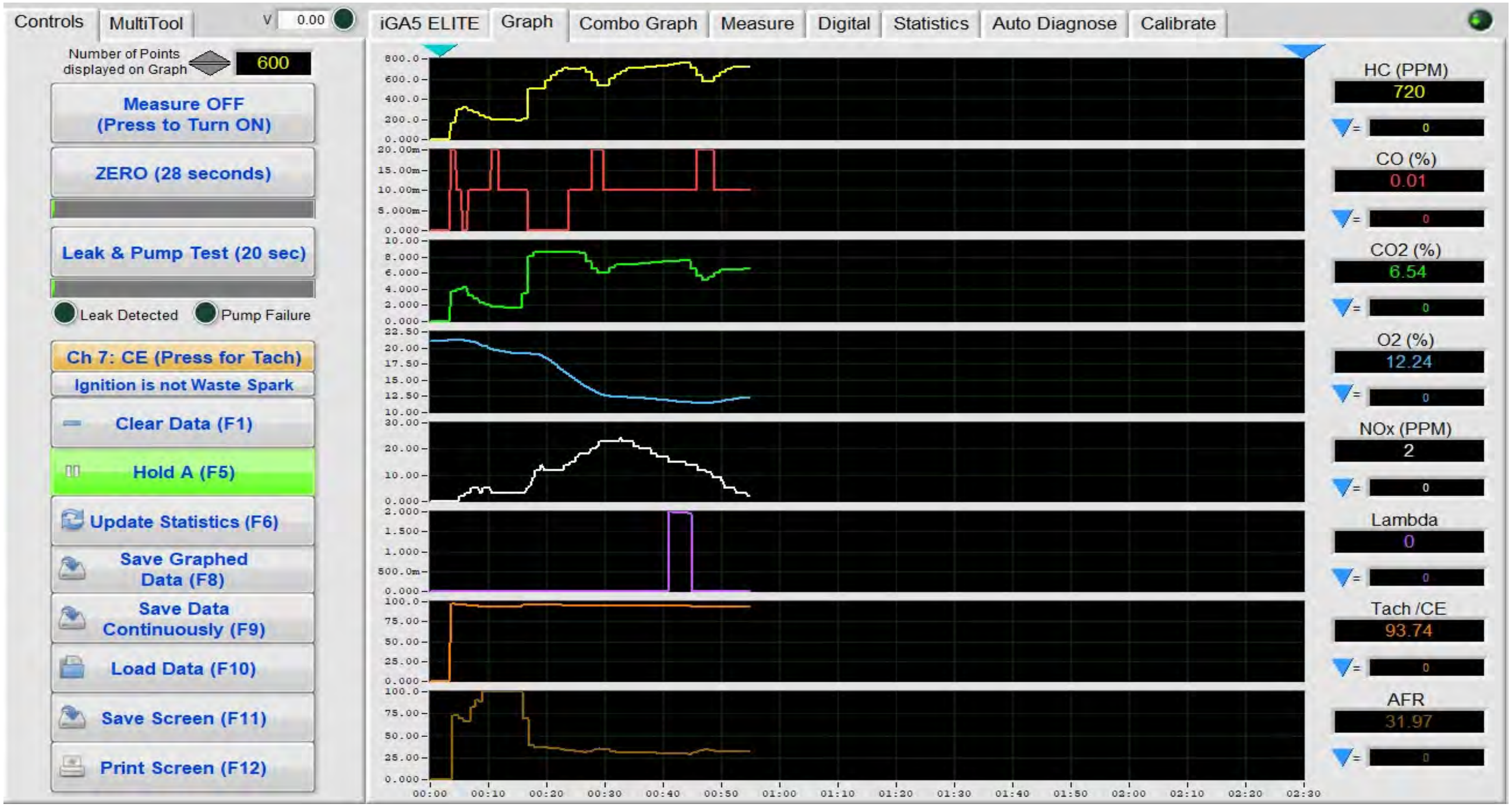
No Start No Spark

WARNING:

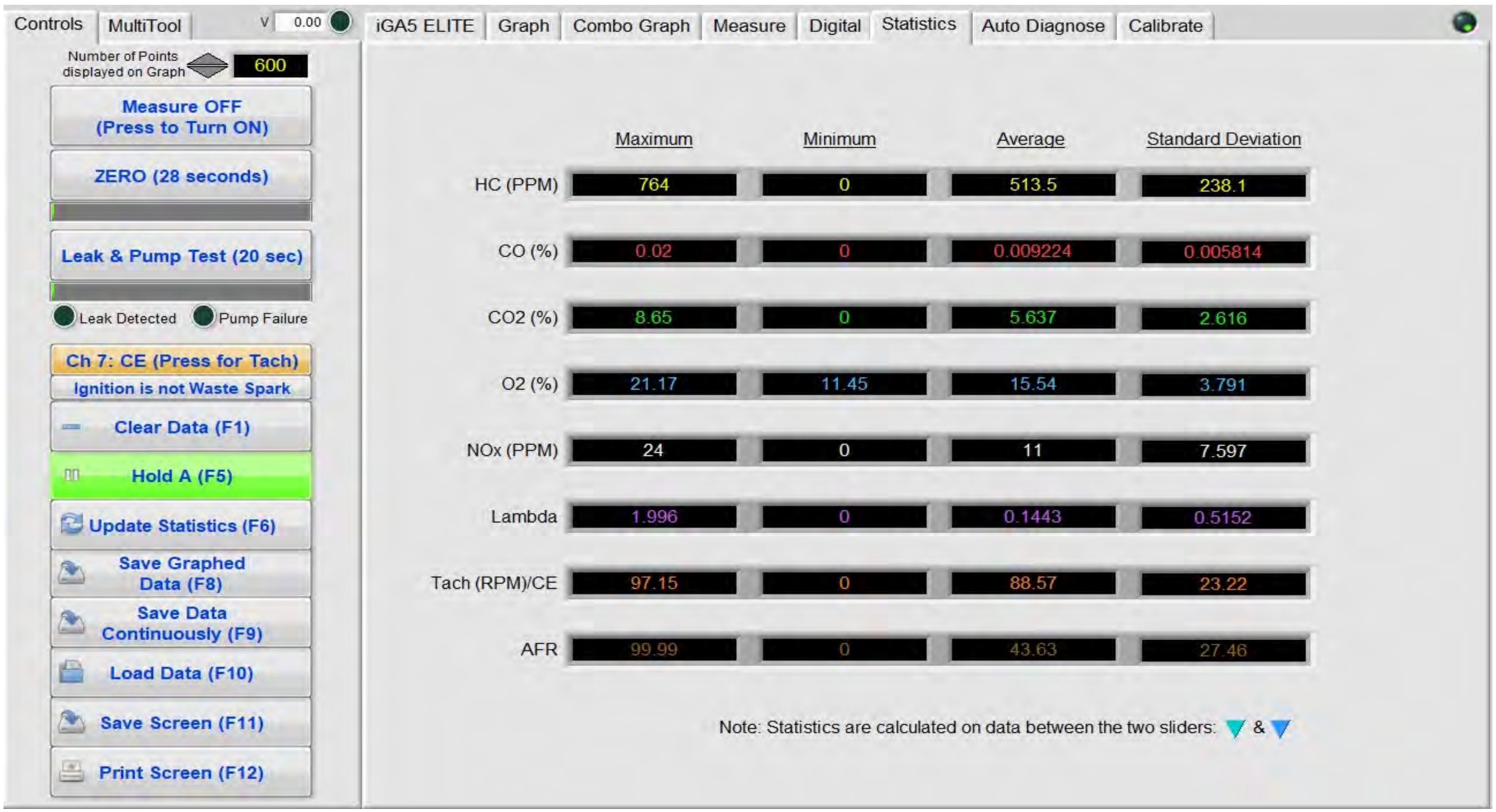
if engine is hot the data will look like spark is present.



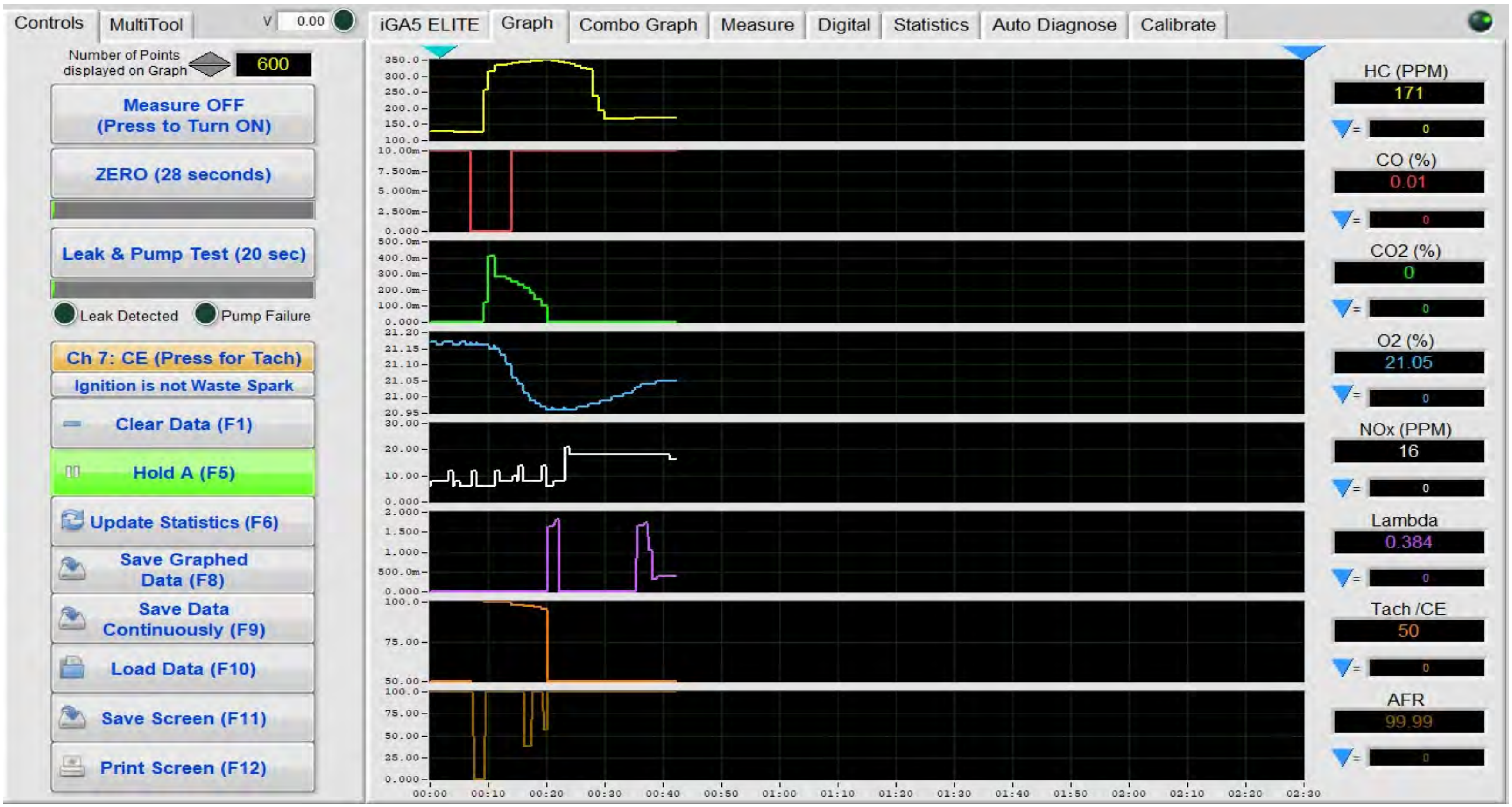
No Start No Spark engine hot



No Start No Spark engine hot



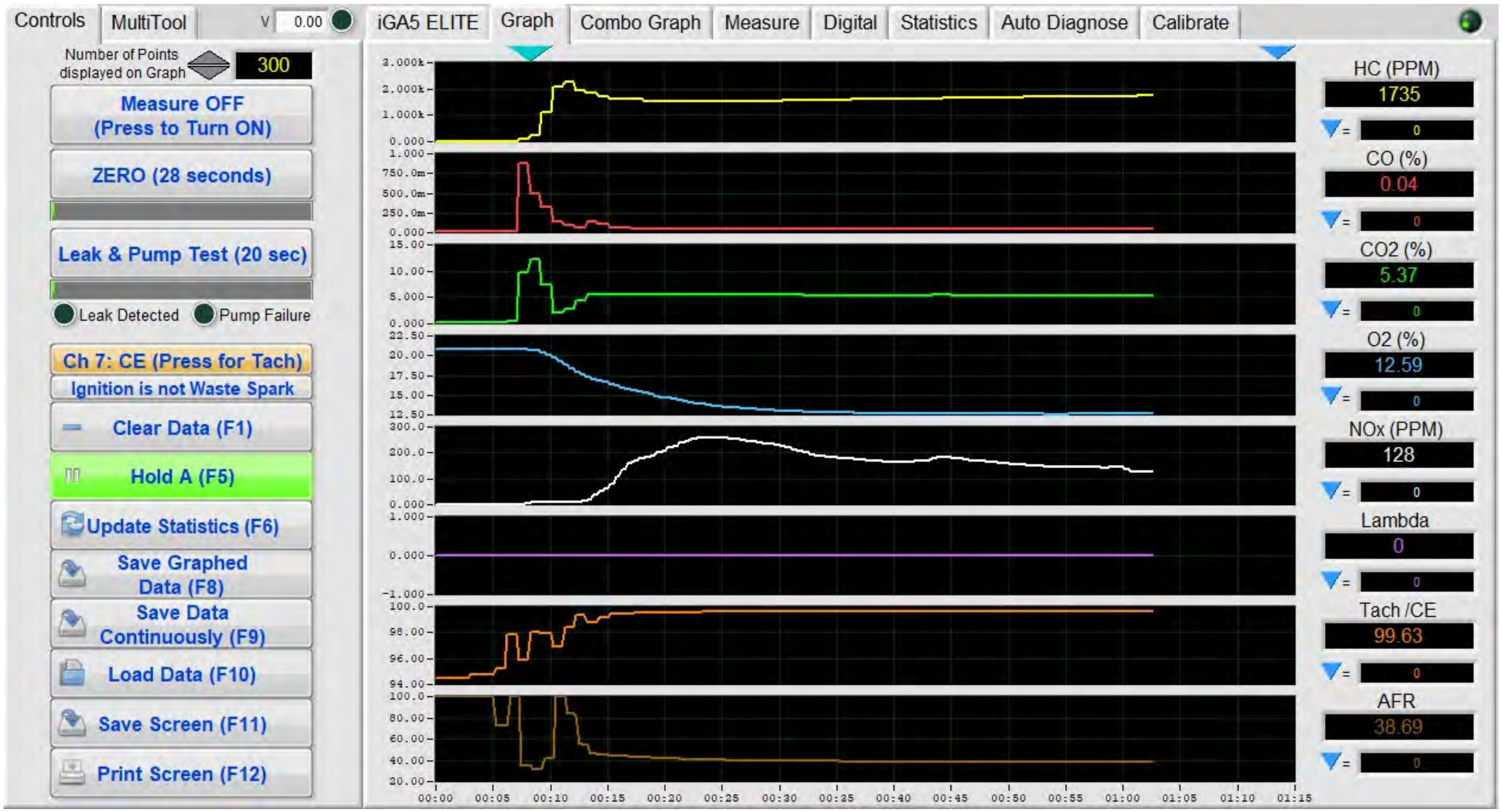
No Start No fuel



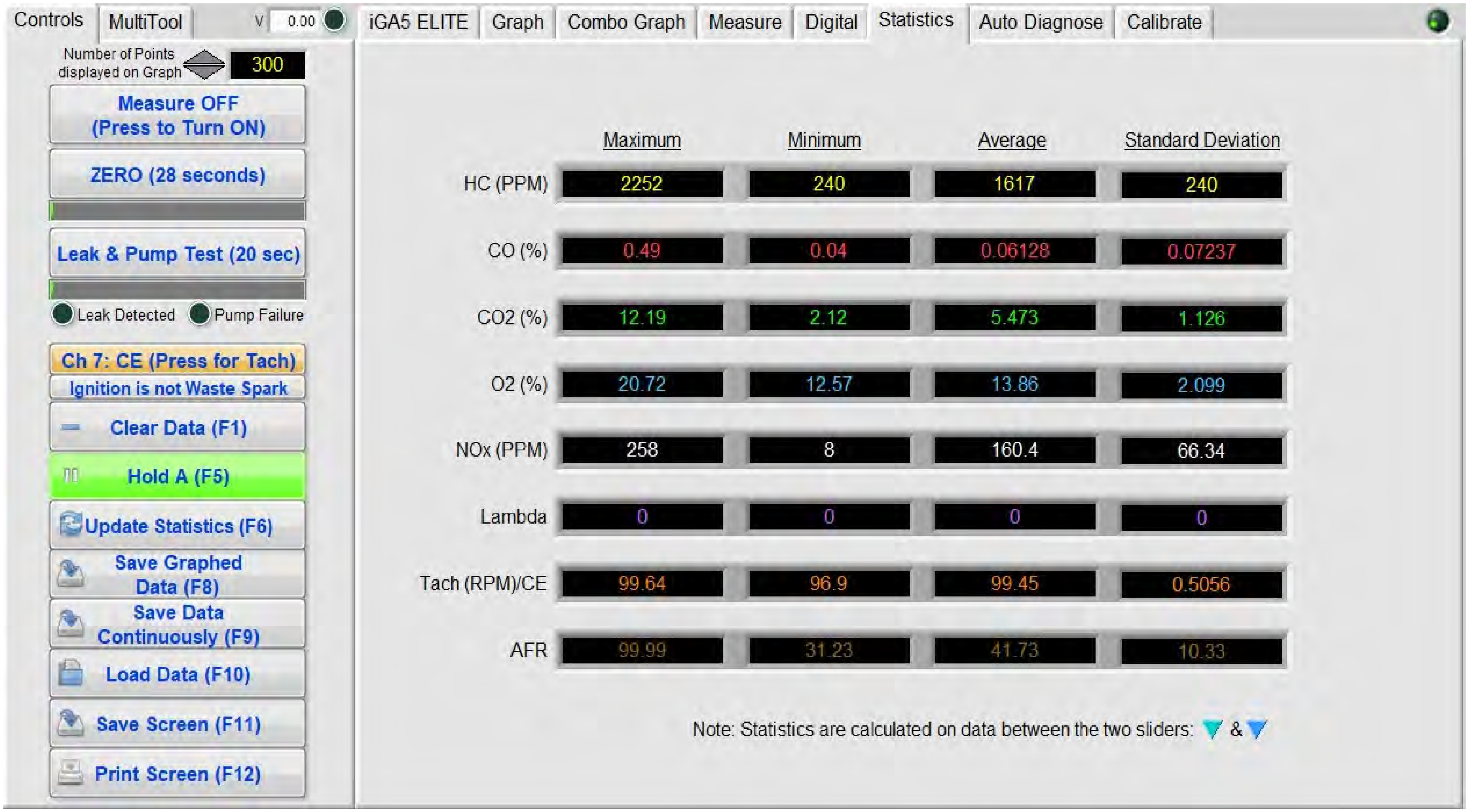
No Start No fuel

	Maximum	Minimum	Average	Standard Deviation
HC (PPM)	349	127	235.7	91.8
CO (%)	0.01	0	0.008343	0.003729
CO2 (%)	0.41	0	0.05982	0.1107
O2 (%)	21.17	20.96	21.05	0.0783
NOx (PPM)	21	6	12.63	5.187
Lambda	1.825	0	0.2152	0.5135
Tach (RPM)/CE	100	50	NaN	NaN
AFR	99.99	0	92.66	23.87

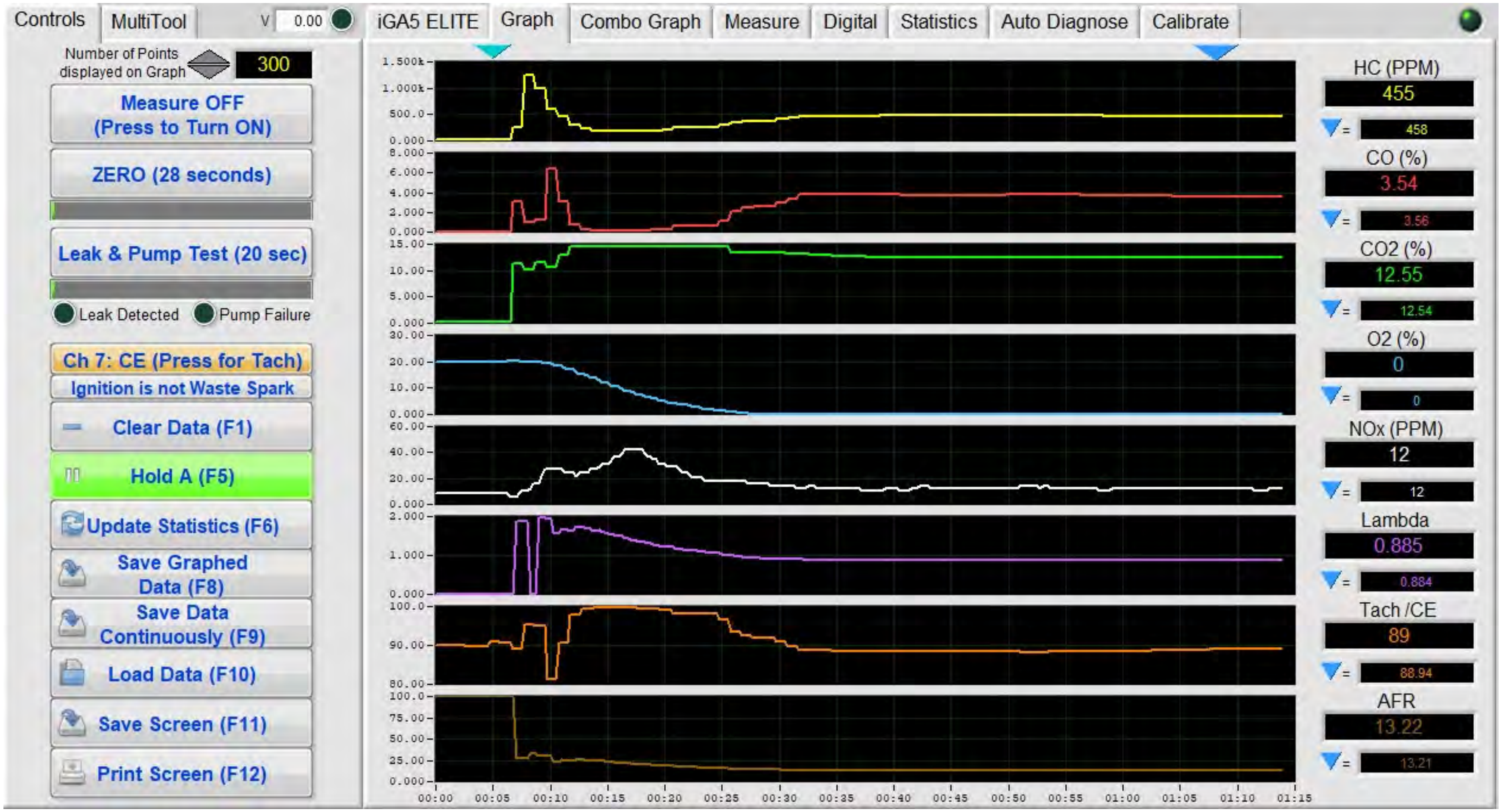
Start LOW power injector unplugged



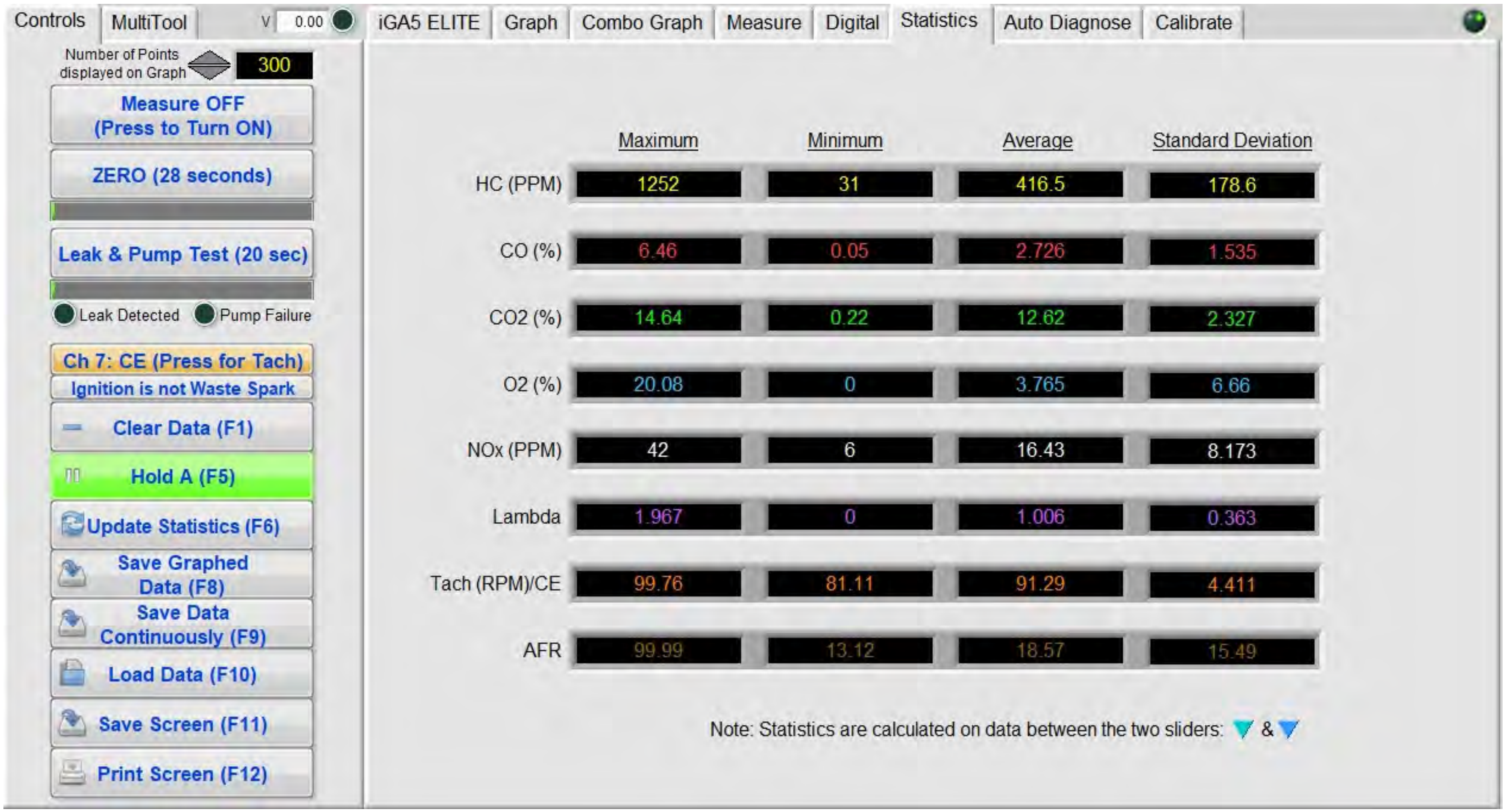
Start LOW power injector unplugged



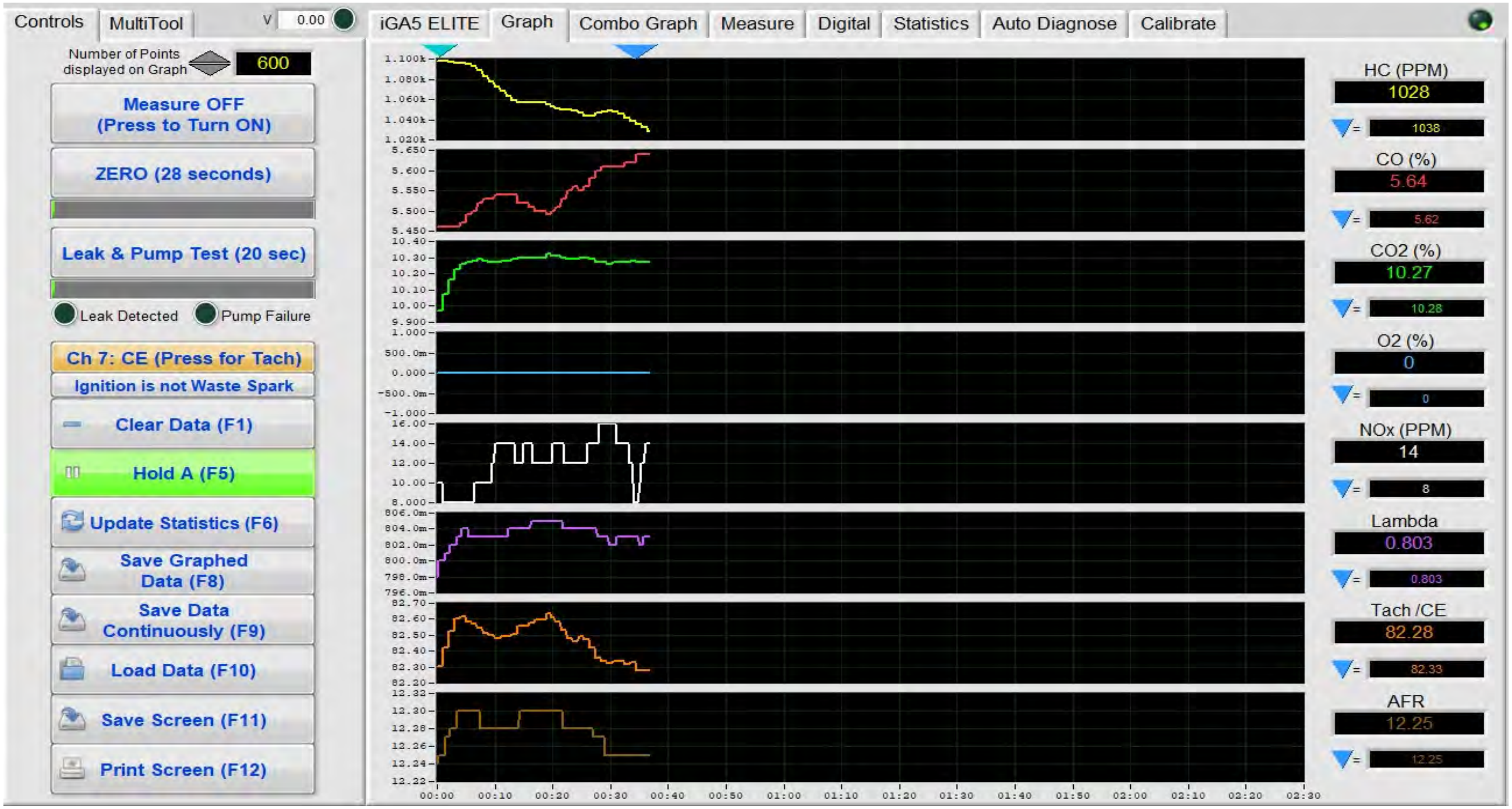
Start low power missing bad coil wire



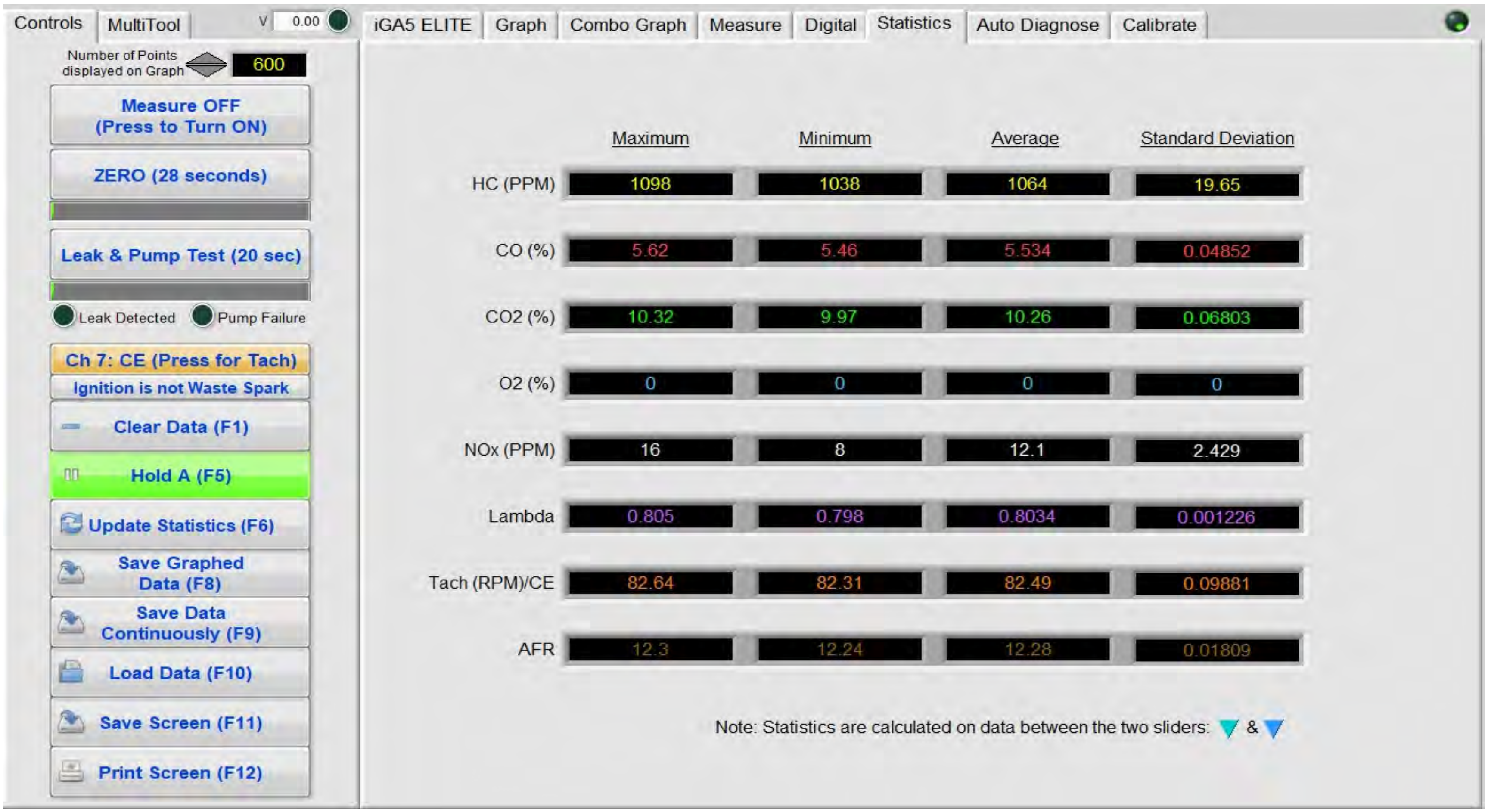
Start low power missing bad coil wire



Start rough idle missing "EGR on"

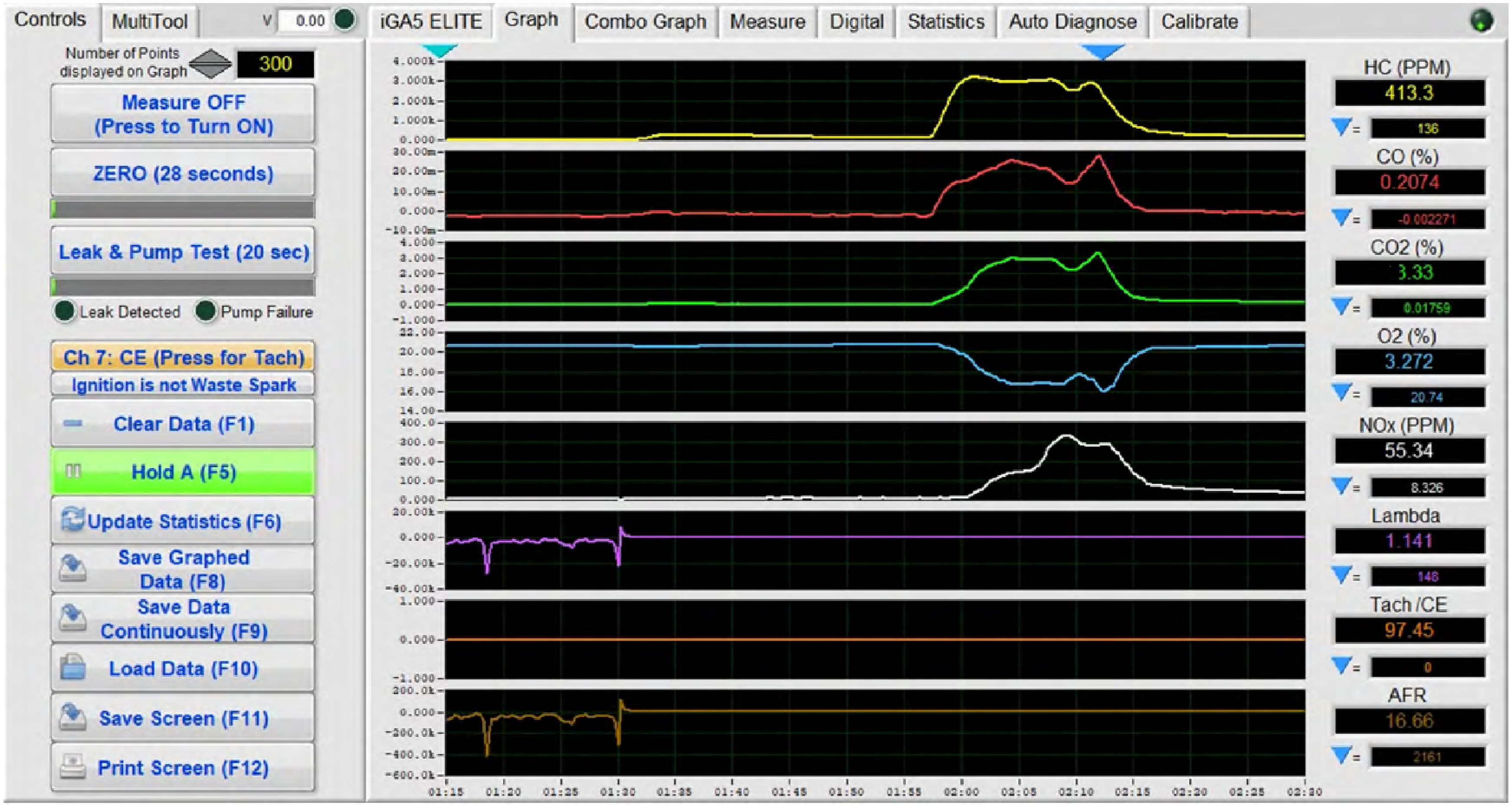


Start rough idle missing “EGR”



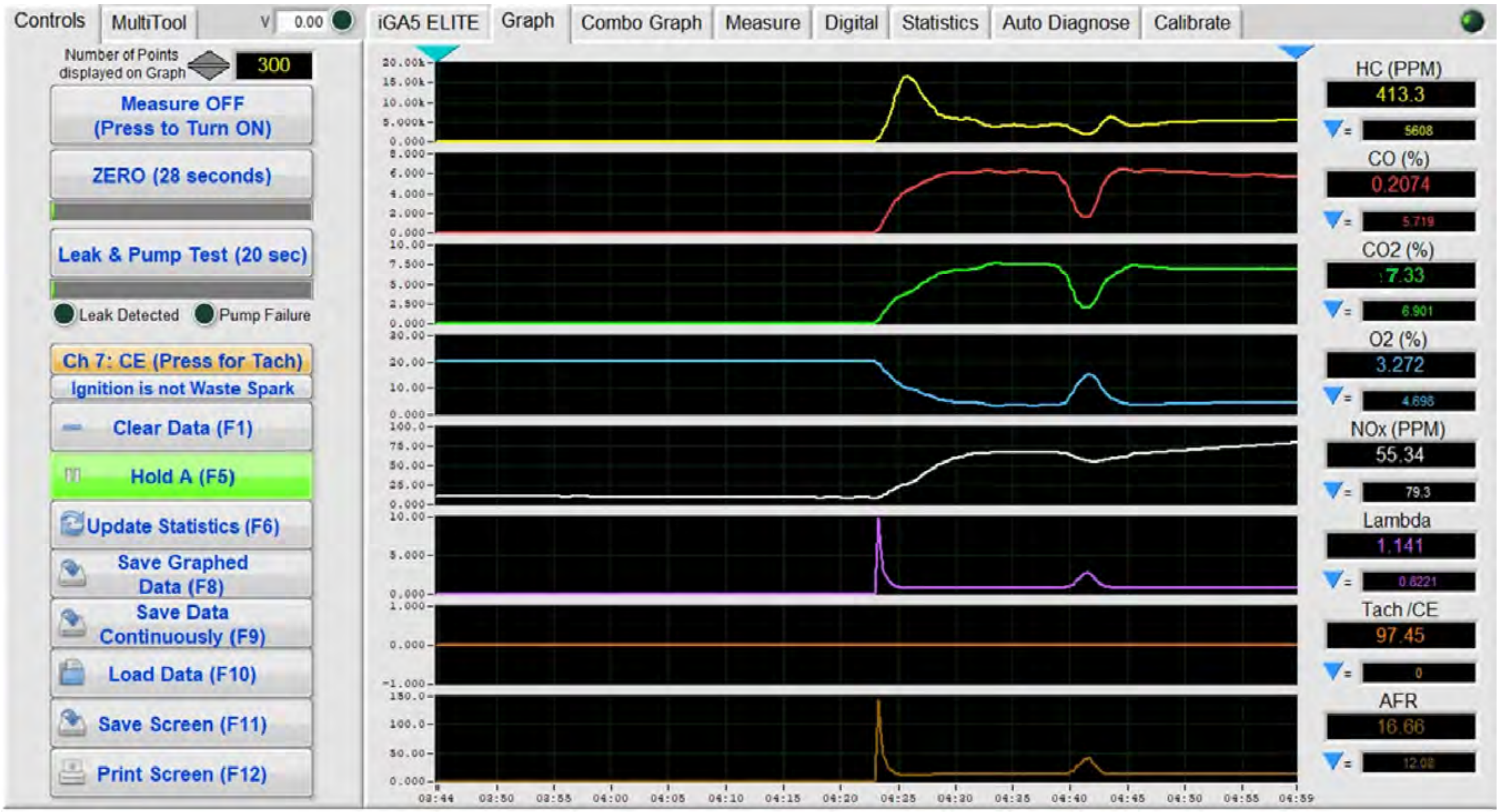
Gasoline exhaust gas Studies

No Start Chevy 3.1L Bad fuel pump low PSI

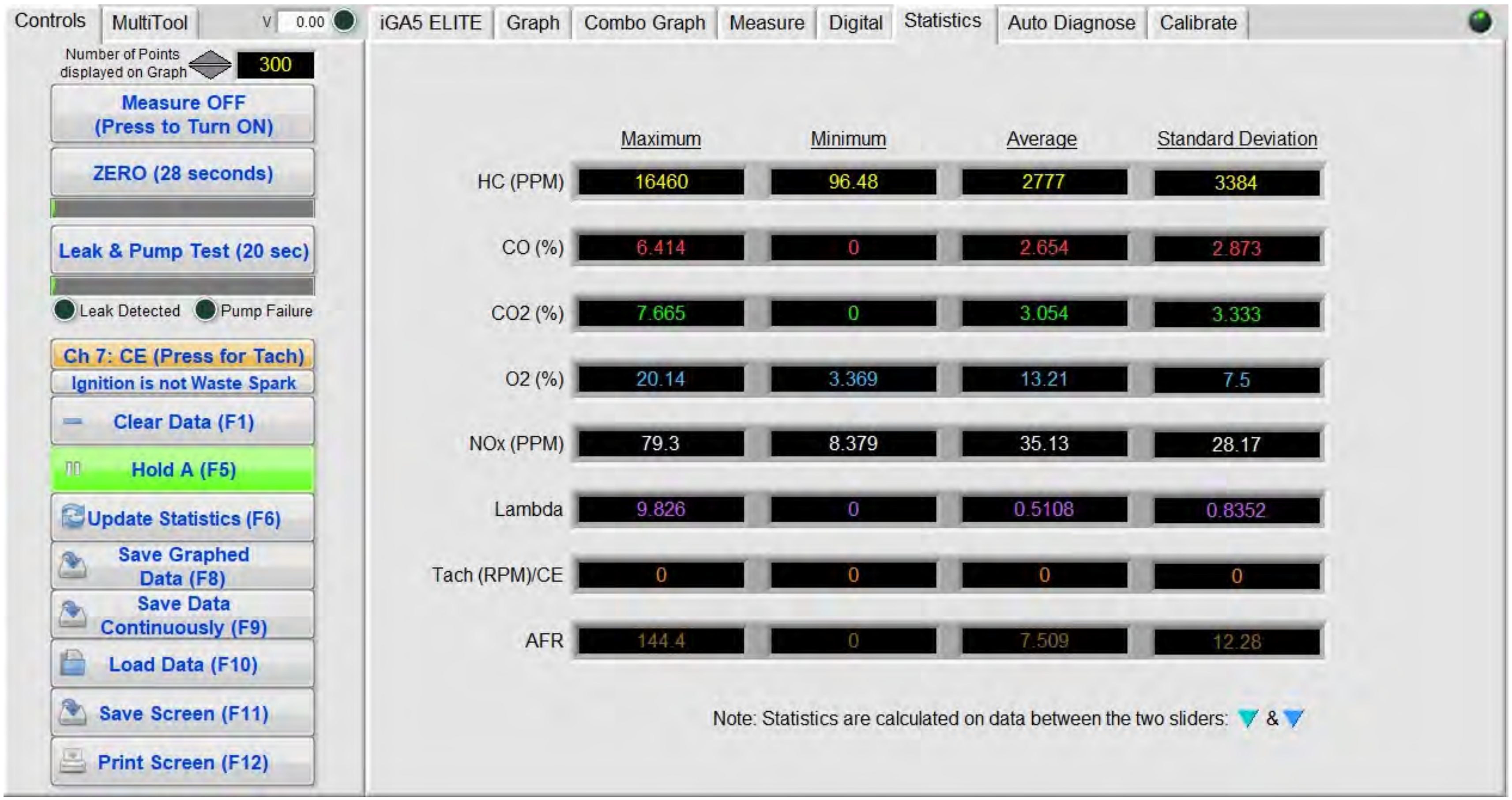


No Start Chevy 3.1L Bad fuel pump low PSI

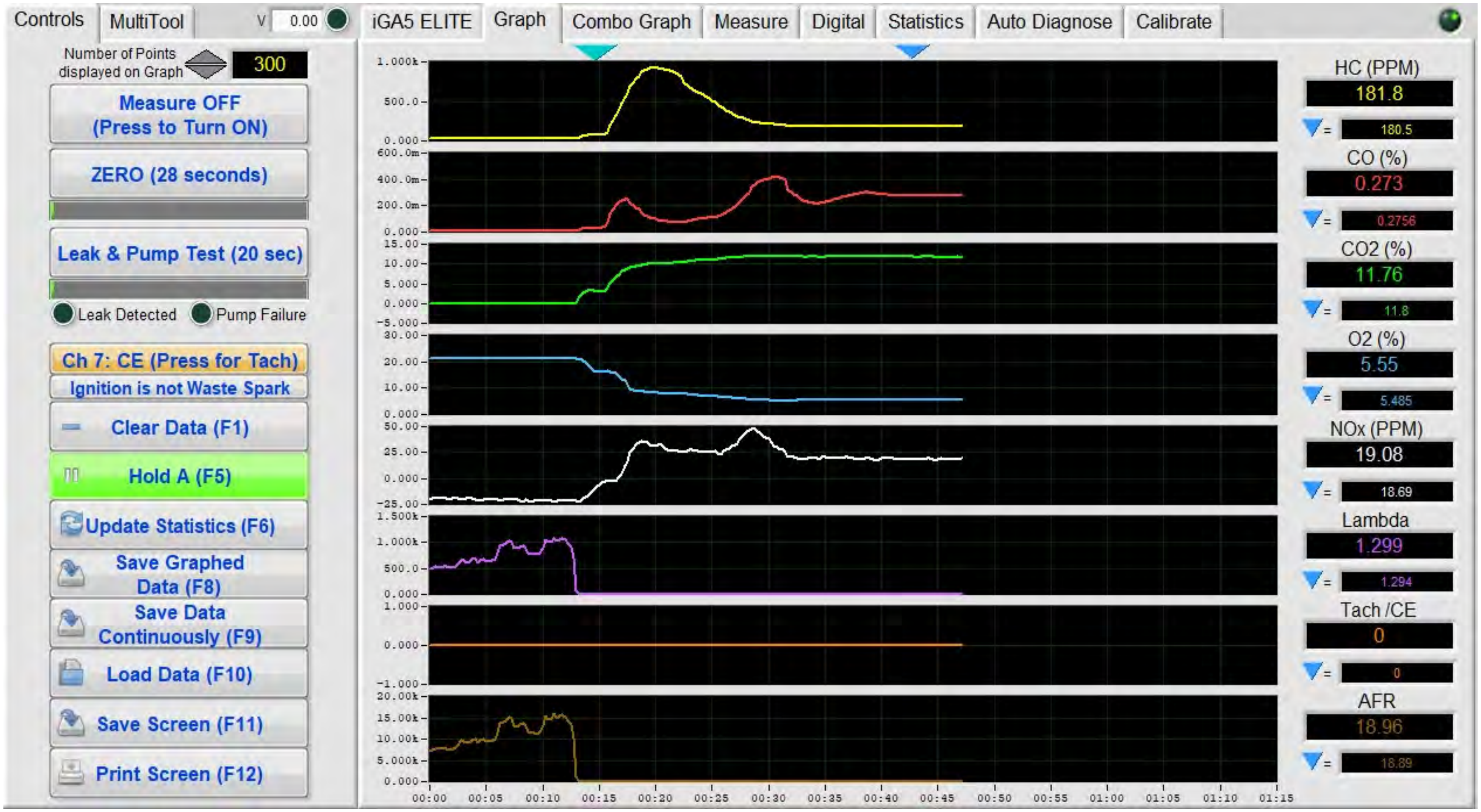
Long Start Chevy S10 4.3L leaking fuel reg



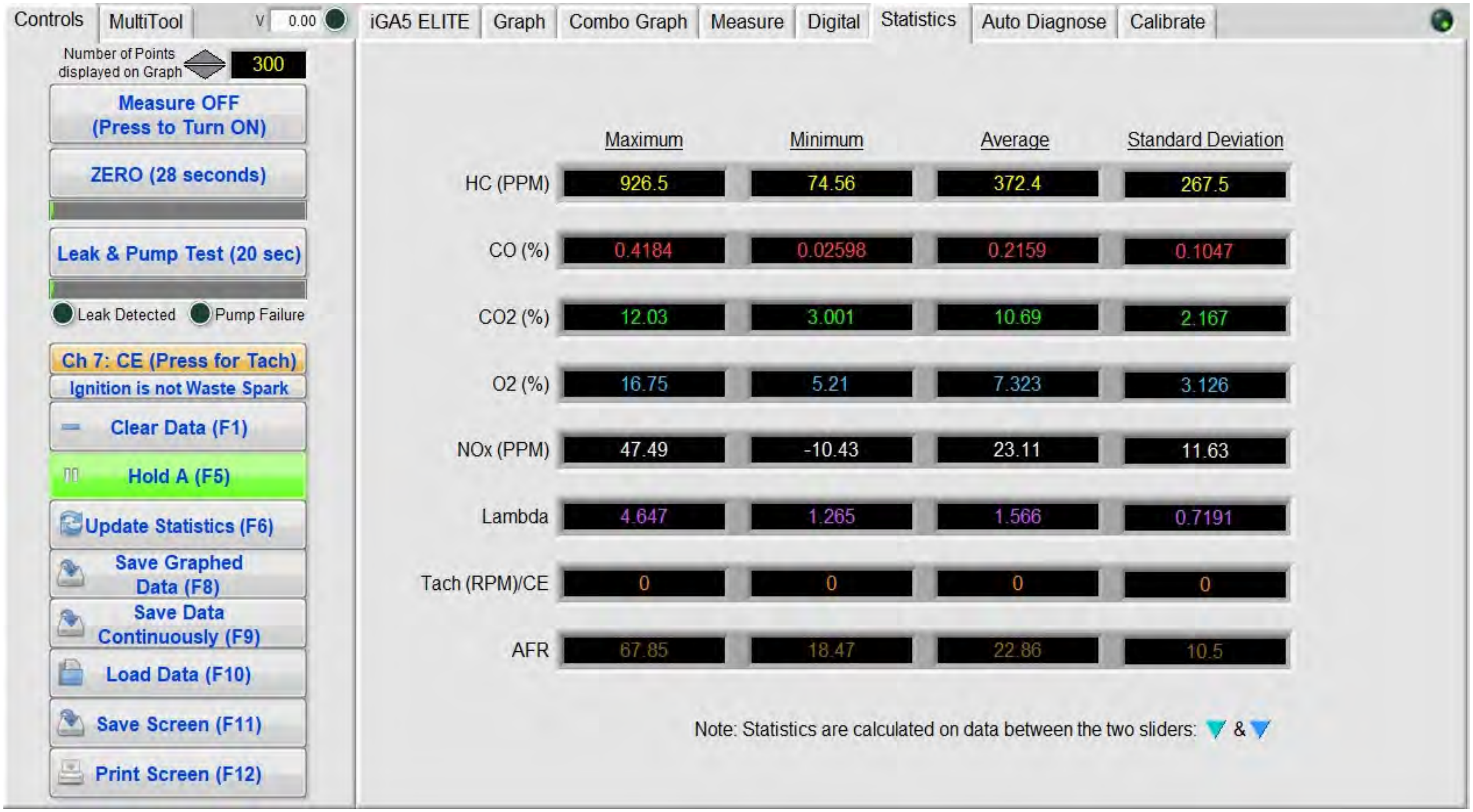
Long Start Chevy S10 4.3L leaking fuel reg



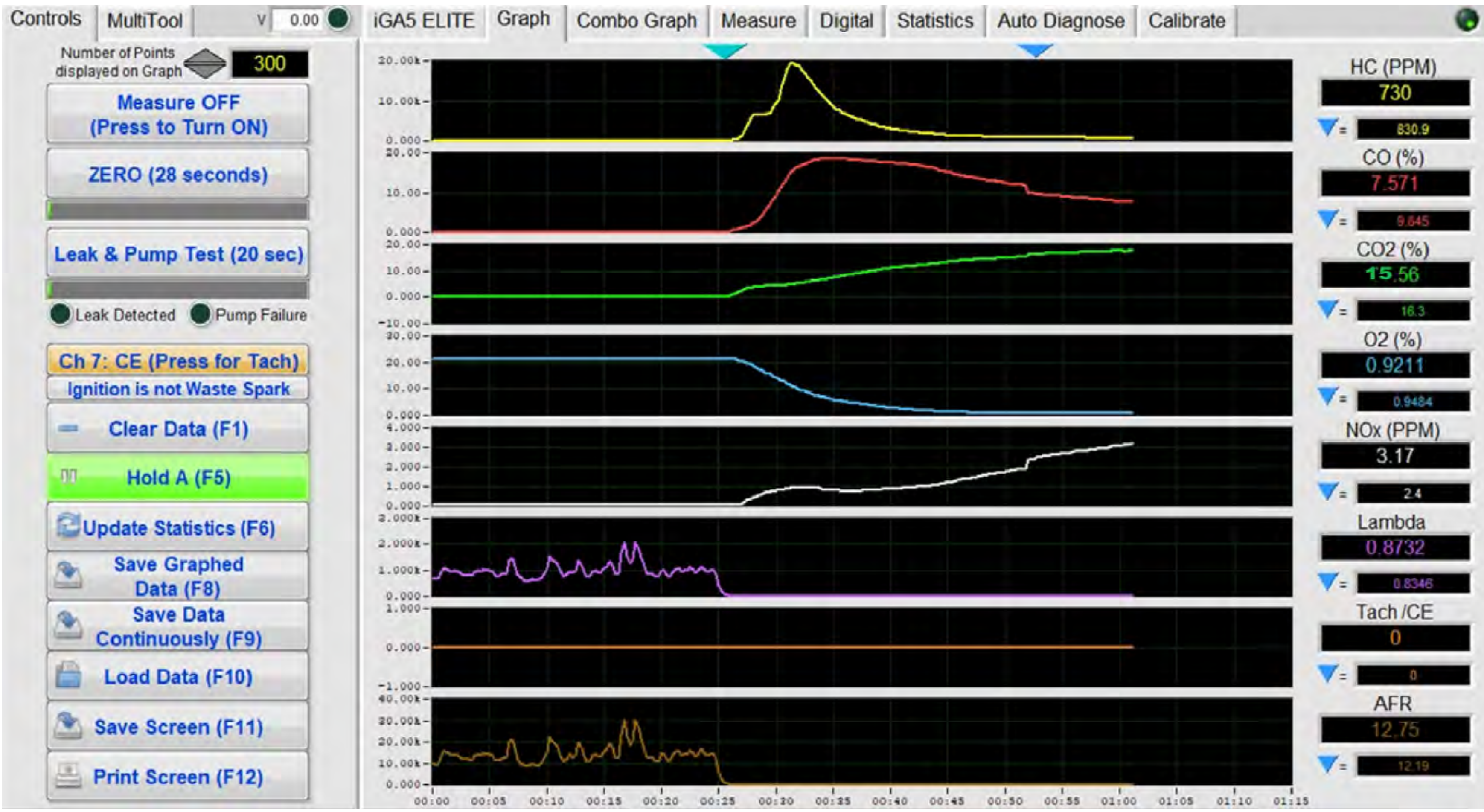
long Start Chevy S10 4.3L low fuel PSI



long Start Chevy S10 4.3L low fuel PSI

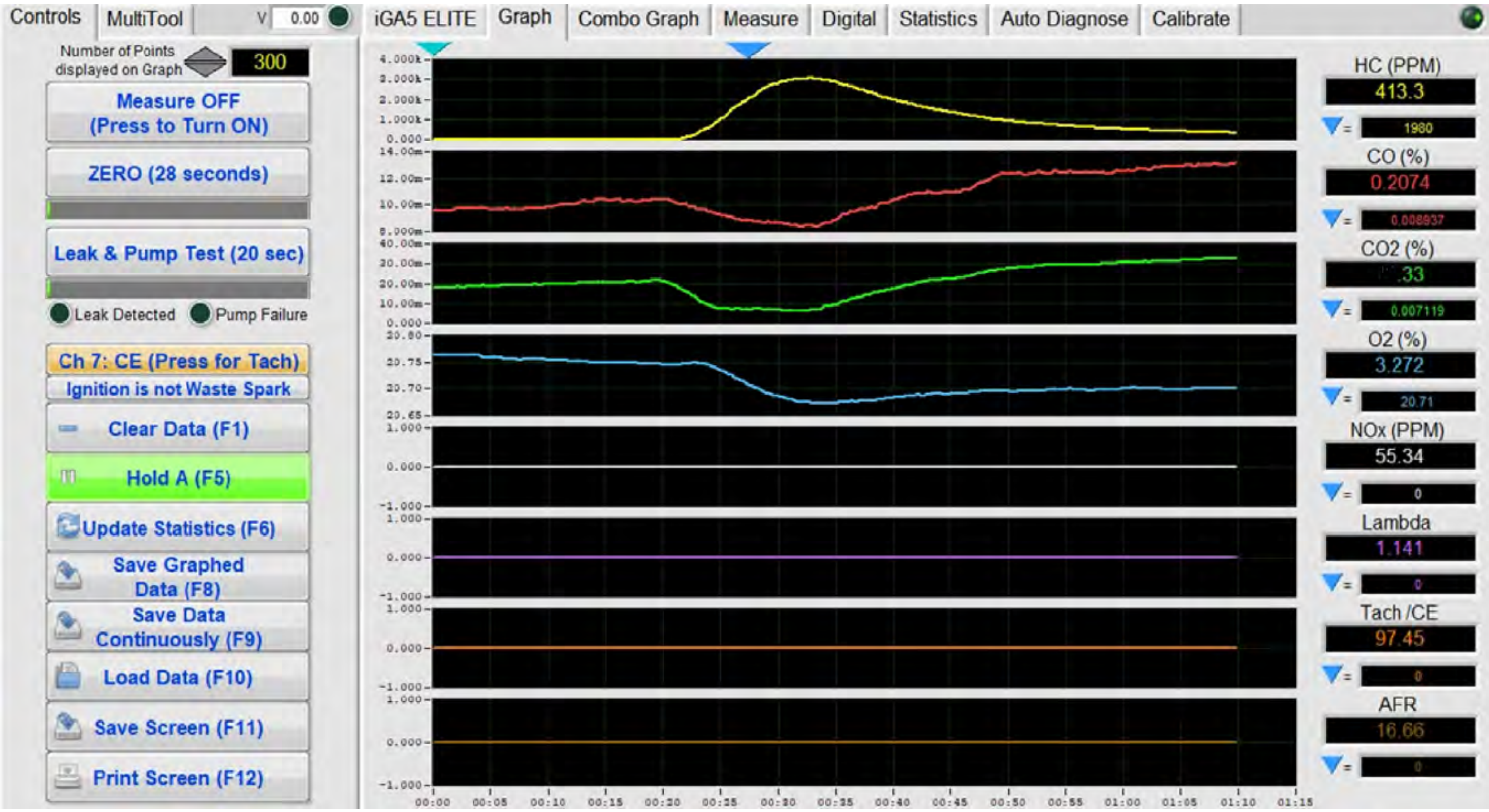


Dodge long Start injector leaking

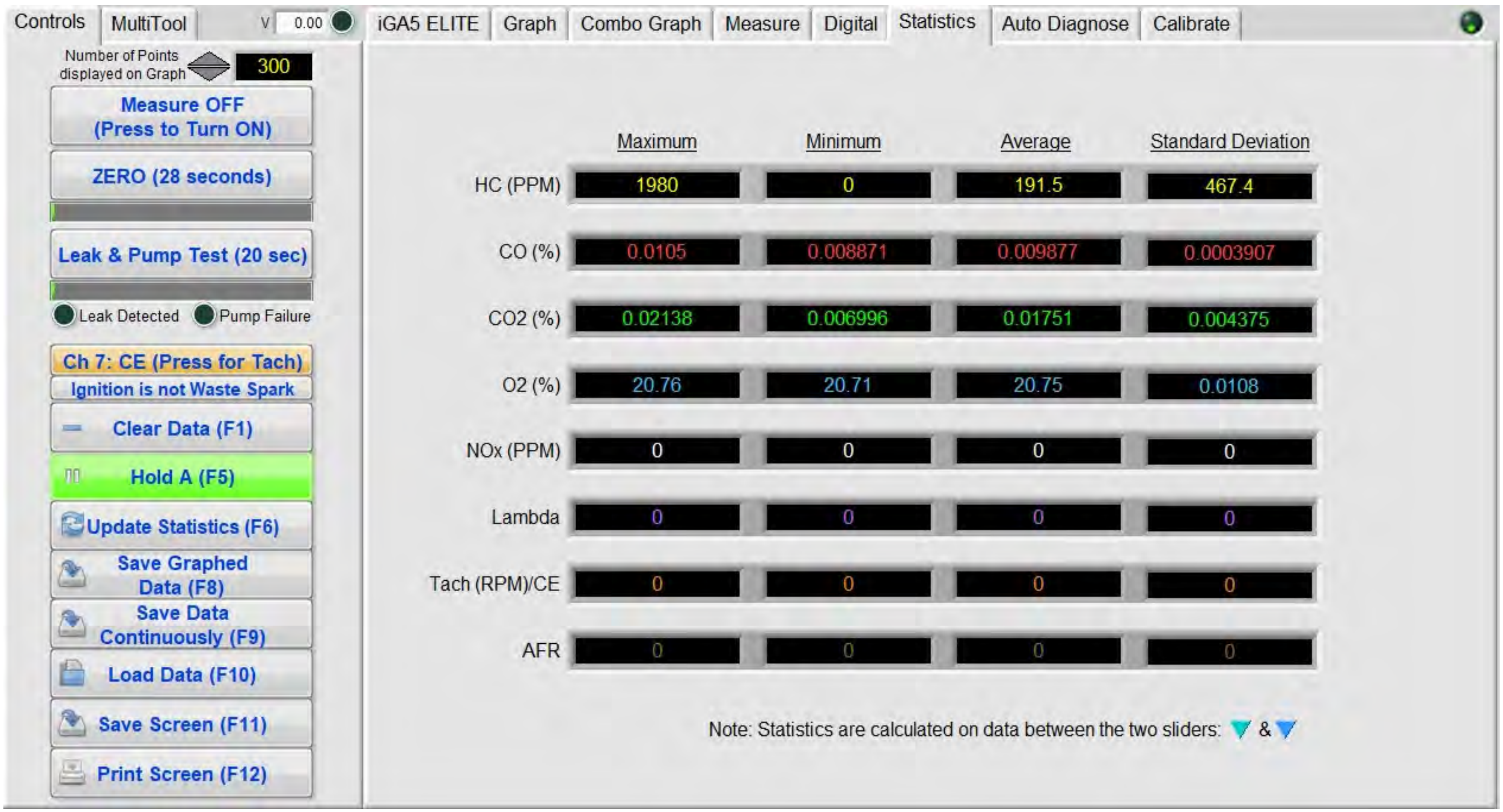


Dodge long Start injector leaking

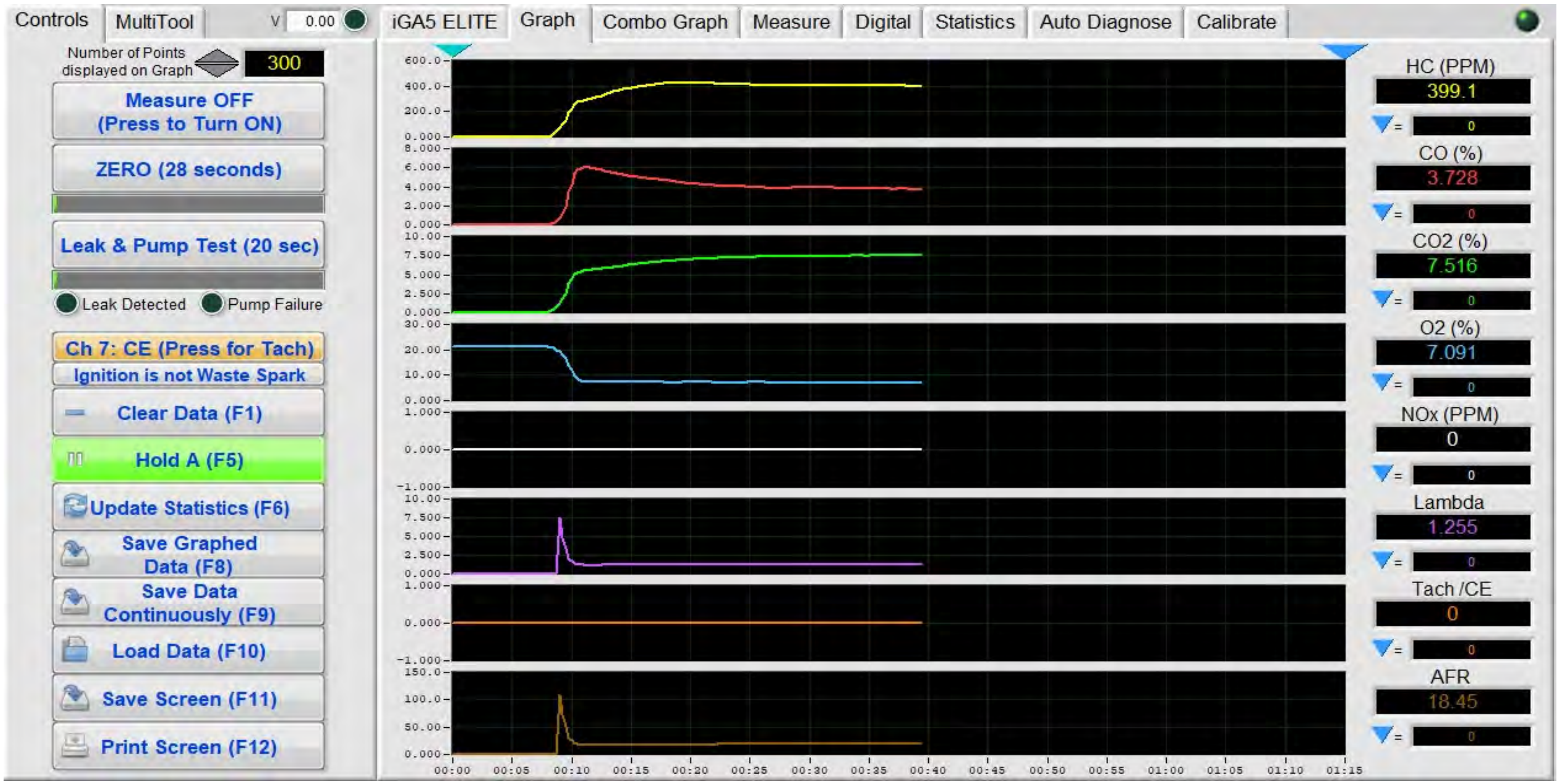
No Start Acura low fuel pressure



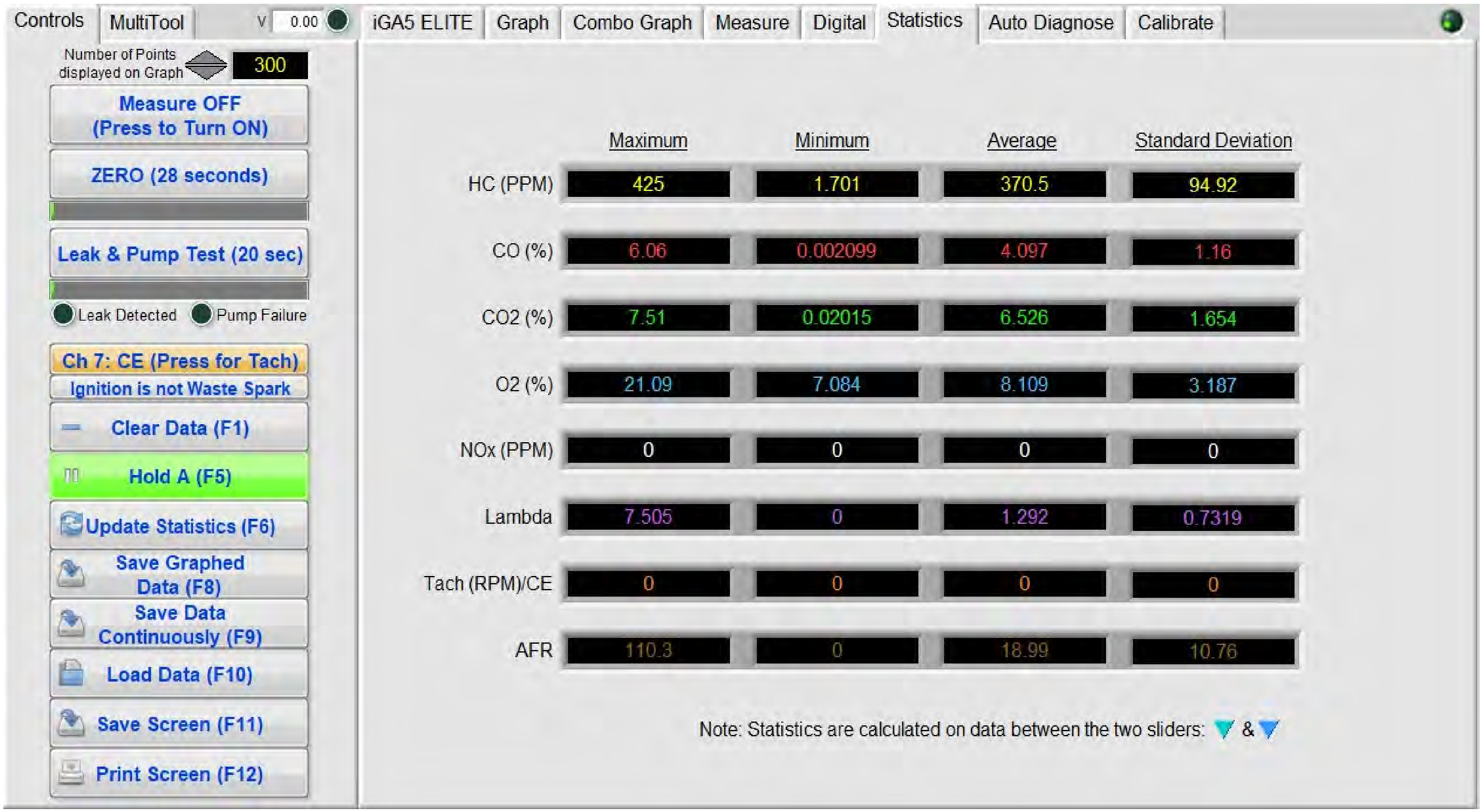
No Start Acura low fuel pressure



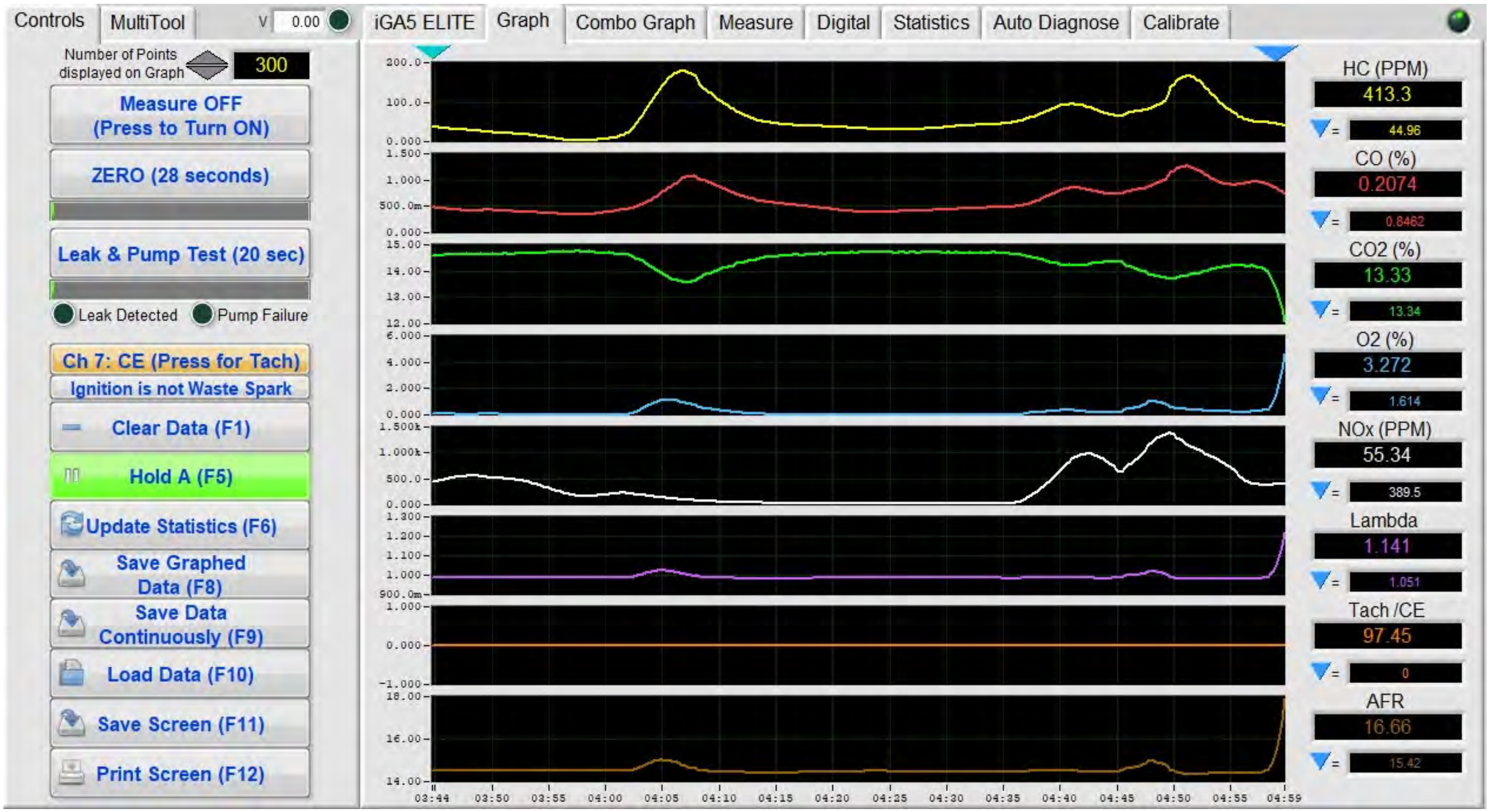
O2 failure -35% LTFT



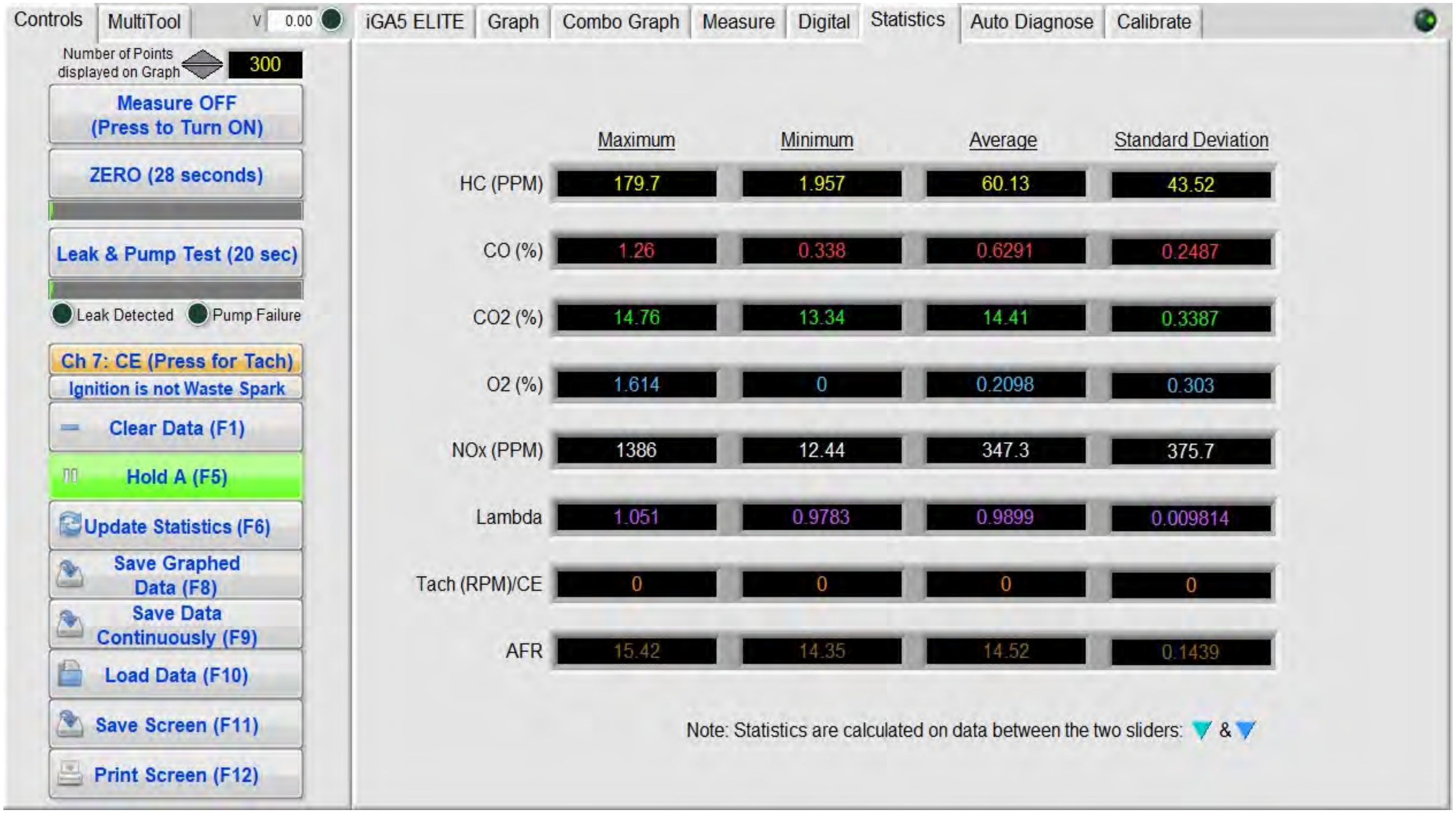
O2 failure -35% LTFT



Toyota Bad Cat

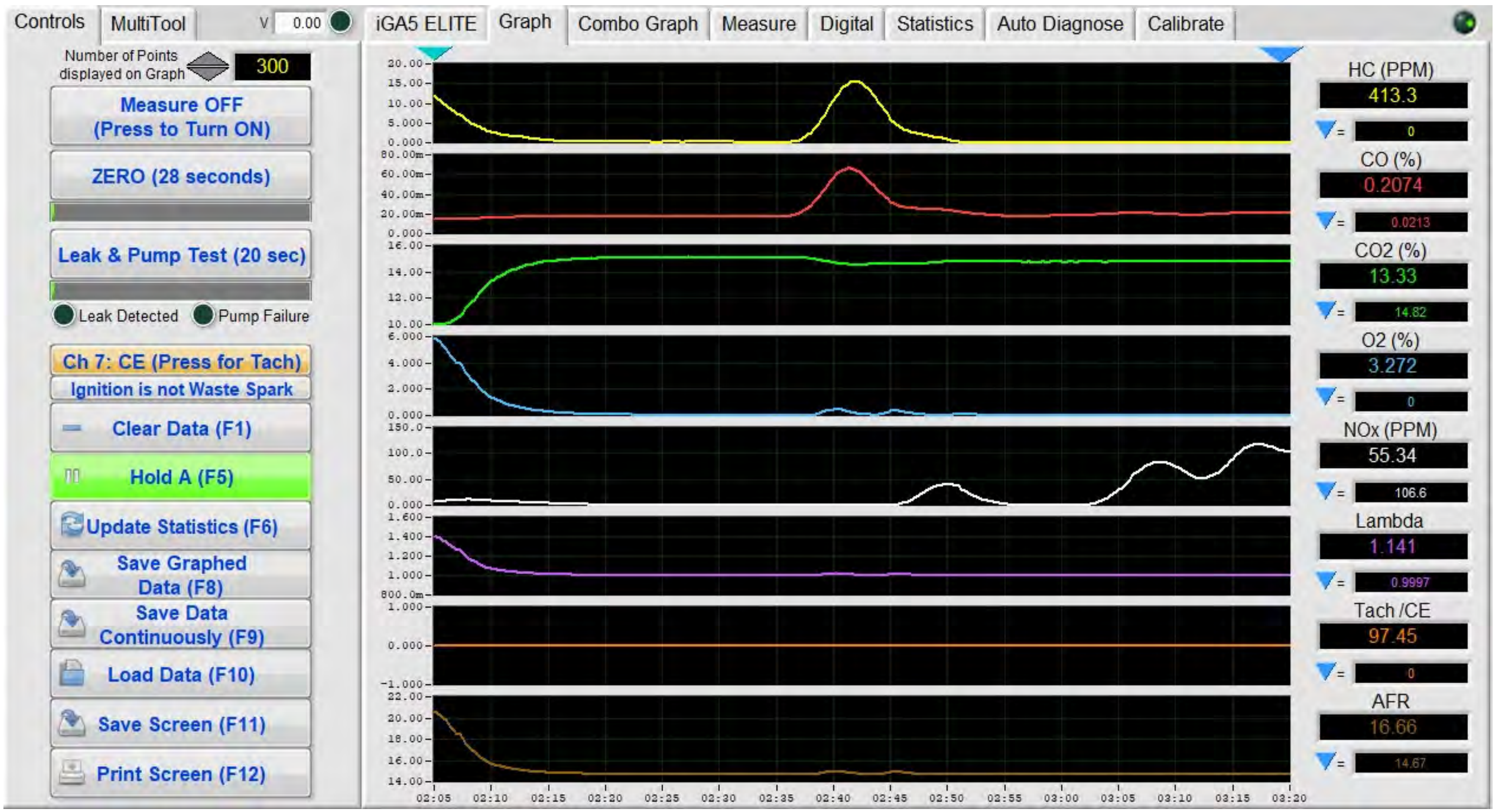


Toyota Bad Cat



	Maximum	Minimum	Average	Standard Deviation
HC (PPM)	179.7	1.957	60.13	43.52
CO (%)	1.26	0.338	0.6291	0.2487
CO2 (%)	14.76	13.34	14.41	0.3387
O2 (%)	1.614	0	0.2098	0.303
NOx (PPM)	1386	12.44	347.3	375.7
Lambda	1.051	0.9783	0.9899	0.009814
Tach (RPM)/CE	0	0	0	0
AFR	15.42	14.35	14.52	0.1439

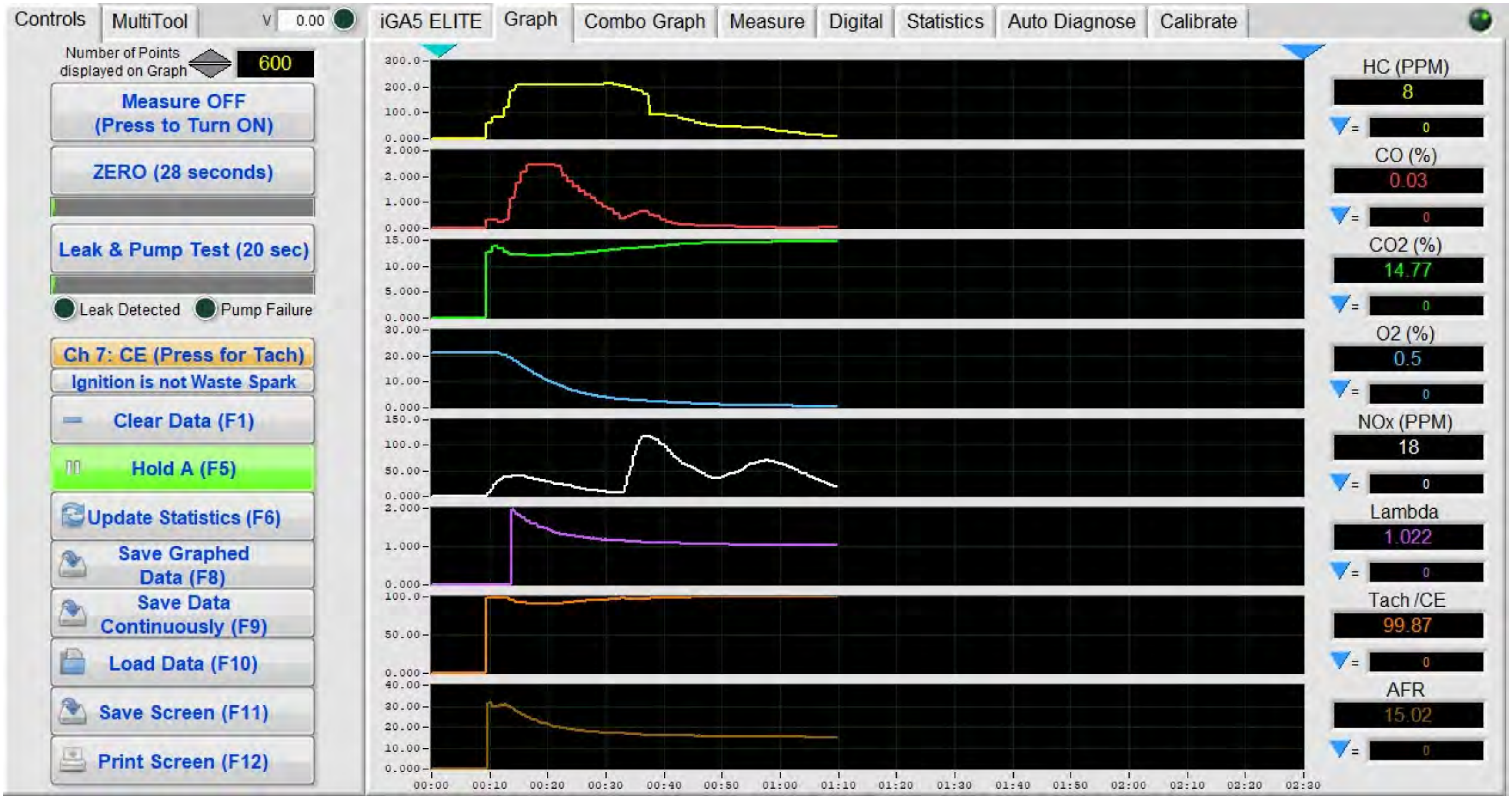
Toyota New Cat



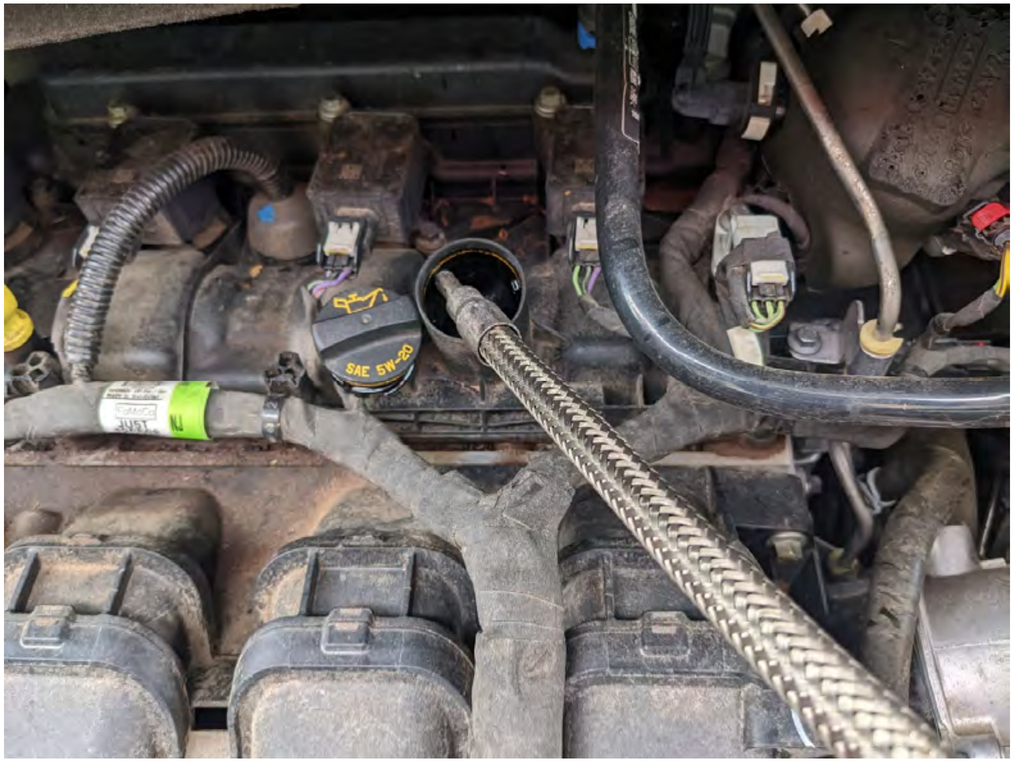
Toyota New Cat

	Maximum	Minimum	Average	Standard Deviation
HC (PPM)	15.48	0	1.817	3.644
CO (%)	0.06633	0.01423	0.02195	0.01046
CO2 (%)	15.12	10.01	14.58	0.965
O2 (%)	5.775	0	0.3287	0.9454
NOx (PPM)	117.6	0	19.61	32.33
Lambda	1.395	0.9994	1.019	0.06202
Tach (RPM)/CE	0	0	0	0
AFR	20.46	14.66	14.95	0.9098

2021 Ford Cat lighting Off



Testing Crank Case Contamination

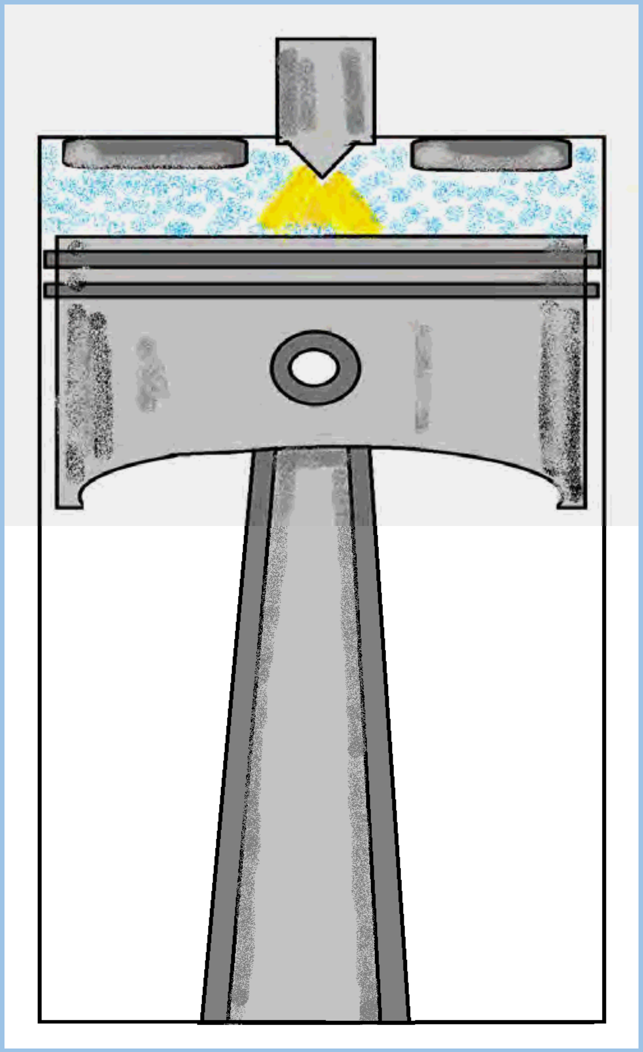


HC reading must be <700ppm

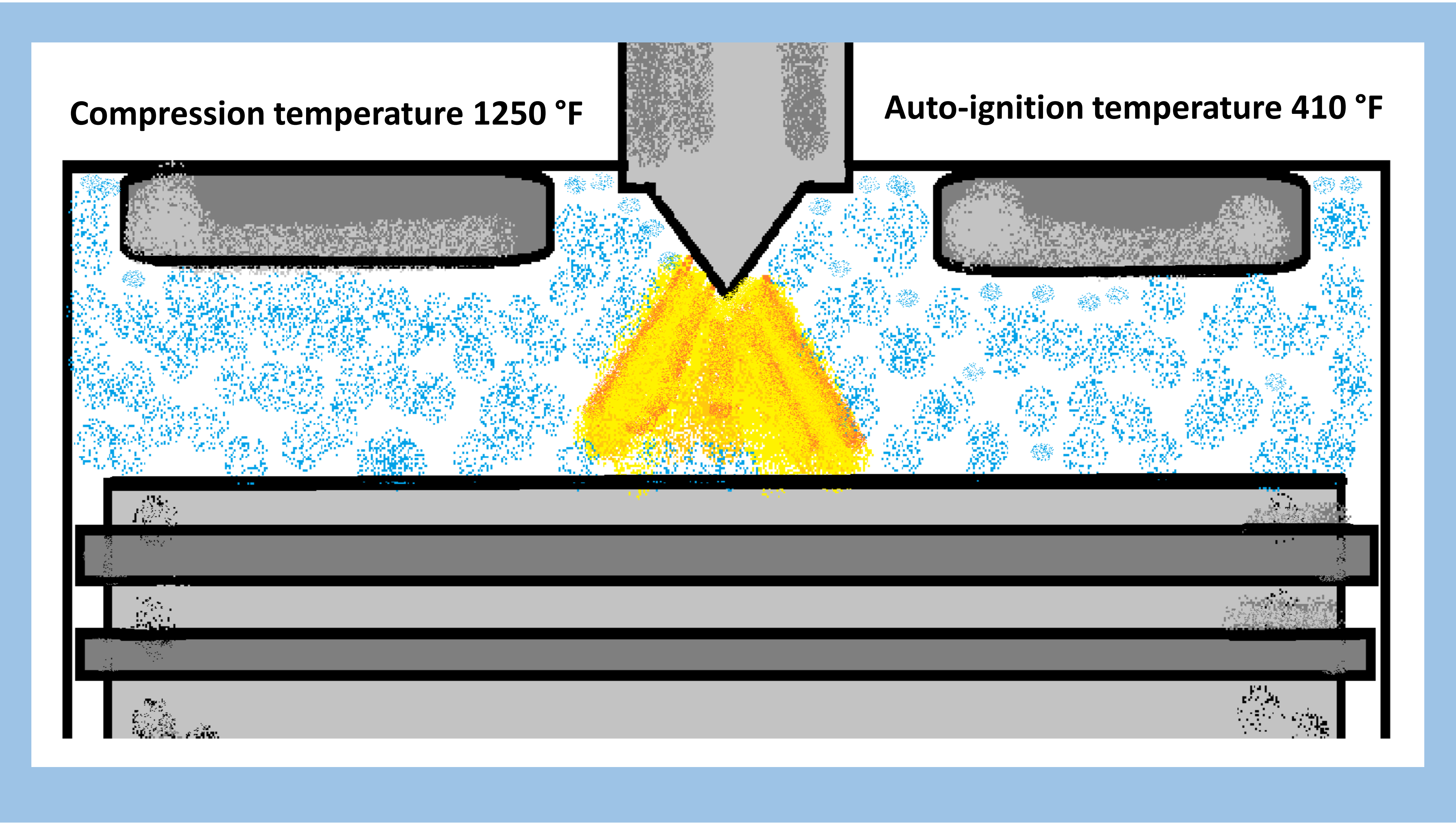
Diesel Combustion

Diesel compression is about 18:1 to 24:1. which allows the temperature during compression to reach 1200°F to 1600°F. Which is well above the auto-ignition temperature of the fuel stock.

The lowest temperature at which the vapor will ignite is the fuel's flash point. Diesel fuel #2 as specified by ASTM D975 has a minimum flash point of 125.6°F.



Fuel	Flash point	Auto-ignition temperature
Petrol (gasoline)	–43 °C (–45 °F)	280 °C (536 °F)
Diesel (2-D)	>52 °C (126 °F)	210 °C (410 °F)
Jet fuel (A/A-1)	>38 °C (100 °F)	210 °C (410 °F)
Kerosene	>38 °C (100 °F)	210 °C (410 °F)


Compression temperature 1250 °F
Auto-ignition temperature 410 °F

stratified

arranged in layers

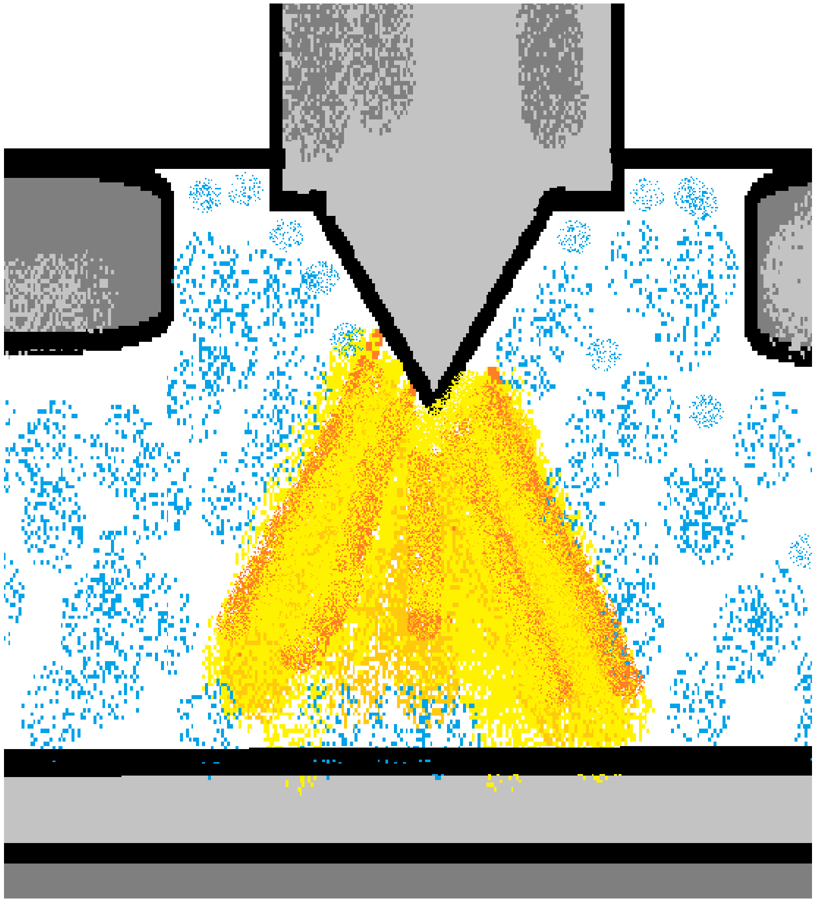
stratified. adjective.

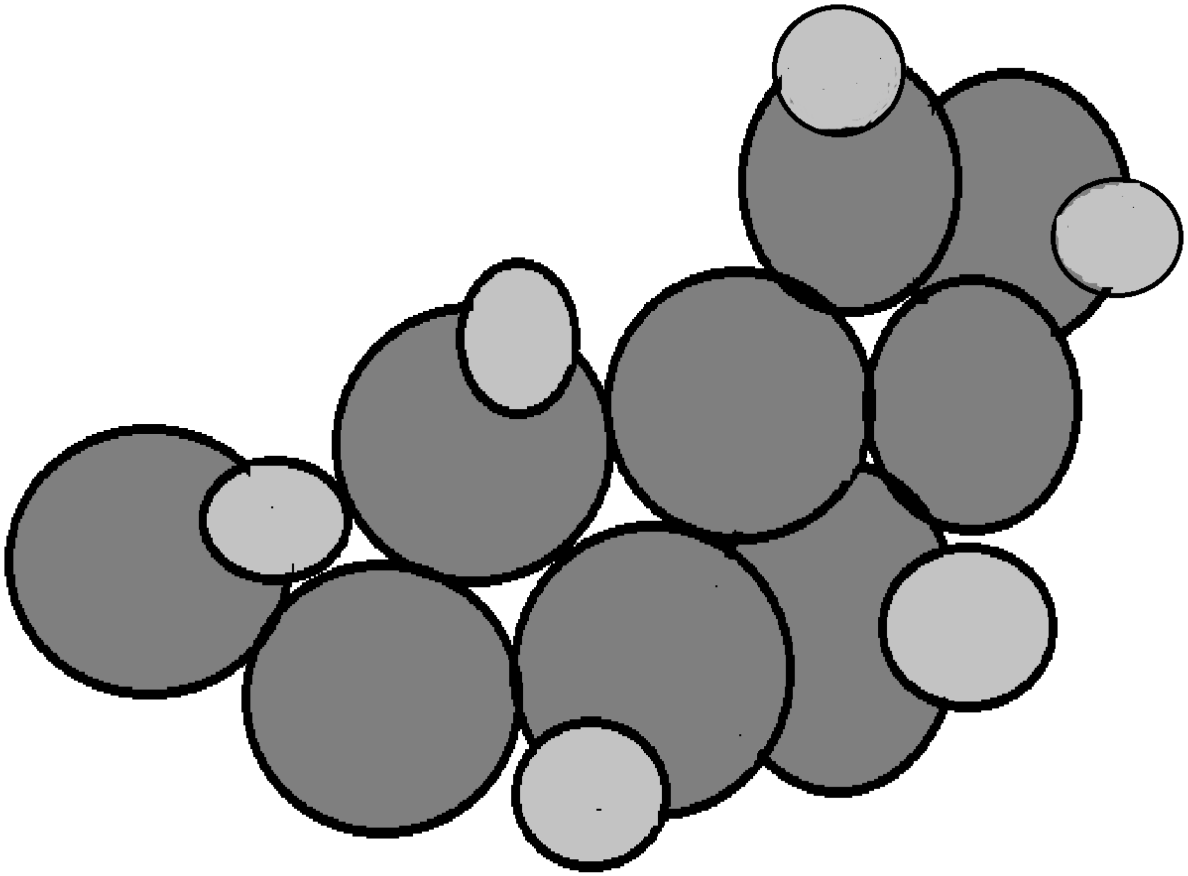
strat·i·fied ˈstrat-ə-ˌfīd.

: arranged in layers.

Which allows for the formation of particulates.

The temperatures and pressure produce NO_x



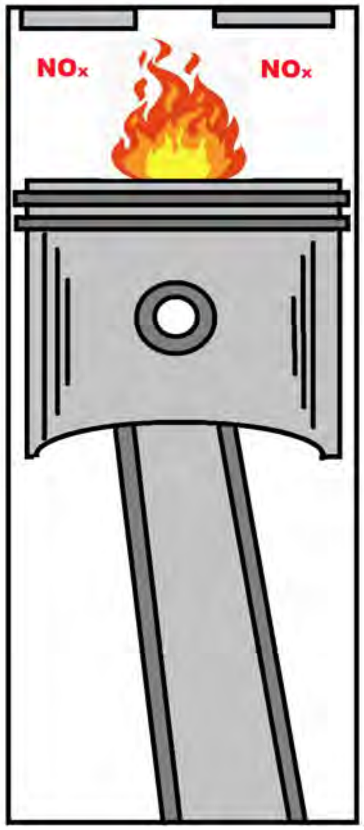


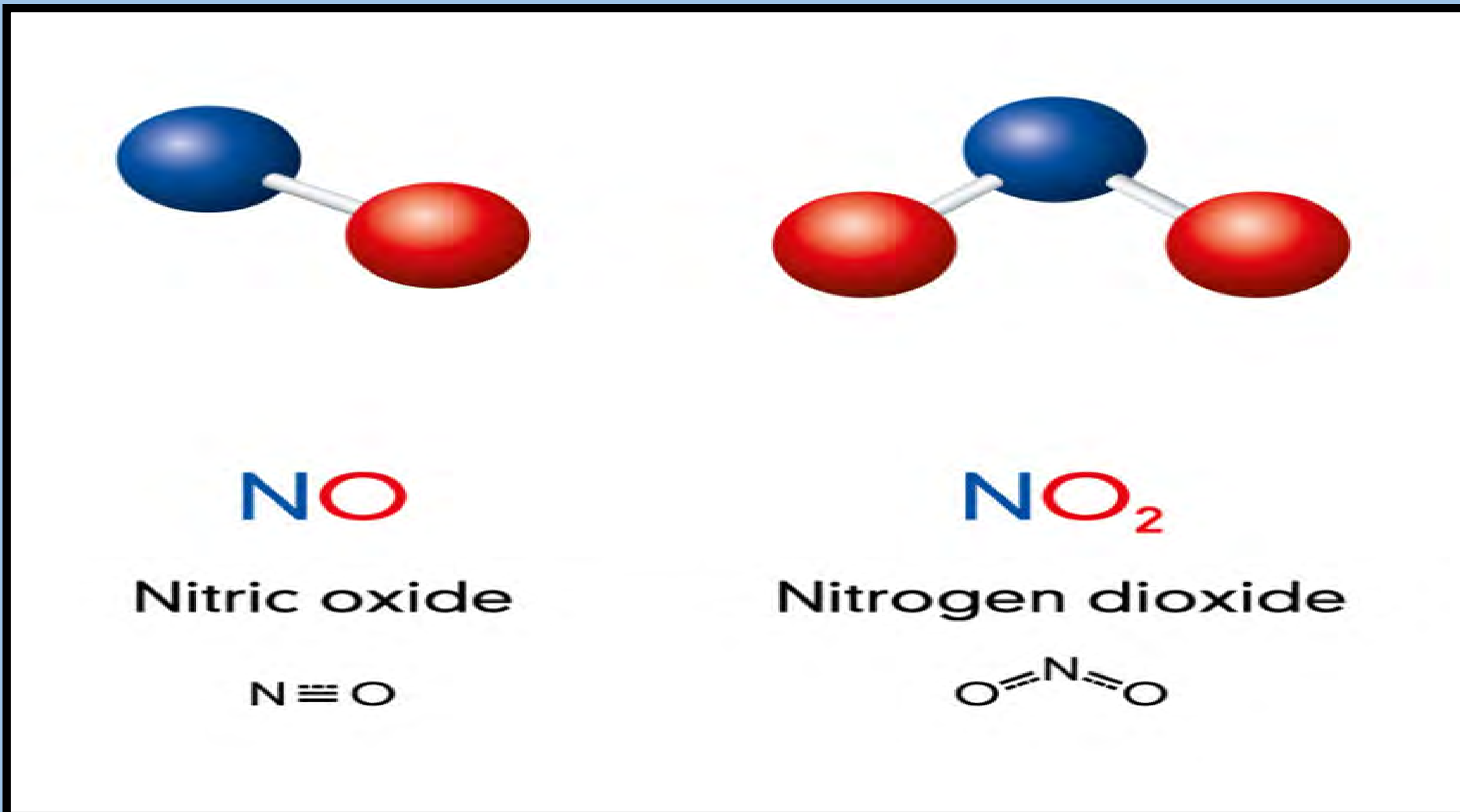
Carbon to carbon bonds

Acetylene Flame

The term 'nitrogen oxides' (NOx) is usually used to include two gases-nitric oxide (NO), which is a colorless, odorless gas and nitrogen dioxide (NO2), which is a reddish-brown gas with a pungent odor. Under normal conditions nitrogen and oxygen will not combine. Nitrogen in the atmosphere is a diatomic molecule, so it doesn't react with oxygen because there is not enough heat or energy to break the bonds of the nitrogen and oxygen molecules in order for them to react together.

The formation of NOx takes place inside the engine during the combustion process. As the diesel fuel burns, the temperature inside of the cylinder is high enough to break apart the nitrogen and oxygen molecules from the air into more reactive atoms that eagerly recombine to form NOx. Nox is produced in high heat and/or high pressures.



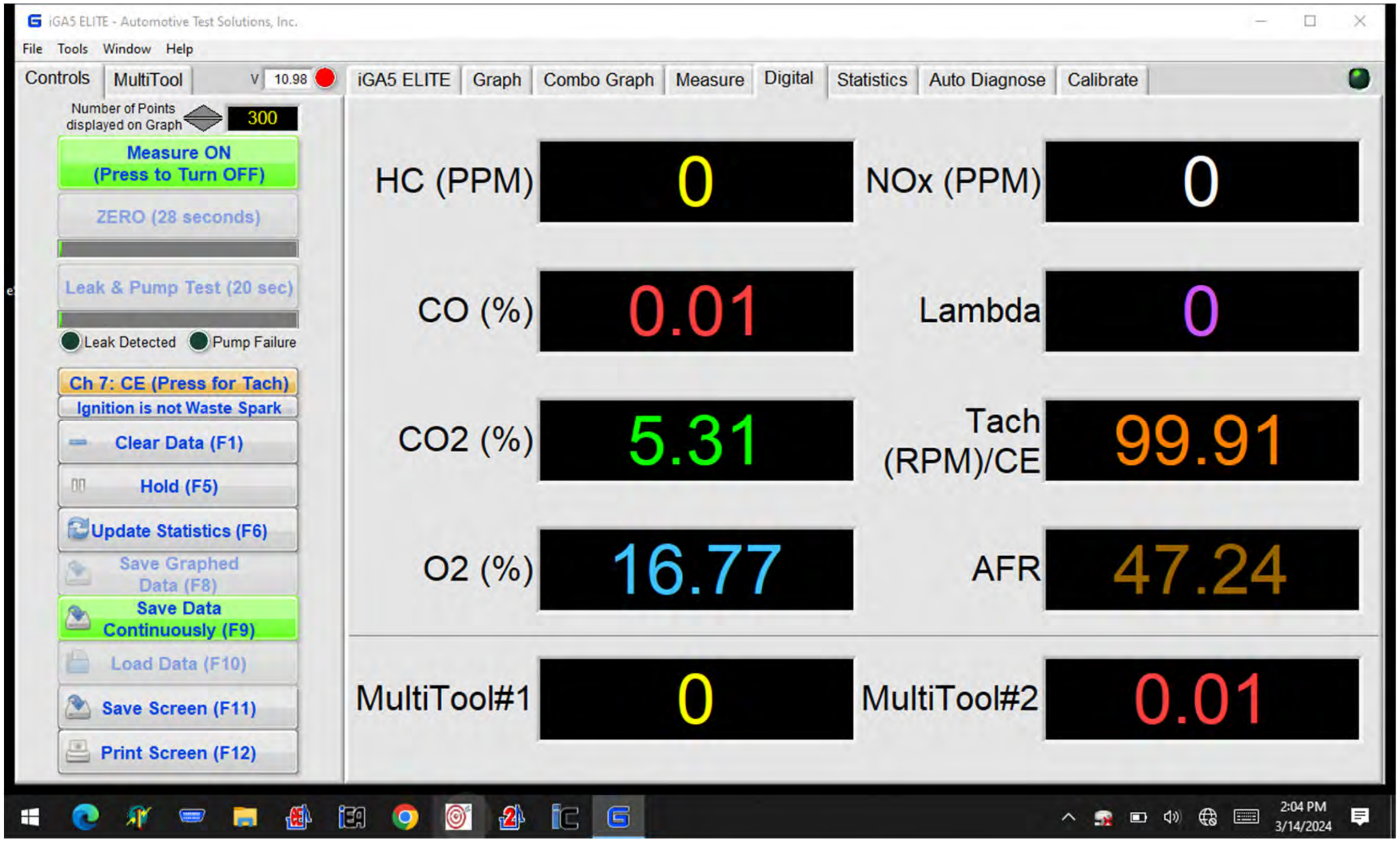

NO
Nitric oxide
N≡O
NO2
Nitrogen dioxide
O=N=O

Diesel engines contain a mixture of gases and solid particles. These solid particles are known as diesel particulate matter (diesel PM). Diesel PM contains hundreds of different chemicals. Many of these are harmful to health. The highest levels of diesel PM are near ports, rail yards and freeways. People are exposed to diesel PM from breathing air containing diesel exhaust.

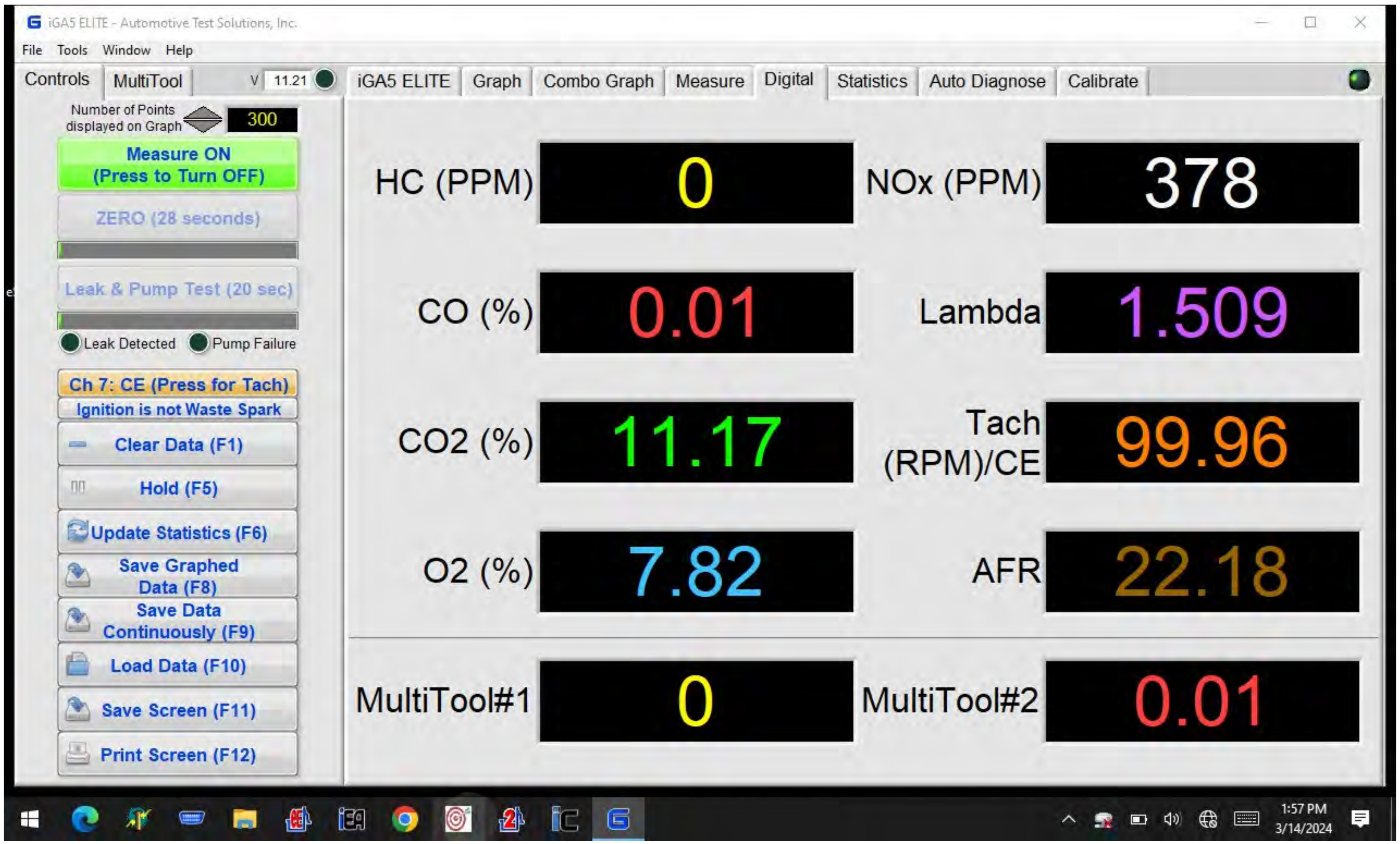
Before using any gas bench on a diesel engine you must install an inline filter on the exhaust probe hose

Diesel fuel exhaust gas Studies

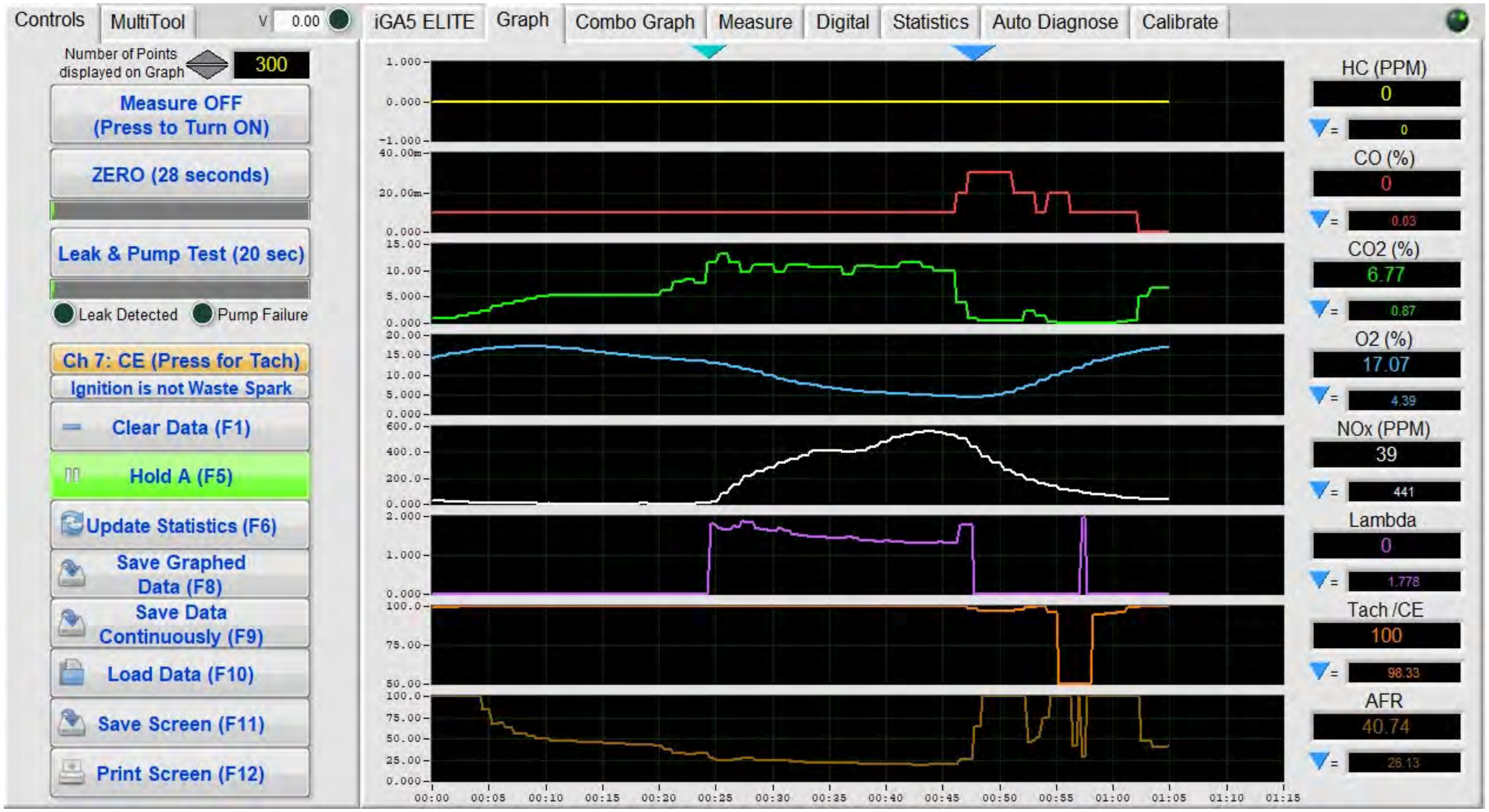
GM 6.6L Idle


iGA5 ELITE - Automotive Test Solutions, Inc.
File Tools Window Help
Controls
MultiTool
V 10.98
iGA5 ELITE
Graph
Combo Graph
Measure
Digital
Statistics
Auto Diagnose
Calibrate
Number of Points displayed on Graph
300
Measure ON (Press to Turn OFF)
ZERO (28 seconds)
Leak & Pump Test (20 sec)
Leak Detected
Pump Failure
Ch 7: CE (Press for Tach)
Ignition is not Waste Spark
Clear Data (F1)
Hold (F5)
Update Statistics (F6)
Save Graphed Data (F8)
Save Data Continuously (F9)
Load Data (F10)
Save Screen (F11)
Print Screen (F12)
HC (PPM)
0
NOx (PPM)
0
CO (%)
0.01
Lambda
0
CO2 (%)
5.31
Tach (RPM)/CE
99.91
O2 (%)
16.77
AFR
47.24
MultiTool#1
0
MultiTool#2
0.01
2:04 PM
3/14/2024

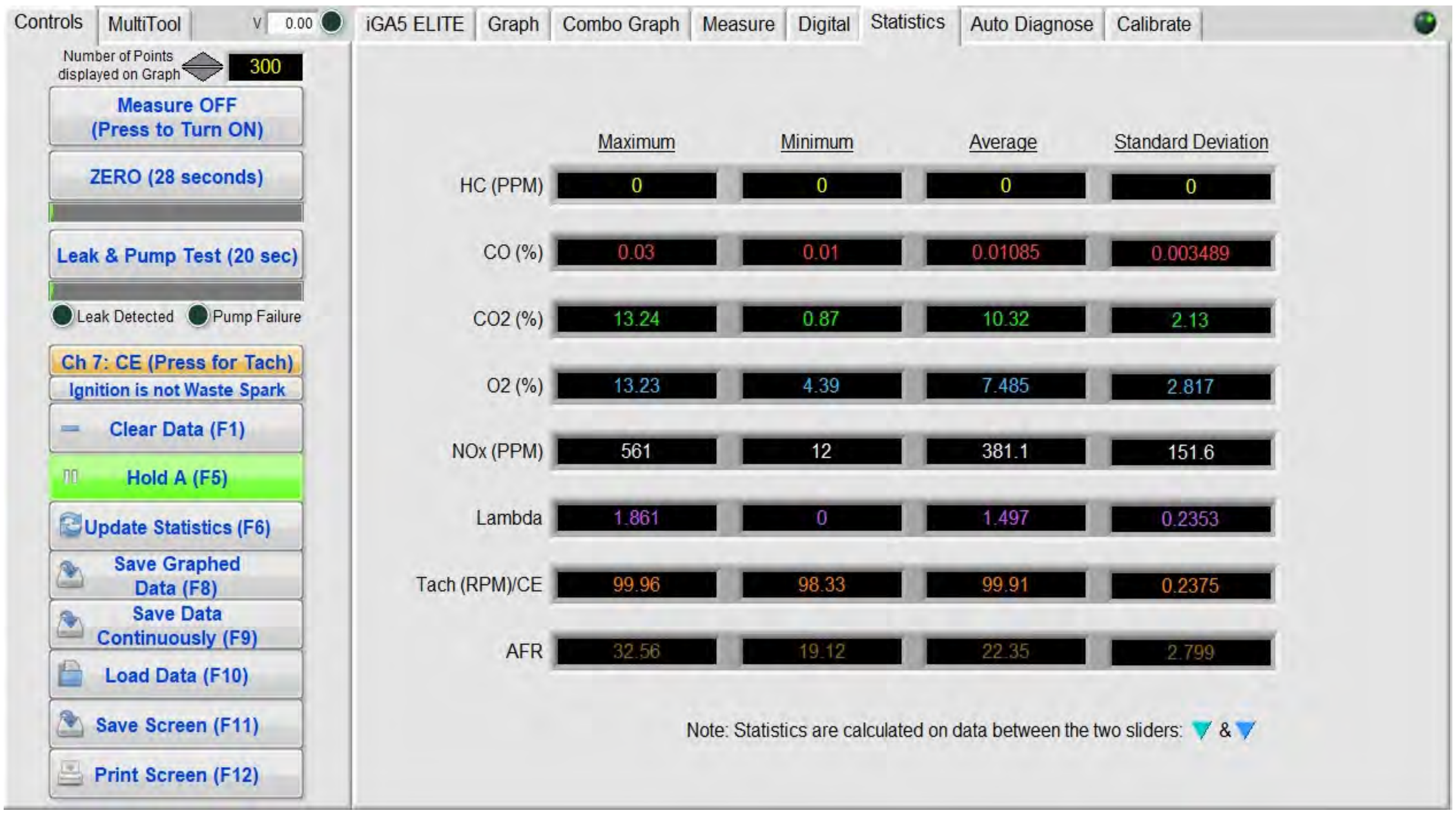
GM 6.6L loaded



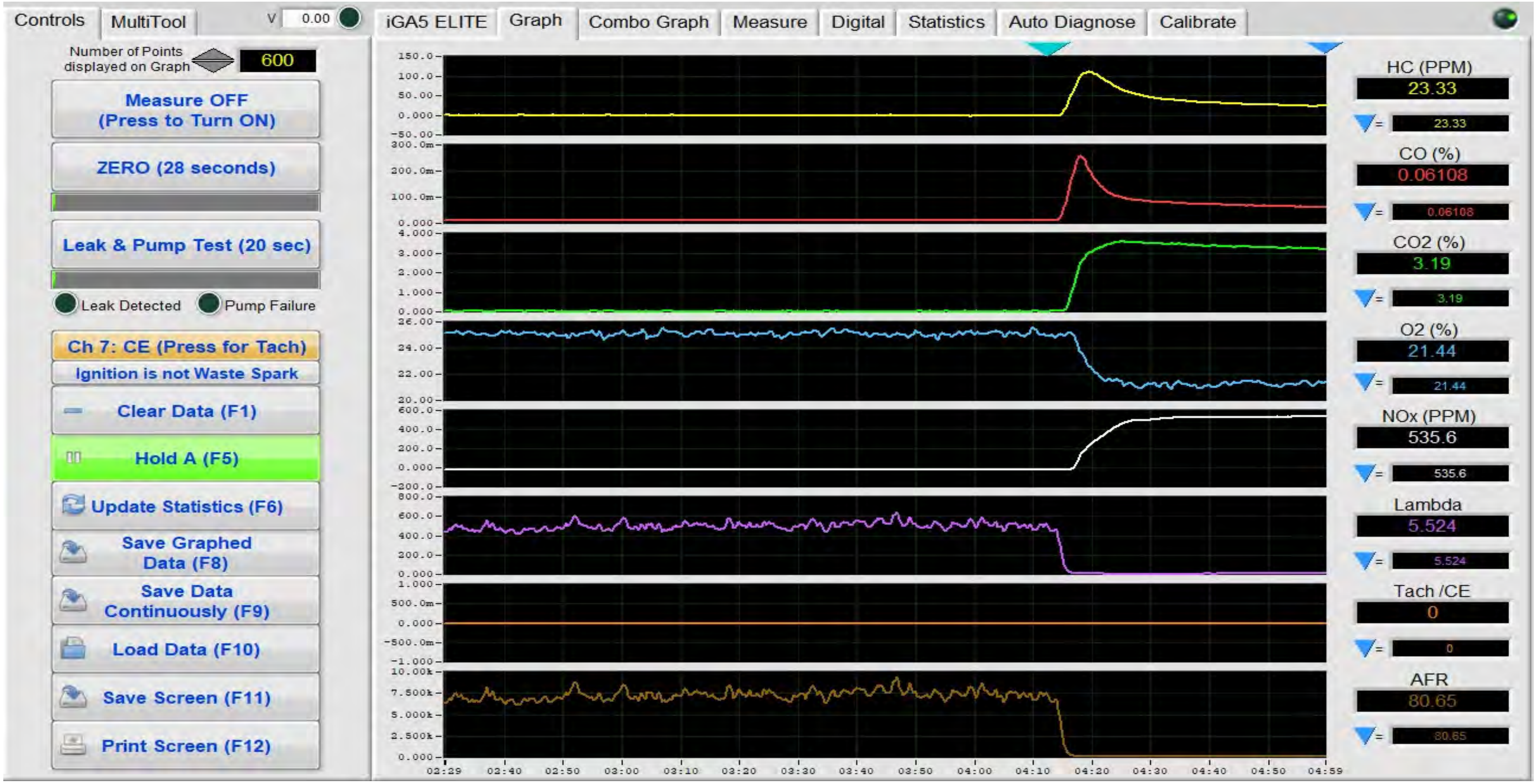
GM 6.6L loaded



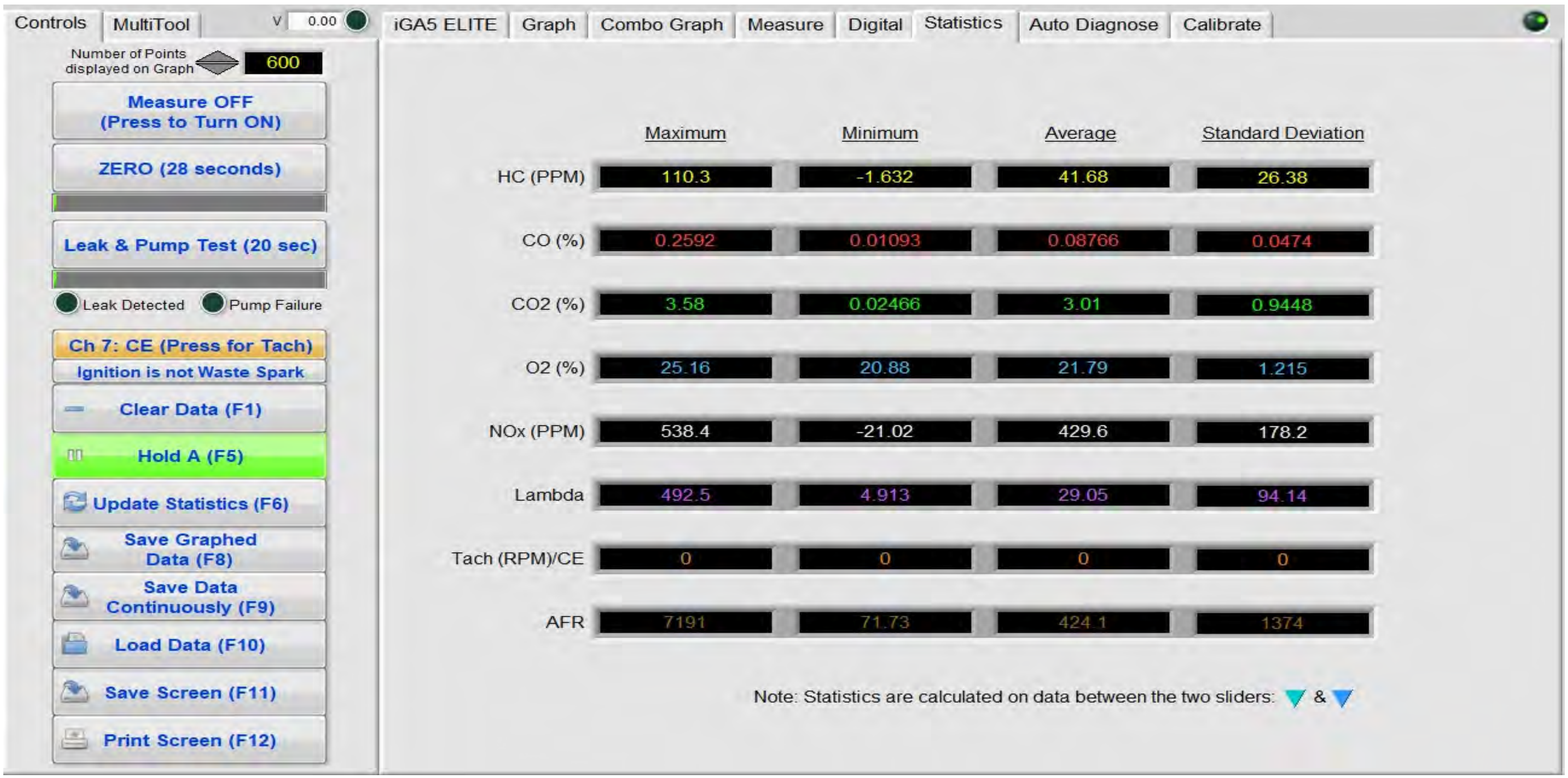
GM 6.6L loaded



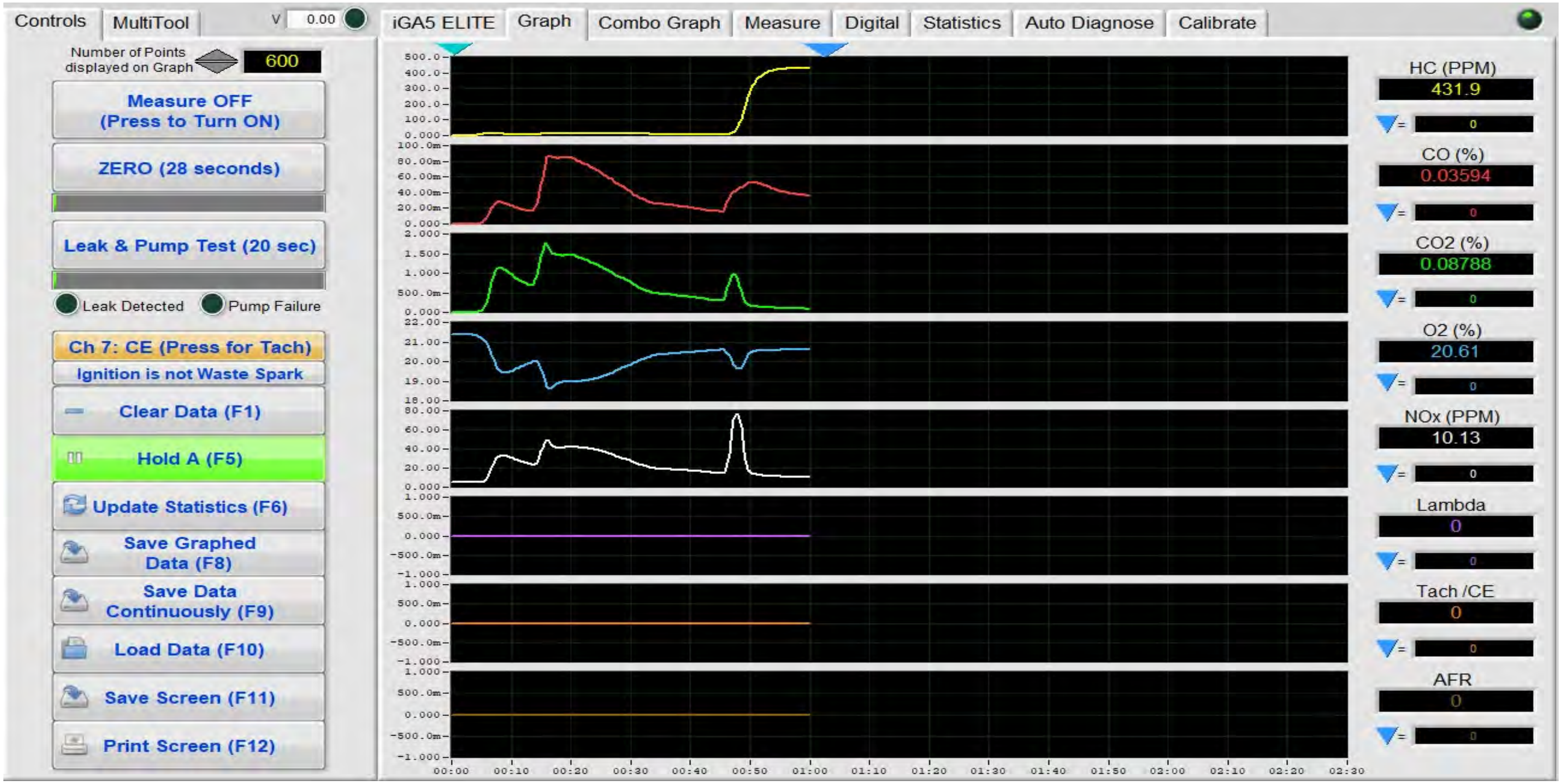
Ford power stroke 60F start ok



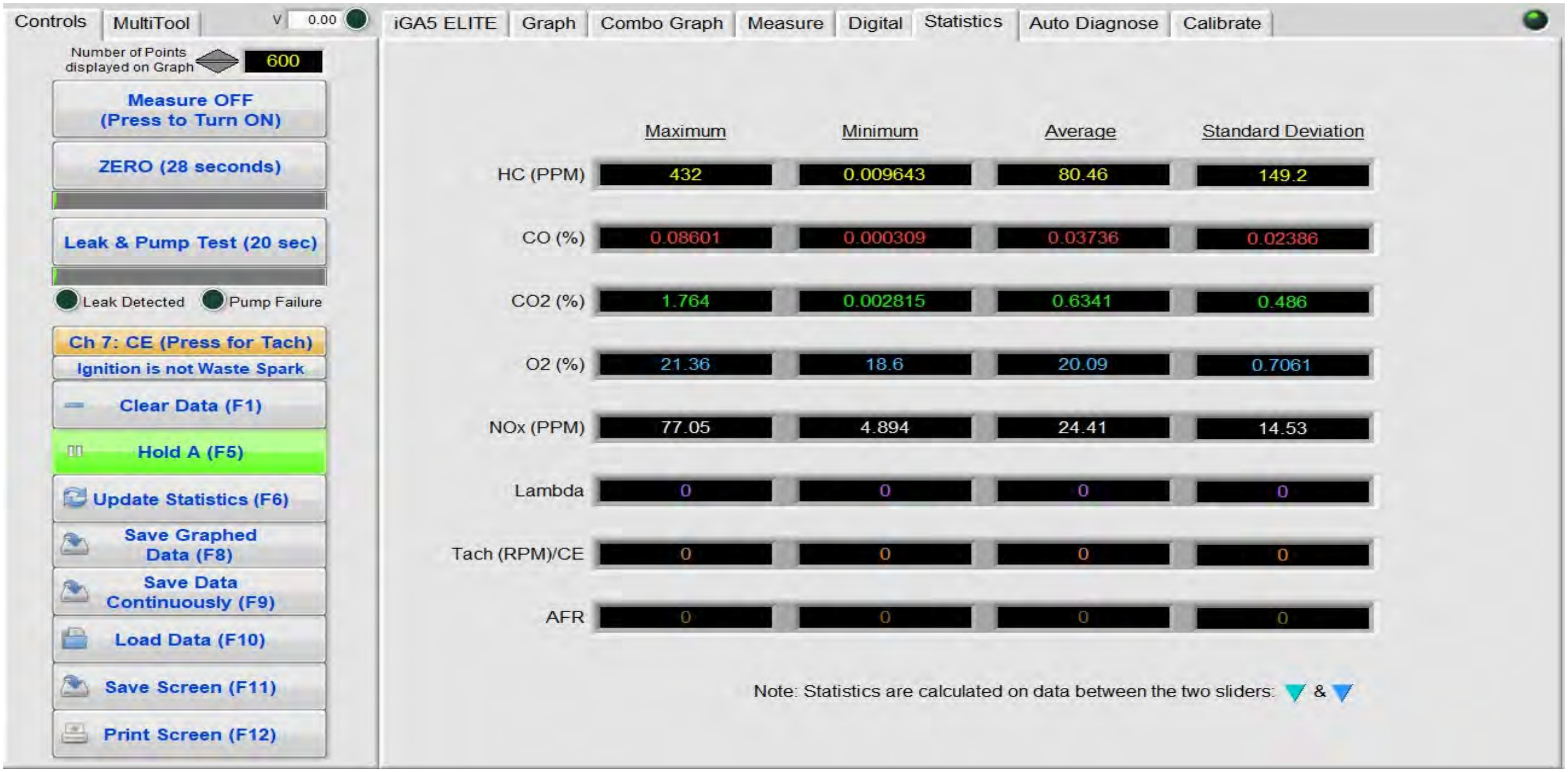
Ford power stroke 60F start ok



Ford power stroke no start short glow plug time

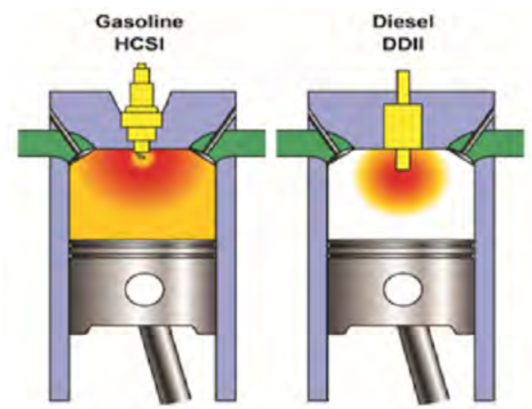


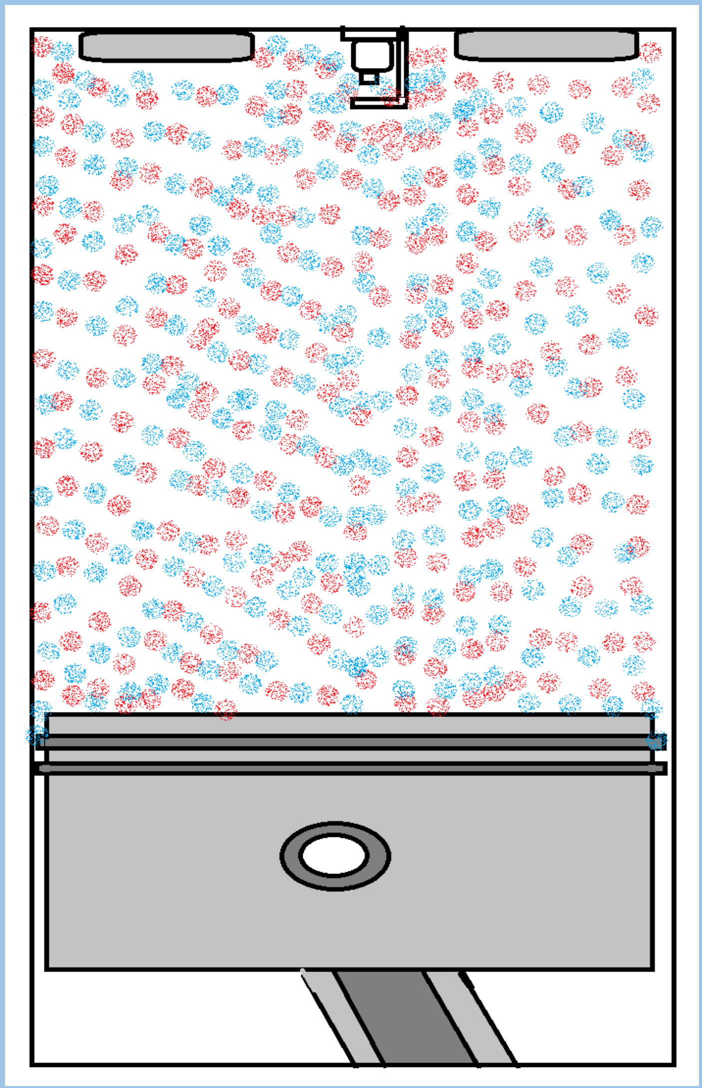
Ford power stroke no start short glow plug time



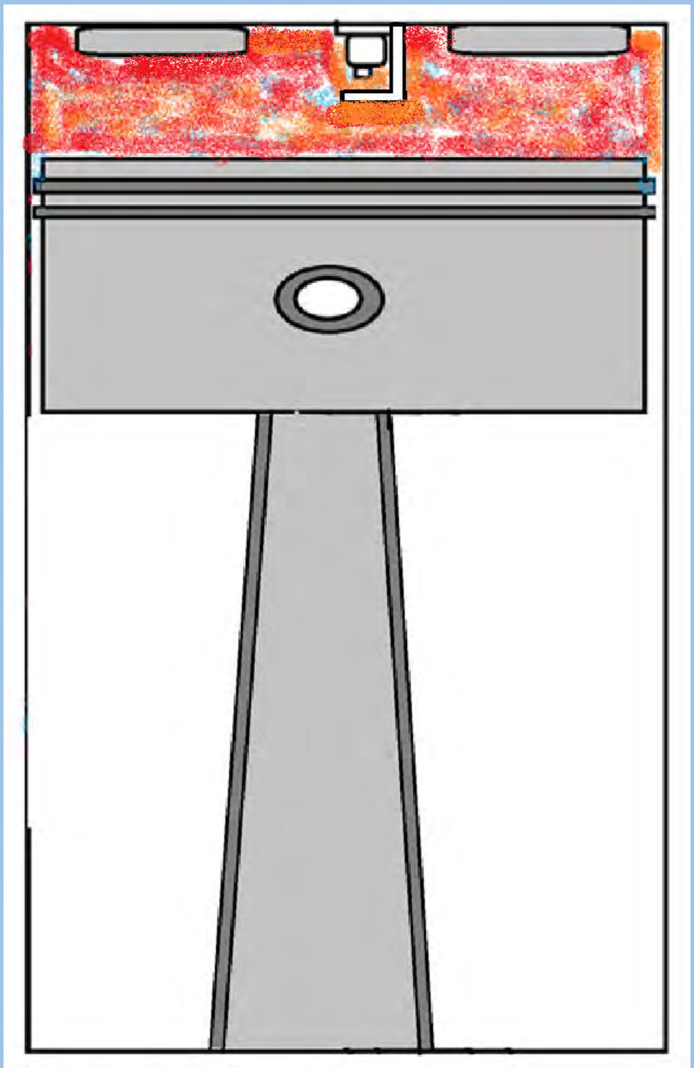
Homogeneous Charge Compression Ignition (HCCI)

As the name implies, this method will combine elements from spark ignition combustion and compression ignition combustion.



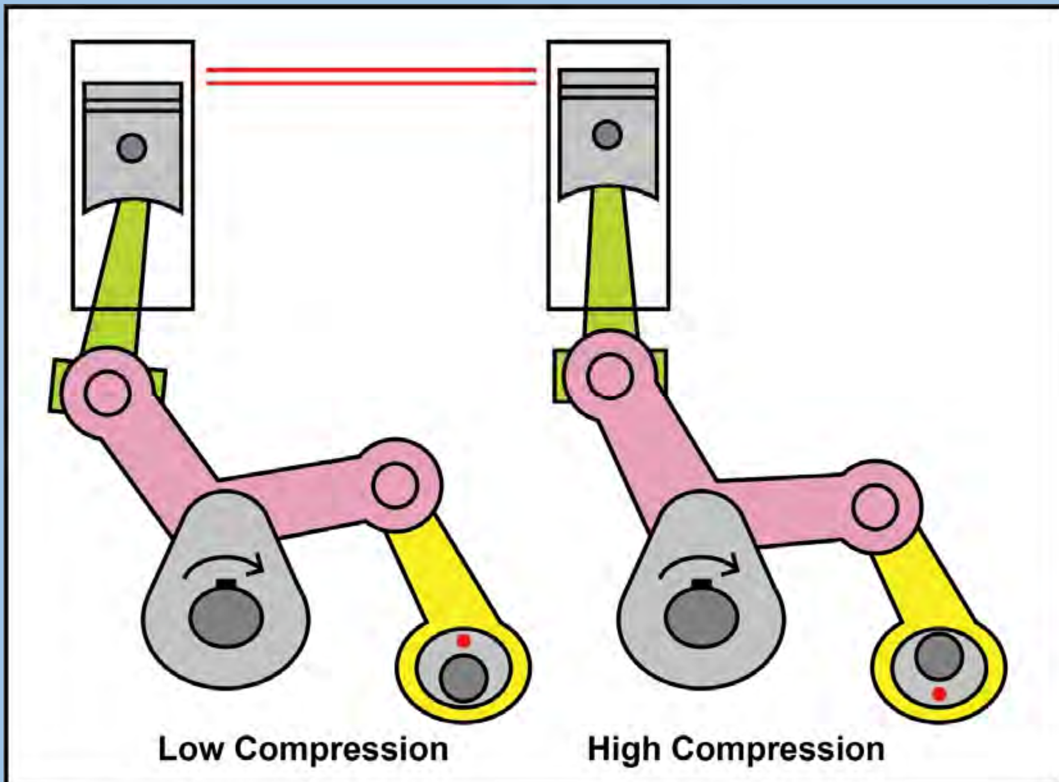


HCCI needs an homogeneous mixture or near complete uniformity of air and fuel mixture. This will be imperative before ignition.



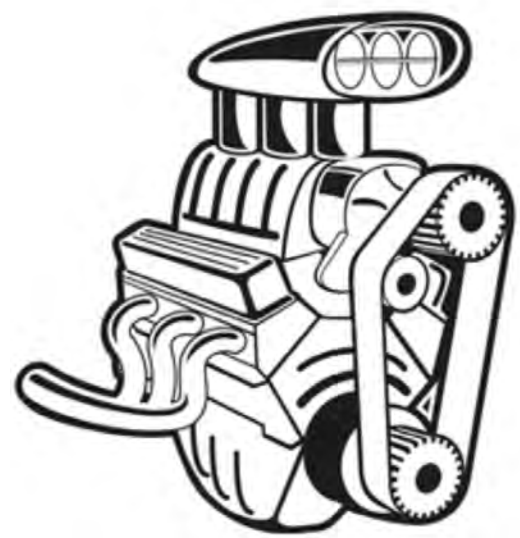
With HCCI engines the compression temperature will need to be higher than with spark ignition. Gasolines auto-ignition temperature is higher than diesel. To auto-ignite diesel fuel you need a compression ratio of 11.0:1. In order to start a cold diesel engine the compression ratio will need to be much higher 18:1-24:1. In order to auto-ignite gasoline the compression ratio will need to be 15:1 or higher. At part load the compression ratio to auto-ignite the gasoline will need to be at least 17:1.

There will be several ways to provide the additional heat for combustion in a HCCI engine.



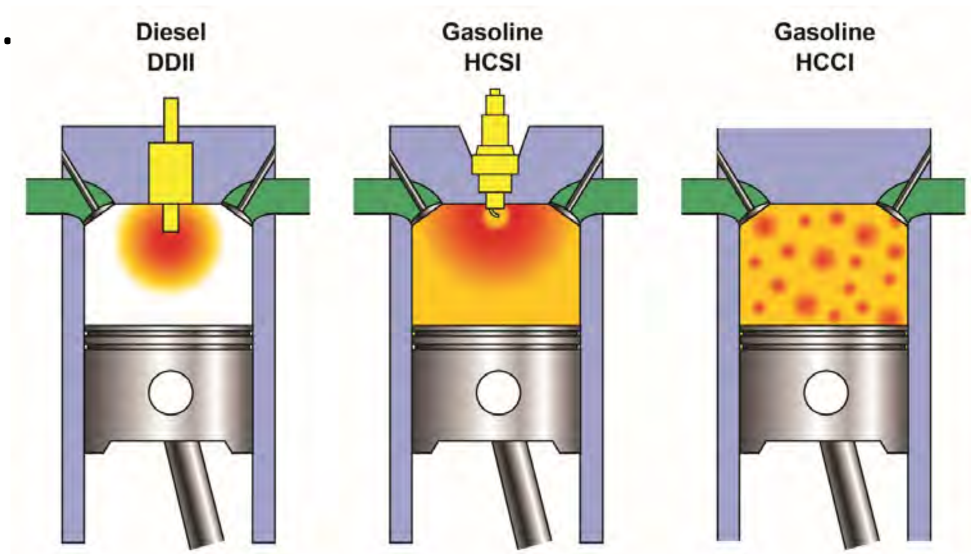
With a need for a higher compression ratio to enable the HCCI combustion event, the engine will need a way in which this can be obtained. One way is to use an engine with a Variable Compression Ratio. This is where the compression can be controlled through changing the Static Compression Ratio of the engine. This Nissan design is just one example.

Another way to control the compression charge rate would be the use of forced air induction. One method would be the use of a supercharger with a constant variable control pulley drive system. With this system the supercharger can spin at speeds that are different from that of the crankshaft speed. This allows the cylinder charge volume to be controlled, an increase in volume raises the compression ratio whereas a decrease in the volume lowers the compression ratio.

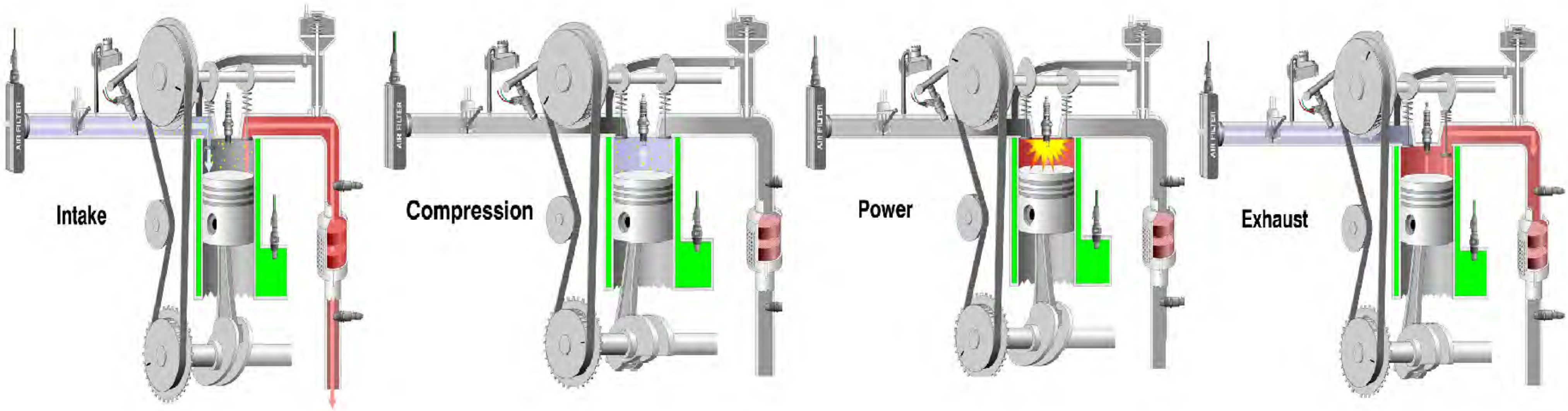


Yet another way to heat the cylinder volume is through exhaust gas dilution. This can be done by rebreathing or by recompression. In rebreathing, the cylinder charge temperature is controlled by exhaust gases being cycled back into the combustion chamber after exiting the exhaust port. In recompression the cylinder charge temperature is controlled by trapping hot residual gas from the previous engine cycle by closing the exhaust valve early during the exhaust stroke. In either method the charge temperature can be controlled.

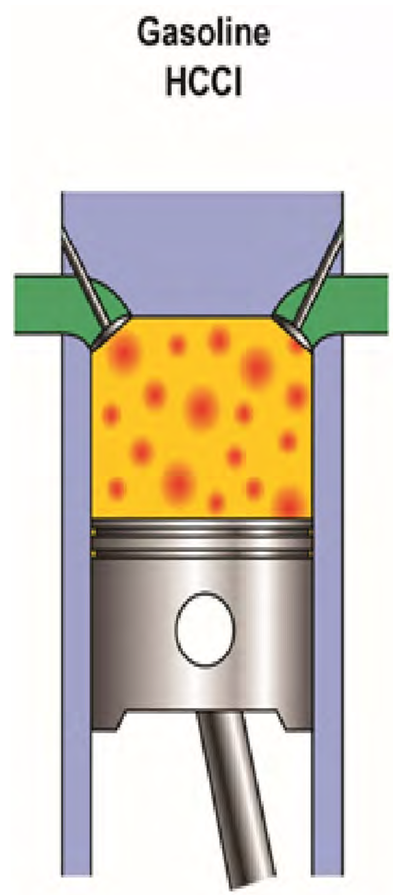
HCCI uses the Otto combustion cycle (4 stroke engine) and was popular before the introduction of spark ignition. Since the internal combustion engine is a heat engine, the fundamental operation of the device is the production and use of heat.



Otto cycle stokes



HCCI allows for a combustion event that is subsonic. This is accomplished due to the different chemicals found in gasoline. These different chemicals have different auto-ignition temperatures, so the combustion process can be some what controlled. The lower auto-ignition chemical will combust first, where as the higher auto-ignition chemicals will combust later. This will provide for a high peak pressure without having an explosion (supersonic), therefore exacting more energy conversion from the fuel stock.



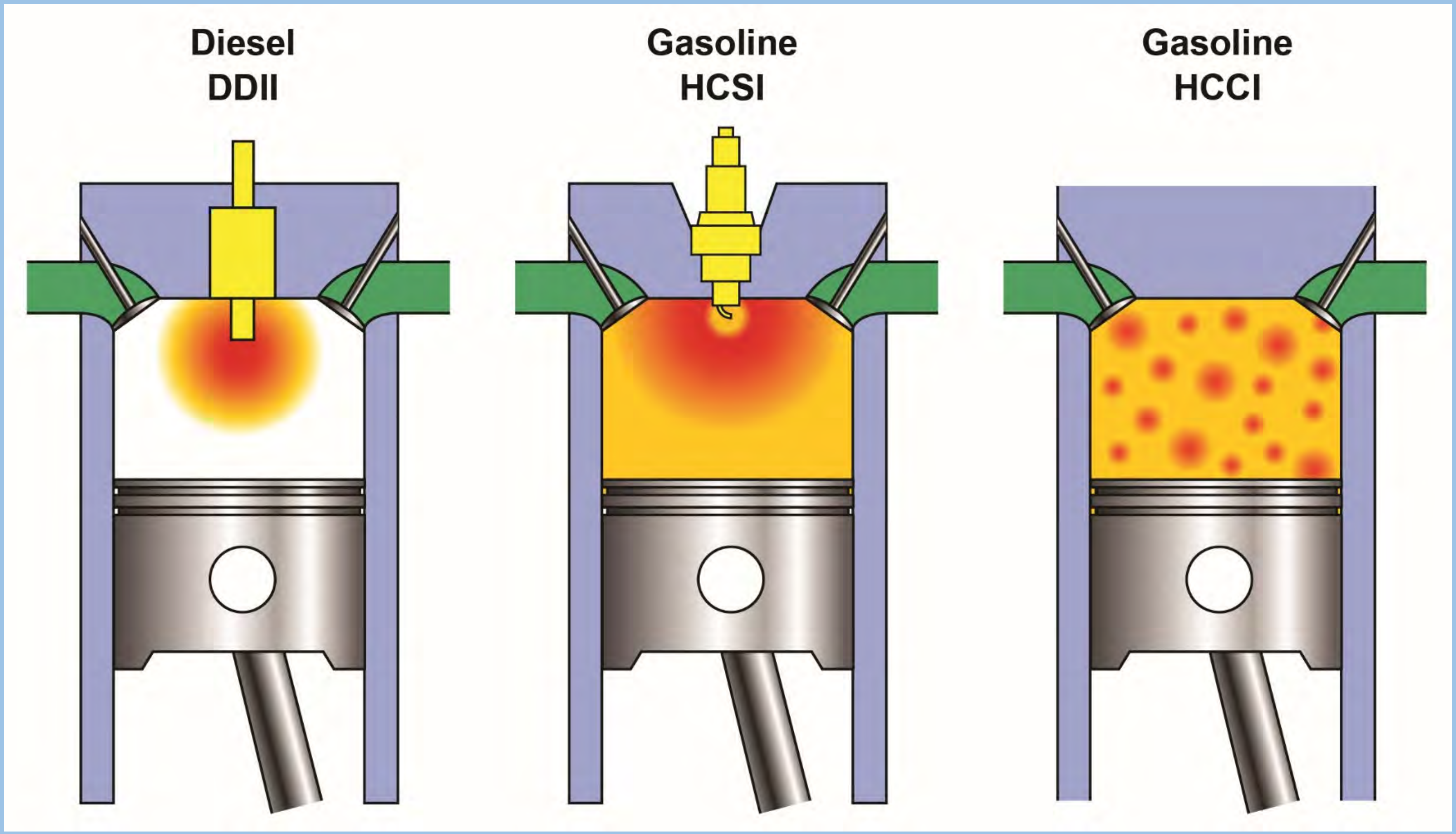
Gasoline is a mixture of hydrocarbon (HC) components. These HC base chemicals have different hydrogen carbon bonds with different chain configurations and lengths. This allows some of the HC chemicals to vaporize at low temperature, while other HC chemicals vaporize at higher temperatures. Additionally the flash points and auto-ignition points of these HC chemicals will vary widely with temperature. One would think that there would be a standard recipe used when blending gasoline, however this is not true. This is a true problem for the HCCI engine.

Gasoline Fuel components

Chemical	Auto-ignition point
Octane	437F
Hexane	428F
N-heptane	428F
Decane	410F
Dodecane	401F
Cyclohexane	473F
2,2,4-Trimethylpentane	782F
Pentane	802F
Naphtha	1022F
Benzene	1031F
Methane	1076F

Pump Gas Number

The large number on the yellow gasoline pump octane label is the minimum octane rating. The (R+M)/2 Method you see on the label refers to the average of the Research Octane Number (RON) and the Motor Octane Number (MON) ratings. To determine the RON, the fuel is tested under engine idle conditions with a low air temperature and slow engine speed. To determine the MON the fuel is tested under the more stressful conditions of higher air temperature and engine speed.


Diesel
DDII
Gasoline
HCSI
Gasoline
HCCI

Fuel Stocks	BTU rating	stoichiometric
Gasoline	125,000 Btu/gallon	14.7:1
Diesel	138,700 Btu/gallon	14.5:1
Compressed natural gas	138,700 Btu/gallon	10.0:1
Propane	91,500 Btu/gallon	15.67:1
E85's	83,950 Btu/gal 51% ethanol, 49% gasoline	12.15:1
Methnol	57,000 Btu/gallon	9.003:1
Ethnol	76,000 Btu/gallon	6.5:1

British thermal unit (Btu) is a measure of the heat content of fuels or energy sources. One Btu is the quantity of heat required to raise the temperature of one pound of liquid water by 1° Fahrenheit (F) at the temperature that water has its greatest density (approximately 39° F).

Stoichiometry is the relationship between the weights of reactants and products before, during, and following chemical reactions. Stoichiometry ratio is used to find the right amount of one reactant to "completely" react with the other reactant in a chemical reaction – that is, the stoichiometric amounts that would result in no leftover reactants when the reaction takes place.

For example, $CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O$

The homogeneous charge is in an aerosol mixture which is in a liquid format that once injected and moved into the cylinder is heated with adiabatic compression. This heat will change the liquid gasoline into a gasoline vapor that can be combusted. If the compression of the air is high enough the heat will continue to be driven into the fuel, this in turn will drive the gasoline past its auto-ignition temperature and will start the combustion process. The HCCI combustion process is different from a spark ignition gasoline engine. In a spark ignition gasoline engine the point source of the ignition event causes a non-uniformity within the combustion chamber as a function of the fuel burn process. During the combustion process in an HCCI engine the fuel throughout the cylinder is heated and ignited near simultaneously.

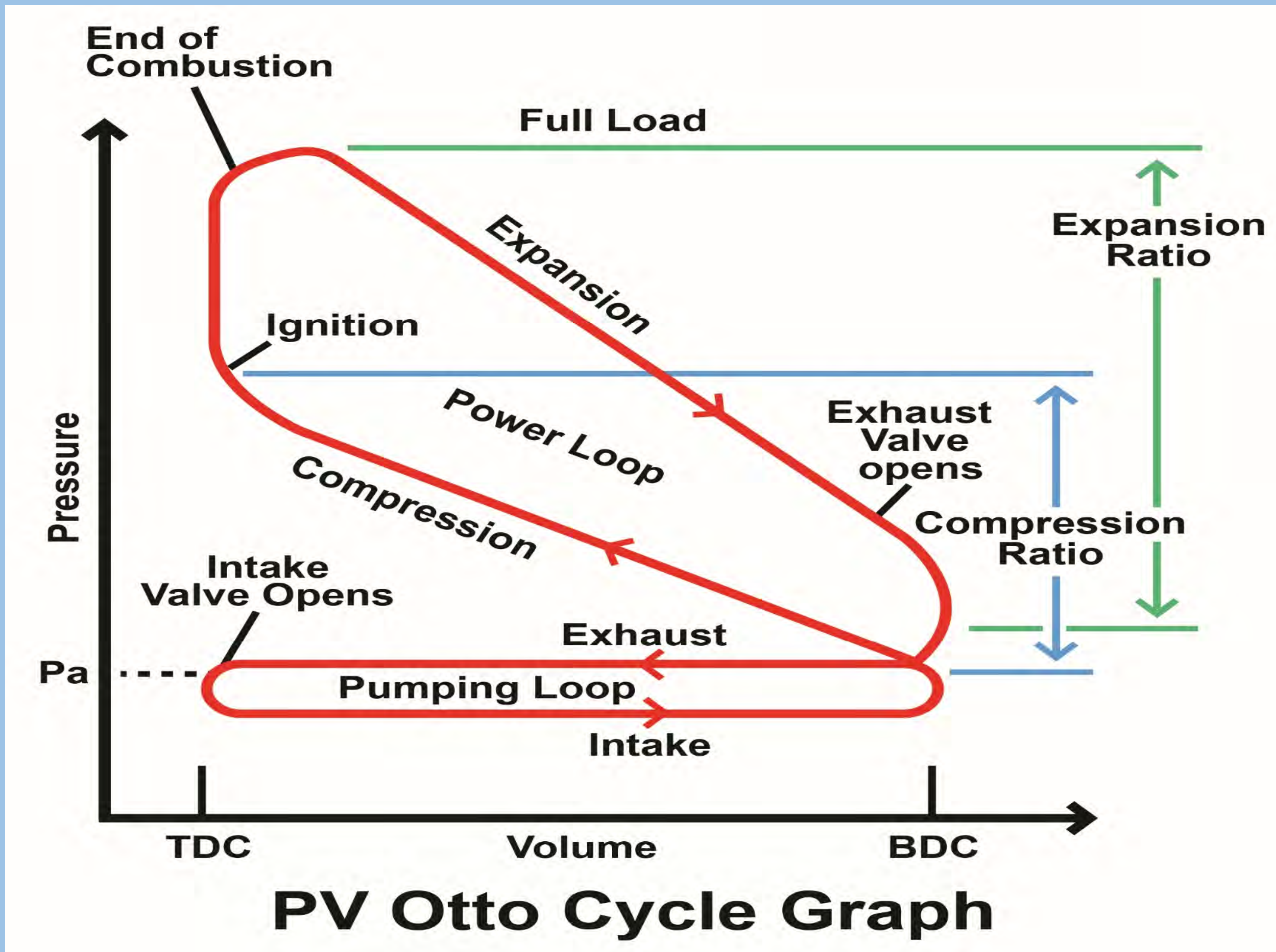
Homogeneous Mixture

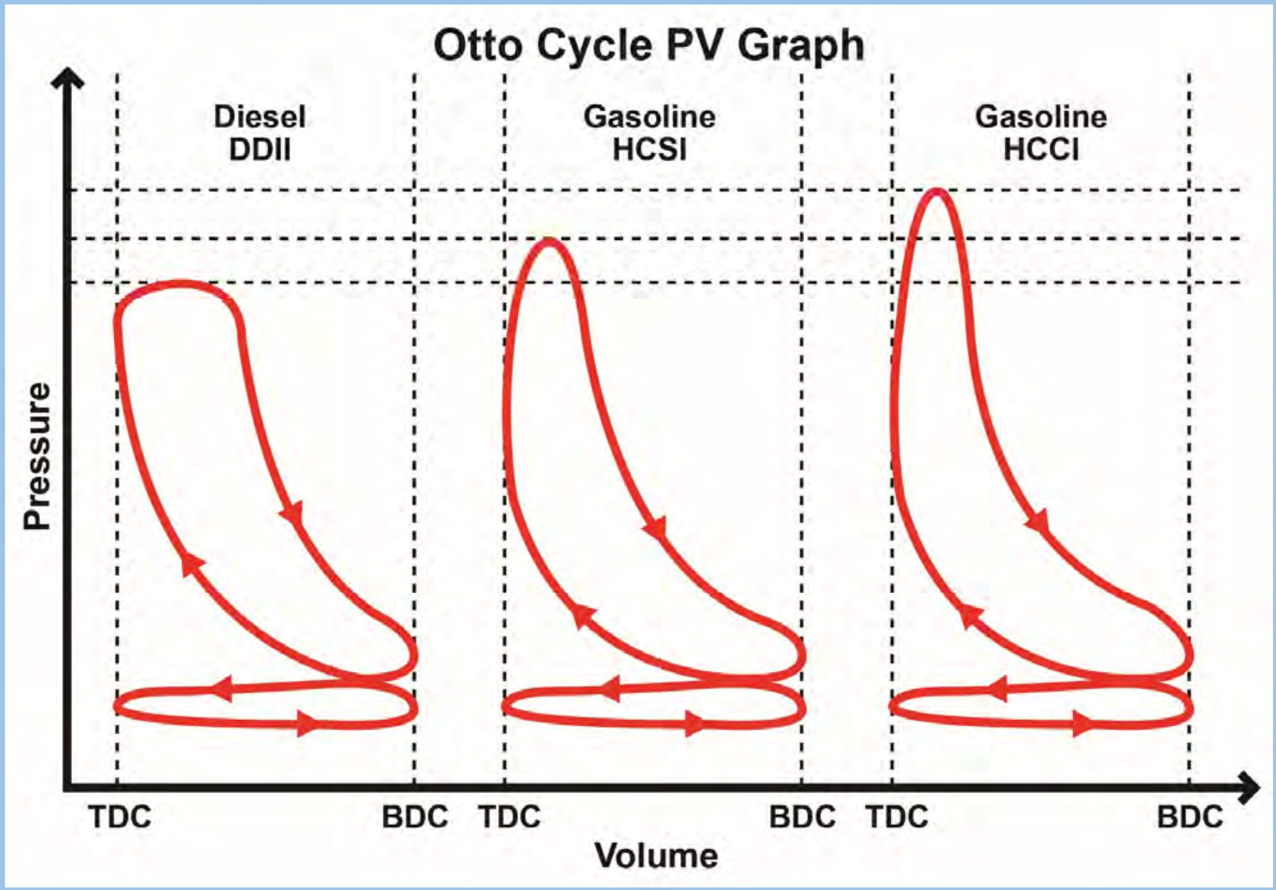
HCCI Combustion

The HCCI Combustion event has benefits over Homogenous Charge Spark Ignition HCSI) and Diesel Direct Injection Ignition (DDII). With spark ignition combustion in order to achieve a complete burn the fuel air mixture needs to be close to that of stoichiometric. With HCCI combustion the mixture can be lean of stoichiometric and still achieve a complete burn with low nitrogen oxide (NOx) production, and low particulates production.

Diesel can also achieve a complete burn lean of stoichiometric, however, due to the way the fuel plume is burned particular matter (soot) is formed with high NOx emissions. Only the HCCI combustion process provides multiple ignition points throughout the cylinder limiting NOx and particular matter. Unlike conventional combustion in the spark ignition or diesel ignition process, HCCI does not rely on a flame front to propagate combustion but instead combustion occurs as spontaneous ignition everywhere in the charge volume when the required conditions are met.

The Otto cycle describes the idealized thermodynamic operation of the 4 stroke engine, shown in the next slide. In these engines everything that is done prior to the combustion of the fuel type is to set up the fuel air in the cylinder so the charge can be ignited, burned, and combusted. The conversion of chemical potential to thermal energy is important. The way in which this conversion takes place can change the engine's thermodynamic efficiency.

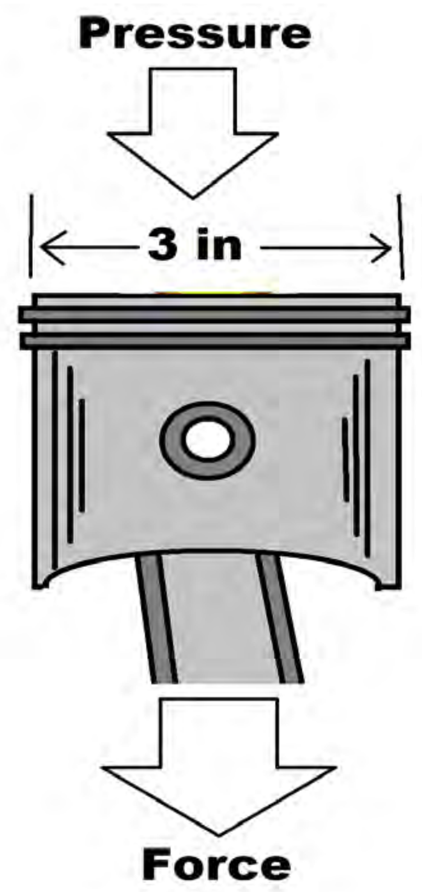

End of Combustion
Full Load
Expansion
Expansion Ratio
Ignition
Power Loop
Exhaust Valve opens
Compression
Compression Ratio
Intake Valve Opens
Exhaust
Pa
Pumping Loop
Intake
Pressure
TDC
Volume
BDC
PV Otto Cycle Graph



HCCI has a greater peak pressure

Piston Size verse pressure

Once the fuel reacts with the oxidant, the thermal energy released heats the working fluid which causes the nitrogen to expand and push down on the piston surface area. This in turn uses the 3 bar linkage to produce torque from the crankshaft. So, chemical energy is turned into heat energy which is turned into mechanical energy. The higher the pressure the more force is created to push down on the piston. For example, if a 3 inch diameter piston were used; 3 inches / 2 = 1.5 radius, 1.5 radius x 1.5 radius = 2.25 radius squared, 2.25 radius squared x 3.14 pi = 7.065 area of a 3 inch piston. Now that we have the area of the piston multiply this by the force, 7.065 x 800 PSI = 5652 pounds of peak force, and 7.065 x 1200 PSI = 8478 pounds of peak force. It is now clear that the higher peak pressure produces a higher force to rotate the crankshaft with, thus producing greater performance. Additionally with a higher pressure the volume ratio change within the combustion chamber has a greater change over the power stoke as well. With a higher pressure at TDC the area is smaller so the pressure or volume, will have a greater change as the piston moves away from the head. This area will change the way the peak pressure in the cylinder decays. An increased pressure over area allows the burning fuel to expand with a greater force over more degrees of crankshafts rotation, thus more energy is extracted from the original high-pressure charge. This in turn helps the engines thermal efficiency.



Live Gas Analysis

Thank You For Your Time