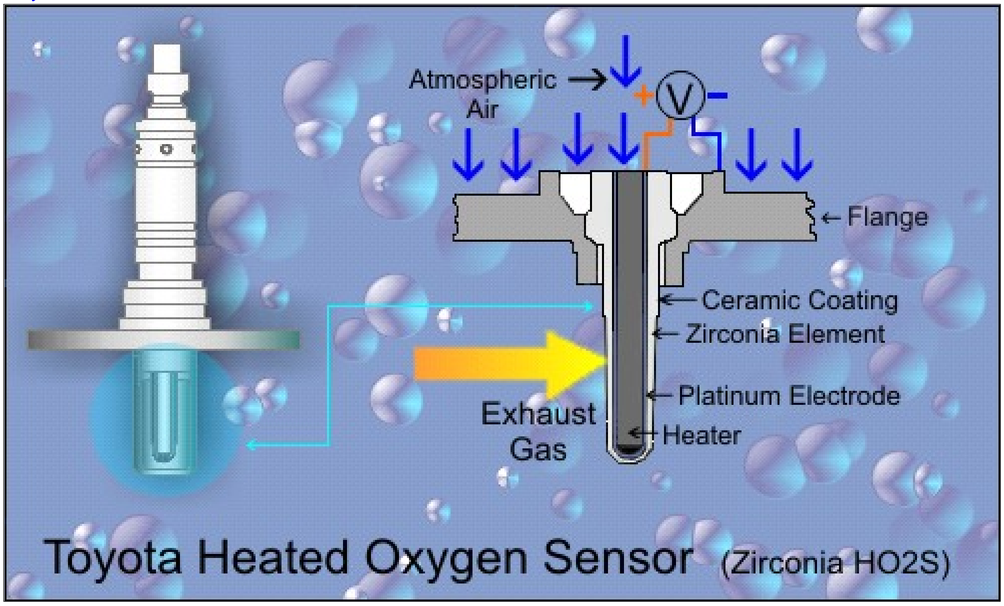
Toyota Zirconia O² Sensor Review

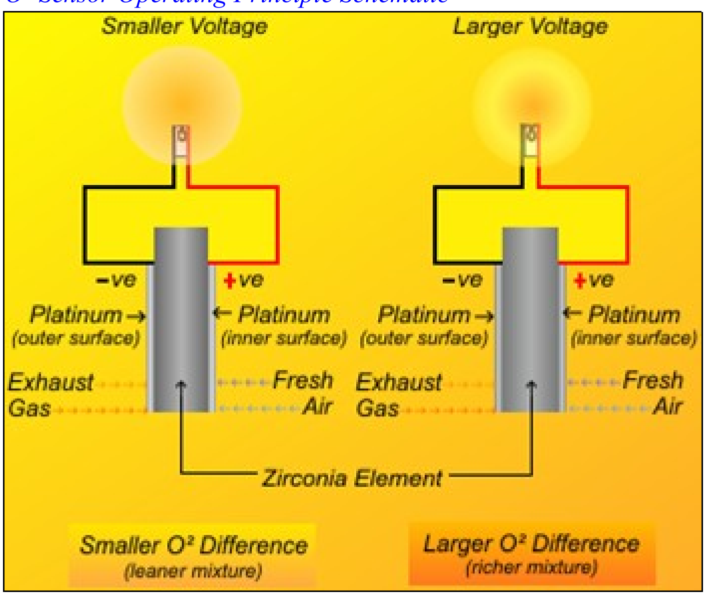
The Zirconia O² sensor has been in service for many years. The sensor uses Zirconium Dioxide and Platinum electrodes with a ceramic substrate cover. Early Toyota applications used a single wire and later applications now are of multiple wiring incorporating heater control for the O² sensor heater element

Toyota Zirconia O² Sensor Schematic



Zirconia O² Sensor Operation Review

O² Sensor Operating Principle Schematic



Less O² in the exhaust gases results in a larger difference in O² content when compared to the atmospheric air content.

This produces a higher sensor signal voltage.

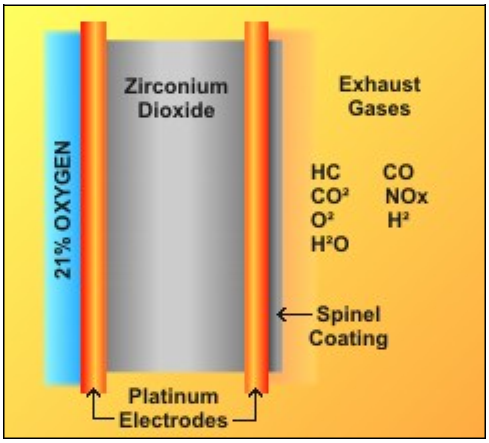
With more O² in the exhaust gas stream the difference is smaller and the voltage signal output is lower.

The O² sensor generates a small voltage signal based upon the oxygen content in the exhaust gas stream with that compared to atmospheric oxygen. The Zirconia sensor has one side exposed to the exhaust stream, the other side exposed to the atmosphere. The platinum electrodes conduct the signal voltage generated. Any contamination of the electrodes or Zirconia elements will cause a reduced signal output.

Zirconia Cell Construction and Operation Review

The cell consists of a solid state electrolyte made of zirconium dioxide (ZrO^2) ceramic. ZrO^2 is used to conduct electrical current using the availability of free moving oxygen ions. The definition of an ion is a group of atoms, an atom or molecule that has gained an electrical charge by acquiring or losing electrons.

Zirconia Sensor Schematic 1



Two porous platinum gas permeable electrodes (atmospheric side electrode and exhaust side electrode) are fused to the ZrO^2layer. The chemically active atmospheric electrode is used to diffuse oxygen molecules into oxygen atoms, thus allowing each freed atom to gain two electrons, forming an ion.

The exhaust side chemically active electrode converts the exhaust gas mixture to attain a state of thermodynamic balance i.e. oxidation of the various gases that penetrate the cell spinel coating. The electrode simulates a catalytic converter in that it needs oxygen to oxidise HC, H^2 and CO. If the oxidation process breaks down due to lack of oxygen on the sensor surface it will pull oxygen ions through the zirconium dioxide.

This action of pulling oxygen ions from one electrode to the other electrode results in sensor output voltage. The spinel coating also acts as a protection layer for the platinum and zirconium dioxide.

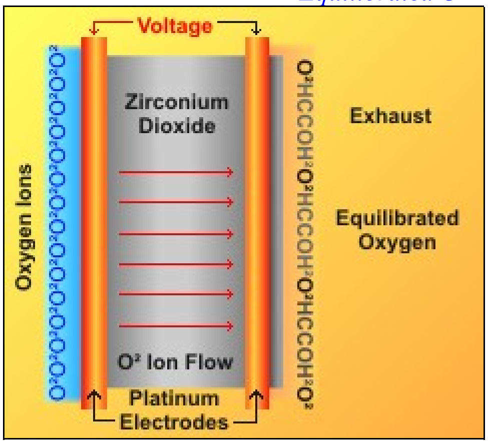
Exhaust Gases Abbreviation Definitions

HC	CO	CO^2	NOx	O^2	H^2	H^2O
Hydrocarbon	Carbon Monoxide	Carbon Dioxide	Oxides of Nitrogen	Oxygen	Hydrogen	Water

Definition of Equilibrate:

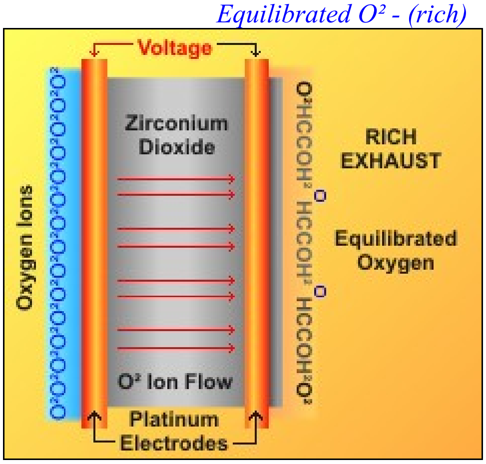
- To balance two ends or sides
- To bring about equilibrium
- A pair of forward and reverse chemical reactions

Equilibrated O²



If the oxygen sensor is to switch properly at Lambda = 1 (stoichoimetry), HC, H² and CO in the exhaust gases must oxidize at platinum/spinel. For this type of catalytic reaction (chemical change) to occur, oxygen is a requirement. Oxygen for the chemical reaction will come from either the atmospheric side or from the exhaust side as the oxygen ions are transported through the zirconium dioxide layer.
The O² sensor allows enough oxygen ion transfer to maintain balance

Equilibrated O² - (rich)

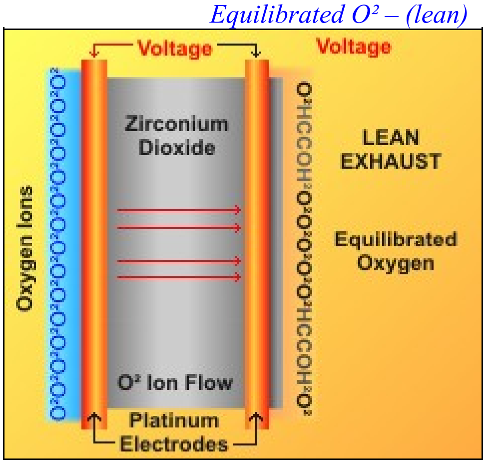


This image depicts a rich exhaust as there is not enough O² (relative to Lambda) to allow complete combustion product burn at the O² sensor outer platinum shell.

The decrease in "exhaust **O²** partial pressure" allows atmospheric **O²** to be drawn to the platinum exhaust side electrode.

The atmospheric platinum electrode is now more positive than the exhaust side electrode.

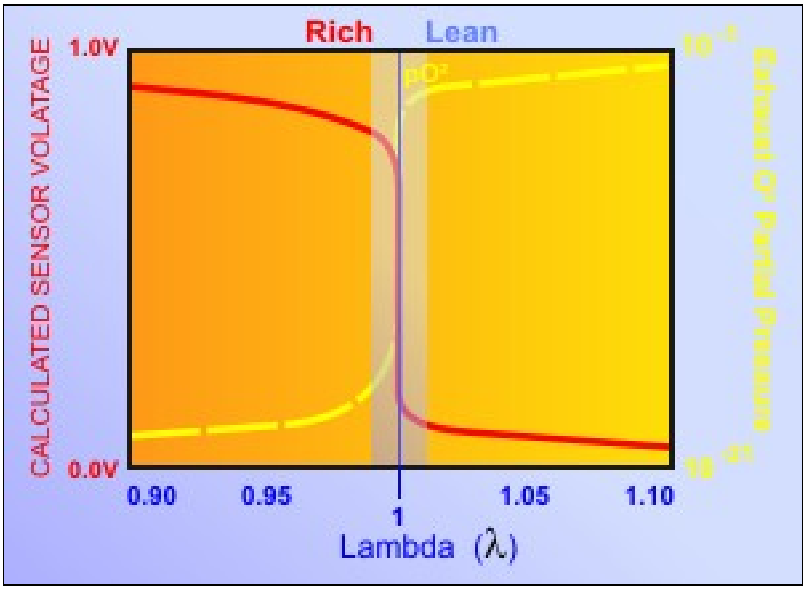
Equilibrated O² – (lean)



This image depicts a lean exhaust as there is ample O² (relative to Lambda) to allow complete combustion product burn at the outer shell.

The increase in "exhaust in **O²** exhaust partial pressure" reduces the atmospheric **O²** ion flow i.e "less pull" and the atmosheric electrode is now closer in potential to the exhaust side platinum electrode.

Lambda vs O^2 Sensor Voltage vs Exhaust O^2 Partial Pressure



Lambda Graph

The above image depicts the relationship between Lambda (stoichiometry = 14.7:1) O^2 sensor voltage and exhaust O^2 partial pressure (pO^2).

If Lambda is **less** than **1**, the air fuel ratio is **rich** and the calculated sensor voltage will be **high**.
If Lambda is **more** than **1**, the air fuel ratio is **lean** and the calculated sensor voltage will be **low**.

The right side of the graph represents the exhaust O^2 partial pressure (pO^2) and the relationship to oxygen ion transport through the zirconia dioxide layer. A greater pO^2 indicates a richer air fuel ratio (greater O^2 ion transport) than the ideal of the required stoichiometry = 14.7:1 i.e. (Lambda).
Conversely, a lower pO^2 indicates a lean air fuel ratio (less O^2 ion transport) than the ideal of the required stoichiometry = 14.7:1 i.e. (Lambda).

The shaded area in the graph (between Rich/Lean) represents the narrow area in which the ECU has authority to attempt to control the air fuel ratio, hence the term narrow band zirconia O^2 sensor.

The ECU determines from the O^2 sensor output voltage signal, if after cylinder combustion, the oxygen content is high (lean) or low (rich) and attempts fuel control.
A richer fuel mixture and combustion will consume nearly all the oxygen so the O^2 sensor voltage output signal will be high, approximately 0.6 volts to 1.0 volt.
Lean fuel mixture will allow for more oxygen to be present in the exhaust gas stream after combustion (incomplete burn) and the O^2 sensor voltage output signal will be low, approximately 0.4 volts to 0.1 volts.
The O^2 sensor voltage output signal when determining that the air fuel ratio (stoichiometry = (14.7:1) is correct, will be 0.45 volts.
Small changes in the air/fuel ratio stoichiometric point (14.7:1) will affect the O^2 voltage output signal greatly.

Toyota O^2 Sensor Diagnostics

Several factors can influence the normal operation of the O^2 sensor. During a diagnostic it is important to isolate outside influences interfering with the sensor operation or if the O^2 sensor has in fact totally failed or is failing due to an aging condition.

If the sensor becomes contaminated (excessive engine oil burning, incorrect type additives to the fuel, additives used in sealants, coolant contamination etc.), a failure or part failure of the O^2 sensor may occur. A partially contaminated sensor can cause the sensor switch (lean/rich) response times to become longer. This will cause an adverse affect on vehicle emissions and vehicle driveability problems.

Other influences that can cause O^2 sensor problems are vacuum leaks, EGR leakage, excessive fuel pressure etc.

If the O^2 sensor incorporates a heater element, check all electrical circuits. Excessive circuit resistance, open circuits and shorts to ground will produce incorrect voltage signals.

In many cases, combined use of your Hanatech scanner and basic testing will help isolate problems.

Use your Hanatech scanner and the Hanatech Host-Pro programme for monitoring, recording and saving O^2 sensor graphed waveforms.

Ensure to keep your diagnostic as simple as possible. All too often the basics, (mechanical, electrical and fuel) are not covered thoroughly and an incorrect diagnosis occurs.

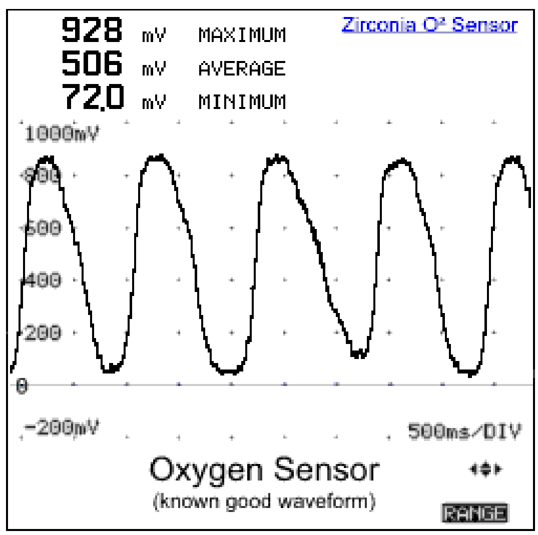
Not only does this lead to lost productivity but can also lead to possible unnecessary expensive repairs.

O^2 Sensor Oscilloscope Waveform

O^2 sensor waveforms depicting O^2 sensor partial/total failure and effects by outside influences are numerous.

Post catalytic converter O^2 sensor operation should not mimic the pre catalytic converter O^2 sensor and again sensor waveforms failures are numerous.

It is beyond the scope of this overview discussion paper to list all types of waveforms.



Oscilloscope Oxygen Sensor Waveform Testing and Evaluation

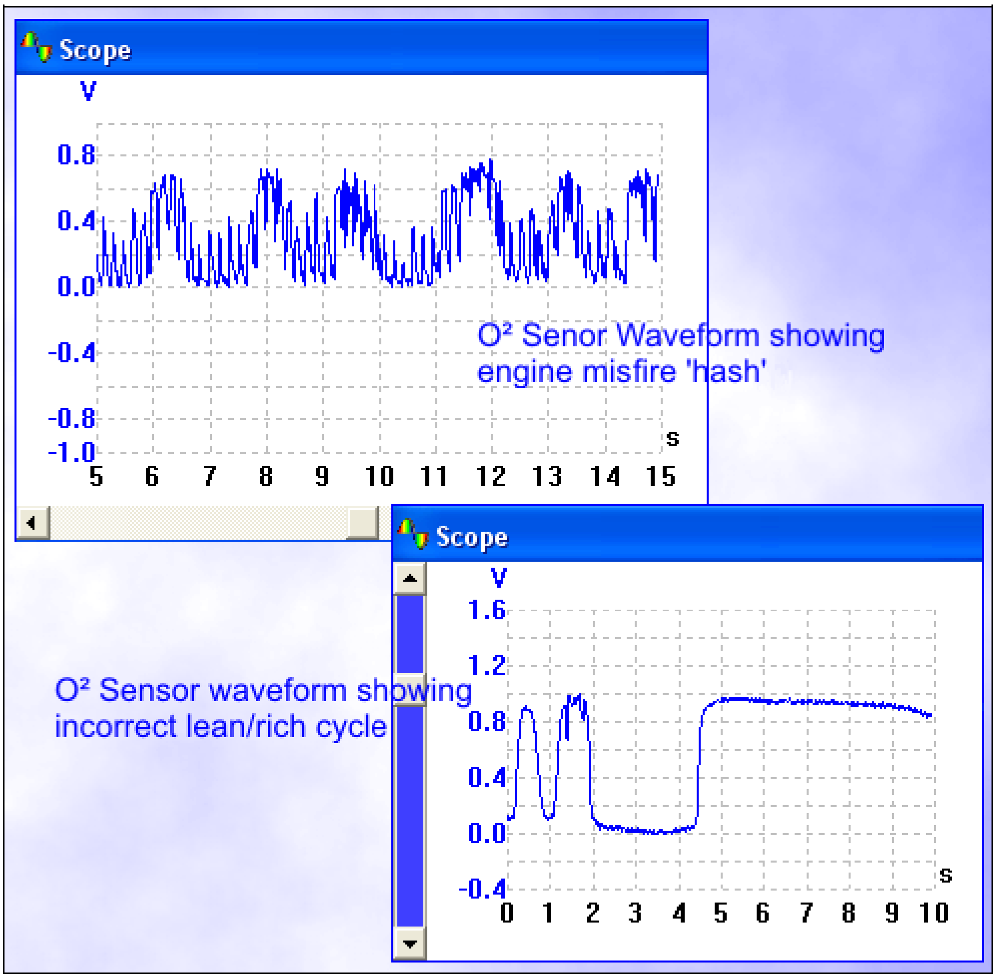
To accurately view all aspects of an O^2 sensor voltage waveform, use a quality oscilloscope. Multiple channel oscilloscopes enable monitoring of pre/post catalytic converter O^2 sensors. Voltage, transition voltage points, switching frequency, min/max voltages etc. can also be measured accurately.

The **PICO** range of oscilloscopes is an ideal diagnostic tool to accompany your Hanatech scanner and Hanatech 4/5 gas analyser.

The **PICO** range of oscilloscopes supports many unique features, including waveform magnification and composite waveform views.

Contact **Mount AutoEquip** for details on pricing and availability.

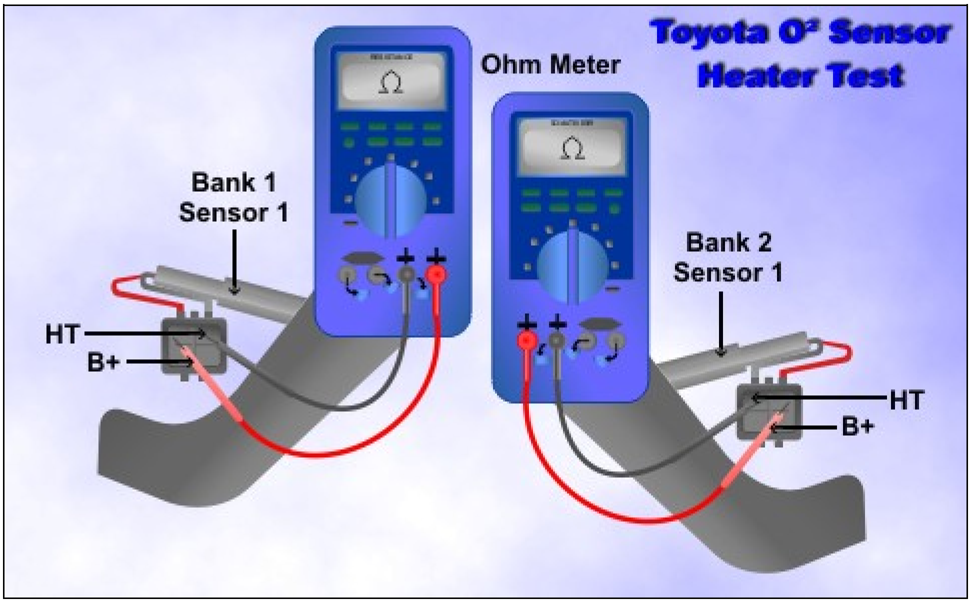
Zirconia Oxygen Sensor Waveform Examples



Pico Oscilloscope O^2 Sensor Waveforms

Toyota O^2 Sensor Heater Element Testing – Resistance Check

O^2 Sensor Heater Element Resistance Test



For an accurate O^2 sensor signal output to enable ECU controlled fuel corrections, the sensor requires heating rapidly. The internal element of the O^2 sensor provides additional heat as current is passed through it. The ECU turns on the O^2 Sensor internal heater circuit using EFI sensor signals based on the requirement needed to keep the O^2 sensor at or above 400°C.

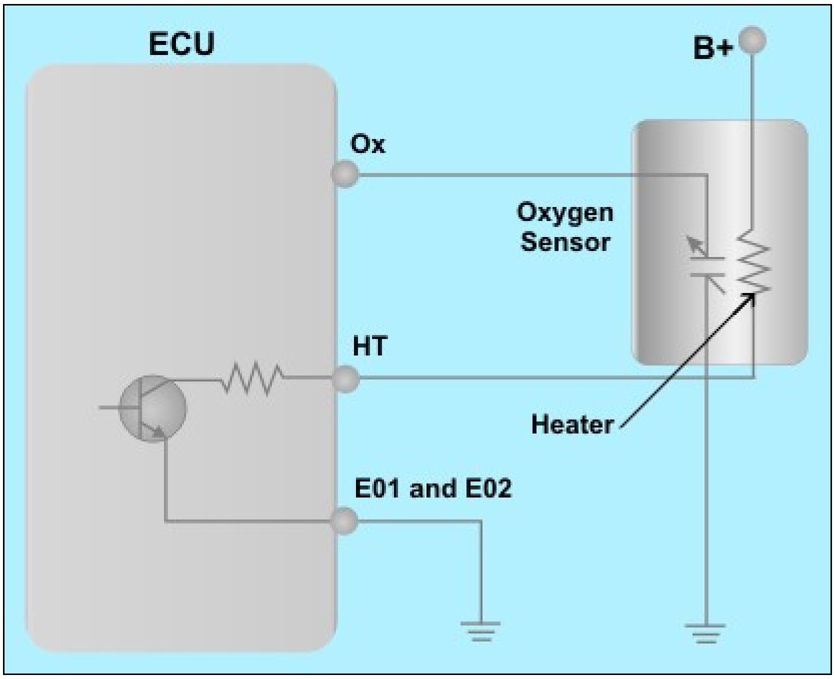
The Engine Coolant Temperature Sensor (CTS) signal data and engine load, Mass Air Flow (MAF) is used by MAF EFI type applications and the CTS signal data and Manifold Absolute Pressure (MAP) sensor output signal data in MAP EFI systems.

The O^2 sensor internal heater element can be as high as approximately 2 amperes. The heater element resistance can be checked with high impedence Digital Volt/OHM Meter.

The higher the temperature of the heater, the higher the resistance of the element will be measured on the DVOM.

Toyota ECU / Oxygen Sensor Heater Element Circuit

Toyota ECU O² Sensor Heater Element Circuit Schematic



Note:
When checking resistance of an OEM heater circuit and it is found faulty, fitting an after market O² sensor may cause EFI system operational problems if the resistance requirement of the O² sensor heater is not to Toyota specifications.

The oxygen sensor heater circuit is monitored by the ECU for proper operation. If a malfunction is detected, the circuit is turned off. If this occurs, the O² sensor will produce very little or no voltage.

For correct systems wiring and systems analysis please refer to the relevant Toyota vehicle service literature.

Acknowledgment - Toyota Motor Corporation
- Bosch technical papers
Composer – Kevin Greenfield – Hanatech Australia – Technical Assistance