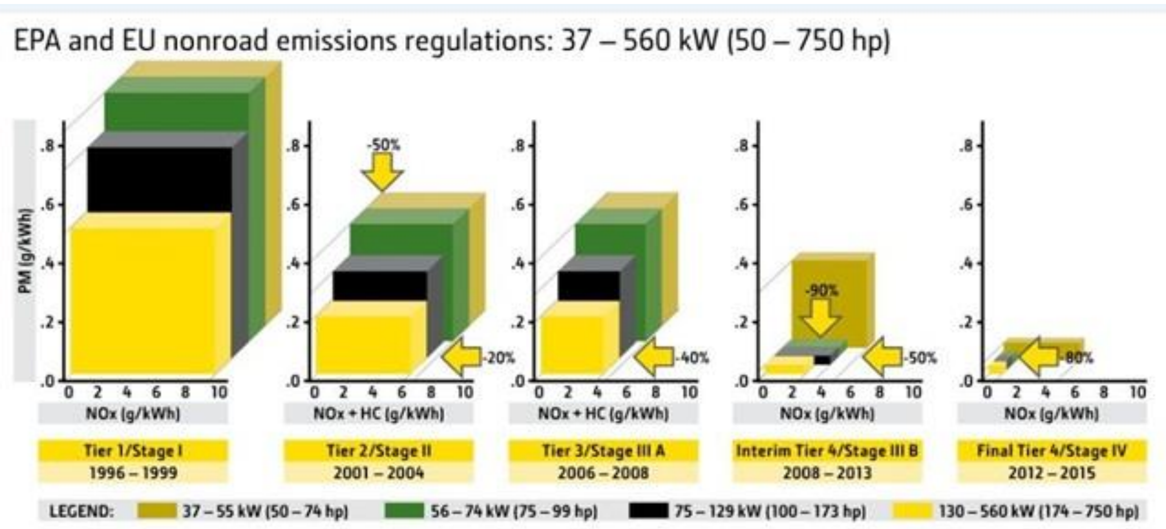
I have been lucky enough to work within Further education for 7 years and have taught many differing units based around agriculture. My main subjects and interests lie within the engine, electronics and machinery topics though I also teach welding and fabrication, business, to name but a few units. My background being from dealers/industry before delving into education. I currently teach level 1, 2 and 3 learners in a FE College in Herefordshire. One of the main areas that learners struggle to comprehend is the relationship between power, engine size, maintenance, setting requirements and emissions, this usually comes to more of a focus when fuel economy is added to the mix although the young opinion still exists that the diesel tank is magically filled irrelevant of use and cost and that their driving methods have no effect on efficiency and emissions. It is very difficult to deliver and teach these in a day to day context without making the subject more palatable and interesting for the learners and hopefully help them reduce their fuel burdens. Many users now prefer to use dealers to service machinery due to the complexity of systems and costs involved, and as such engineering is sadly going larger and more costly. The home mechanics are sadly in decline.

It is therefore with gratitude that I have received a bursary to attend some manufacturers courses on the above topic to develop a project which I intend to launch with groups this year and hopefully continue developing into the future as an evolving development. Learners have to undertake research projects within their courses of study of which I encourage some to pick up the mantle and try and improve the current prototype which has been constructed by myself and current learners.

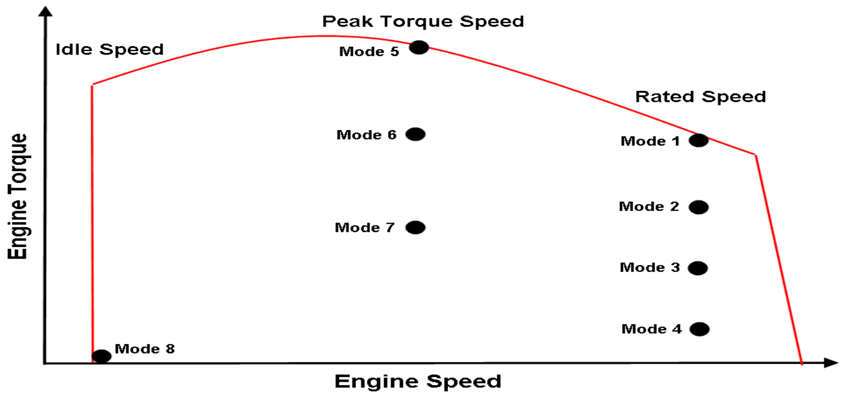
The whole aim of my funding is to attend manufacturer training courses within agriculture and engine technology and learn how emission systems work and the way differing manufactures have overcome achieving emissions requirements whilst producing engines with the characteristics needed for agricultural purpose e.g. high torque, low rpm, good economy and reliable. It is always a concern that as technology increases alongside cost, reliability and durability may decrease. As I learn this current information I will then cascade onto future learners.

As can be seen in the table below emissions in agricultural machinery are split into two main concerns particulate matter (PM) and oxides of nitrogen (NoX). Both have to be controlled and managed to achieve legal requirements for the production of engines (though as yet no testing is required to make sure these machines stay within these tolerances after purchase but that is a whole different argument). A similar system is used in the motor vehicle world (euro standards) although these have differing quantities and parameters the fundamentals are the same. As time progresses these two emissions have been reduced in tiers to the current levels seen at present. The table below shows an excellent layout showing just how hard emissions have been affected by regulations.

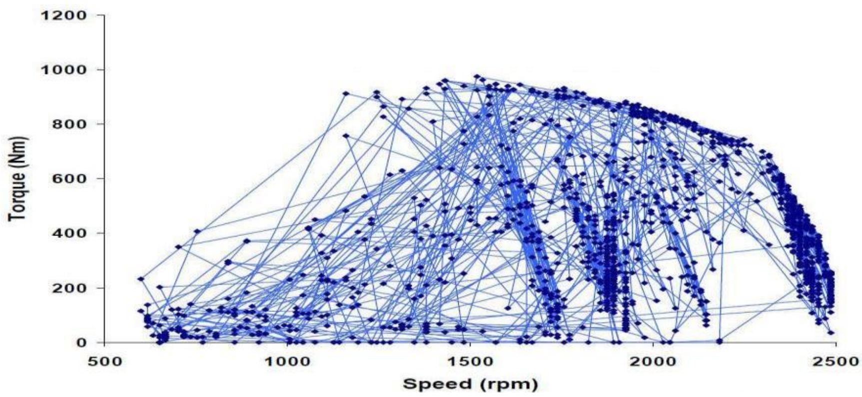


PM is the black soot that comes from the exhaust when the engine is working hard, not running correctly or running outside optimal temperatures/conditions. It is a by product of unburned diesel exiting the machine via the exhaust system. NoX is produced when the combustion temperature within the engine rises above 2500 degrees Celsius. These two have a seesaw effect, when manufacturers increase exhaust temperatures to reduce pm, the nox rises and vice versa, to combat this manufacturers are going down two different routes. Using Adblue a chemical which reacts with the exhaust gasses from an engine to reduce the Nox (often combined with cooled exhaust gas recirculation to reduce combustion temperatures). Using a diesel particulate filter to collect PM which can be force regenerated (self cleaned by increasing the temperature within the filter by injecting diesel into the system or service exchange), or both of these systems. This is to get emissions down to comply with current tier4 emissions. As emissions regulations continue manufacturers will combine these technologies into one unit. Current levels of egr recirculation are hovering around the 30-35% region. Although one effect of this high level of recirculation is engines cylinder capacities have to get bigger to cater for the power deficit of an egr engine.

Tier 3 testing (now outdated) used 8 set test points, this meant fuelling could be trimmed within these test areas via careful mapping, this would cause slight hesitation and flat spots in certain ranges of operation although these spots would be considered outside optimum operating areas. This trimming or mapping meant the engines met the emission regulations to enable them to be produced commercially.



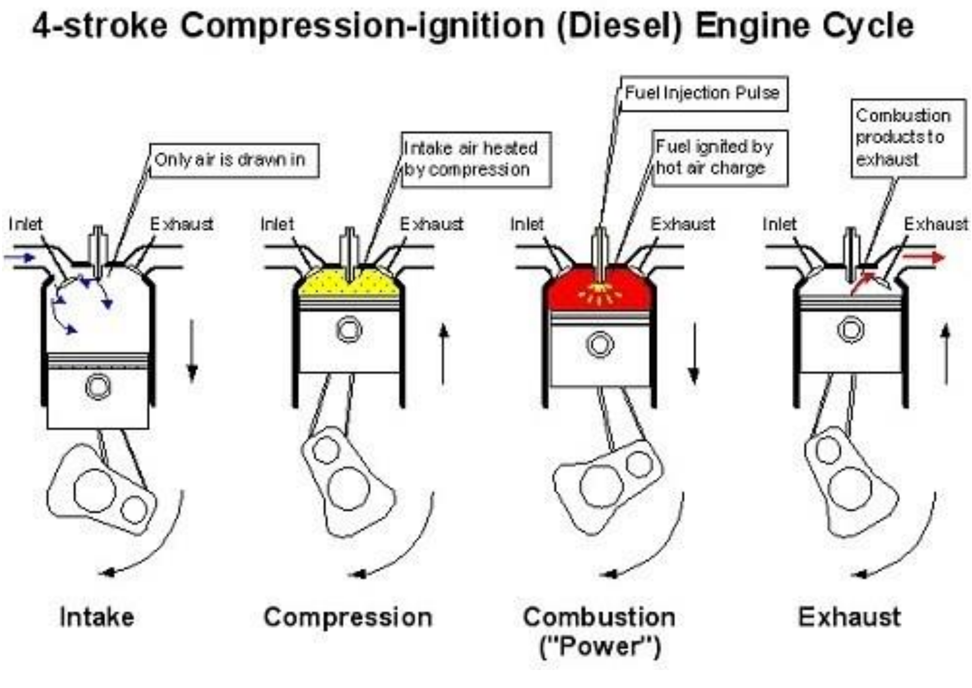
Tier 4 testing has 1200 set points to reduce this possibility resulting in a much more stringent testing procedure and requiring a much more vigorous emissions monitoring system. Manufacturers can no longer trim the fuelling within these test points as they are spread across engine operating range. This means engines must become cleaner overall.



Manufacturers are currently producing engines which produce a very high torque requirement for agricultural use yet when maintained correctly have a very clean burn for reducing emissions. I intend to use this information and much more gained from these courses to produce teaching sessions to help the next generation understand the importance of these systems.

A quick explanation of diesel combustion engines traditional and modern.

The main power source for tractors is the four stroke diesel engine. Traditionally diesel engines were mechanically governed (fuelled). On the induction stroke the piston travels down the cylinder drawing in air only. On the compression stroke the piston rises trapping the air within the cylinder compressing it anything from 7 to 20 times its original size depending on the engines design and cylinder size/stroke length ratio. Just before the piston gets to the top of its stroke fuel is injected into the air (this is produced mechanically i.e. the injection pump which is driven off the timing gear pressurises the fuel till the injector releases it (once injector crack off pressure has been reached). This atomised fuel starts to combust increasing in pressure (the fuel is ignited due to the heating of the air during compression a little like a bike pump getting hot when pumping up a tyre). The pressure then rises and pushes the piston down the cylinder producing power to operate the machine. The exhaust gasses are then pushed out of the cylinder by the piston rising and remnants of expansion from combustion.



This system has flaws, mainly due to the technology available at time of production. Common rail engines have opened up a whole world of change. The engine operates in a similar manner however now the injectors are told when to pulse fuel by an electrical signal from an electronic control unit (this reads information from the engine sensors such as engine temperature, throttle demand, exhaust lambda sensor reading, fuel temperature) and maps fuel delivery accordingly. This means more than 1 injection of diesel can take place during the power stroke (up to 8 currently) and at differing times and quantities. It also allows much higher injection pressures to be used reducing atomisation size and increasing surface area. This results in engines being able to produce a lot more power for greater degrees of angle within the stroke, smoother in operation, easily re mapped for more or less power and much more carefully controlled, direct injection is now becoming the fashion due to its advantages compared to indirect injection, an issue previously was the differing shock wave times between idle and full rpm causing changes to injection delivery. There is a great deal more than this but just a brief introduction. Manufacturers are currently working on homogenous injection where diesel is atomised to produce multi point combustion in areas around the combustion chamber to further increase power (and reduce burn time) but I am told this is a little way off yet (the reason being multi ignition points should result in faster burning of atomised fuel at higher pressures resulting in more power and cleaner burning).

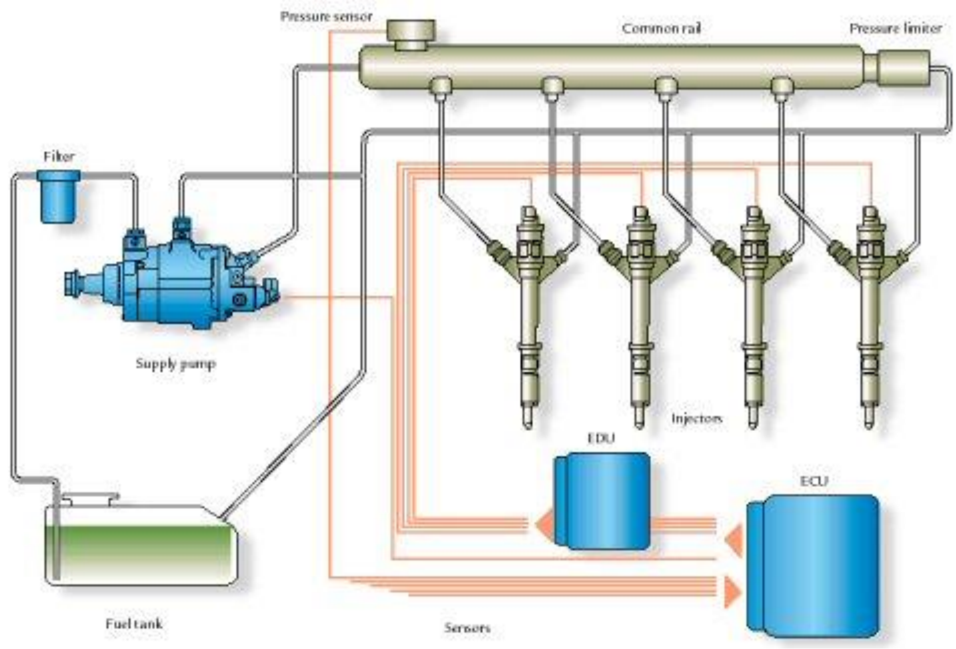
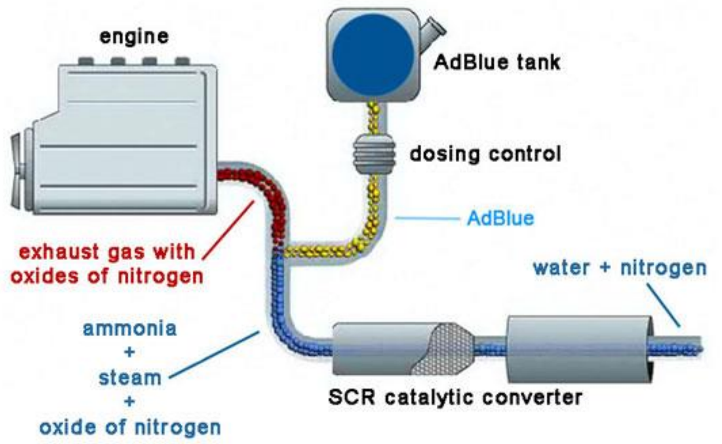


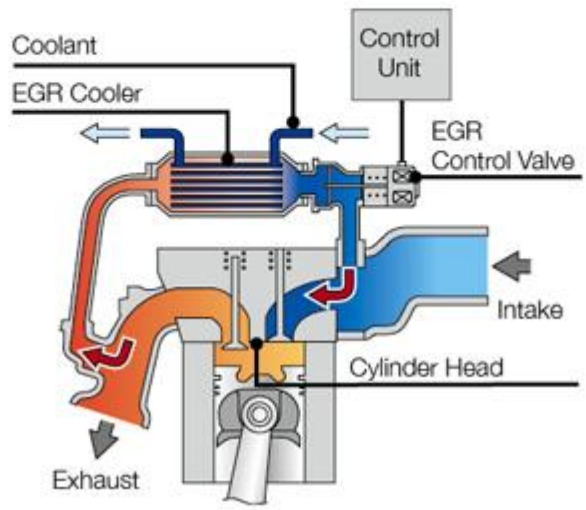
Image depicting typical common rail system.

Adblue/Selective catalyst reduction

A by-product of the plastics industry Adblue is a urea based product that when injected into the exhaust system reduces Nox by breaking it down into nitrogen and water vapour. Two sensors upstream and downstream of the mixing chamber monitor the Adblue effects and change dosing as required. Adblue crystallises quickly so pipework needs venting after every use. Adblue consumption varies widely dependant on operating/environmental conditions. I was fortunate enough to be present during horse power testing of two tractors of similar size in a training workshop, one with Adblue and one without. During the Adblue Dynonometer test apart from the noise and sound waves the environment was comfortable. Upon commencement of the non Adblue machine the air became so polluted it made talking uncomfortable due to the emissions of the engine. Adblue has been used within the transport industry for many years now and has finally become mainstream within the agricultural sector. Research is currently being undertaken however as to the effects of adblue on bee’s as it has been suggested the chemical has adverse effects on the bee’s ability for locating pollen, although this research continues.

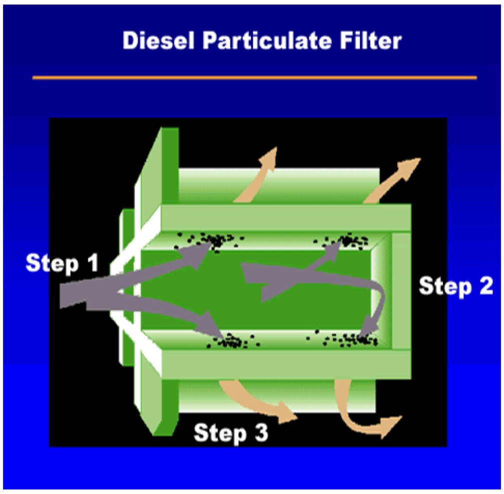


Cooled EGR/SCR
This system draws some exhaust gasses back into the engine via a heat exchanger. This reduces cylinder temperature as the air cannot be re-burnt so reduces flame spread within the combustion chamber. Larger engines struggle to run this system due to the high demands on the engine cooling system which is utilised to cool the heat exchanger. Thus larger engines require particulate filters to catch the pm resulted from the cooler burning. EGR valves do appear to produce current running issues such as fouling of the air induction systems due to dirty emissions sticking to the walls of the inlet manifold hindering the airs ability to enter the cylinder ultimately reducing volumetric efficiency. Many countries did not utilise egr systems though have now had to embrace this technology to reduce nox.



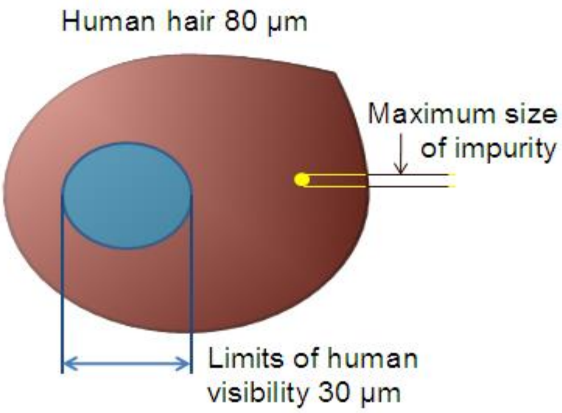
Diesel particulate filter
This type of filter has a pocketed style construction in which pm is trapped within the filter under normal operating conditions. A pressure sensor monitors the flow of gasses and warns when the filter is getting blocked. The machine then performs a regeneration to heat the filter to burn out the pm (by burning extra fuel). This is done automatically by the machine during use, however a hotter burn can be activated by the dealer via the diagnostic system (forced regeneration). Although it appears strange to capture these particulates then release them at a given time through controlled burning, this process does reduce the PM to less harmful ash. Some machines have had software written to send the machine into a limp home mode when the filter blocks to de rate engine power to help protect mechanical systems. Certain parameters have to be met before this happens e.g. in

commercial vehicles the machine must be travelling below certain speeds and have stopped momentarily to prevent de rating at inconvenient times for safety reasons. One manufacturer has chosen to limit the amount of times an engine can be started and how long it will run for to protect the complex systems that could potentially be damaged.



As with all of these systems fuel quality has always been a problem. The fuel which was produced Post war to aid agricultural companies to produce cheap food is now too dirty to be used in modern machines due to the tolerances of the fuel components. This poor quality fuel clogged filters (bacteria grows in moisture) and the sulphur caused damage to sensitive high pressure systems. As such red diesel has now changed. In 2011 it became cleaner and with less sulphur. One of the main problems being these systems were working fine on the continent but when introduced to poor uk red diesel system failure was problematic. As such fuel prices have increased but this has allowed manufacturers to continue developing clean systems with lower and lower emissions.

Size of impurities considered harmful currently to high pressure injection systems.



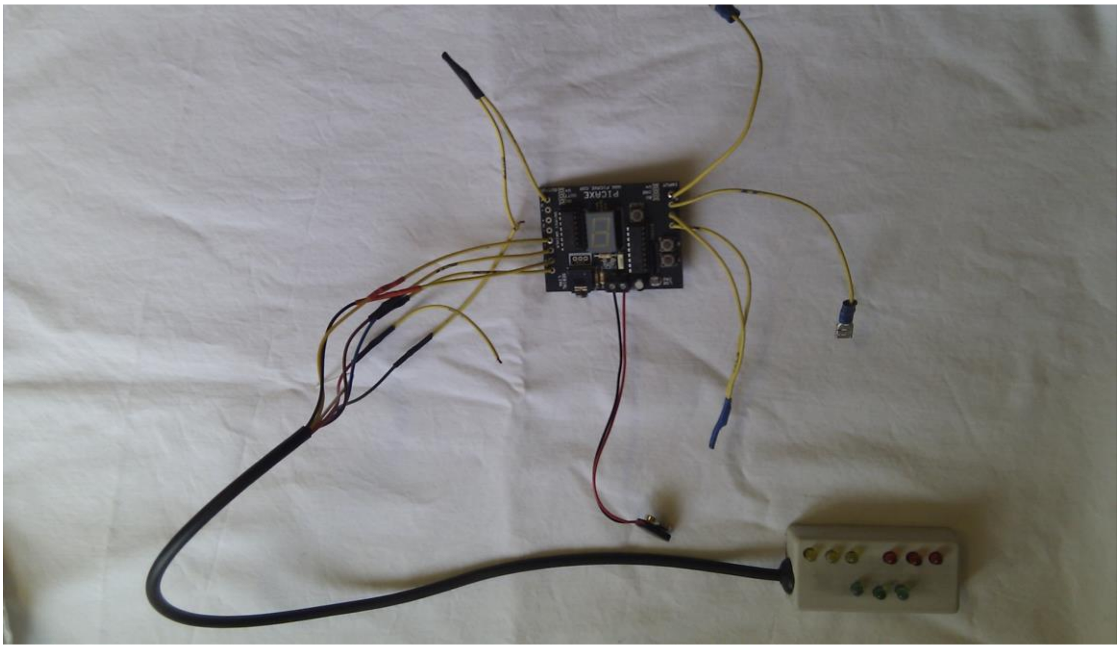
Now I have attended many courses the next stage of my project is to use this information to both deliver to learners how these systems work and to create an emissions testing system which can be utilised in the field to demonstrate the effects differing settings and conditions will have on emissions and economy. I was lucky enough to obtain an Adblue system from a well-known uk agricultural manufacturer which I intend to mount on a stand to show its travels through the exhaust system.

I now aim to develop emissions testing system with my learners that can be retro fitted to any machine to enable the learners to understand how the above systems work and their relationships with other systems. It is very difficult to show people how all the differing systems react to one another due to the size and complexity of them, it is my hope that by breaking them down and working on a measurement system that will actually show in real time the emissions being produced at any given time these systems will be understood.

The system I aim to make (though fairly simple in idea) operates on a complex system. I intend to use a broadband or similar diesel lambda sensor (found currently in the motor vehicle world) and produce a fixing to retro fix it into the exhaust system of the agricultural machine. These sensors "sniff" the exhaust gasses and send signals to the ecu to tell it how much unburned oxygen is in the system thus showing whether the machine is running lean or rich. The sensor will be connected to a reprogrammable micro controller to enable myself and my learners to write the software for the controller and be able to set the parameters for it to measure. This will also then have the effect of making the learners understand simple programming software (a basic need for future agricultural engineers). This ecu will then show the emissions output as coloured led's on a display that can be fitted to the dash of the machine. Yellow for lean burning, Green for ideal conditions (called lambda 1 at a stoicheometric ratio of 14.7 air to 1 part fuel) and red for too much diesel being burnt. These readings will also be fed to a reader which uses blue tooth to send this information to a data logger which will store this information for analysis later as graphical and table format. I would also like to add a fuel consumption meter to demonstrate alongside consumption figures.

It is with this information that I hope to get the learners to be able to answer questions on reducing emissions and fuel economy such as:-

Is it better to have a smaller engine working harder or a larger one less stressed?
What effects does routine maintenance have e.g air filter, tyre pressure, clean/stale fuel?
What effect do differing atmospheric conditions have?
Is it possible to modify driving styles to reduce costs and improve outputs?
This system I hope to fit during activities such as ploughing, fertiliser spreading, baling and other crop operations. It could also be fitted to machinery such as combines, telehandlers, foragers.



This is my current prototype which has been developed with current learners although crude development continues. I have issues with the lambda sensors being adapted for agricultural use although with more development I am sure this will be rectified. The lambda sensor shown below connects into the push fit connectors.

Above was the first generation intended to fit over the end of the exhaust pipe. Issues with this revolved around the exhaust gasses cooling as it travels along the length of the pipe reducing the sensors reaction efficiency. The second generation will be screwed into the exhaust system near the manifold.

I have trialled two types of lambda sensor, a zirconia and a titania. The zirconia works by emitting a voltage whilst sensing the air in the exhaust emissions, titania change resistance dependant on emissions. The titania works better with the system though needs boosting with a transistor. My next prototype I would like to use a wideband diesel sensor. These operate much faster and have a much more accurate level of measuring where as the zirconia and titania tend to operate within the two extremes of rich or lean showing limited degrees of within. These sensors need to be 350degrees celcuis to start operating correctly as it is heat that makes them work. This means the sensor needs to be added as near to the combustion chamber as possible. Some have internal heaters which run off the vehicles ecu reading cooling system temperature and / or exhaust temperature to determine whether to switch on the heater or not. This is as addition I would like to further develop within the mk3 version, a relatively simple addition of writing software to turn on the heating element if coolant temperature is below optimum thus indicating exhaust temperature would be at a similarly reduced level. This system will next be trialled with a NOx sensor which will demonstrate levels within the emissions system.

The tester uses a Picaxe reprogrammable micro controller. Software is written and downloaded via an uplink cable. These are marvellous systems and are available at an affordable price which make experimentation with learners possible and limits expensive damage.

Below is a snippet of an example of the software myself and the learners have written. It tells the control module to look at the resistance if the lambda sensor and light the led's dependant on the resistance although it determines this by sending a voltage to the sensor (5v) and then comparing this to the output voltage thus working out the resistance. This is not the syntax used but shows the principle.

```
main:       readadc C.0, b1              ; read the value
  if b1 < 17 then light1 ; range 0-17   = 1
  if b1 < 18 then light2 ; range 18-34 = 2
  if b1 < 35 then light3 ; range 35-51 = 3
  goto main

light1:     high B.1           ; switch on  LED 1
  low  B.2           ; switch off LED 2
  low  B.3           ; switch off LED 3
  goto main          ; loop

light2:     low  B.1           ; switch off LED 1
  high B.2           ; switch on  LED 2
  low  B.3           ; switch off LED 3
  goto main          ; loop

light3:     low  B.1           ; switch off LED 1
  low  B.2           ; switch off LED 2
  high B.3           ; switch on  LED 3
Goto main:
```

It is within this development I hope to inspire and encourage the future of engineers and agricultural members to possibly reduce running costs and improve emissions. Whilst I am aware there are issues with the above prototype as a learner focused project I hope the development will continue to de bug some of the current issues. This project has turned into a constant source of investigation as once a path has been fully researched and experimented another idea/theory presents itself.