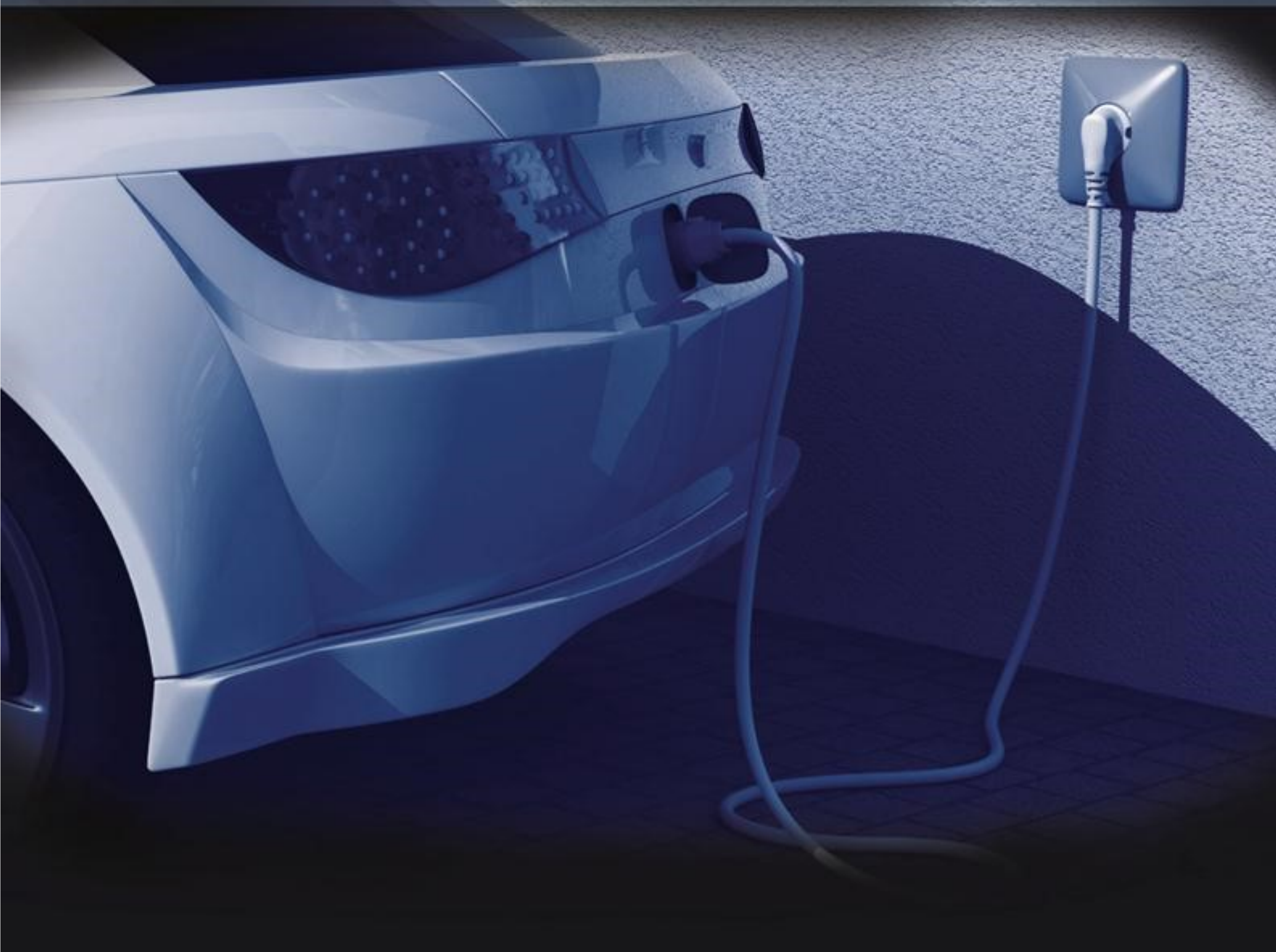
Hybrid Vehicle Systems

Simplifying Electricity



LK4483

www.matrixmultimedia.com

Contents

Hybrid engine demonstrator

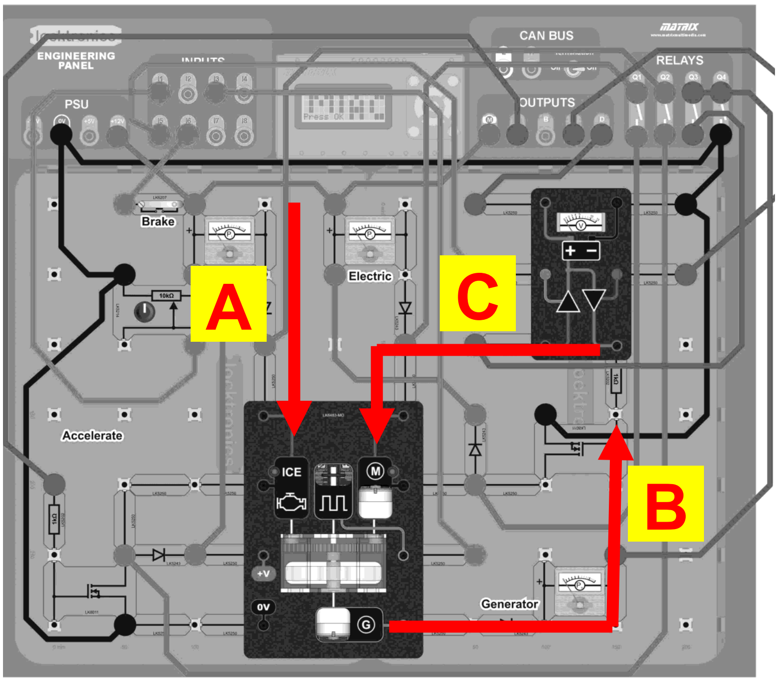
Equipment overview	3
Locktronics system wiring	5
Role of the MIAC	6
Worksheet 1 - Discovering hybrid power modes	7
Worksheet 2 - Regenerative braking	9
Worksheet 3 - Assisted acceleration	11
Worksheet 4 - SOC and battery voltage	13
Worksheet 5 - SOC and decision making	15
For your records	17
Quiz	18
Instructor guide	20
Quiz answers	25

About this document:
Developed for product code LK6483 – Locktronics Hybrid engine demonstrator

Date	Release notes	Release version
Oct 2011	First version released	1
Oct 2011	Revised for updated hardware	2
Nov 2013	Revised for updated hardware	3
Dec 2013	Revised for v009 MIAC software	4
Apr 2014	Minor Corrections - display/button labels	5
Jun 2019	Amends to worksheet 4 table	6

Equipment overview Locktronics system

Hybrid engine demonstrator



The Hybrid demonstrator is modelled on the Toyota Prius.

The energy paths into and out of the engine are shown by the three red arrows:

- **A** - the power being used by the internal combustion engine;
- **B** - the electrical power generated by the engine and fed into the battery;
- **C** - the power flowing from the battery into the electric motor.

The accelerator potentiometer and brake switch control the whole system.

The operation of the system is governed by the state of charge (SOC) of the battery and the actions of the driver. The table illustrates this:

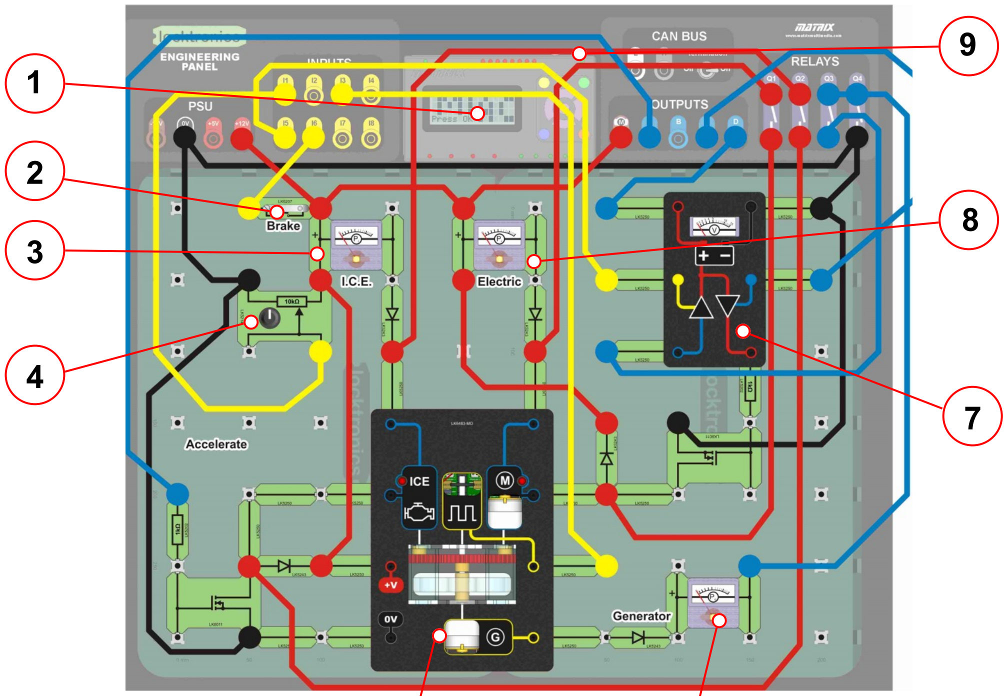
Power demand	SOC	Power flow
low	low	A,B
low	high	C
med	low	A,B
med	high	A
high	low	A
high	high	A,C

In addition to showing power flow under various conditions, the trainer demonstrates the effect of regenerative braking. When the brake switch is pressed at high engine speed, additional power flows into the battery through channel **B** and the engine slows down.

The MIAC ECU controls the whole system, and displays the current operating mode, and the state of charge of the battery.

Equipment overview Locktronics system

Hybrid engine demonstrator



1.The MIAC Electronic Control Unit (ECU) controls the whole system. The display shows the:

- current operating mode;
- target speed set by the 'Accelerator'(Acc);
- actual speed (Vel);
- state of charge (SOC) of the battery;
- time, controlled by the user.

2.The press switch acts as the vehicle’s brake pedal.

3.The internal combustion engine (ICE) meter shows the power going into the system from the combustion engine.

4.The potentiometer mimics the operation of the accelerator pedal.

5.The hybrid engine contains an electric motor, a generator, and an internal combustion engine, (simulated by a second electric motor.) The three units are linked by a gear train. A flywheel simulates the momentum of the vehicle.

6.The power generated and fed into the battery is shown on the generator meter

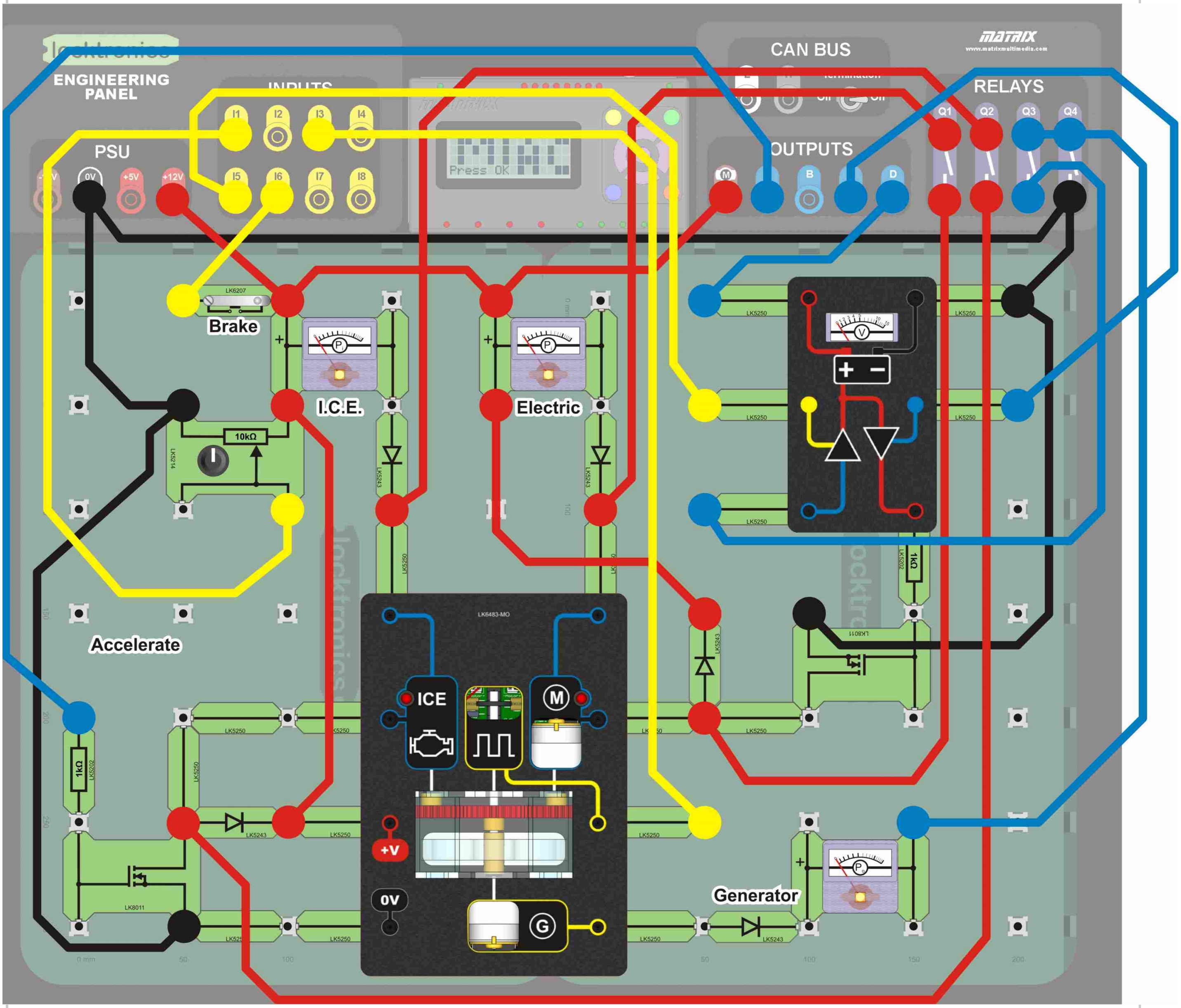
7.The battery module demonstrates the storage of energy in the system, including a meter to show the battery’s voltage, which also acts as an indicator of the state of charge.

8.The motor meter is used to show the power being fed into the electric motor.

9. The Reset switch returns the state of charge of the battery to zero

Locktronics system wiring

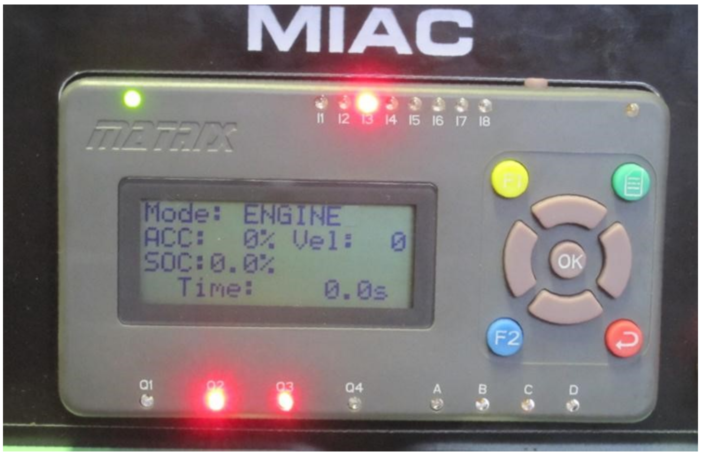
Hybrid engine demonstrator



The diagram shows how to wire the hybrid training system.

Don't worry about the circuit diagram - just build it!

Role of the MIAC



The MIAC is an Electronic Control Unit that controls the power flow in the hybrid trainer
It displays what is happening in the engine, and allows the user to control the system.

It has eight inputs, labelled **I1** to **I8**, four relay outputs, **Q1** to **Q4**, and four transistor outputs, **A**, **B**, **C** and **D**. The status of the inputs, relays and transistor outputs is shown by LEDs on the front of the unit, labelled to indicate their function.

A Reset switch, found above and slightly to the left of the USB LED returns the state of charge of the battery to zero.

MIAC display

Row	Displays
1	Current operating mode: **Mode: ENGINE** **Mode: DUAL** **Mode: MOTOR** **Mode: ASSIST** **Mode: BRAKE**
2	**Accelerator** position - controlled by the potentiometer; **Speed** - revolutions per minute
3	**Battery** (SOC) - as a percentage of full charge Battery power flow: either **Charge** or **Drain**
4	**Time** lapsed - a simple ‘stopwatch’ controlled via the buttons: **Green** - timer start **Red** - timer stop **Yellow** - enable timer / reset time

Worksheet 1

Discovering hybrid power modes

Hybrid engine demonstrator

Hybrid car design aims to address two issues:

- the high price of oil;
- the environmental effects of burning fossil fuels.

At present, most hybrid cars have an internal combustion engine (ICE) and an electric motor.

These two power sources can be connected to drive the vehicle in a number of ways.
This worksheet illustrates the different modes used in a series / parallel hybrid.

w7a

Over to you:

- Press and release the Reset button on top of the MIAC ECU.
- Press the 'OK' button to start the program.

1. What is the state of charge of the battery? Record it in the table.

- Turn the 'accelerator' potentiometer clockwise to a value of around 20 or until the engine starts to move - the flywheel starts to rotate.

2. Look at the meters and the MIAC display. Record the `Mode`, `SOC` and note the effect on the battery. (At this stage, just use words like 'zero', 'non-zero', 'rising' or 'falling'.)

- Rotate the 'accelerator' potentiometer until `ACC` on the MIAC reads 50 and wait until the battery `SOC` reaches around 50%. Then turn the 'accelerator' potentiometer back to zero.

3. Now repeat the process - turn the 'accelerator' potentiometer so `ACC` on the MIAC reads around 20 and the motor starts to move. Record what is happening on the meters and display in the table.
4. Use the 'accelerator' potentiometer to charge the battery to around 50% SOC and let the motor glide to a halt. When the motor is at rest wind the 'accelerator' potentiometer up to maximum. Look at the ICE and Motor power meters. Make a note of what the meters are reading.

	Mode	CHARGE / DRAIN	SOC %	ICE meter	Motor meter	Generator meter	Battery Voltage meter
1			0%	zero	zero	zero	zero
2							
3							
4							

Worksheet 1
Discovering hybrid power modes

Hybrid engine demonstrator

So what?

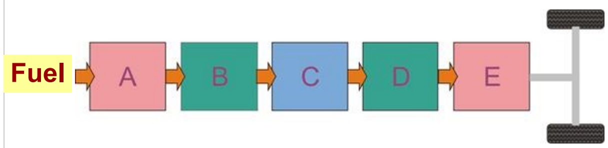
Normally, the engine of a non-hybrid vehicle must operate at a range of speeds, and so often runs at below optimum efficiency. Car diesel engines can have efficiencies up to 40% but more often return around 30%. Efficiencies of petrol engines are around 10% lower. Fuel is burned in such conditions which produces emissions, including hydrocarbons and oxides of nitrogen and carbon, that are hazardous to health and to the environment. Hybrid vehicles aim for optimum efficiency on the ICE, by running at optimal engine speeds wherever possible, and by using a range of other techniques, such as regenerative braking.

At present, most hybrid cars have an ICE and an electric motor.

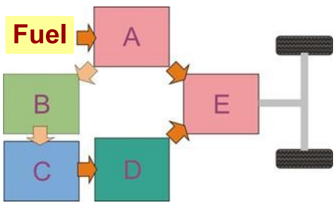
- A fuel tank supplies energy to the ICE, and a battery supplies energy to the electric motor. Energy can flow in either direction in the battery - it can be re-charged by regenerative braking. There is no equivalent for the fuel tank.
- The ICE can be smaller and lighter because it can be supported by the electric motor.
- The electric motor delivers high torque at low rotational speed, whereas the ICE delivers maximum torque at higher 'rpm'.

These two power sources can be connected in a variety of ways, including:

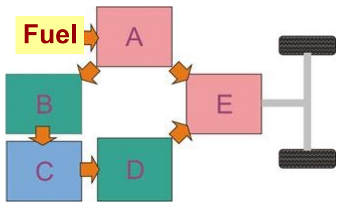
- **the series hybrid** - The ICE drives a generator, which can either charge a battery or power an electric motor that drives the car. There is no mechanical connection between ICE and wheels. This returns better fuel consumption than the parallel hybrid. A disadvantage is the large number of energy changes that take place between fuel and motion.
- **the parallel hybrid** - Both ICE and electric motor can drive the vehicle at the same time. The ICE may also charge the battery through a generator. The transmission hardware is conventional, but fuel economy is worse than that of the series hybrid.
- **the series-parallel hybrid** - This combines advantages of both At low or zero speed, the electric motor drives the vehicle, delivering high torque and nearly zero emissions. At higher speed, the ICE and the electric motor work together to give greater responsiveness. This flexibility requires a distinctive 'power-splitter', to allow one or both power sources to drive the vehicle.



series hybrid



parallel hybrid



series-parallel hybrid

Key to diagrams:

A - internal combustion engine
B - generator
C - battery
D - electric motor
E - gearbox

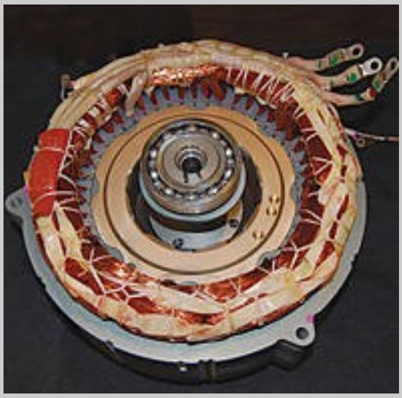
Worksheet 2
Regenerative braking

Hybrid engine demonstrator

A moving car has got kinetic energy - the faster it moves, the more it has. To slow it down, you have to get rid of that energy.

In a conventional car, friction between brake pads and rotating disc turn this kinetic energy into heat, which heats up the surroundings, and is lost.

In regenerative braking, the rotating wheels connect to a generator. Some of the kinetic energy is converted into electricity, which charges the battery. This is used later to help drive the vehicle down the road.



Over to you:

- Enable the timer by pressing the yellow button.
- Turn the ‘accelerator’ potentiometer fully clockwise.
- Allow the battery to charge to 70%. It will charge no further, in order to avoid stressing it.
- The vehicle is now running at top speed. Start the timer on the MIAC by pressing the green button, and at the same time quickly wind back the ‘accelerator’ potentiometer to zero.
- Stop the timer, by pressing the red button on the MIAC, when the vehicle comes to rest.
- Record the time taken to stop in the first line of the table.
- Reset the timer by pressing the yellow button.
- Now do the same thing again, but when the vehicle is running at full speed, press the ‘brake’ switch, until the vehicle stops.
- Record the time taken to stop in the second line of the table.
- For the next part, the battery needs to be at about 50% charge level.
  If necessary, discharge the battery, by running the engine at low speed, so that only the electric motor is providing power, or run the system in ‘Engine’ mode to charge the battery to around 50%.
- Record the state of charge of the battery in the third line of the table.
- With the vehicle running at around half of full speed, press the ‘brake‘ switch to bring the vehicle to a halt.
- Record the new value of state of charge of the battery in the fourth line of the table.

Measurement	Value
Time taken to stop without regenerative braking	
Time taken to stop using regenerative braking	
State of charge before regenerative braking	
State of charge after regenerative braking	

Worksheet 2
Regenerative braking

Hybrid engine demonstrator

So what?

In regenerative braking, the electric motor that normally drives the vehicle is operated in reverse. Instead of using electrical energy to create motion to drive the vehicle along, the motor is rotated by the vehicle's wheels and generates electricity that charges the vehicle's battery. The kinetic energy that would normally be lost as heat through friction in conventional brakes is turned into electrical energy, which is stored in the vehicle's battery.

However, there are limitations to this technology, which means that it is usually accompanied by conventional friction brakes as well.
The issues:

- Regenerative braking effect works best at high speeds.
  At lower speed, less electricity is generated, requiring less energy input from the moving vehicle, resulting in a reduced braking effect.
- A conventional friction brake is still needed to bring the vehicle to a complete halt.
- Once stationary, the regenerative brake no longer works - no kinetic energy to convert!
  A conventional 'handbrake' or 'parking brake' is still needed to stop the vehicle from rolling away.
- Regenerative braking applies only to wheels linked to the drive motor.
  For vehicles with two-wheel drive, or when driving in difficult conditions, such as on wet or icy roads, a combination of regenerative and friction-based braking is still the best option.

Worksheet 3

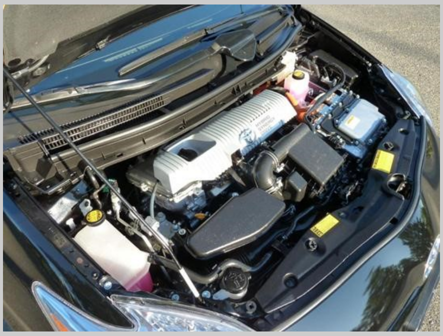
Assisted acceleration

Hybrid engine demonstrator

Hybrid vehicles often use smaller internal combustion engines than other cars. This is made possible because of the addition of the electric motor.

When maximum acceleration is needed, both are used to advantage.

This worksheet looks at assisted acceleration.



w11a

Over to you:

- Press the reset button on the MIAC to reduce the state of charge of the battery to zero.
- Press the 'OK' button to start the engine.
- Press the yellow button to enable and reset the timer.
- Turn the 'accelerator' potentiometer fully clockwise, and, at the same time, start the timer on the MIAC.
- Time how long it takes to reach full speed in 'ENGINE' mode.
- Press the Yellow button on the MIAC to reset the timer.
- Run the engine at full speed to charge the battery to 70% SOC.
- Turn the 'accelerator' potentiometer back to zero, and wait for the vehicle to come to rest.
- Repeat the process to find the time it takes to reach full speed in ASSIST mode.

Measurement	Value
Time to reach full speed in ENGINE mode	
Time to reach full speed in ASSIST mode	

Worksheet 3
Assisted acceleration

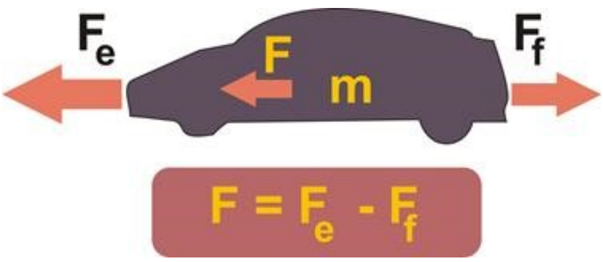
Hybrid engine demonstrator

So what?

There is an important relationship that comes from Newton's Laws of Motion. It says:

F = m x a

where **F** is the net force applied to a body of mass **m**, and **a** is the resulting acceleration.



w12a

This means that:

- the bigger the force the bigger the acceleration;
- the bigger the mass, the smaller the acceleration;
- with no net force, the acceleration is zero.

The significant implications for car designers are that, to improve acceleration:

- reduce the mass of the car;
- reduce the opposing force of air resistance;
- increase the forward force.

Manufacturers of hybrid vehicles embrace lightweight materials like aluminium and plastic to reduce the overall mass of the vehicle, with reductions of around 50% over conventional vehicles. However, there are cost implications, as the lightweight materials may be more expensive to machine and assemble.

As a vehicle moves through the air, there is a resistance to that motion. The faster the movement, the greater the air resistance. In fact, the air resistance is four times greater if the speed is doubled. The air resistance provides a force that opposes the motion. The vehicle engine is pushing the vehicle forwards, but air resistance is pushing in the opposite direction. The net force on the vehicle is the difference between the force of the engine and the frictional forces such as air resistance. The faster the vehicle goes, the greater the frictional force. Eventually, the vehicle is going so fast that the frictional forces equal the driving force of the engine. Then the net force is zero, and the vehicle no longer accelerates. It has reached its top speed. Should the driver reduce the force of the engine, by lifting the accelerator pedal, the vehicle slows down because the frictional force is then greater than the forward push of the engine.

As a hybrid vehicle has two sources of forward thrust, the ICE and the electric motor, the size of the ICE can be reduced. The advantage of doing so is that smaller engines are lighter, and so more efficient. In addition, techniques like the Atkinson cycle can increase the efficiency of the engine by effectively increasing the compression ratio.

Worksheet 4
SOC and battery voltage

Hybrid engine demonstrator

Hybrid vehicles rely on the battery to:

- start the internal combustion engine (ICE);
- provide power to drive the vehicle;
- store energy recovered by regenerative braking;
- power vehicle ancillary equipment while the ICE is off.

Battery performance is assessed using a range of parameters:

- **voltage** - the ‘force’ that drives an electric current around a circuit;
- **internal resistance** - how much energy is wasted in warming up the chemicals inside the battery;
- **capacity** - how long the battery can maintain a given electric current.

None of these measures how fully charged the battery is. A lead-acid car battery, nominally a 12V battery, can have a terminal voltage of over 12V and yet still be only 25% charged.

Over to you:

- Press the reset button on the MIAC to reduce the battery state of charge to minimum (30%)
- Press the OK button to start the program running
- Turn the “accelerator” potentiometer clockwise until the vehicle is moving slowly
- Watch the state of charge (SOC) of the battery, displayed on the MIAC
- Record the initial battery voltmeter reading at the 30% SOC
- Repeat this process recording the battery voltage for the SOC values in the table

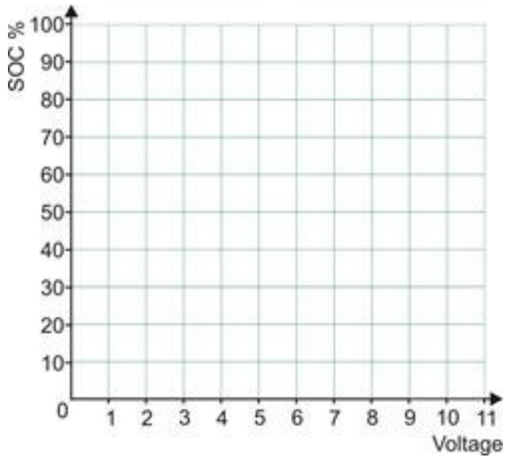
State of charge (%)	Battery Voltage
30	
35	
40	
45	
50	
55	
60	
65	
70	
75	

Worksheet 4
SOC and battery voltage

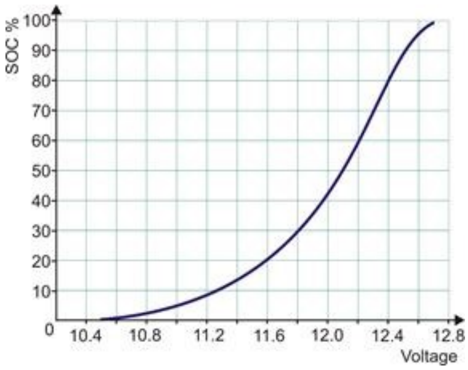
Hybrid engine demonstrator

So what?

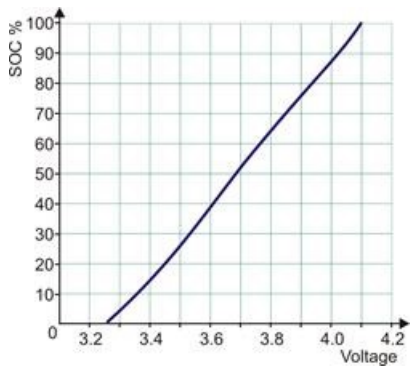
- Plot your results on a graph, like that shown opposite.
- Draw a smooth line, using your results as a guide.



The graphs below show the behaviour of a lead-acid battery and a lithium ion cell. Although these may look similar, bear in mind the voltage scales!



Lead-acid battery



Lithium-ion cell

State of charge (SOC) is the equivalent of a fuel gauge for the battery pack. It is quoted as a percentage, so that 0% means ‘discharged’ and 100% means ‘fully charged’. On the demonstration panel, the charge is kept between 30% and 75%,as it would on a real vehicle, in order to reduce the amount of stress on the battery.

Determining SOC

There are a number of methods, but some apply only to certain types of cell.

- Voltage method (this investigation) : uses the discharge curve for the cell, like those above, to convert a battery voltage measurement into SOC. However, other factors, particularly temperature, also affect the result.
- ‘Coulomb counting’: calculates the SOC by using current and time measurements to measure the charge transferred to the cell.
- Chemical method: works only with batteries that have a liquid electrolyte which is accessible. Measuring the specific gravity (relative density) indicate the SOC.
- Pressure method: used with some NiMH batteries, where the internal gas pressure increases rapidly as the battery is charged. Usually, a pressure switch activates when the battery is fully charged.

Worksheet 5

SOC and decision making

Hybrid engine demonstrator

Hybrid vehicles are smart!

They know when to change from electrical drive to internal combustion. They know when the battery needs to be re-charged.

How? Sensors monitor the state of the engine and vehicle. The ECU has been programmed to behave as the designer chose.

w15a

In this system, the ECU is the MIAC controller. It has been pre-programmed to control the vehicle in a way that meets the designer's brief. This worksheet looks at that brief.

Over to you:

- Press the reset button on the MIAC to reduce the state of charge of the battery to zero.
- Turn the 'accelerator' potentiometer clockwise until the vehicle is running at about half-speed, in ENGINE mode.
- Leave the system like this until the SOC has reached around 50% of maximum.
- Turn the 'accelerator' potentiometer anticlockwise until ACC reads around 25, so that the vehicle slows down. Leave the system like this. It is now in MOTOR mode with only the electric motor powering the vehicle.
- Watch the MIAC display.
- At what SOC reading does the system switch off the electric motor and run in ENGINE mode?
- Leave the system running at this speed. The battery is slowly charging. At what state of charge reading does the combustion engine switch off, and the system move into MOTOR mode?
- Record your results in the table below.

Change	Battery State of Charge (%)
Moves from MOTOR into ENGINE mode	
Moves from ENGINE into MOTOR mode	

Worksheet 5
SOC and decision making

Hybrid engine demonstrator

So what?

The table below lists properties of the more common types of hybrid vehicle batteries.

Battery Type	Lead-Acid	Advanced Lead-Acid	Nickel-Metal Hydride	Nickel-Cadmium	Lithium-Ion
Energy density in Wh/kg	30	38	65	45	125
Power Density W/kg	100	330	200	125	300
Cycle Life	300	650	1000	1500	800
Current Cost in $/kWh	110	750	530	450	2000
Potential		55 Wh/kg, 450 W/kg, 2000 cycles	120 Wh/kg, 2200 cycles	2200 cycles	1000 Wh/kg

Lead Acid:

- lead plates suspended in dilute sulphuric acid.
- widely understood technology - currently used universally in non-hybrid vehicles.

Advantages: low cost / widely available technology / no memory effect (see below.)

Disadvantages: potential for damage if fully discharged / low energy density / low charging-cycle life / lead is toxic.

Advanced Lead Acid:

- use techniques such as gel electrolytes and mesh electrodes;
- some incorporate large capacitors to handle short-term charging.

Advantages: readily available / longer charging-cycle life than conventional lead acid.

Nickel-Metal Hydride:

- consists of a hydrogen storage metal alloy, a nickel oxide cathode, and a potassium hydroxide electrolyte.
- widely used to power lap-top computers, and mobile telephones.

Advantages: quickly recharged / widely available technology / high efficiency / environmentally friendly

Nickel-Cadmium:

- nickel hydroxide cathode and a cadmium anode in an alkaline electrolyte .

Advantages: higher energy density / widely available now / high current at relatively constant voltage.

Disadvantages: memory effect - storage capacity reduced if only partly discharged before re-charging / cadmium is toxic

Lithium-Ion:

Advantages: light / high voltage per cell / non-toxic so environmentally friendly

Disadvantages: lithium is chemically highly reactive

For your records

Worksheet 1:

	Mode	CHARGE / DRAIN	SOC %	ICE meter	Motor meter	Generator meter	Battery Voltage meter
1			0%	zero	zero	zero	zero
2							
3							
4							

Worksheet 2:

Measurement	Value
Time taken to stop without regenerative braking	
Time taken to stop using regenerative braking	
State of charge before regenerative braking	
State of charge after regenerative braking	

Worksheet 3:

Measurement	Value
Time to reach full speed in ENGINE mode	
Time to reach full speed in ASSIST mode	

Worksheet 4:

State of charge (%)	Battery Voltage
30	
35	
40	
45	
50	
55	
60	
65	
70	
75	

Worksheet 5:

Change	Battery State of Charge (%)
Moves from MOTOR into ENGINE mode	
Moves from ENGINE into MOTOR mode	

Quiz

1. Which of the following statements is true about regenerative braking:

A. It is most effective at low speed.

B. It removes the need for friction braking systems completely.

C. It converts electrical energy from the battery into kinetic energy in making the vehicle slow down.

D. It reduces the amount of energy transformed into heat.

2. Which of the following statements is true about the term 'state of charge'?

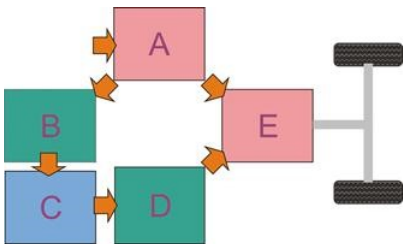
A. It is another term for 'battery terminal voltage.

B. It depends on the number of coulombs transferred to the battery.

C. The higher the battery voltage, the lower the state of charge.

D. When the state of charge is 100%, all types of battery have the same terminal voltage.

3. Which one of the following cars has the hybrid configuration shown in the diagram?



A. Toyota Prius (2011)

B. Nissan Leaf (2011)

C. Chevrolet Volt (2010)

D. Peugeot iOn (2011)

4. What is another name for the series hybrid?

A. Power-split hybrid

B. Parallel hybrid

C. Range-extended electric vehicle

D. PHEV

5. Which of the following statements is true?

A. The bigger the mass of the vehicle, the bigger its acceleration, for a given force.

B. The bigger the nett force, the smaller the acceleration for a given vehicle.

C. The higher the acceleration, the bigger the force needed, for a given mass.

D. The higher the speed of the vehicle, the smaller the force needed to stop it in a given distance.

6. Which of the following electric cells has the advantage of containing no toxic materials?
A. Lead-acid
B. Advanced lead-acid
C. Nickel Cadmium
D. Lithium-ion

7. Which of the following electric cells has the disadvantage of the ‘memory effect’?
A. Lead-acid
B. Advanced lead-acid
C. Nickel Cadmium
D. Lithium-ion

8. Which one of the following power modes produces no exhaust emissions?
A. ENGINE
B. MOTOR
C. ASSIST
D. DUAL

9. Why is the combination of electric motor and internal combustion engine (ICE) particularly effective?
A. The electric motor provides high torque at low rpm, while the ICE provides it at high rpm.
B. The electric motor provides high torque at high rpm, while the ICE provides it at low rpm.
C. Both provide high torque at high rpm.
D. Both provide high torque at low rpm.

10. Which one of the following statements about air resistance is true?
A. Air resistance acts as a constant retarding force, regardless of the vehicles’ speed and shape.
B. Air resistance is greater when the shape of the vehicle is made aerodynamically stream-lined.
C. The faster the vehicle moves, the greater the air resistance.
D. The higher the acceleration of the vehicle, the smaller the air resistance.

About this course

Introduction

This workbook is intended to reinforce learning that takes place in the classroom or workshop. It provides a series of practical activities and investigations based around Hybrid vehicles.

Aim

The course aims to introduce students to the basic principles and concepts involved in hybrid vehicle design and implementation.

Prior Knowledge

It is recommended that students have followed the ‘Electricity Matters 1’ and ‘Electricity Matters 2’ courses, or have equivalent knowledge and experience of electrical concepts.

Learning Objectives

On successful completion of this course the student will have learned to:

- identify and distinguish between series, parallel and series-parallel hybrid configurations;
- distinguish between the power modes in a series-parallel hybrid vehicle;
- describe what happens during regenerative braking;
- explain the advantages of regenerative braking over conventional friction brakes;
- describe the limitations of regenerative braking, and the reason for using a combination of friction and regenerative brake systems;
- describe the factors affecting the acceleration of a vehicle;
- explain what is meant by the following terms:
    - battery voltage;
    - internal resistance;
    - capacity;
    - state of charge;
- list and compare common types of battery found in hybrid vehicle systems;
- appreciate the role of the ECU in controlling the changes between power modes.

Using this course:

It is expected that the series of experiments given in this course is integrated with teaching or small group tutorials which introduce the theory behind the practical work, and reinforce it with written examples, assignments and calculations.

The worksheets should be printed / photocopied / laminated, preferably in colour, for the students' use.

Students should be encouraged to make their own notes, but are unlikely to need their own permanent copy of each worksheet. The 'For your records' sheet on page 17 can be copied and distributed to each student so that they can complete the results tables for each investigation.

Each worksheet has:

- an introduction to the topic under investigation;
- step-by-step instructions for the investigation that follows;
- a section headed 'So What', which aims to collate and summarise the results, and offer some extension work. It aims to encourage development of ideas, through collaboration with partners and with the instructor.

This format encourages self-study, with students working at a rate that suits their ability. It is for the instructor to monitor that students' understanding is keeping pace with their progress through the worksheets. One way to do this is to 'sign off' each worksheet, as a student completes it, and in the process have a brief chat with the student to assess grasp of the ideas involved in the exercises it contains.

Time:

It will take students between two and three hours to complete the worksheets.

It is expected that a similar length of time will be needed to support the learning that takes place as a result.

Instructor guide

Scheme of Work

Worksheet	Notes for the Instructor	Timing
1	The first aim is that students become familiar with the common hybrid configurations - series, parallel and series-parallel. The instructor will need to offer support here so that the distinctions between the modes are firmly established with the students. The advantages and disadvantages of series and parallel modes should be made clear, and then the student should appreciate reasons for the series-parallel option. Then the investigation into the various power modes of a series-parallel configuration will make more sense to the student. Although there is no need, and indeed no advantage to the student in trying to work out the circuit diagram, the instructor should encourage the student in examining what sensors and actuators are connected to the ECU so that it can control the system.	**20 - 30 mins**
2	This worksheet investigates regenerative braking, a technique widely used in all varieties of hybrid vehicles. The instructor should check that students are aware that an electric motor, normally supplied with electrical energy which it turns into motion, can operate 'the other way round' and generate electricity, if it is driven. Using such a system can make a difference of tens of percent to the overall efficiency of the vehicle. However, there are issues with the implementation. Some of these are listed on the second page of the worksheet. Others are more difficult, and the instructor must decide whether to introduce them to the students. One of these is the ability of the system to accept the generated electricity. When the battery is fully charged, and no electrical equipment is switched on, the regenerative braking will not function. Some battery systems, such as advanced lead-acid cells, incorporate large capacitors specifically to store this electricity. Another concerns the forces that are generated by the regenerative braking. Normally, a vehicle is capable of braking harder than it accelerates. The electrical machines in a hybrid are designed to deliver sufficient acceleration, and may not be 'powerful' enough to deliver a sufficient braking force. In any case, the laws of electromagnetic induction dictate that the current generated (and so the braking effect) is greater when the vehicle is moving fast, and declines to zero when the vehicle comes to rest. All in all, the common solution is a combination of friction and regenerative braking.	**20 - 30 mins**

Instructor guide

Scheme of Work

Worksheet	Notes for the Instructor	Timing
3	To appreciate the design characteristics of hybrid vehicles, the student must appreciate some basic physics. Probably obviously, the greater the force the engine delivers, the greater the acceleration. This is the focus of the current investigation. The student times how long it takes to reach top speed in ASSIST mode, compared to simply ENGINE mode. Equally, lighter vehicles have greater acceleration under given conditions. Vehicle manufacturers go to great lengths to reduce the mass of the vehicle for this reason. Smaller engines are lighter engines. The aim of hybrid vehicle design is to make use of smaller, more efficient power units. One less obvious aspect is that acceleration must soon come to an end. Otherwise, vehicles would not have a 'top speed'. As a vehicle moves faster and faster, the opposition to its motion from air resistance increases. This is a retarding force that reduces the forward push of the engine, reduces the nett force, and so reduces the acceleration. Eventually, the force caused by air resistance exactly cancels out the forward drive of the engine. At that point, the nett force is zero, and so the vehicle no longer accelerates. It hasn't stopped moving - just stopped gaining speed. The moral - an aerodynamic body shape that reduces the air resistance.	**30 - 40 mins**
4	The intellectual hurdle here is the idea that the battery voltage is not necessarily a good indicator of the state of charge of the battery. Indeed, battery designers go to great lengths to ensure that the battery voltage stays as steady as possible as the battery discharges. In everyday life, it is no test of the condition of a battery simply to measure the voltage across its terminals. The battery needs to be delivering a current at the same time. The worksheet starts by listing some of the electrical parameters associated with battery performance - voltage, internal resistance and capacity. In a way, these are the easy concepts to get across. Internal resistance may need further explanation. The instructor could ask why conventional vehicles use expensive lead-acid batteries rated at 12V instead of cheap zinc-carbon batteries. The answer concerns internal resistance. To deliver the high currents needed to start the engine, the battery must have a very low internal resistance, so that the chemicals inside it do not impede current flow. The lead-acid battery offers this. The zinc-carbon battery does not. The expense incurred is to buy low internal resistance, not voltage. The investigation uses the MIAC ECU to illustrate the difference between battery terminal voltage and state of charge. The second sheet provides data on lead-acid and lithium ion cells, and describes ways in which the state of charge of a battery can be measured.	**25 - 40 mins**

Worksheet	Notes for the Instructor	Timing
5	Here, the focus is the role of the MIAC ECU. The electric motor and the internal combustion engine have different dynamic characteristics. The former delivers high torque (turning effect) at relatively low speed (rpm), whereas the internal combustion engine offers high torque at higher speed. The ECU decides when to switch from one source to the other. Another aspect of the design is that the battery and generator have other jobs, as well as driving the vehicle along. Modern vehicles have an extensive range of electrical equipment, demanding energy from these sources. It would be unwise for the control system to allow the battery to go ‘flat’ through driving the vehicle along. Equally, the vehicle designer must take into account demands of local authorities for low emissions while driving in built-up areas. Electrical drives offer much lower levels of emission than do internal combustion engines. The worksheet finishes by reviewing a range of different types of electrical cell used in the current range of hybrid vehicles. Each has strengths and weaknesses. Considerable effort is devoted to improving battery technology, and so this list is not exhaustive, and will change.	**30 - 40 mins**
Quiz	This is offered as one means of assessing progress with the topics covered in the worksheets. It can be run as a conventional test, answered by each student individually , or can be organised as a ‘pub’ quiz for the whole class, where the instructor splits the pupils into teams. The questions can be printed out for the teams, or can be projected onto a screen with a data projector.	**15 - 30 mins**
Discussion topics	Student progress can also be evaluated through class or small group discussion. Here are suggestions for topics on which to base that discussion: • Describe the power modes possible in (a) series, (b) parallel and (c) series-parallel hybrid configurations. • Describe why generating power reduces engine speed, and describe what the effects on SOC are during braking. • Why is it NOT desirable that the vehicle battery drains completely ? • Why would the control system NOT wait until the battery was fully charged before starting the electric motor again? • List advantages and disadvantages of including both ICE and electric motor in a vehicle.	**40 - 60 mins**

Quiz answers

Here are the answers to the quiz questions on page 17:

1. **D**
2. **B**
3. **A**
4. **C**
5. **C**
6. **D**
7. **C**
8. **B**
9. **A**
10. **C**