

The 2019 API STELR Solar Car Challenge is an initiative of the Australian Power Institute and is proudly supported by the STELR Program

The logo for STELR, featuring the word "STELR" in a bold, dark teal, sans-serif font.

www.stelr.org.au

www.api.edu.au

www.powerengineering.org.au

STELR is an initiative of the Australian Academy of Technology and Engineering

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INTRODUCTION

This 2019 API STELR Solar Car Challenge manual is designed for STELR schools participating in the 2019 API STELR Solar Car Challenge. This should be read in conjunction with the *Solar Car Student Instructions* supplied with each Solar Car Kit. An additional support PowerPoint presentation and two videos showing how to construct the car and change the gears are available on the STELR website at: <https://stelr.org.au/stelr-modules/solar-cars/>

STUDENT TASKS

Construct a solar powered car from the given equipment and make it go.

Modify the car to meet one or more of these challenges:

MAKE THE FASTEST CAR

Whose car can cover a set distance in minimum time?

The speed of the car = distance travelled / time taken

Hint

You can make the car go faster by:

- changing gearbox ratios
- changing wheel diameters
- reducing air resistance
- reducing friction between the cogs in the gear box
- getting a bigger voltage from your solar cells (How can you do this?)

Is front wheel drive better than rear wheel drive?

MAKE THE MOST POWERFUL CAR

Whose car can climb the steepest hill?

Whose car can carry a load up an incline in the shortest time?

Add weights to compare pulling powers. Whose car can carry the biggest load up an incline?

Hint

You can make the car produce a bigger force by:

- changing gearbox ratios,
- changing wheel diameters

Is air resistance important in this case?

Is front wheel drive better than rear wheel drive?

MAKE THE MOST EFFICIENT CAR

Use the capacitor to store energy from the solar cells to power your car indoors.

Whose car can go the greatest distance on one capacitor charge? This is an indication of efficiency.

Hint

You can make the car go further by:

- changing gearbox ratios
- reducing friction in the gearbox (How?)
- changing wheel diameters e.g. use CDs as the drive wheels
- reducing air resistance

What else will give you an advantage?

MAKE THE BEST LOOKING CAR

What factors contribute to a pleasing car design?

- Shape
- Colour
- Decorations
- Materials
- Wheel trim
- Comfort
- Noise
- Lights (Can you use the capacitor to power LED lights?)
- Other ideas?

THINGS TO THINK ABOUT

Use the knowledge you gained from doing solar cell experiments when you were using the STELR Renewable Energy equipment.

- What voltage will you need from your solar panels?
- Will you use one solar panel or two?
- How will you connect the solar panels to each other?
- How will you connect the solar panels to the motor?
- How will you mount the panels to the chassis?
- Will the angle of the panels matter?
- Where will the Sun be in the sky when you race the car?
- In which direction will the car travel?
- Will the weight (total mass) of the car affect its speed?
- How can you get more energy or power from your solar panels?
- Can you store energy and then use it during the race?
- What will happen if your car goes through a shadow?
- Will your car work on a cloudy day?
- What is the most appropriate gear ratio for your car? A car which is optimised for maximum speed on the flat may not do so well up significant inclines.
- What will happen if you use different sized drive wheels?
- How can you reduce air resistance?
- Will different wheel sizes and different gear settings give your car maximum climbing power or maximum speed?

LOG BOOK / JOURNAL

Keep a log of your group's progress. Each day write a sentence or two describing what you did that day. Then describe:

1. the difficulties, challenges, or questions you encountered in the lesson,
2. the steps you took to overcome these difficulties/challenges or find answers to questions, and
3. how successful you were in solving your problems and achieving your goal.

GLOSSARY

Add any new and important words and their meanings to the glossary table.

GLOSSARY

[illegible]

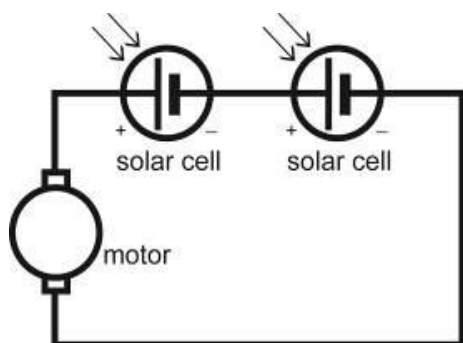
BUILDING A SOLAR CAR

THE BASIC CAR

The students can make a basic model by connecting the solar panels in series and then connecting directly to the motor. This will run in direct sunlight. A push might be needed to start the car moving.

1. Place the solar cells side by side on the sponge on top of the car.
2. Use rubber bands to hold the cells in position. (See picture on page 9)
3. Connect the solar panels in series:
 - a. Connect the red lead of cell 1 to the positive terminal
 - b. Connect the black lead of cell 1 to the negative terminal
 - c. Do the same with cell 2
 - d. Connect the negative terminal of cell 1 to the positive terminal of cell 2.
4. Connect the negative terminal of cell 2 to the bottom terminal of the motor.

Connect the top terminal of the motor to the positive terminal of cell 1.



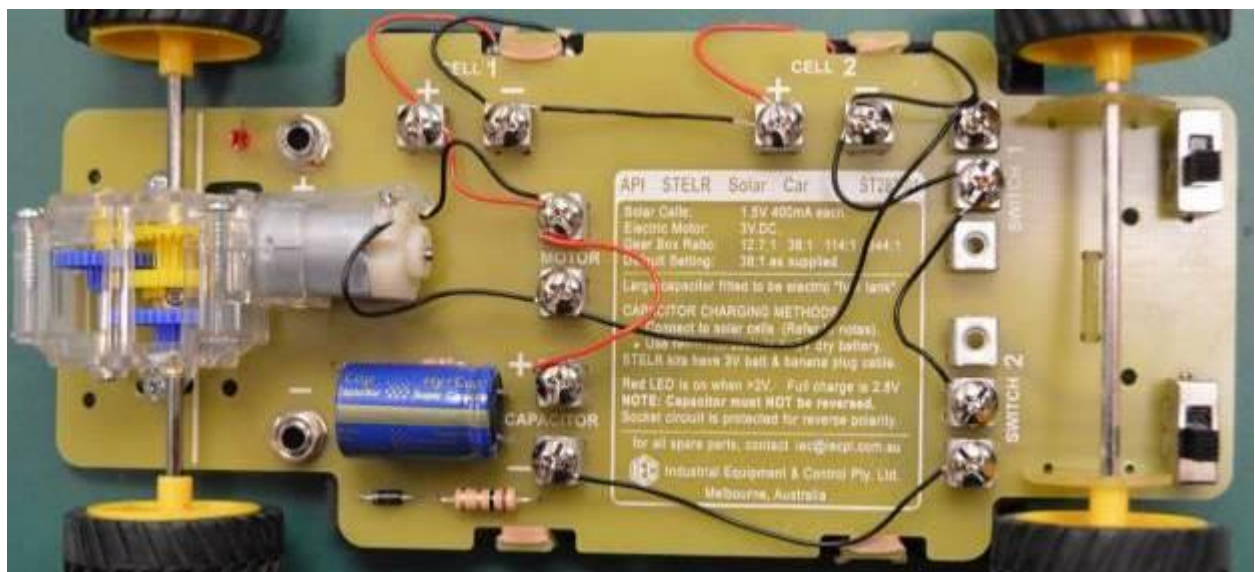
THE FULLY FUNCTIONING CAR

More confident students can make a fully functioning car that uses both switches and the capacitor. They can then charge the capacitor using either the car panels or the STELR battery pack. A step-by step PowerPoint presentation and videos are available on the STELR website at: <https://stelr.org.au/stelr-modules/solar-cars/>

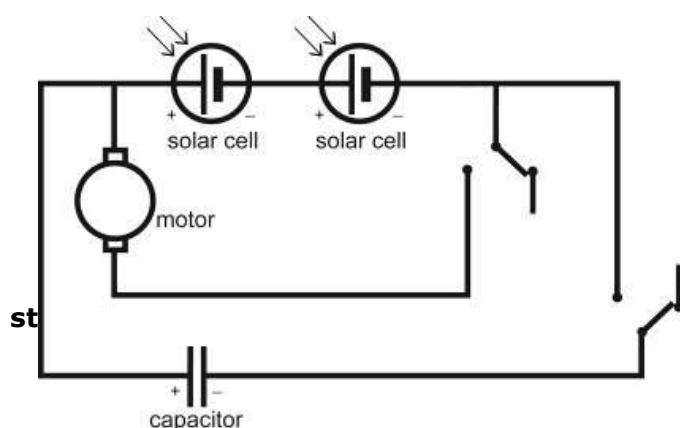
1. Connect the solar panels in series.
2. Connect the negative terminal of cell 2 to the centre terminal of switch 1.
3. Connect the centre terminal of switch 1 to the centre terminal of switch 2.
4. Connect the bottom terminal of switch 2 to the negative terminal of the capacitor.
5. Connect the positive terminal of the capacitor to the top terminal of the motor.
6. Connect the top terminal of the motor to the positive terminal of cell 1.
7. Connect the top terminal of switch 1 to the bottom terminal of the motor.

This will run in direct sunlight when switch 1 is closed (up in the photo below), and switch 2 is open (up in the photo below). You might have to give it a push to start the car moving.

This circuit will charge the capacitor from the solar cells with both switches down (switch 1 open and switch 2 closed), as shown in the photo.



In this image, switch 1 is shown in the open position and switch 2 is shown in the closed position.



This circuit diagram shows both switches 1 and 2 in the open position

CHANGING THE GEAR RATIOS

We suggest that students only work on changing the gears once they have constructed and tested their car.

Before attempting these activities it is recommended that you watch the video that shows how to change the gears of the STELR Solar car. The video also explains the principles of gear radius, angular velocity and torque.



[How to Change the Gears](https://australiascience.tv/episode/api-stelr-solar-powered-car-how-to-change-the-gears/)

<https://australiascience.tv/episode/api-stelr-solar-powered-car-how-to-change-the-gears/>

You can build the gearbox to make your car go fast on a flat surface or to have more force so it can climb up an inclined surface. Chose which model you want to make and follow one set of the following instructions.

Parts needed

Tamiya single gearbox (supplied)

Extra gear parts provided with your car kit in the jar.

What to do

Remove the gearbox from the car.

Take the gearbox apart by undoing the screws.

Reconfigure the gearbox by following the diagrams in the diagrams on the following pages.

Note the different positions of the axles in the gearbox.



高速から低速まで4種類のギヤ比を選ぶギヤボックスです。ギヤ比を決めてから組み立ててください。

●This set can be assembled for 4 different gear ratio. Select one according to your application before commencing assembly. Gear ratio can be altered from 12.7 : 1 to 344.2 : 1 by gear combinations.

タイプ Type	ギヤ比 Gear ratio	回転トルク Torque	回転数 Rotations
A	12.7 : 1	94 gf・cm	1039 rpm
B	38.2 : 1	278 gf・cm	345 rpm
C	114.7 : 1	809 gf・cm	115 rpm
D	344.2 : 1	2276 gf・cm	38 rpm

●3V電源における出力軸の実測トルクです。
●Torque of type FA-130 motor (3V)

Type A, C
B, Dタイプ
Type B, D

ピニオンギヤ (紫)
Pinion gear (Purple)
G1

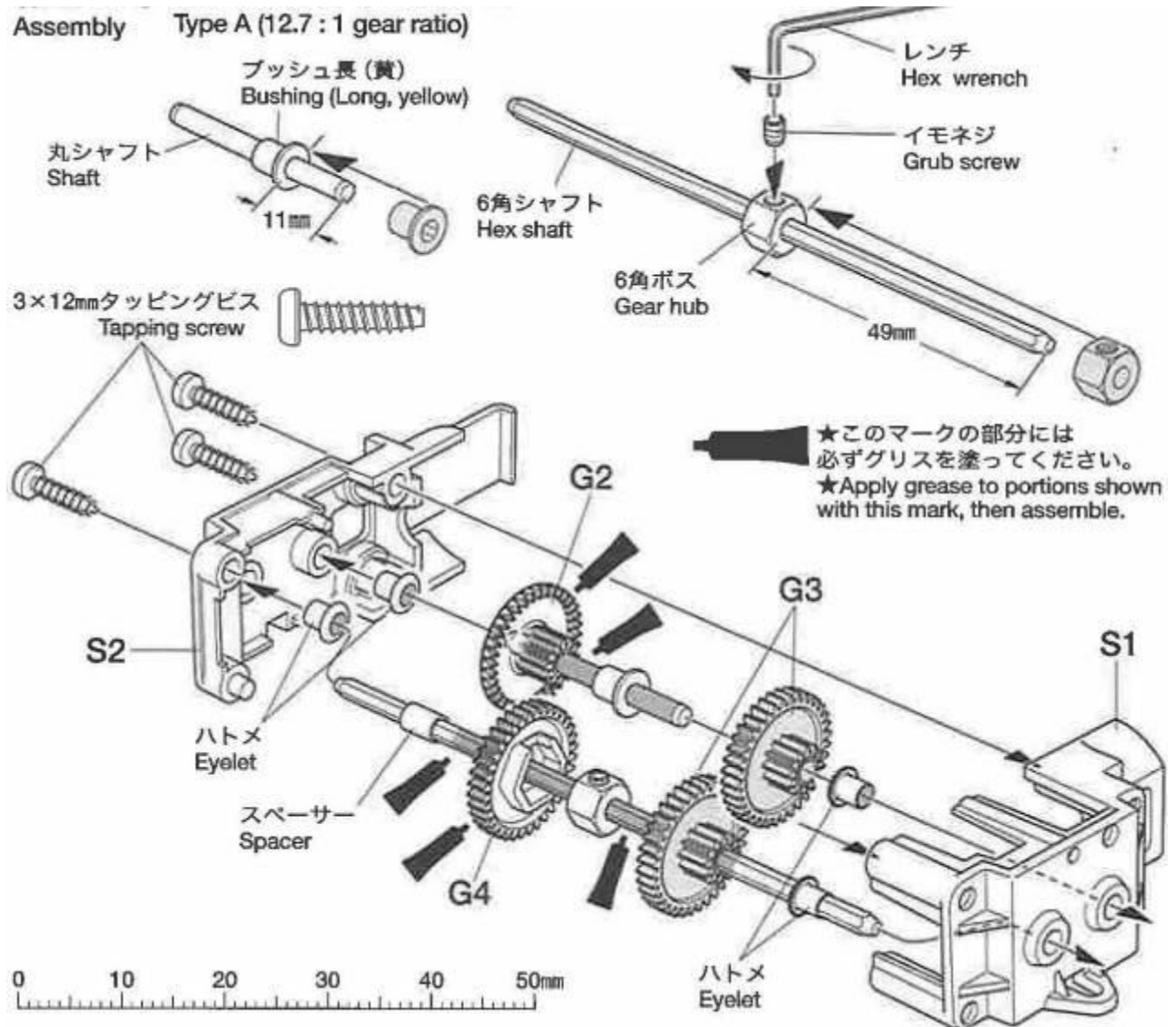
クラウンギヤ (黄)
Crown gear (Yellow)
G2

2段ギヤ (青)
2-step gear (Blue)
G3

ファイナルギヤ (黄)
Final gear (Yellow)
G4

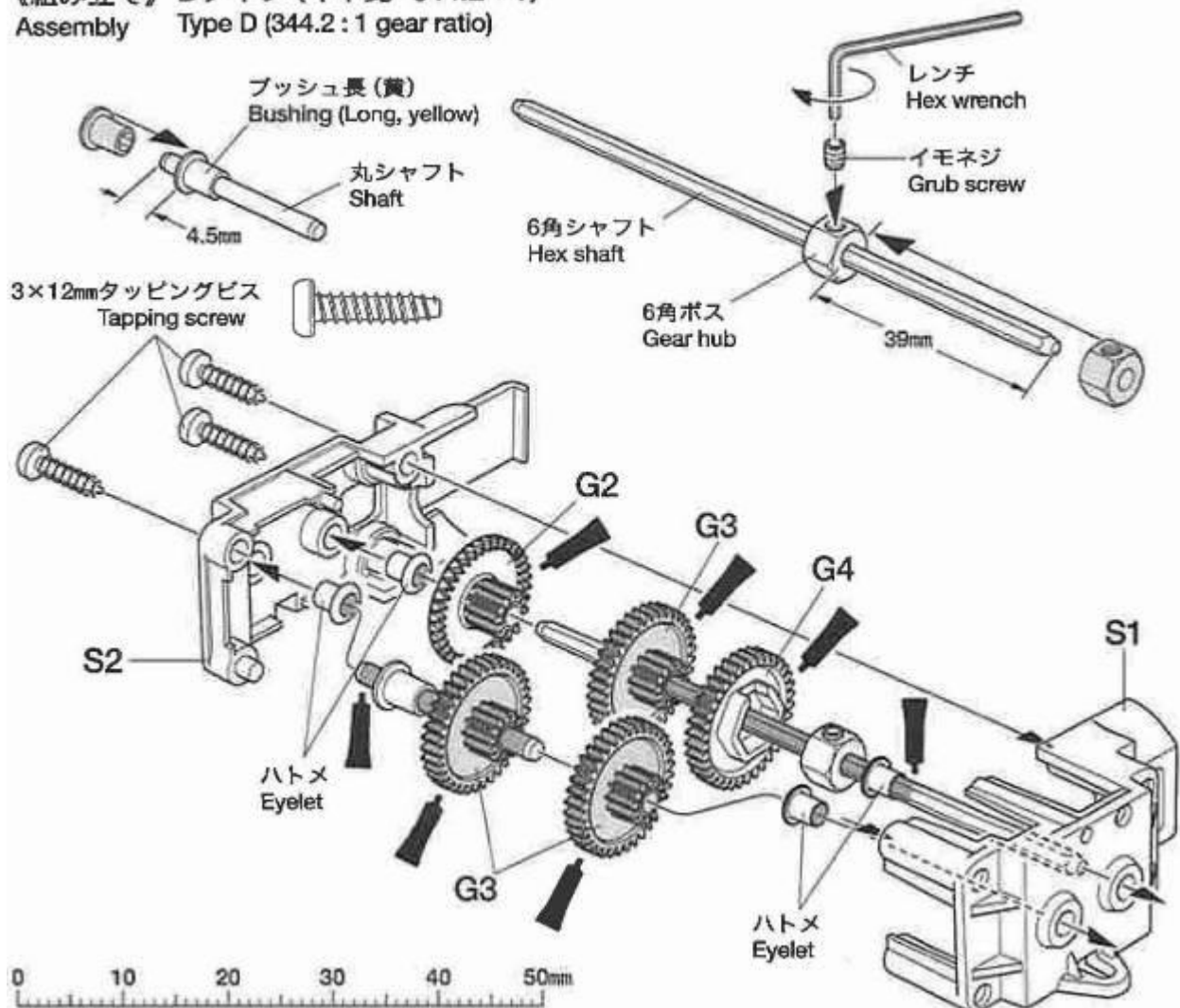
8T
34T/12T
36T/12T
36T

TO BUILD A GEARBOX FOR MAXIMUM SPEED

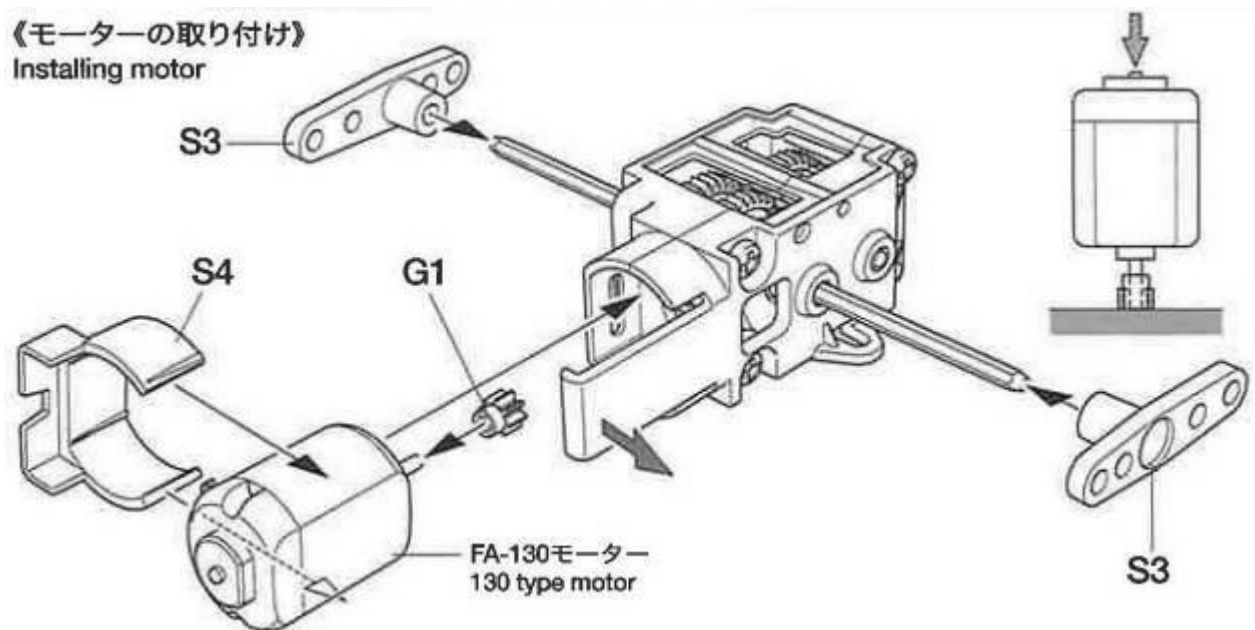


TO BUILD A GEARBOX FOR MAXIMUM FORCE

《組み立て》 Dタイプ (ギヤ比 344.2 : 1)
 Assembly Type D (344.2 : 1 gear ratio)



TO RECONNECT THE MOTOR TO THE GEARBOX



THE MATHEMATICS OF GEARS

An additional resource which explored the theory of different types of gears and contains maths activities on gear ratios can be downloaded from the STELR website here:



[The Mathematics of Gears](https://stelr.org.au/stelr-modules/solar-cars/)

<https://stelr.org.au/stelr-modules/solar-cars/>

ADDITIONAL INFORMATION

SOLAR CELLS THEORY

Solar cells are also known as photovoltaic (PV) cells. Solar cells are devices that transform light energy directly into electrical energy.

SOLAR ENERGY

Solar energy is the energy we receive from the Sun. The Sun emits the full range of the electromagnetic spectrum. This page only considers transforming solar energy into electrical energy.

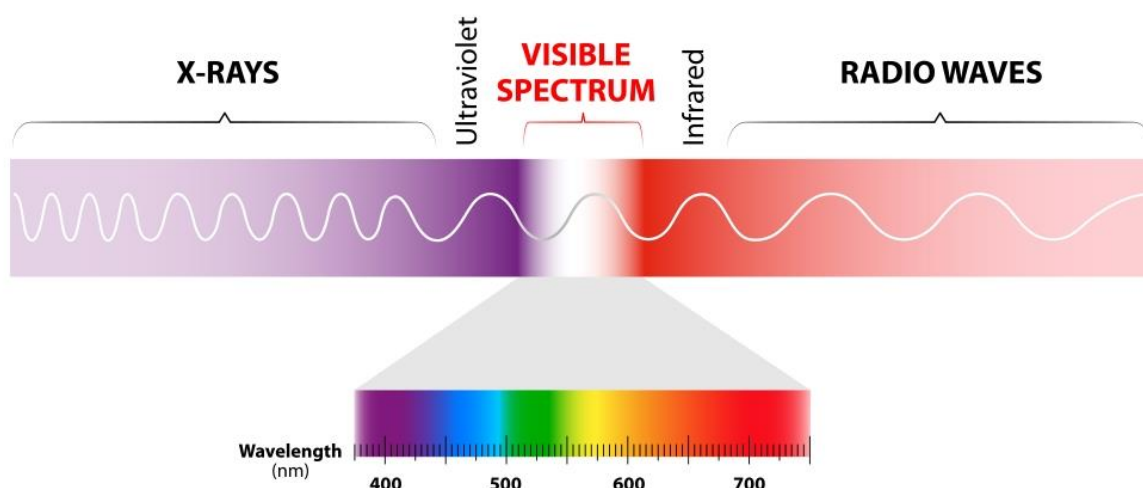


Figure 1: The electromagnetic spectrum

HOW DO SOLAR CELLS WORK?

The general principles by which all solar cells work are:

- Light consists of little 'parcels' or 'packets' of energy called photons.
- When photons shine on a solar cell, they are absorbed by the cell.
- If the photons have enough energy, they cause the cell to release electrons.
- If the photons do not have enough energy, their energy is transformed into heat energy.
- The released electrons enter wires and travel around an electrical circuit.
- The resulting electrical current is in the form of a direct current (DC). This current flows in one direction only.

- If the light is more intense, (brighter light) more electrons will be released each second and the electrical current will be bigger. The voltage of the cell will stay the same.

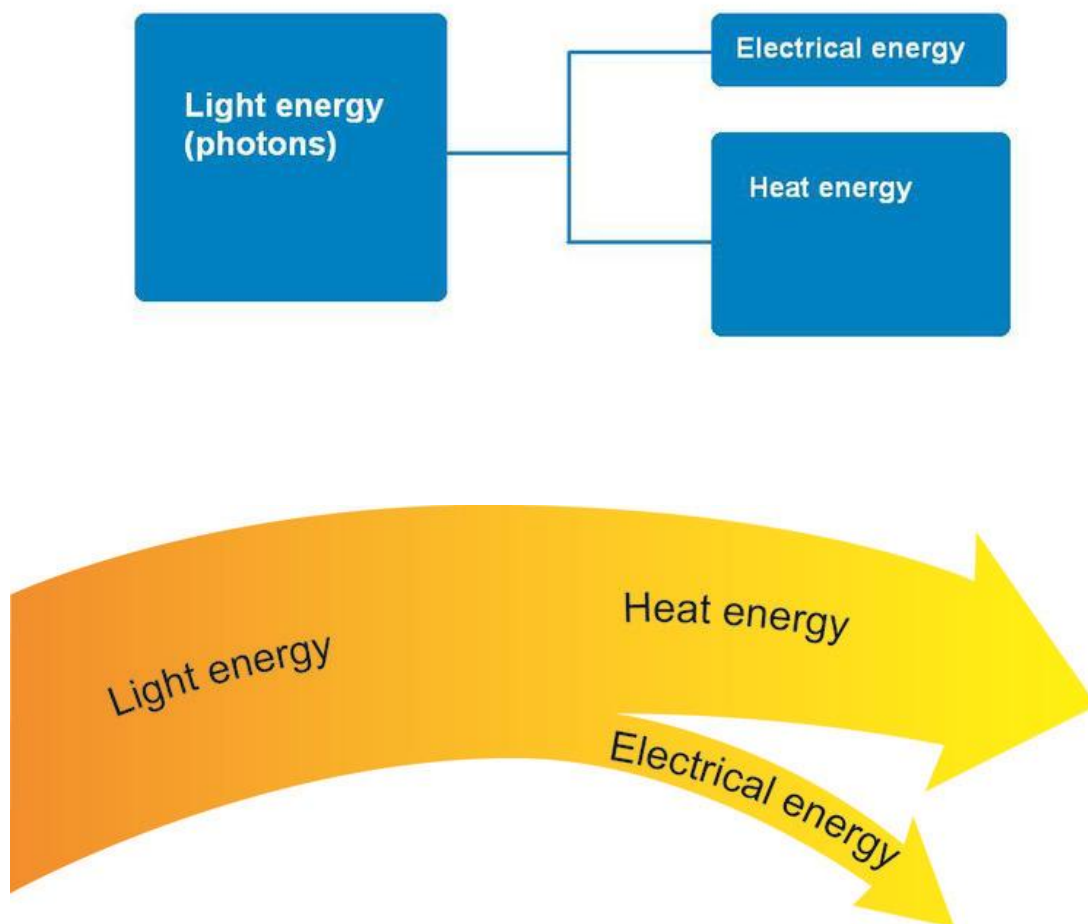


Figure 2: Flow chart and Sankey diagram of the energy transformations of a solar cell.

SILICON-BASED SOLAR CELLS

Silicon-based solar cells are not all the same. There are a number of different types, and researchers are developing new technologies all the time in order to improve their energy efficiency.

What they do have in common, however, is that the material that releases electrons when light shines on it is mostly made from the element silicon. This is a very abundant element on Earth. Sand, for example, is made from silicon.

One kind of silicon-based solar cell has two wafer-thin layers of silicon sandwiched together inside the cell, as shown in Figure 3.

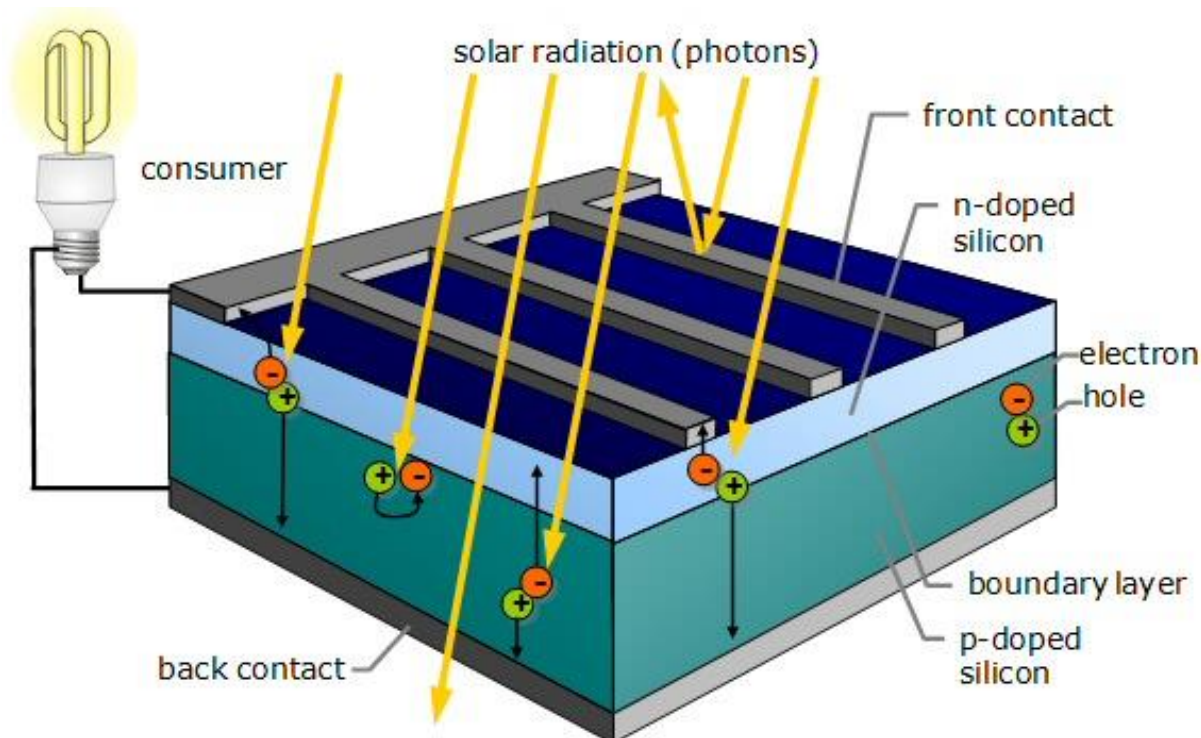


Figure 3: Inside one kind of silicon-based solar cell

The two silicon layers you can see in the cell in Figure 3 are both made from highly purified silicon. Of these two layers, the top layer is the one exposed to the light. This is made up of a material that releases electrons when it absorbs light energy.

FOR THE EXPERT

In the top silicon layer, shown in Figure 3, some phosphorus atoms have been inserted amongst the silicon atoms, in a process called 'doping'. Phosphorus atoms have one more electron in their surface than silicon atoms. This extra electron is held quite loosely, which is why a phosphorus atom releases an electron when it absorbs energy from a light photon. This layer is called an n-type layer because it can be a source of negatively charged electrons.

In the bottom layer, the silicon has been 'doped' with boron atoms. Boron atoms have one less negatively charged electron in their surface than silicon atoms. The presence of boron atoms therefore creates what might be called 'positive holes'.

This is called a p-type layer because of these 'positive holes'.

Where the two layers meet is termed a p-n junction.

When light shines on the top layer, a voltage is produced between the two layers. The top layer becomes negatively charged and the bottom layer becomes positively charged.

Electrons from the top layer move downward. (The 'positive holes' virtually move upward, at the same time.) The result is the generation of an electric current.

SOLAR PANELS AND SOLAR ARRAYS

A solar panel consists of a set of solar cells connected in series and/or in parallel to produce a desired voltage and current. The solar cells are set into a frame.

A single solar cell has an output voltage of about 0.6 V DC. In some solar panels there are modules of 60 - 72 solar cells connected in series. The manufacturer states a nominal output voltage of 24 V DC. The maximum voltage for 60 cells would be about 36 V and for 72 cells it would be about 43 V. The output depends on a number of factors including the intensity of sunlight and the angle of the panels.

A solar array (also known as a PV cell array) is set of solar panels connected in a grid like those in Figure 4. Solar arrays are used on the rooftops of buildings, including homes and schools, to help meet their energy requirements.



Figure 4: The solar cells on the Willetton SHS solar car are connected in series and parallel to give a desired DC voltage.

ADVANTAGES AND DISADVANTAGES OF SOLAR PANELS

ADVANTAGES OF SOLAR PANELS

- They are a renewable energy resource. Solar energy will be available for millions of years, and there is more than enough to supply all of the world's energy needs.
- Solar energy is free and solar panels have a long life. (They can last for up to 50 years.) Therefore they are a good long term investment.
- Whilst operating, solar panels do not produce greenhouse gases or other pollutants. And as they last for up to 50 years, they soon more than compensate for the greenhouse gases emitted in making them, especially if they replace polluting forms of lighting such as kerosene lamps.
- They operate without noise.
- They can be used in remote areas, where there is no access to an electricity grid.
- The heat energy also produced can be used to heat water.

DISADVANTAGES OF SOLAR PANELS

- Variable light intensity due to:
 - Cycle between day and night
 - The daily path of the Sun across the sky
 - Clouds
 - Shadows
 - The changing angle of the sunlight to the panel, due to the changing position of the Sun in the in different seasons.
 - Dirt or other obstructions
- They do not produce electrical power at night, the time when most electrical power is needed in homes (the use of batteries can overcome this disadvantage)
- Some people think that they look ugly
- Distance to grid connections (for solar farms)
- Silicon-based solar panels contain some toxic materials, and energy is required to extract and transport the raw materials, and to manufacture, transport and install the panels, which means that greenhouse gases and various pollutants are produced at these stages
- They have low energy efficiency (However this improving with the development of new technologies).

Figure 5: Mirrors can be used to increase the intensity of light on the solar panels.



FULL-SIZED SOLAR CARS

Up until now, solar cars have been largely experimental, being built as 'one-offs' for racing in events such as the World Solar Challenge. The World Solar Challenge is a biannual 3,000 km race from Darwin to Adelaide which began in 1987. Full-sized solar vehicles compete in the race like the one below. These cars are usually fairly cramped and are built for speed rather than comfort.



Figure 6: Students from Park Ridge State High School in Queensland with the Clenergy Team Arrow car that competed in the 2015 World Solar Challenge.

ROAD-REGISTERED SOLAR CARS

At least two Australian companies are now developing commercial solar cars that can be road registered. These cars look more like conventional road vehicles and are designed to carry the driver and one passenger.

They include:

eVe from the Sunswift Team <https://www.sunswift.com/history/5/eve>

and

The Arrow STF from Team Arrow <http://www.teamarrow.com.au/>

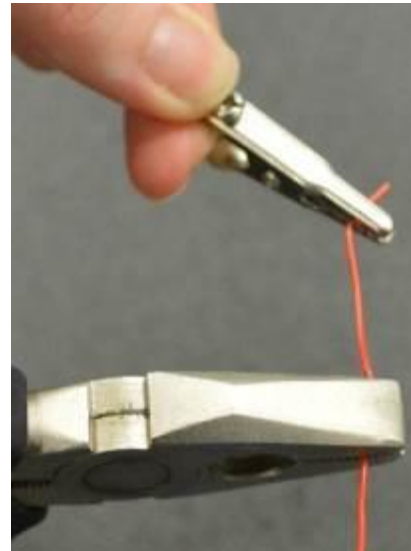
TEACHER NOTES

PRACTICAL HINTS

STRIPPING THE WIRE

It is a good idea to grip the wire with pliers to prevent damaging the connections to the motor or solar panel.

Hold the end of the wire with the supplied alligator clip a few millimetres from the end and twist the alligator clip 10 to 15 times then pull the covering off.



CAPACITOR CARE

Never short out the capacitor by connecting the positive and negative terminals underneath the car.



GOING AROUND IN CIRCLES

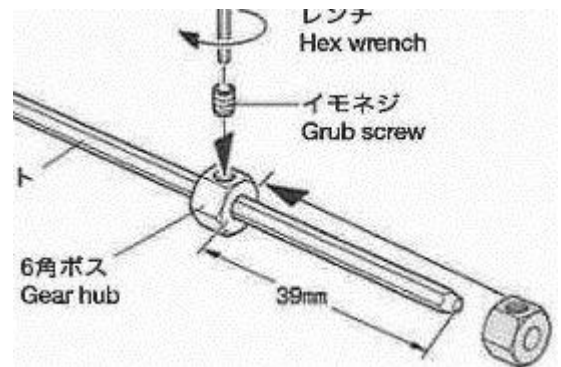
The car can be designed to go around in circles by swivelling the gearbox in its mountings.

Students can measure the diameter of the circle to calculate the distance travelled. Then work out the average speed by measuring the time taken to travel a full circle.

IMPROVING EFFICIENCY

Use grease in the gear box. (Students should identify that energy is being transformed into sound energy as the car runs.)

The drive cog on the motor might be pressing against the first cog in the gearbox with too much force. Try to ease the pressure before mounting the gearbox to the chassis. (The position of the 'gear hub' (see diagrams pages 11 & 12) is very important!



Advice from a Power Engineering Student and API Bursary Holder, Chris Cabrera, who assisted students to build their cars:

The car is really cool. It has a surprising amount of power when charged up. In fact, it seems to retain it for a long time too, despite the fact there looks as though there is a bleeder resistor there.

It was quite easy and straightforward to build. The instructions look terrifying though. There's a lot of small text on there - it might scare people off - as a "that's too hard". I wouldn't imagine this is a big problem, so long as it is emphasised that it is **easier** than it looks.

I have specific tips:

1. Trimming the wheel hubs with some scissors is helpful.
2. When securing the gearbox I needed something to hold the nut - I just used some pliers.
3. Using the alligator clips was surprisingly successful, but doing that to strip the motor or solar panel wires will likely result in the wires or solder tabs being ripped off. I used the pliers as a wire brake, which worked perfectly.
4. I haven't toyed around with the gear ratios yet, though looking at I'd say it'd be more for an engineering studies class.
5. Drawing a circuit diagram made it very easy to wire. I'm proud 3 years of tertiary education have paid off there... (See pages 9 & 10 of this manual for circuit diagrams.)

This was a pretty cool project. It would be good if the kids could build it from its disassembled state each time (maybe with the exception of the gearbox)

Also, from a technical standpoint, I disagree with the concept of this being a "Hybrid". It is literally a full electric car. The capacitor is simply a convenient battery. In the real world, this would not turn into a petrol motor, but a large battery array. (I paralleled the cells, cap and motor, with switches on the motor and cap)

I also really liked the way it would run on full solar, once you gave it a starting push. That was cool. It is worth noting that the motor is still providing torque (driving force) and heating up.

ADDITIONAL EQUIPMENT AND PARTS

BUY ADDITIONAL CAR SETS

Schools can buy additional solar cars from STELR for \$75 (ex GST) each or \$1000 for a class set of 14 solar car kits and one teachers' jar. Download the order from the STELR website: <https://stelr.org.au/stelr-modules/solar-cars/>

Or send an email to STELR.Admin@atse.org.au.

SOLAR CAR COMPONENTS

Components supplied for one API STELR solar car (ST282-40):

ST282-03	BODY PCB, with switches & soldered components Including ST282-08 CAPACITOR used as 'fuel tank'	1
ST282-05	SOLAR CELL, with 2 wires connected	2
ST282-07	MOTOR / GEAR BOX, WITH AXLE set at 38:2 ratio	1
ST282-10	AXLE ONLY FOR FRONT WHEELS	1
ST282-12	WHEEL AND TYRE	1 set of 4
ST282-14	SET OF 3x FIBREGLASS PARTS TO CARRY FRONT AXLE	1
ST282-18	ELASTIC BANDS, 2 for cells, 1 for front axle	1 set
ST282-20	2x SCREWS, WASHERS & NUTS to mount gear box to body	1 set
ST282-26	INSTRUCTION SHEET	1

Components supplied in a class set of API STELR solar cars:

ST282-40	Solar car	14
	Teachers jar containing: 10 blue gears, 10 mini grease tubes, 2 rolls red wire, 2 rolls black wire, 6 alligator clips, 6 Allen keys	1

The solar car Kits are designed to be taken apart after use so they can be reused by other classes. In doing so, be careful not to lose the small parts including screws, washers and nuts, and also the small grub screw in the gearbox.

CURRICULUM LINKS

SCIENCE UNDERSTANDING

Year 6

Physical Sciences:

Electrical energy can be transferred and transformed in electrical circuits and can be generated from a range of sources ([ACSSU097](#))

Year 7

Physical Sciences:

Change to an object's motion is caused by unbalanced forces, including Earth's gravitational attraction, acting on the object ([ACSSU117](#))

Year 8

Physical Sciences:

Energy appears in different forms, including movement (kinetic energy), heat and potential energy, and energy transformations and transfers cause change within systems ([ACSSU155](#))

Year 10

Physical Sciences:

Energy conservation in a system can be explained by describing energy transfers and transformations ([ACSSU190](#))

The motion of objects can be described and predicted using the laws of physics ([ACSSU229](#))

SCIENCE AS A HUMAN ENDEAVOUR

Scientific understanding, including models and theories, are contestable and are refined over time through a process of review by the scientific community ([ACSHE191](#))

Advances in scientific understanding often rely on developments in technology and technological advances are often linked to scientific discoveries ([ACSHE192](#))

People can use scientific knowledge to evaluate whether they should accept claims, explanations or predictions and advances in science and emerging sciences and technologies can significantly affect people's lives, including generating new career opportunities ([ACSHE194](#))

The values and needs of contemporary society can influence the focus of scientific research ([ACSHE230](#)).

SCIENCE INQUIRY SKILLS

Formulate questions or hypotheses that can be investigated scientifically ([AC SIS198](#))

Plan, select and use appropriate investigation methods, including field work and laboratory experimentation, to collect reliable data; assess risk and address ethical issues associated with these methods ([AC SIS199](#))

Select and use appropriate equipment, including digital technologies, to systematically and accurately collect and record data ([AC SIS200](#))

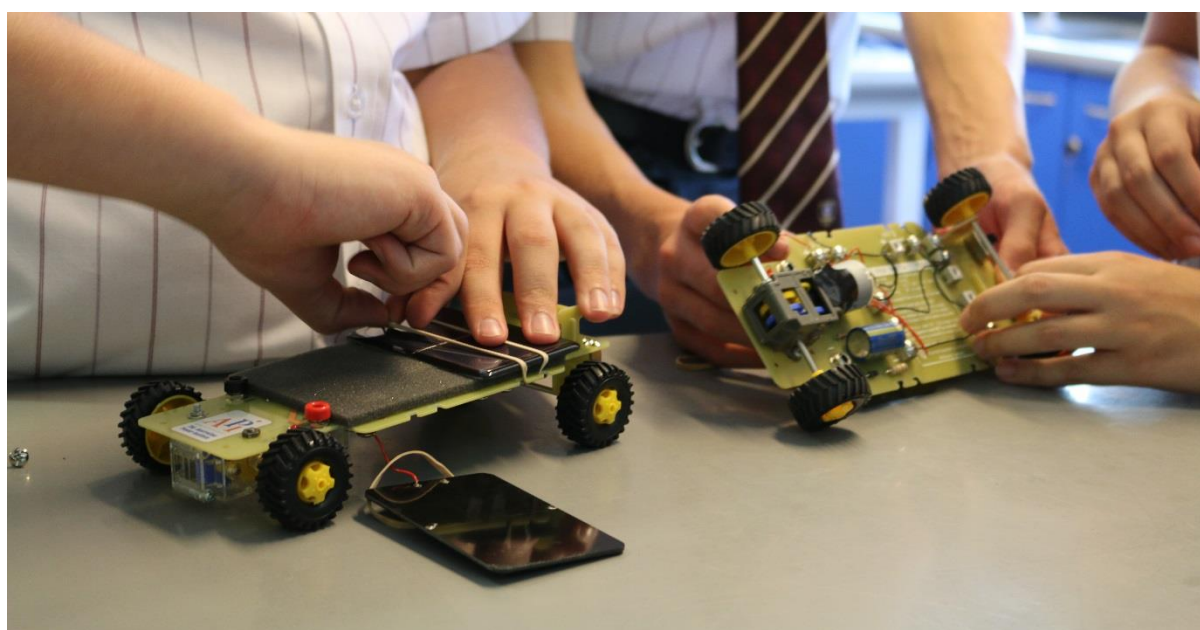
Analyse patterns and trends in data, including describing relationships between variables and identifying inconsistencies ([AC SIS203](#))

Use knowledge of scientific concepts to draw conclusions that are consistent with evidence ([AC SIS204](#))

Evaluate conclusions, including identifying sources of uncertainty and possible alternative explanations, and describe specific ways to improve the quality of the data ([AC SIS205](#))

Critically analyse the validity of information in secondary sources and evaluate the approaches used to solve problems ([AC SIS206](#))

Communicate scientific ideas and information for a particular purpose, including constructing evidence-based arguments and using appropriate scientific language, conventions and representations ([AC SIS208](#)).





Become a power engineer and power our world!

BRAIN TEASER

A) At midday, there is approximately 1 kilowatt (1kW) per square metre of solar energy reaching the tropical latitudes. If solar panels were 20% efficient at converting solar energy to electricity, how many panels, each 2 metre long and 1 metre wide, do we need to supply the average household load of 2kW?

B) How many solar panels would you need to supply a 1000 megawatt (1000 MW) aluminium smelter at midday under the same conditions, 1 MW being 1000 kilowatts.

Is this a practical solution? What are the alternatives given that we still need to make aluminium 24/7? Continuing with coal fired generation and closing the aluminium smelter are only two of them. This indicates the kind of challenges you'll encounter as a power engineer!

Electricity impacts everyone's life. Although it is invisible, it is something real and essential. Think about life with limited or no electricity - it would be near impossible to live like we do today. By choosing power engineering as your career choice today, you can make sure we have electricity for tomorrow. You will also have the opportunity to champion change and help the electricity industry control greenhouse gases and develop sustainable energy solutions to help us maintain our lifestyle.

Power engineering offers opportunities to work across Australia and the world, and it can reward you with good pay, a good lifestyle and a great career. Even better, the industry offers scholarships, bursaries and work experience to assist you in your studies, and graduate programs that provide jobs straight out of university. If you enjoy teamwork, practical problem solving, maths and science, you may have what it takes!



For more information about power engineering and relevant universities, visit www.api.edu.au and www.powerengineering.org.au



Answers to brain teasers: a) 5 panels b) 2.5 million panels

www.api.edu.au