b) In Sydney a 15 kW solar array can average about 5 to 6 kWh per day o electricity. This can be fed in via a Gross metering scheme (all electricit going into grid, or a net Time of Use (TOU) metering scheme where electricit at any one time is either being used by the house or the excess is bein exported to the grid.

Let us consider system connected using a Net TOU metering scheme.

Before Net TOU metering the house would pay electricity at two rates Normal (20.6 c/kWh) and Controlled-Load Off-Peak (for water heating at 10. c/kWh) and unaffected by the solar panels. The Service Charge is 48 c per day

Under new solar connection a three tier system is used so that Peak (2 pm to pm weekdays) is 40.6 c/kWh, Shoulder is 16.4 c/kWh (7am - 2pm weekdays, am to 8 am weekends and holidays) and off peak (9.6 c/kWh). The off Peal Water Heating is not affected by the solar panels. Excess energy is exported a 6 c/kWh. The following data is logged for a particular **Quarter (92 days)**:

Energy Used	Used [kWh]	Cost rate [c/kWh]
Peak	118.8	40.6
Shoulder	330.7	16.4
Off Peak	400.0	9.6
Off Peak Water Heating	340.0	10.8

Energy Fed to Grid	Supplied [kWh]	Cost rate [c/kWh]
Peak	44	6
Shoulder	261	6

Energy used in house	[kWh]
Peak	35
Shoulder	165

Service Charge: 59 c per day.

Calculate the savings per year assuming that the Normal and Controlled-Loa Off-Peak rates would be used without the solar panels, and payback time if th system costs $5000. [13]

b) Quite an involved question.
Calculate under old billing scheme of 20.6 c/kWh and 10.8 c/kWh for off-peak water heating.
Energy used $= 118.8 + 330.7 + 400 + 35 + 165 = 1049.5$ kWh
Cost:- Normal $= 0.206 \times 1049.5 = 216.20$
o/p water $= 0.108 \times 340 = 36.72$
Service charge $= 0.48 \times 92 = 44.16$
$\$\ 297.08$

New Rates
Peak $= 118.8 \times 0.406 = 48.15$
Shoulder $= 330.7 \times 0.166 = 54.23$
O/P $= 400 \times 0.096 = 38.40$
O/P water $= 340 \times 0.108 = 36.72$
Service Ch $= 92 \times 0.59 = 54.28$
Generation $= 305 \times 0.06 = -18.3$
$\$\ 213.48$

Quaterly saving $= 297.08 - 213.48 = \$83.6$
Per year $= 83.6 \times 4 = \$334.40$
Payback $= \frac{5000}{334.4} = 15$ years. But is this the true pay-back since rates changed!

Under smart meter
saving $= 35 \times 0.406 = 14.21$
$165 \times 0.164 = 27.06$ (into grid)
$\$\ 59.57 + 18.3 = 59.57$ per quater
Per year $= 4 \times 59.57 = 238.28$
Payback $= \frac{5000}{238.28} = 21$ years!

Therefore either 15 or 20 years depending on view point. The TOU metering is really power metering with 15 minute logging periods.
If the grid power could be used then saving would be higher:- $44 \times 0.406 = 17.87$
$261 \times 0.164 = 42.80$
60.67

$60.67 + 41.27 = 101.94$ per quater
$= 407.78$ per year
So payback if no power returned to grid
$= \frac{5000}{407.78} = 12$ years

As time goes on then prices will rise so pay-back will shorten. (however, what about interest on panels if you kept the money and did not buy them?) [13]

a) A hybrid electric car has a tare weight of 1500 kg and can carry one driver an four passengers. The average weight of the driver and passengers is 75 kg eac person. The car was running at 70 km/hour when the driver saw a red traffic ligh about 150 m away and applied the brake immediately. The regenerative brakin system of the car is designed to capture the kinetic energy of the car until th speed is reduced to 15 km/hour, and then switch to the mechanical brak automatically to bring the car to complete standstill. It was noticed by the drive that the reading of the car speedometer was 15 km/hour when the car was 15 m away from the traffic lights and the car stopped right in front of the traffic lights few seconds later. Assume the car speed was reduced linearly during the period of both the regenerative braking and mechanical braking, and ignore all the powe losses due to mechanical friction and wind drags, etc.

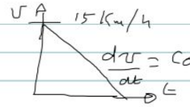
Determine:

i) The total amount of time it takes to brake the car from 80 km/hour to complet standstill;
ii) The ratio between the energy captured by the regenerative braking and the tota kinetic energy before braking;
iii) The minimum rated power of the generator, assuming 100% generato efficiency;
iv) The minimum capacity of the super-capacitor bank required to store th captured kinetic energy in the form of electrical charges if the rated termina voltage of the super-capacitor bank is 200 V DC and ignore the electrica power loss during the charging process. [10]

b) Review the different bio-energy solutions that are available. List their advantage and disadvantages. In this review make reference to key indicators such a conversion rates, ease of processing, greenhouse gas emissions, practicality an final usage. [10]

5 $M = 1500 + 4 \times 75 = 1800$ kg
$v_1 = 70$ Km/h $= 19.4$ m/s
$v_2 = 15$ Km/h $= 4.17$ m/s
$v_1 - v_2 = 55$ Km/h $= 15.28$ m/s
$L = 150$ m
$L_{regen} = 150 - 15 = 135$ m
$\frac{dv}{dt}$ is constant over each range
i) To get total from 70 Km/h to zero requires the problem to be split up into sections.

From 15 Km/h → 0



$v = v_1(T-t)/T$
$\frac{dx}{dt} = v \quad \int_0^x dx = \int_0^T v\,dt$
$x = \int_0^T \frac{4.17(T-t)}{T}\,dt \rightarrow 15 = \left[4.17t - \frac{4.17t^2}{2T}\right]_0^T$
$T = \frac{15}{4.17/2} = 7.19$s

From 70 to 15 Km/h $135 = \int_0^T \left(19.4 - \frac{15.28t}{T}\right) dt$
$135 = 19.4T - \frac{15.28}{2}T \quad T = 11.48$s
Total $T = 11.48 + 7.19 = 18.67$s

ii) Total Kinetic energy $= \frac{1}{2}Mv^2 \rightarrow E = \frac{1800 \times 19.4^2}{2} = 338.7$ kJ
at 15 Km/h $E = \frac{1800 \times 4.17^2}{2} = 15.65$ kJ
Regen $= \frac{338.72 - 15.65}{338.72} = 0.954 = 95.4\%$
In reality it would be much lower than this due to mechanical and electrical losses

iii) $a = \frac{dv}{dt} = \frac{-15.28}{11.48} = -1.322$ m/s
$F = ma = 1800 \times 1.322 = 2380$ N
$P = Fv = 2380 \times 19.4 = 46.2$ kW

OR $E = \frac{1}{2}Mv^2 = \frac{1}{2}M\left[19.4 - \frac{15.28t}{T}\right]^2$
$= \frac{1}{2}M\left[19.4^2 - \frac{2 \times 19.4 \times 15.28}{11.48}t + \frac{15.28^2 t^2}{11.48^2}\right]$
$\frac{dE}{dt} = \frac{1}{2}M\left[\frac{-2 \times 19.4 \times 15.28}{11.48} + \frac{2 \times 15.28^2}{11.48^2}t\right]$
when $t = 0$ max $\frac{dE}{dt}$
$\therefore P = \frac{1800 \times 2 \times 19.4 \times 15.28}{2 \times 11.48} = 46.17$ kW
Phew!!

iv) $E = \frac{1}{2}CV^2 = E_{regen}$ [10]
$C = \frac{323.07 \times 2 \times 1000}{200^2} = 16.15$F long!

b) Same as 2012 Q6a) but with added pointers to what is required. Typically low conversion rates, need of much processing because of mixed solids and volatile gases, energy crops use a lot of space. Burning biofuels is not green but crops do put CO_2 back into the atmosphere and methane is a relatively "clean" carbon fuel [10]

Fuel	Energy content		Fuel	Energy content	
	[GJ/t]	[GJ/m³]		[GJ/t]	[GJ m³]
Wood (green, 60 % moisture)	6	7	Straw (as harvested, baled)	15	1.5
Wood (air-dried, 20 % moisture)	15	9	Sugar cane residues	17	10
Wood (oven-dried, 0 % moisture)	18	9	Domestic refuse (as collected)	9	1.5
Carcoal	30	---	Commercial wastes (UK average)	16	---
Paper (stacked newspaper)	17	9	Oil (petroleum)	42	34
Dung (dried)	16	4	Coal (UK average)	28	50
Grass (fresh-cut)	4	3	Natural gas (as supply pressure)	55	0.04

World Totals	
Total mass of living matter (including moisture)	2000 billion tonnes
Total mass in land plants	1800 billion tonnes
Total mass in forests	1600 billion tonnes
World population (2017)	7.5 billion
Per capita terrestrial plant biomass	300 tonnes
Energy stored in terrestrial biomass	25000 EJ
Net annual production of terrestrial biomass	400 000 Mtonnes/year

- Charcoal is traditionally produced in the forests where the wood is cut. The kiln, consisting of stacked wood covered with an earth layer, is allowed to smoulder for a few days in the near absence of air, typically at 300-500oC, a process called pyrolysis. The volatile matter is driven off, leaving the charcoal – almost pure carbon, with about twice the energy density of the original wood and burning at a much higher temperature so it is much easier to design a simple and efficient stove for use with this high quality fuel.
- The term refuse derived fuel (RDF)refers to a range of products resulting from separation of unwanted components, shredding, drying and otherwise treating the raw material.
- The most fully processed product, known as densified RDF or d-RDF (figure), is the result of separating out the combustible part which is then pulverized, compressed and dried to produce solid fuel pellets with perhaps twenty times the energy density of the original material. Their reduced ash content makes the pellets suitable for cocombustion with coal in conventional plants.
- Anaerobic digestion – landfill gas and biogas. – In the former case, the digester is the landfill itself, and the operator has only limited control of the process. – In the case of biogas, the feedstock, dung or sewage, is converted to a slurry with up to 95% water, and fed into a purpose built digester whose temperature can be controlled. Digesters range in size from perhaps 1 m3 for a small household unit to some ten times this for a typical farm plant and more than 1000 m3 for a large installation. The input may be continuous or in batches, and digestion is allowed to continue for a period of from ten days to a few weeks. – The process of anaerobic digestion is complex, but it appears that bacteria break down the organic material into sugars and then into various acids which are decomposed to produce the final gas leaving a residue whose composition depends on the system and the original feedstock. – In a well run digester, each dry tonne of input will produce 200-400 m3 of biogas with 50% to 75% methane, an average energy output of perhaps 8 GJ per tonne of input. This is only about half the fuel energy of dry dung or sewage, but the process may be worthwhile in order to obtain a clean fuel and dispose of unpleasant wastes.
- Pyrolysis to produce bio-oil – This is the simplest and almost certainly the oldest method of processing one fuel in order to produce a better fuel. The term of pyrolysis is now normally applied to processes where the aim is to collect the volatile components and condense them to produce a liquid fuel or bio-oil. It is characteristic of biomass that the volatile matter carries more of the energy than the char, so this process should be more efficient.
- The technologies to convert bio-energy to other useful forms are direct combustion, conversion into gaseous fuels, and liquid fuels.
- Bio-diesel and ethanol may have great significance in replacing petrol in vehicle applications.
- Biomass is not a clean energy source, but planting energy crops, e.g. trees, and use of bio-fuels in more energy efficient forms may contribute to CO2 mitigation.
- Bio-energy is land demanding since large area is required to plant energy crops.
- Bio-energy can be economically viable.

Geothermal

- There are two sources of geothermal energy: (1) When the earth was formed around 4600 million years ago the interior was heated rapidly as the kinetic and gravitational energy of accreting material was converted into heat. (2) The earth contains tiny quantities of long lived radioactive isotopes, principally thorium 232, uranium 238, and potassium 40, concentrated in upper crustal rocks, all of which releases heat when they decay.
- Geothermal resources of most types must have three important characteristics: an aquifer containing water that can be accessed by drilling, a cap rock to retain the geothermal fluid, and a heat source.

	Material	Porosity [%]	Hydraulic conductivity
Unconsolidated sediments	Clay	45-60	$<10^{-2}$
	Silt	40-50	10^{-2}-1
	Sand, volcanic ash	30-40	1-500
	Gravel	25-35	500-10000
Consolidated sedimentary rocks	Mudrock	5-15	10^{-8}-10^{-6}
	Sandstone	5-30	10^{-4}-10
	Limestone	0.1-30	10^{-5}-10
Crystalline rocks	Solidified lava	0.001-1	0.0003-3
	Granite	0.0001-1	0.003-0.03
	Slate	0.001-1	10^{-8}-10^{-5}

1

- The geothermal heat pump (GHP) concept can be used to extract heat from warm shallow ground water to supply a single domestic dwelling (figure, left). In winter heat is removed from the earth and delivered in a concentrated form via a heat pump. Because electricity is used to increase the temperature of the heat, not produce it, the GHP can deliver three to four times more energy as heat.
- Geothermal energy is independent of sun
- Around the world, there are many spots suitable for exploitation of geothermal energy in the form of either electricity generation or direct use of heat.
- The major impacts of geothermal energy on the environment are the noise and pollution caused by drilling of wells, and releasing of gases originally trapped underground.
- Compared with the conventional electricity generation technologies, the cost of electricity generated from the geothermal energy is slightly higher. However, it is within the acceptable range.

Energy Storage

- Common energy storage devices are: • Batteries, • Supercapacitors, • Flywheels, • Superconducting magnetic energy storage (SMES) • Compressed air.
- Batteries store energy in the form of chemical energy. The one way conversion efficiency is about 85 to 90%

The ***state of charge* (SOC)** of the battery at any time is defined as:

$$SOC = \frac{\text{Ah capacity remaining in the battery}}{\text{Rated Ah capacity}}$$

- There are many types of rechargeable batteries. The commonly used ones are: – Lead-acid (Pb-acid) – Nickel-cadmium (NiCd) – Nickel-metal hydride (NiMH) – Lithium-ion (Li-ion) – Lithium-polymer (Li-poly) – Zinc-air
- Lead-acid battery is the most common type of rechargeable battery used today because of its maturity and high performance over cost ratio, though it has the least energy density by weight and volume.

The table gives the average cell voltage during discharge in various rechargeable batteries

Electrochemistry	Cell volts	Remark
Lead-acid	2.0	Least cost technology
Nickel-cadmium	1.2	Exhibits memory effect
Nickel-metal hydride	1.2	Temperature sensitive
Lithium-ion	3.6	Safe, contains no metallic lithium
Lithium-polymer	3.0	Contains metallic lithium
Zinc-air	1.2	Requires good air management to limit self-discharge rate

- Nickel-cadmium battery is a matured electrochemistry, in which the positive electrode is made of cadmium and the negative electrode of nickel hydroxide. The two electrodes are separated by NylonTM separators and placed in potassium hydroxide electrolyte in a stainless steel casing.
- Lithium-ion battery is a new development, which offers three times the energy density over that of Pb-acid. Such a large improvement in energy density comes from lithium's low atomic weight of 6.9 vs. 207 for lead. Moreover, Li-ion has a higher cell voltage, 3.5 V vs. 2 V for Pb-acid and 1.2 V for other electrochemistries. This requires fewer cells in series for a given battery voltage, thus reducing the manufacturing cost.
- The C/D ratio is defined as the Ah input over the Ah output with no net change in the SOC.

Electro-chemistry	Operating temperature [°C]	Overcharge tolerance	Heat capacity [Wh/kgK]	Mass density [kg/l]	Entropic heating on discharge [W/A]
Lead-acid	-10 to 50	High	0.35	2.1	-0.06
Nickel-cadmium	-20 to 50	Medium	0.35	1.7	0.12
Nickel-metal hydride	-10 to 50	Low	0.35	2.3	0.07
Lithium-ion	10 to 45	Very low	0.38	1.35	0
Lithium-polymer	50 to 70	Very low	0.40	1.3	0

- Normal charging has three phases: – Bulk (fast) charge, which deposits 80 to 90% of the drained capacity – Taper charge, in which the charge rates is gradually cut back to top off the remaining capacity – Trickle (float) charge after the battery is fully charged to counter the self-discharge rate.
- The supercapacitor is still a young technology that has yet to experience widespread implementation. It does, however, enjoy a great amount of attention with regards to its potential application in a number of areas.
- The flywheel stores kinetic energy in a rotating inertia. It has been used as a mechanical device for equalizing the speed of rotation.
- Therefore, a smaller rotor can run at a higher speed. The thin rim type rotor has a high inertia to weight ratio and stores more energy per kilogram weight.
- Batteries are most commonly used energy storage with acceptable energy density and specific power for most applications.
- Super capacitor features in high specific power and hence is suitable for applications which needs fast charging and discharging, e.g. electrical vehicles.
- Flywheel can have higher energy density and efficiency than batteries and are suitable for middle or large systems.
- SMES has high efficiency and long life time, and is most suitable for power grid applications, e.g. power quality compensation.
- Compressed air does not need any high technology and are suitable for large scale applications.