

SOLUTIONS

QUESTION 1

- a) What is the total force required to accelerate the vehicle?

$$\text{Total vehicle mass} = 11800\text{kg} + (67 \times 100\text{kg}) = 18500\text{kg}$$

$$\text{Rolling resistance} = 18500\text{kg} \times 9.81 \times 0.01 = 1815 \text{ N}$$

$$\text{Acceleration resistance} = 18500 \times 1.2 = 22,200 \text{ N}$$

$$\text{Total force} = 1815 + 22,200 = 24,015 \text{ N}$$

- b) What is the distance covered during the acceleration phase?

$$\text{Final speed is } 30\text{kph} = 8.33 \text{ m/s}$$

$$\text{Acceleration is } 1.2 \text{ m/s/s}$$

$$\text{Time during accel} = 8.33 / 1.2 = 6.94 \text{ secs}$$

$$\text{Distance travelled} = (8.33 / 2) \times 6.94 = 28.9\text{m}$$

- c) How much energy is required from the battery to accelerate the vehicle?

$$\begin{aligned} \text{Kinetic Energy} &= 0.5 \times \text{mass} \times \text{velocity}^2 \\ &= 0.5 \times 18,500 \times 8.33 \times 8.33 = 641,847 \text{ Joules} \end{aligned}$$

$$\text{Rolling resistance energy} = 1815\text{N} \times 28.9\text{m} = 52,454 \text{ J}$$

$$\text{Total tractive energy required} = 641,847 + 52,454 = 694,300 \text{ J}$$

$$\text{Energy from battery} = \text{total tractive energy} \times \text{efficiency} = 694,300 \times (1/0.8) = 867,875 \text{ J}$$

- d) What is the maximum tractive power required at the end of the acceleration at point B?

$$\text{Power} = \text{force} \times \text{velocity} = 24,015\text{N} \times 8.33\text{m/s} = 200.045\text{kw}$$

- e) How much energy is required from the battery during the constant speed phase?

$$\begin{aligned} \text{Aero dynamic resistance} &= 0.5 \times \text{area} \times \text{cd} \times \text{density of air} (1.2 \text{ kg/m}^3) \times \text{velocity}^2 \\ &= 0.5 \times (2.5 \times 4.4) \times 0.8 \times 1.2 \times 8.33 \times 8.33 = 366.4 \text{ N} \end{aligned}$$

$$\text{Total resistance} = \text{Aero resistance} + \text{rolling resistance} = 366.4 + 1814.9 = 2181.3\text{N}$$

$$\text{Traction energy required} = 2181.3\text{N} \times 150\text{m} = 327,195 \text{ J}$$

$$\text{Energy from the battery} = 327,195 \times (1/0.8) = 408,994 \text{ J}$$

- f) How much energy can be recovered and stored to the battery during the deceleration phase?

$$\text{Kinetic energy of vehicle} = 641,847 \text{ J}$$

$$\text{Losses during decel} = 52,454 \text{ J}$$

$$\text{Kinetic energy available for recovery} = 641,847 - 52,454 = 589,393 \text{ J}$$

$$\text{Energy into battery} = \text{Kinetic energy available for recovery} \times \text{efficiency.}$$

$$= 589,393 \text{ J} \times 0.6 = 353,636 \text{ J}$$

- g) Assuming the ICE is not operational. What is the total energy reduction from the battery pack per cycle?

Energy reduction = energy used A to B plus B to C minus energy recovered.
 $= 867,875 \text{ J} + 408,994 \text{ J} - 353,636 = 923,233 \text{ J}$

- h) If the battery pack state of charge (SOC) must not reduce to more than 50%, how many cycles can the bus achieve before the ICE must be started to provide additional power?

$17 \text{ kWh} = 17000 \times 60 \times 60 \text{ J} = 61.2 \text{ MJ}$

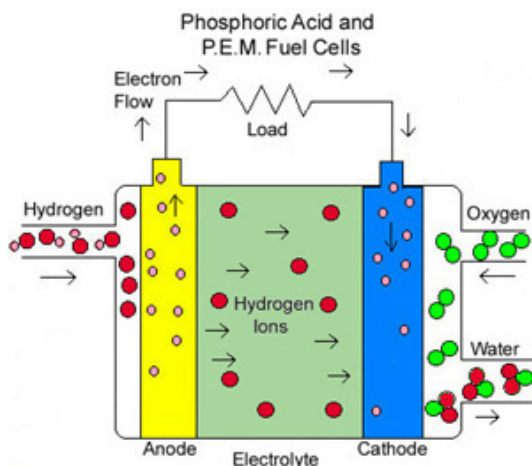
$50\% \text{ SOC} = 61.2 / 2 = 30.6 \text{ MJ}$

Number of cycles = useable capacity / energy per cycle
 $= 30600000 / 923,233 = 33.144$

QUESTION 2

Intelligent Energy and Suzuki are working together to design and develop a hydrogen powered Fuel cell motorcycle.

- a) Explain the function and chemical reaction of the Proton Exchange Membrane (PEM) fuel cell
5 marks



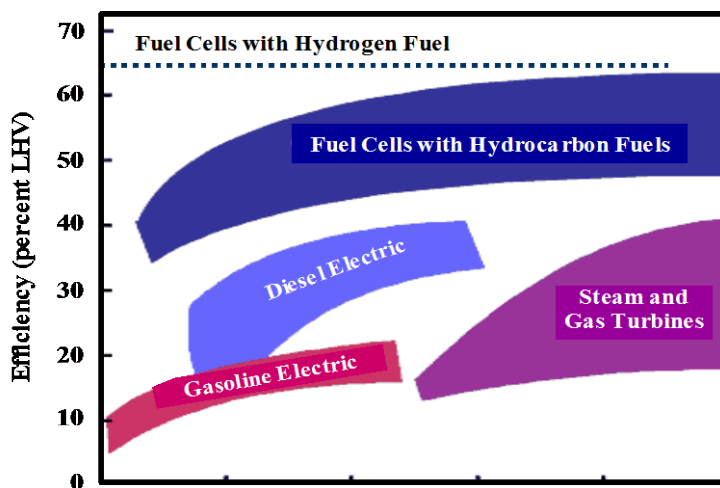
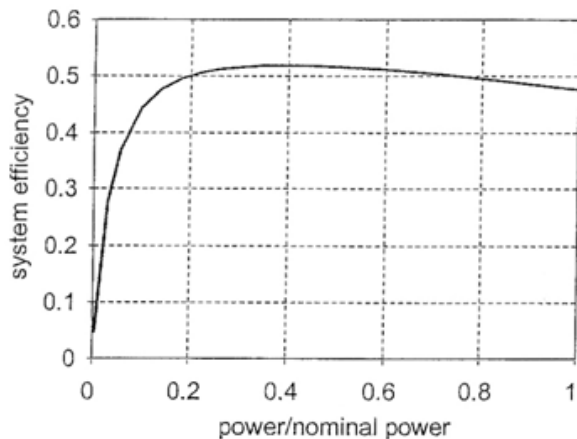
Proton Exchange Membrane (PEM) fuel cells work with a polymer electrolyte in the form of a thin, permeable sheet. Efficiency is about 40 to 50 percent, and operating temperature is about 80 degrees C (about 175 degrees F). Cell outputs generally range from 50 to 250 kW. The solid, flexible electrolyte will not leak or crack, and these cells operate at a low enough temperature to make them suitable for homes and cars. But their fuels must be purified, and a platinum catalyst is used on both sides of the membrane, raising costs

Student will discuss function of catalysts surface to strip electrons and the later reforming process back into water with oxygen.

- b) Contrast the alternatives of burning hydrogen in an internal combustion engine against a chemical reaction within a PEM fuel cell.
5 marks

Burning hydrogen is limited by theoretical thermal efficiency for ICE engine

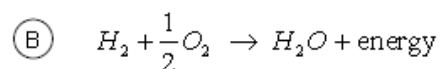
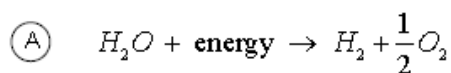
ICE engine efficient at high power operating points. Therefore operation (for high efficiency) tends to be start-charge then stop ICE and discharge. Therefore it's tempting to have high batt capacity
 PEM fuel cell more efficient at low load operational points. Therefore same unit can provide temporary peak power whilst operating efficiently at low load



- c) Hydrogen does not exist in a pure state and consequently it is not literally considered as a fuel but as a carrier of energy. Consequently the application of energy is required to release hydrogen from an existing compound.

Explain ways that hydrogen could be extracted from water, methanol and methane

5 marks



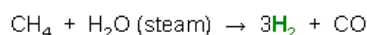
The splitting of water (Reaction A) is an endergenic (endothermic) reaction, meaning that it requires a net input of energy because the products are inherently more energetic than the original molecule.

Conversely, Reaction B is exergenic (exothermic), meaning that it creates a net release of energy to the environment.

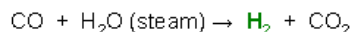
However, the "energy" terms in Reactions A and B are not equal due to the Second Law of Thermodynamics.

possible chemical reactions

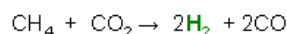
Steam reforming (750 – 800°C)



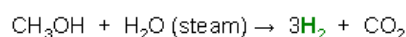
Water gas shift (200 or 350°C)



Dry reforming (600 – 700°C)



Partial oxidation of methanol (250°C)



Or electrolysis

A typical value for the amount of energy needed to produce hydrogen by electrolysis is 367 kJ/mol.

(Note that this is appreciably higher than the ΔH value, 286 kJ/mol).

This means that 1 kW of electricity can produce $1/367 = 0.00272$ mole/s or 0.00545 g/s of H_2 .

Equivalently, 1 MW can produce 0.00545 kg/s.

- d) Hydrogen has a high calorific value and a low density. Compare three alternatives for storing hydrogen within a vehicle. Use calculations and diagrams to support your discussion.

5 marks

Students will discuss and compare :

- 1) Pressure storage upto 350 bar in al or steel vessels
Upto 700 bar in carbon fibre based vessels
Energy required to compress gas, the higher the pressure the less efficient.
Hydrogen is small and hence has a tendency to leak out
Discuss safety issues with high pressure hydrogen storage
Filling under such high pressure
Crash behaviour
- 2) Liquid hydrogen storage
Used on the BMW V12 ICE engine vehicle
Very low temp cryogenic storage – hydrogen boils at about 20k
Could have some light pressure to reduce boiling
Lots of energy needed to drop temp of hydrogen so low.
Must use vehicle to use up hydrogen
If left hydrogen will boil off.
Discuss safety issues
Danger of expolsion with hydrogen emissions in enclosed space.
Danger of burning with such low temperatures.
- 3) Hydrides
Solid storage of hydrogen in hydride materials with the ability to reverse the process.

Lithium Nickel typical example, or magnesium

Hydrogen can be stored in one of three ways (depending on position within the periodic table)

Ionic

Covalent

Metallic

The hydrogen is also pressurised to increase the storage capacity of the hydride.

The hydrogen is released by raising the temperature.

QUESTION 3

Oaktec and Honda have worked together developing a Hybrid rally car based on the Honda civic. The vehicle is expected to work on both tarmac and gravel stages, as well as slower speed, on road, economy rallies. They hope to gain the following improvements:

Reduced fuel consumption

Lower emissions

Performance advantage for the 1.4 litre class

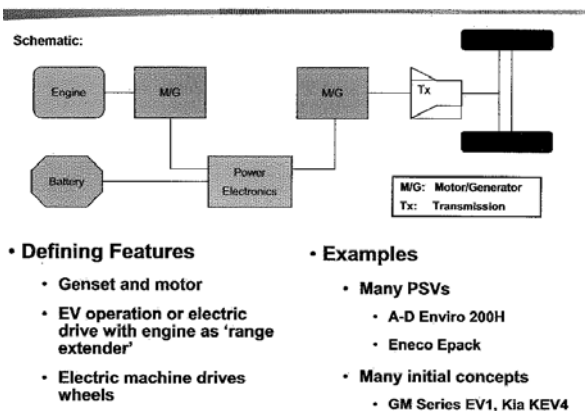
A greener image

a) Analyse alternative hybrid vehicle architectures

(2 marks)

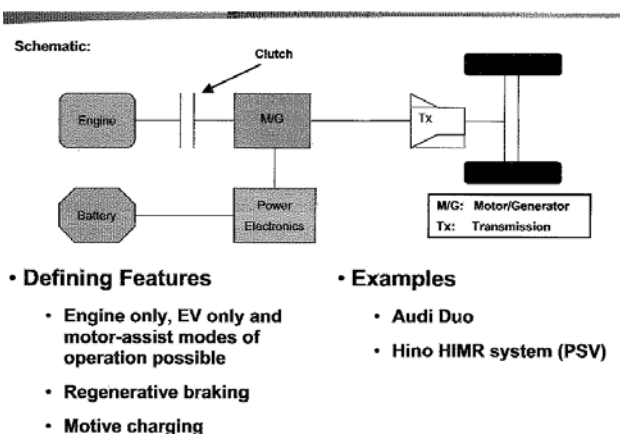
The student should explain and contrast series hybrid

Series Hybrid



And parallel hybrid

Full Parallel Hybrid



b) Investigate and contrast alternative technologies for

1 Energy storage

Battery technologies

LiON, NiMH, Pb acid, hot Zebra

Super Caps

Possible flywheel

Student should discuss, energy density, power density, number of cycles, acceptable SOC's, any memory effects

2. Transmission and driveline

CVT/IVT, to keep engine in effective operating point

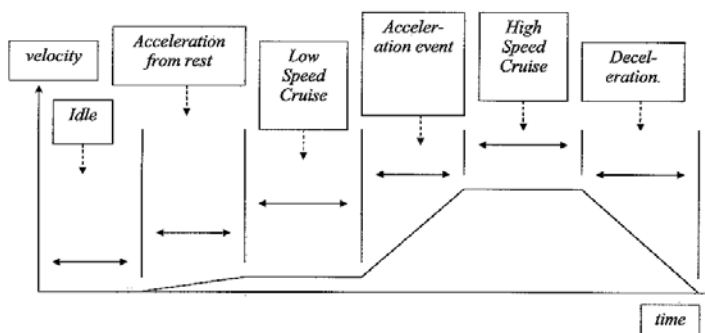
Or manual to reduce transmission losses.

3 Electrical machine ideally placed upstream of gearbox to ensure operation over a wide speed range and gain torque multiplication benefits

(6marks)

c) Develop a brief typical drive cycle

(2 marks)



The student should note

- Variable speeds, low speed accel and high speed running
- High levels of NVH, shock and vibration, possible ingress into the system
- High peak power demand
- Fairly consistent vehicle mass

a) Recommend a rally car hybrid solution and demonstrate how it may meet the requirements

(10 marks)

Students should (hopefully) use information above.

1.4 petrol engine prodrives direct drive

Parrel hybrid a good option. (but not the only solution, esp as initial car was a series Insight)

Low power ICE augmented with boost from energy storage.

KERS can be used to charge storage

Excess ICE power can be used to charge storage on part throttle.

Limited storage capacity required

High power capability required

Battery or supercapacitors or combination to provide high specific power density.