U3A Sustainability Group TALK 5 July 2010

MATERIALS, ENERGY AND CARBON FOOTPRINT: AN INTRODUCTION

1. Introduction to the Talk

To manage something and understand it properly it is necessary to have some reliable numbers.

We will look at the meaning**s** of energy, the units of measurement and relate this to everyday experience. We will ask where energy comes from and how it is used in

Making materials

Manufacture of products

Using the product

Disposal of product at end of life

We will also mention carbon footprints associated with each of these stages and the concept of embodied energy.

As an example, we will look in a quantified manner at the various material options for a bottle/container and see which would be best.

Finally we will touch on product life cycles and sustainability.

Post meeting note:SEE ANNEX A for a brief definition of terms used. **It is suggested that you might like to read this first in order to get a deeper understanding.**

2. ENERGY

Popular remarks: "I've got no energy today"

"She (rarely he) is so energetic" to describe a person who gets a lot of work done, who makes things happen.

Our word energy comes from the Greek words **en** meaning in and **ergon** which means work.

This ties up with the scientific and technical definition. If you do work on a body or a system it is given energy. If a child sits on a swing and you give a push the system has extra energy. If you wind a watch you give it energy. The energy in the system, in both cases, comes from doing work on it. The technical definition of work is that work is done when a force acts through a distance. For example a block of wood is pushed along a floor; or a hod of bricks is carried up a ladder.

>> Force is that which gets something moving or makes it accelerate or decelerate. **The SI unit is the Newton.** If a force of one Newton acts on a body with a mass of one kg it increases or decreases the velocity of the body by one metre per second for every second that the force is applied.

Sir Isaac Newton's first law of motion says that **acceleration is proportional to the force** applied, for a body of fixed mass. Force = mass x acceleration <<

The SI unit of work is the Joule. One Joule of work is done when a force of one Newton acts through one metre. The joule is rather a small unit.

The everyday unit of energy is the kilowatt-hour. (Kilo=1,000)

One kilo-Watt hour (1kWHr) = 3.6million Joules (3.6 Mega joules).

Think of a one bar electric fire on for one hour or

a 100 Watt light bulb on for 10 hours.

Energy = Power x time

3. EXAMPLES OF POWER AND ENERGY

a) Agricultural horse

One horsepower is the power output of a farm horse which he can sustain over one working day.

One HP = 746 Watts =0.746kWatts

Energy provided over an 8 horse-hour day is Power x Time = 0.746x8 = 6 kWHr

Peak power, sustainable by the horse for only a few seconds, is 14.9 HP =11kWatts.

b) Humans

Professional sprint cyclist can produce up to 2 HP = 1.5 KWatts for a short time

Basal metabolic rate of typical human is about 100Watts = 0.1 kW

Power consumption of human brain = 20 to 40 Watts = 0.02 to 0.04 kW

If a 50kilogram (8stone) person runs up a flight of steps 10 metres high in 10 seconds the power needed is 500 Watts = 0.5 kW

Similarly a 75 kg (12 stone) person working at 500 Watts would climb 6.7 metres

c) Electronics and machines

An electronic wrist watch takes one millionth of a Watt (one microwatt)

Pentium 4 Central Processor consumes 130 Watts = 0.13 kW

40-200 kW = power of typical automobiles

1.5 Mega Watts (MW) = power of standard GE Wind Turbine

140MW= average power of Boeing 747 airliner

190MW = peak power of Nimitz class aircraft carrier

4. SOURCES OF ENERGY

SUN * → Wind, waves, hydro, photochemical, photovoltaic

MOON → Tides

NUCLEAR DECAY, UNSTABLE ELEMENTS → Fission reaction, geothermal

HYDROCARBON FUELS → Fossilised plants, energy from the sun

*Power from the sun is up to 750 Watts per square metre in tropics, less in temperate zones because the sun is not overhead and the sunlight has a longer path through the atmosphere, hence there are more losses.

5. ENERGY AND MATERIALS FOR PRODUCTS

Materials used in products have a **life cycle.** (Ashby Ref 1, Fig. 3.1)

Ore and feedstock are mined and processed to yield a material. (Feedstocks are the material inputs to a processing operation; they can be organic or inorganic)

The material is manufactured into a product which is

Used until the end of its life

Discarded

Recycled, or less commonly, refurbished and reused.

Energy and materials are consumed in each phase generating

*** waste heat,**

__emissions (solid , liquid and gas)__

There is also **depletion of natural resources**

Gases emitted include Carbon dioxide, oxides of sulphur and oxides of nitrogen

One major problem is that the sum of the unwanted by-products often exceeds the capacity of the environment to absorb them.

Environmentally Conscious Design

People have been manufacturing products for a long time. The engineering properties of materials such as strength, density, electrical and thermal properties etc are well understood and accurate data is available.

For eco-objectives we also need the following properties of materials:

Embodied energy i.e. the energy used in making one kilogram of material.

Carbon footprint i.e. the amount of carbon released when one kg is made.

These are newer concepts and the data available is less accurate and comprehensive than the engineering data. However it is usually possible to make correct technical decisions.

6. WHICH CONTAINER IS BEST?

Ashby (Ref 1) describes an audit for a plastic (PET, polyethylene terephthelate) bottle which showed that The phase of the product's life which dominates energy consumption and Carbon Dioxide emission is that in which **the material is made. In other words embodied energy dominates.**

Drink containers can be made from glass, aluminium, PET, steel and polyethylene. Which would be the best environmental choice?

Design requirements:

Not corrode, easy to shape, recyclable.

Minimise embodied energy **per unit of capacity**

Ashby calculated the embodied energy per litre of capacity for a container made of each of the materials:

CONTAINER TYPE	EMBODIED ENERGY **kWHr per litre of capacity**
PET 400 ml bottle	1.47
PE 1 litre milk bottle	1.06
(Soda) Glass 750ml bottle	1.86
Al (5000 series alloy) 440ml can	2.64
(Plain carbon) Steel 440 ml can	0.92

Steel and polyethylene are the best choices. A large quantity of glass is needed to make a bottle so one bottle embodies a lot of energy. Aluminium is the least good option.

Additional notes:

The above audit is oversimplified. In practice cost would be a major driver, as would attractiveness to the customer. Ease of recycling is an issue. The value of recycled materials depends on impurities picked up.

Real cans and bottles are made with some recycled content but not enough to change the above ranking.

Legislation may subsidise or penalise various materials.

Nevertheless the primary finding stands; Containers differ in their life energy and steel is the least energy intensive.

7. END OF LIFE OPTIONS FOR PRODUCTS

When stuff is useful we call it material

When it ceases to be useful we call it waste.

The human race is consuming materials, and therefore generating waste, at an ever growing rate.

What happens to waste material?

Landfill…is getting filled up.

Combustion for heat recovery… issues

Recycling… a topic in its own right

Reengineering…e.g. axe has had two new heads and a new handle

Re-use….Redistribute product to a sector which will accept it in its used state and use for the original purpose or a new one

The capacity of these mechanisms needs to match the rate at which stuff is thrown away.

The life expectancy is the shortest of the following:

Physical life. Breaks down, repair is uneconomical.

Functional life. A need for the product no longer exists.

Technical life. Advances in technology have made product obsolete.

Economical life. Advances in technology and design make it possible to do the job more cheaply.

Legal life. New legislation, restrictions etc make product illegal.

Loss of desirability. Changes in fashion and taste make product no longer attractive.

How to reduce resource consumption? Easy! Extend product life.

8. SUSTAINABILITY

New fashions, advances in technology and new legislation can shorten the useful life of products which are otherwise serviceable. These factors are all drivers of higher GDP, which is what governments say that they want. On the other hand shortening product life generates more waste, increases carbon emissions, puts more stuff into landfill and seems to militate against a sustainable economy.

9. CONCLUSIONS

I hope that you have got a better feel for energy, power multiplied by time. It is surprising how hard and long a person, or a horse, has to work to generate one unit (kilowatt hour)!

We mentioned that the human body uses about 100 Watts just to stay alive and the brain alone can consume 20 to 40 Watts.

We have learned how many kilowatt hours are embodied in simple products like a lager can. Embodied energy dominates in such products and steel cans are much better than aluminium ones in that respect.

We have touched on a number of topics such as carbon footprint, factors affecting product life cycle, and options at the end of a product's life. There is scope to do more on these topics.

Reference 1 Materials and the Environment by Michael F. Ashby
Butterworth Heinemann 2009
ISBN 978-1-85617-608-8

Annex A Introduction to mechanics

Sir Isaac Newton's first law of motion:

A body will continue in a state of rest (i.e. stationary), or travelling in a straight line at constant speed, unless acted on by a force.

As a schoolboy in Lincolnshire, where the strong East wind was often felt, Newton devised a measure of wind strength by measuring how far he could jump firstly into the wind and then against it. I suspect that this is where he began to realise that, *in the absence of air or other source of friction, and without other forces such as gravity*, a moving body would carry on moving at the same speed in a straight line. Previously, most people had believed that in order to keep a body moving in a straight line at constant speed it would be necessary to keep pushing or pulling it.

The unit of force in Standard International (SI) units is the **newton** (N).

If you are stationary on the Earth's surface and hold a weight of 102 grams (0.102 kg or about three and one half ounces) in your hand the force you feel is one newton.

Velocity

Velocity is speed with not only magnitude but also direction specified. Velocity is measured in metres per second.

Mass is measured in kilograms (kg), **length** in metres (m) and **time** in seconds (s) in the SI system. Length and time are difficult to define in a non circular way but we all know what they mean. Mass is not the same as weight but it is measured in kilograms and for our purposes we can say that a one kg "weight" or a one kg bag of sugar has a mass of one kg.

Sir Isaac Newton's second law of motion:

Rate of change of velocity is proportional to the force applied.

Force = mass x acceleration

or **Acceleration = Force divided by mass.**

(This applies for a body of constant mass. For a rocket or aircraft, say, which burn fuel and therefore loses mass as time goes on the formula has to be modified).

Acceleration is the rate of change of velocity with time. Units are metres per second per second.

For example if a car accelerates in a straight line from rest to a velocity of 10 metres per second (about 22 miles per hour) in 2.5 seconds the average acceleration is 4 metres per second per second. After one second the velocity is 4 m/s, after 2s it is 8m/s and after 2.5s it is 10m/s.

For constant acceleration, a, the velocity, v ,after time t is given by

$$\mathbf{V = u + at}$$

where u is the initial velocity at t=0 and at means a multiplied by t.

Work and energy

The scientific unit of work is the joule (after the physicist James P. Joule). One joule of work is done when a force of one newton is applied over a distance of one metre. For example if the weight of 102 grams referred to above is raised one metre vertically against the force of gravity the work done is one joule.

The “potential energy” of the body, i.e. its potential ability to do work, has increased by one joule. If weight is allowed to fall it could, with a suitable mechanism, wind a clock or perform some other useful task.

As a body falls under gravity it is accelerated at a constant rate of 9.81metres per second per second. This figure is often represented by g. (The forces experienced by aircrew and passengers in manoeuvring aircraft are expressed in “g” rather than newtons).

The potential energy gained by raising a body to a height is transformed to kinetic energy (energy of motion) as it falls.

ANNEX B

CARBON FOOTPRINT

For materials this is the amount of carbon released when one kg of the material is made.

CARBON TRADING

A note on this will follow later.