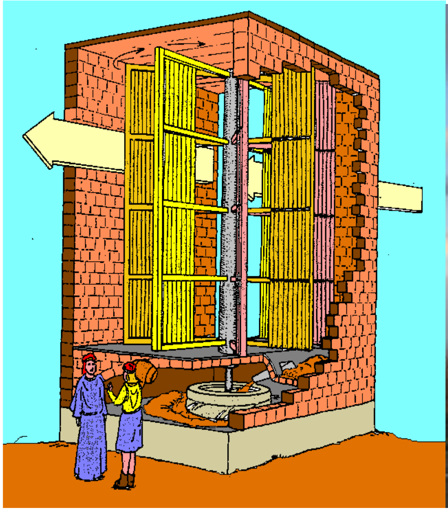
Name ....



NBSLM01E Climate Change and Energy – Past, Present and Future 2010

N. K. Tovey

For an electronic version of this handout please access the following WEB SITE
http://www2.env.uea.ac.uk/gmmc/env/energy.htm

University of East Anglia

Norwich
Business School

UEA LONDON
University of East Anglia

CONTENTS

The website for the part of the course taught by Dr N.K. Tovey may be accessed at http://www2.env.uea.ac.uk/gmmc/env/energy.htm. Copies of the power point presentations used may be accessed as can electronic versions of this handout. Finally additional information and links will be provided on this site together with spreadsheets for practical exercises.

Photo graphs on cover page

- Persian Wind device c700 AD.
- Horsey Wind Pump, Norfolk
- Great Yarmouth Combined Cycle gas Turbine Station
- Scroby Sands Offshore Wind Farm, Great Yarmouth
- Drax 4000 MW Coal Fired Power Station, Yorkshire [Daily Mail]
- Sizewell B Nuclear Power Station [
- ZICER Building, University of East Anglia with 34 kW photovoltaic array
- Syphon mini-hydro scheme, Itteringham Mill, Norfolk
- Open Hydro – Eday, Orkney – world’s first grid connected tidal stream device
- Pelamis Wave Power Device under service at Lyness, Orkney

SUMMARY LECTURE NOTES

1.1 Introduction

Energy is essential for all walks of modern day society and the developed world is typically consuming 5 kW per person. Carbon dioxide levels are rising, and this has caused a noticeable increase in global temperatures in the last 200 years which, if unchecked may cause significant changes to society. Some of the likely effects are:

- Increased flooding in some parts
- Increased incidence of droughts
- Increased global temperatures
- General increase in crop failure, although some regions may benefit in short term
- Catastrophic climate change leading to next Ice Age.

Energy must also be studied from a multi-disciplinary standpoint (Fig. 1.1).

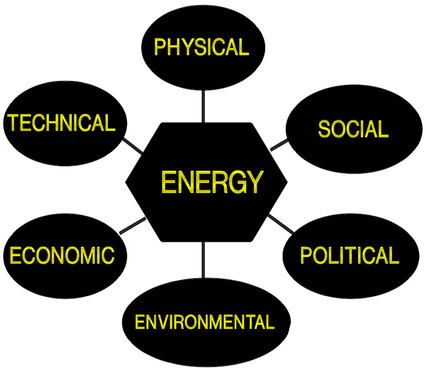


Fig. 1.1 Factors to be considered when studying Energy Issues

1.2 THE ENERGY CRISIS - The Non-Existent Crisis

There is no shortage of energy on this planet, nor has there ever been, nor will there ever be.

There is a potential shortage of energy in the form to which we have become accustomed.

We should more correctly talk of a **FUEL CRISIS.**

1.3 HISTORICAL USE OF ENERGY up to 1800

Man consumes about 15% of energy derived from food in collecting more food to sustain life. To this must be added energy expended in providing/making clothing and shelter.

Two early forms of non-human power harnessed were:-

1) fire
2) animal power

OTHER ENERGY FORMS HARNESSED

1) Turnstile type windmills of Persians
2) Various water wheels (7000+ in UK by 1085)
3) Steam engines (?? 2nd century AD by Hero)
4) Tidal Mills (e.g. Woodbridge, Suffolk 12th Century)

1.4 The First Fuel Crisis

LONDON - late 13th /early 14th Century

- Shortage of timber for fires in London Area
- Import of coal from Newcastle by sea for poor
- Major environmental problems for high sulphur content of coal

Pressure on fuel resources reduced following a halving of population as a result of **The Black Death.**

1.5 The Second Fuel Crisis:-

UK - Late 15th/early 16th century

- Shortage of timber - prior claim for use in ship-building
- Use of coal became widespread -even eventually for rich
- Chimneys appear to combat problems of smoke
- Environmental lobbies against use
- Interruption of supplies - miner's strike
- Major problems in metal industries led to many patents to produce coke from coal (9 in 1633 alone)

1.6 Problems in Draining Coal Mines and Transport of coal threatened a third Fuel Crisis in Middle/late 18th Century

Overcome by Technology and the invention of the steam engine by Newcommen.

- a means of providing substantial quantities of mechanical power which was not site specific (as was water power etc.).

NEWCOMMEN's Pumping Engine was only 0.25% efficient (see Fig. 1.3)

WATT improved the efficiency to 1.0% (Fig. 1.4)

Current **STEAM** turbines achieve 40% efficiency, **but further improvements are LIMITED PRIMARILY BY PHYSICAL LAWS AND NOT BY OUR TECHNICAL INABILITY TO DESIGN AND BUILD THE PERFECT MACHINE.**

Coal fired power station will never be more efficient than about 45% (even with the most advanced developments in technology). This figure assumed IGCC technology - Integrated Gasification Combined Cycle Stations.

Gas fired CCGT (Combined Cycle Gas Turbine) Stations (of DASH FOR GAS notoriety) are currently 47-51% efficient, and there are prospects that these could improve ultimately to 55% or a little higher.

1.7 Energy Capabilities of Man

Explosive sports - e.g. weight lifting
500 W for fraction of second
Sustained output of fit athlete --> 100 - 200 W
Normal mechanical energy output << 50 W

Heat is generated by body to sustain body at pre-determined temperature:-

approx.: 50 W per sq. metre of body area when seated
80 W per sq. metre of body area when standing.

1.8 Forms of Energy

- **NUCLEAR**
- **CHEMICAL -** fuels:- gas, coal, oil etc.
- **MECHANICAL** - potential and kinetic
- **ELECTRICAL**
- HEAT - high temperature for processes
  - low temperature for space heating

All forms of Energy may be measured in terms of Joules (J), BUT SOME FORMS OF ENERGY ARE MORE EQUAL THAN OTHERS

1.9 ENERGY CONVERSION

Energy does not usually come in the form we what it in and we must therefore convert it into a more useful form.

All conversion of energy involve some inefficiency:-

- Physical Constraints (Laws of Thermodynamics) can be very restrictive leading to MASSIVE ENERGY WASTE.

This is nothing to do with our technical incompetence. The losses here are frequently in excess of 35-40%

- Technical Limitations (e.g. friction, aero-dynamic drag in turbines etc.) are things which can be improved. Losses here are usually less than 30%, and in many cases around 5%.

Some forms of energy have low physical constraints and may be converted into another form with high efficiency (>90%).

e.g. mechanical <--------> electrical
mechanical/electrical/chemical -----------> heat

Other forms can only be converted at low efficiency

e.g. heat -----------> mechanical power - the car!
or in a power station

USE APPROPRIATE FORMS OF ENERGY FOR NEED IN HAND. e.g. AVOID using ELECTRICITY for LOW TEMPERATURE heating

1.10 WHAT DO WE NEED ENERGY FOR?

- **HEATING** - space and hot water demand
  80%+ of domestic use excluding transport)

- **LIGHTING**
- **COOKING**
- **ENTERTAINMENT**
- **REFRIGERATION**
- **TRANSPORT**
- **INDUSTRY** - process heating/ drying/ mechanical power

IT IS INAPPROPRIATE TO USE ELECTRICITY FOR SPACE HEATING

2.11 GRADES OF ENERGY

- **HIGH GRADE:** - Chemical, Electrical, Mechanical
- **MEDIUM GRADE: -** High Temperature Heat
- **LOW GRADE:** - Low Temperature Heat

All forms of Energy will eventually degenerate to Low Grade Heat, and may thus be physically (and technically) of little practical use - i.e. we cannot REUSE energy which has been degraded.

1.12 ENERGY CONSERVATION

- Energy Conservation is primarily concerned with MINIMISING the degradation of the GRADE of ENERGY (i.e. use HIGH GRADE forms wisely - not for low temperature heating!!).
- To a limited extent LOW GRADE THERMAL ENERGY may be increased moderately in GRADE to Higher Temperature Heat using a HEAT PUMP.
- However, unlike the recycling of resources like glass, metals etc., where, in theory, no new resource is needed, we must expend some extra energy to enhance the GRADE of ENERGY.

2. UNITS

The study of **ENERGY** is complicated by the presence of numerous sets of ***UNITS OF MEASURE*** which frequently confuse the issue.

*It is **IMPORTANT** to recognise the DIFFERENCE between the **TWO BASIC UNITS:-***

a) the JOULE (a measure of quantity)
b) the WATT (a *RATE* of acquiring/ converting/ or using ENERGY).

2.1. QUANTITY OF ENERGY

The basic unit of Energy is the **JOULE**.

It is defined as the *WORK DONE* when a force moves through a distance of 1 metre *in the direction of the force.* The SI unit is the JOULE, and all forms of Energy should be measured in terms of the JOULE.

FORCE is measured in **Newtons (N)**
DISTANCE is measured in **metres (m)**

Thus WORK DONE = Newtons x metres = Joules.

A 1 kg lump of coal, or a litre of oil will have an equivalent Energy Content measured in Joules (J).

Thus 1 kg of UK coal is equivalent to 24 x 10^6 J.
or 1 litre of oil is equivalent to 42 x 10^6 J.

The UNITS of (QUANTITY of) ENERGY in use are shown in the Table 2.1:-

In earlier literature, the situation is confused further by the fact that both the US (short) ton and Imperial (long) ton are used in place of the metric tonne.
Finally, the situation is further confused in that the energy content of coal and oil depends on its calorific value, and this in turn varies

from one grade to another. However, it is common, but not universal to use a standard International convention that 1 tonne of oil equivalent is 41.868 GJ, and similarly 1 tonne of coal equivalent is 29.3076GJ. However, though these might be values declared in overall National Balance Tables this may not necessarily be the case when data on individual fuel types are presented. i.e. in such cases an attempt is made to display the physical tonnes consumed rather than the equivalent energy content. You are advised to check this actual calorific value in the relevant data source when using units of coal or oil. An example in the UK. Coal used in power stations has a calorific value of around 24 GJ tonne and thus the physical weight of coal at this calorific value will be around 20% higher than data presented in tonnes of coal equivalent according to the International value of 29.398GJ per tonne.

Factors to convert one quantity of Energy into another are given in the Data Book. Always use the SI unit (JOULE) in all essays etc if at all possibhle. If necessary cross refer to the original source unit in brackets.

CONSIDERABLE CONFUSION SURROUNDS THE USE OF THE KILOWATT-HOUR -- DO NOT USE IT!!!!

• JOULE (J). • calorie (cal) • erg • Kalorie (or kilogram calorie Kcal or Kal) • British Thermal Unit (BTU) • Therm • kilowatt-hour (kWh)	• million tonnes of coal equivalent (mtce)million tonnes of oil equivalent (mtoe) - (often also seen as - mtep - in International Literature). • litres of oil • gallons (both Imperial and US) of oil • barrels of oil • million tonnes of peat equivalent

Table 2.1 Energy units in common use.

2.2. RATE OF USING ENERGY

The RATE of doing WORK, using ENERGY is measured in WATTS.

i.e. 1 Watt = 1 Joule per second
1 W = 1 J s^{-1}

Thus if we burn a kilogram of coal (Energy Content 24 x 10^6 J) in 1 hour (3600 seconds) we would be using Energy at the rate of:-

$$\frac{24 \times 10^6}{3600} = 6666.7\ \mathrm{W}$$

Equally, a Solar Panel receiving 115 W m^{-2} (the mean value for the UK), the total energy received in the year will be:-

$$115 \times 24 \times 60 \times 60 \times 365 = 3.62 \times 10^9\ \mathrm{J}.$$

NOTE: THE UNITS:-

KILOWATTS per HOUR
KILOWATTS per YEAR
KILOWATTS per SECOND

are MEANINGLESS (except in very special circumstances).

WARNING: DO NOT SHOW YOUR IGNORANCE IN EXAM QUESTIONS BY USING SUCH UNITS

2.3. SI PREFIXES

milli - m x 10^{-3}
kilo - k x 10^3
Mega - M x 10^6
Giga - G x 10^9
Tera - T x 10^{12}
Peta - P x 10^{15}
Exa - E x 10^{18}

NOTE:-

1) The prefix for kilo is k *NOT* K
2) There are no agreed prefixes for 10^{21} or 10^{24}
3) Avoid mixing prefixes and powers of 10 wherever possible.

i.e. 280 GJ is permissible but not 28000 GJ or 2.8 x 10^4 GJ.

2.4 EXAMPLE OF UNITS AN CONVERSION - GDP/ENERGY RELATIONSHIPS.

The energy used to produce one unit of wealth can be a useful indicator of the overall efficiency (financial) of using energy within a country. This is often declared in terms of the energy required to generate one unit of wealth defined by the Gross Domestic Product (GDP) of a country. For a more realistic parameter it is probably more relevant to use the parameter GDP – PPP. Clearly it is important to normalise the monetary values in terms of standard currency units according to a declared base year.

The data shown in Table 2.3 have been extracted from relevant data tables from the Digest of UK Energy Statistics (2009) – popularly known as DUKES which gives historic data back to 1970. These data sets are extended back to 1950 using information from previous versions of DUKES. For consistency, the currency units for the measure of GDP have been normalised to 2005 UK pounds, while to provide an exercise in unit conversion, the energy consumption data for gas is displayed in Therms as it always was historically even though in recent years it is now displayed in units of kWh for easy comparison with electricity.

The data may be downloaded from the relevant course website link. The following conversion factors should be used in the exercise – the information is also displayed in cells E1 to G5 in the spreadsheet.

Table 2.2. Standard Conversion Factors

1 toe	41.868	GJ
1 tce	28.3076	GJ
1 MWh	3.6	GJ
1 Therm	0.105506	GJ

The actual spreadsheet is a template with additional columns to the right of those shown in Table 2.3. To begin a temporal analysis.

Table 2.3 UK Energy Consumption Data and Gross Domestic Product – from DUKES (2009) Table 1..1.4 and other tables.

	Total Energy Consumption (temperature corrected)	Gross domestic product (2005 £)*(1)*	Total electricity consumption (2)	Total Gas Consumption (3)	Total Oil Consumption (4)	Total Coal Consumption (5)		Overall Energy	Overall Energy Ratio
	Million tonnes of oil equivalent	£ billion	TWH	billion Therms	Million Tonnes	Million Tonnes		PJ	MJ/£
1950	143.5	314.9	53.890	2.337	19.619	205.842	1950		
1951	148.4	320.8	58.856	2.449	17.044	211.125	1951		
1952	147.4	323.2	61.098	2.453	23.228	210.109	1952		
1953	152.0	336.0	64.359	2.436	26.228	211.125	1953		
1954	156.6	350.2	71.595	2.527	28.579	217.221	1954		
1955	159.4	363.0	78.583	2.583	28.280	218.643	1955		
1956	160.7	367.9	85.380	2.591	29.006	220.980	1956		
1957	159.8	374.0	89.336	2.537	28.954	216.306	1957		
1958	159.2	373.3	97.066	2.577	34.274	205.638	1958		
1959	160.5	388.3	104.474	2.515	39.739	192.430	1959		
1960	170.7	410.1	121.654	2.711	45.587	199.858	1960		
1961	171.5	421.3	127.588	2.682	49.855	194.879	1961		
1962	172.4	427.1	141.292	2.838	53.512	194.269	1962		
1963	177.8	444.0	152.809	3.020	54.500	197.114	1963		
1964	183.5	468.7	160.530	3.121	60.255	190.205	1964		
1965	189.5	482.6	176.471	3.405	65.405	187.564	1965		
1966	190.8	491.8	182.777	3.757	72.663	177.505	1966		
1967	191.1	502.6	188.552	4.048	74.239	166.430	1967		
1968	197.2	524.6	202.036	4.515	84.555	167.148	1968		
1969	203.5	537.7	215.187	5.081	94.395	163.746	1969		
1970	211.9	544.0	224.900	5.854	97.18	156.886	1970		
1971	211.9	555.4	232.244	7.596	98.17	140.932	1971		
1972	211.9	575.7	239.402	9.905	104.89	122.884	1972		
1973	211.9	617.2	255.617	10.916	106.84	133.370	1973		
1974	211.9	609.1	247.089	12.877	100.39	117.888	1974		
1975	211.9	605.3	247.795	13.350	88.85	122.217	1975		
1976	211.9	621.2	250.070	14.251	87.92	123.604	1976		
1977	211.9	636.0	257.165	14.904	89.00	123.978	1977		
1978	211.9	656.5	263.055	15.706	90.56	120.477	1978		
1979	211.9	674.1	275.251	17.142	91.09	129.378	1979		
1980	206.2	660.1	262.432	17.357	77.50	123.460	1980		
1981	198.7	651.3	256.937	17.474	71.70	118.386	1981		
1982	196.3	665.0	252.740	17.680	72.79	110.998	1982		
1983	197.5	689.1	256.895	18.038	69.77	111.475	1983		
1984	196.7	707.5	261.798	18.582	86.79	77.309	1984		
1985	203.1	732.9	274.742	19.849	74.96	105.386	1985		
1986	206.8	762.4	282.730	20.087	74.62	114.234	1986		
1987	210.0	797.1	291.340	20.959	72.92	115.894	1987		
1988	217.7	837.2	297.850	20.294	77.80	111.498	1988		
1989	217.8	856.3	304.380	19.808	78.85	107.581	1989		
1990	221.6	863.0	309.410	20.372	79.78	108.256	1990		
1991	221.4	851.0	317.060	21.898	80.56	107.513	1991		
1992	220.6	852.3	315.240	21.866	81.55	100.580	1992		
1993	222.5	871.2	318.590	24.477	82.18	86.757	1993		
1994	221.5	908.5	323.830	26.091	81.22	81.767	1994		
1995	223.6r	936.2	334.240	27.597	80.17	76.942	1995		
1996	227.1r	963.2	349.114	32.035	82.01	71.400	1996		
1997	229.2r	995.1	348.203	32.765	79.25	63.080	1997		
1998	236.8r	1,031.0r	355.168	34.302	78.44	63.152	1998		
1999	238.0	1,066.8r	361.915	36.611	77.97	55.724	1999		
2000	239.6r	1,108.5r	371.440	37.722	77.20	59.931	2000		
2001	240.5	1,135.8r	374.57r	37.934	76.41	63.850	2001		
2002	237.3	1,159.6r	375.07	37.406	76.23	58.554	2002		
2003	237.5	1,192.2r	378.69	37.628	77.15	63.023	2003		
2004	240.2	1,227.4r	380.89	38.386	79.07	60.450	2004		
2005	239.6r	1,254.1r	385.10r	37.202	80.73	61.832	2005		
2006	236.5r	1,289.8r	381.39r	35.262	79.75	67.522r	2006		
2007	231.6r	1322.8	379.49r	35.693	77.72	62.932r	2007		
2008	225.3	1,332.7	378.98	36.749	75.95	58.212r	2008		

(1) GDP revised to be at 2005 prices 1970 onwards. Prior to 1970 values djusted to allow for change in baseline year from 2002 to 2005

(2) Electricity Data from Long Term Electricity Tables from DECC Website (DUKES Table 5.1.2 - 2009)

(3) Gas Data from DUKES Table 4.1.1 (version in Therms) -data in early years were originally provided in Therms - this unit has been retained for practice in unit conversion

(4) Oil from DUKES Table Table 3.1.2 - however data prior to 1970 needs checking

(5) Long Term Coal data refers to inland Consumption data published in Dukes 2.1.2

As an exercise, download the above spreadsheet from the WEB Page and proceed as follows.

- Data in columns A, B, and C have been obtained from the Digest of UK Energy Statistics (DUKES) 2009 with additional data extracted from earlier editions to cover the period back to 1950. The total Energy relates to the total national primary energy consumption and is expressed in million tonnes of oil equivalent

- For consistency the energy values should be converted into PJ.

- I tonne of oil equivalent has a calorific value of **41.868 GJ** as declared in **cell F2**

- In cell **i11** type the formula **=B11 * F$2 –** this will display the total energy consumption in PJ. Note: the quantity in column B is in millions of tonnes (i.e. 10^6) and GJ is already in terms of 10^9 so multiplying the two quantities will give units in units x 10^{15} i.e. PJ

- Now copy contents of cell **I11** through the range **i11:i74.**

- Make sure you understand the purpose of the **"$"** in the formula typed in cell **i11** **[**entering $ before the 2 ensures that as the formula is copied, reference always points to the cell F2, whereas the reference to B11 changes progressively to reflect the different rows of the spreadsheet in column B]/

- In cell **J11** type the formula **= i11/c11** – this will give the amount of energy required to generate £1 of wealth i.e. the Energy Ratio [1 unit of electricity is equivalent to **3.6 MJ**]

- Now plot the Energy ratio against time. A graph similar to that shown below should be obtained.

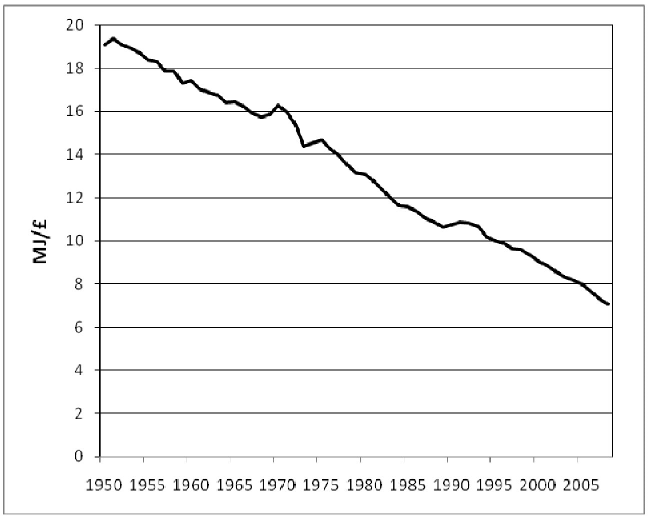


Fig.2.1 Energy Ratio against time for UK. Monetary values in 2005 pounds. Compared to 1950, the UK is producing wealth at around 40% of the energy required in 1950

- As An exercise for you to do in you own time, repeat the above procedure separately to the four fuels – coal, oil, gas, and electricity.

- Note you will have to be careful with the powers of 10 for the different fuels. – this will apply particularly to gas

- How do the trends differ for the different fuels?. Can you explain the trends?

3. ENERGY - DEFINITIONS

3.1 Definition of Efficiency

All uses of energy involve the conversion of one form of energy to another.

All energy conversion processes will be inherently inefficient, meaning that in most cases we cannot realise the full potential of the unconverted energy.

We define efficiency as:-

$$\frac{\textbf{the amount of useful energy out}}{\textbf{the amount of energy put in}} \times 100\%$$

Some typical efficiencies (*):-

steam (railway) engines	10%
cars	20 - 25%
electric fire	~100%
gas central heating boiler	70 - 75%
oil central heating boiler	65 - 70%
condensing gas or oil boiler	~ 90%
UEA boiler	~87%
Power Station Boiler	90-92%
Open Coal fire	10%
Coal Central Heating	40-50%
Steam Turbine	45-50%

3.2 PRIMARY ENERGY -

The energy content of the energy resource when it is in the ground.

3.3 DELIVERED ENERGY -

The energy content of the fuel as it is delivered to the place of use.

3.4 USEFUL ENERGY -

The actual amount of energy required for a given function *IN THE FORM USABLE FOR THAT FUNCTION.*

3.5 PRIMARY ENERGY RATIO (PER):-

$$= \frac{\textbf{Primary Energy Content of fuel}}{\textbf{Delivered Energy content of fuel}}$$

EXAMPLES:-

Gas - 1.06
Oil - 1.08
Coal - 1.02

Thus for gas, 6% of the energy extracted is used either directly, or indirectly to deliver the energy to the customer. It will cover aspects such as the energy used in:-

- exploration
- making production platforms
- making pipelines
- pumping
- administration and retail of fuel
- fractionating/blending fuel

3.6 Appliance Efficiency (η)

At the consumers premises, appliances are not, in general 100% efficient in converting the fuel into a useful form of energy.

Thus (from 4.1 above):-

The efficiency of the appliance may be expressed as:-

$$\eta = \frac{\textbf{useful energy out (in form required)}}{\textbf{energy input to appliance (+)}}$$

in most cases, the efficiency will also be:-

$$= \frac{\textbf{useful energy}}{\textbf{delivered energy}}$$

3.7 FURTHER COMMENTS ABOUT EFFICIENCY

If we want 1 GJ or useful energy, how much energy must we dig from the ground if we require the energy as heat from as gas boiler with an efficiency of 70%?

Primary Energy Required

$$= \frac{1}{0.7} \times 1.06 = \underline{\underline{1.51\ \text{GJ}}}$$

Be sure you understand this relationship, and why it is not:-

0.7 x 1.06

or 1.3 x 1.06

3.8 ENERGY EFFICIENCY

Energy Efficiency is the efficient use of energy.

IT DOES NOT NECESSARILY MEAN A SAVING OF RESOURCES.

e.g. Producing 20% more products for same energy input would not save energy overall even though it would reduce energy requirement per product.

Insulating a poorly heated house will increase the efficiency of using energy, but the savings in resources will be small - increased temperature - avoiding hypothermia is efficient use of energy.

3.9 ENERGY CONSERVATION

Energy Conservation is the saving of energy resources.

Energy Efficiency is a necessary pre-requisite for Energy Conservation

(remember Energy Efficiency does not necessarily mean Energy Conservation).

It is interesting to note the Government Office is termed

THE ENERGY EFFICIENCY OFFICE

3.10 OTHER DEFINITIONS OF ENERGY CONSERVATION

- **Industry/Commerce often consider Energy Conservation only as a saving in MONETARY terms**
- **The moral definition is the saving of resources. This often will not result in a MONETARY saving**
- **The so called Energy Conservation Grants to Industry in late 1970's early 1980's were not Conservation Grants at all, but Grants to encourage switching of fuels from oil to coal.**

3.11 LOAD FACTOR – sometimes referred to as Capacity factor

The Load Factor is a measure of the utilisation of plant and is important in all Energy related topics. Thus a coal fired power station may have a capacity of 2000 MW which is a measure of the peak electrical output it can archive. On the other hand, there will be times when it is under maintenance, and/or not required to generate because the demand is low. Typically for a modern coal fired station this will be 70+%.

A nuclear power station may actually have a 100% load factor one year as it is running continuously, but because of statutory maintenance period which may last 60 days or so, the load factor in the following year will be much lower. Unlike fossil fired stations, nuclear stations are not readily capable of following demand and thus tend to be run for extended period. Load factors in any one year of 90+% have been achieved but at other times much lower, and average around 80+%.

Renewable generation has two separate aspects to consider. Not only is there the variation in demand, but more importantly there is the variation in the resource itself. In some cases, say on a windy day the supply for wind may be so high that it exceeds the local demand or capacity of interconnecting cables and some of the plant have to be shut down.

Typical Load Factors for renewable generation for 2006 are reproduced here from the Project Assignment Section. For details for other years see the Project Assignment Section

Load factors	2006
Onshore wind	27.4%
Offshore wind (from 2004 only)	27.2 %
Photovoltaic	8.1%
Hydro	34.8 %
Biofuels and wastes (excluding co-firing)	56.8%

Fig. 3.1 Current Load Factors for Renewable Generation

3.12 CALORIFIC VALUE

This is the Energy Content of the fuel per unit mass or unit volume. It represents the maximum amount of energy that can be extracted from a unit of the fuel.

There are two Calorific Values:-

lower calorific value

This is amount of energy derived by combusting a fuel when the products of combustion are emitted at temperatures in excess of 100^{o}C i.e. any water present is emitted as steam.

upper calorific value

This is amount of energy derived by combusting a fuel when the products of combustion are emitted at temperatures below 100^{o}C i.e. any water present is emitted as water vapour.

The difference between the two calorific values is about 5% (UCV > LCV)

3.13 SPECIFIC HEAT

This is the Energy required to raise the temperature of 1 kg of a body through 1 degree Celsius.

Space for notes

4. POTENTIAL OF ENERGY RESOURCES

4.1. CURRENT AND PROJECTED USAGE

Country	Energy Requirement		
		Population	Per Capita
World	**12.0 TW**	**6000 M**	**2.0 kW**
USA	**3.0 TW**	**300 M**	**10.0 kW**
Europe	**2.0 TW**	**350 M**	**5.7 kW**
UK	**0.3 TW**	**60 M**	**5.0 kW**

Projected Saturation Population in 2050 -- 10000 M

- If per Capita consumption averages current UK value
- Energy Requirement in 2050 = 50 TW i.e. 5 x 10^{13} W.
- If per Capita consumption reaches current USA value
- Projected Requirement in 2050 will be 100 TW
  i.e. 10 times current demand.
- Range of forecasts 20 - 100 TW with a likely value
- in range 30 - 50 TW (say 40 TW).

4.2 PROJECTED LIFESPAN OF RESOURCES

decades:-	oil, gas, ^{235}U (tar sands, oil shales)
centuries:	coal, geothermal, D - T fusion ^{238}U, ^{232}Th
millennia:	D - D fusion

With a project average consumption of 40 TW
annual consumption will be:- 1.25 x 10^{21}

Compare this to the Current World *Proven* Reserves:-

Oil Reserves:-	**5 x 10^{21} J**
Gas Reserves:-	**4 x 10^{21} J**
Uranium:-	**1 x 10^{21} J**
Coal Reserves:-	**2.6 x 10^{22} J**
Uranium (Fast Breeder):-	**1 x 10^{23}**
Fusion (Deuterium):-	**1 x 10^{30}**

4.3 "RENEWABLE ENERGY RESOURCES"

Orders of magnitude only

Practically Achievable:-

10^{10} - Tidal (i.e. 1 x 10^{10} to 1 x 10^{11})

10^{11} - Geothermal; OTEC; Biomass; Wastes

10^{12} - Hydro; Wind; Waves

10^{13} – Solar

4.4 POTENTIAL RENEWABLE RESOURCES (installed Capacity)

	Theoretical	**Practical**	**Realised to date (2007)**	
	TW	**GW**	**GW**	
NON-SOLAR				
Tidal	3	50	0.25	France, Russia, China
Geothermal	30	60+	10.5 (Electrical)	Italy, Iceland, USA, New Zealand
			0.5 (Heat)	
SOLAR Direct				
Solar	30000	30000	3.6 (Electrical – PV and thermal)	USA, Israel: Germany, Spain; third world
			0.02 (Heat/Hot Water)	Does not include Passive Solar
SOLAR Indirect				
Wind	30	1000	80 GW	USA, Denmark, Germany, Netherlands, Spain ~ 4 GW in UK (Dec 2009)
Waves	3	30	0.01	UK, Norway, Japan, Portugal
OTEC	30	300	0.001	USA (Hawaii)
Hydro	30+	3000	800	USA, Brazil, Canada, Scandinavia, Switzerland, Malaysia etc.
Biomass/Wastes	300	1000	43 (electrical)	Various countries also increasing use of biofuels for transport which are currently included – e.g. Brazil - Bioethanol
			28 (Heat)	

Data for 2007 is based on actual amounts supplied according to IEA Statistics and assumed average Load Factors.

4.5 POTENTIAL RENEWABLE RESOURCES (Actual produced Worldwide)

	Municipal Waste*	Industrial Waste	Primary Solid Biomass**	Biogas	Liquid Biofuels	Geothermal	Solar Thermal	Hydro	Solar Photovoltaics	Tide, Wave, Ocean	Wind
Unit	*GWh*	*GWh*	*GWh*	*GWh*	*GWh*	*GWh*	*GWh*	*GWh*	*GWh*	*GWh*	*GWh*
Gross Elec. Generation	**56561**	**11473**	**158237**	**28669**	**3562**	**61819**	**681**	**3162165**	**4104**	**550**	**173317**
Unit	*TJ*	*TJ*	*TJ*	*TJ*	*TJ*	*TJ*	*TJ*				
Gross Heat Production	**166754**	**86631**	**328261**	**15274**	**21744**	**10572**	**137**				
From IEA Statistics											

5. BARRIERS TO CONSERVATION

5.1 GOVERNMENTAL

- preference to support supply rather than conservation; partly because of long term historic memories, and consequential political overtones if they under estimate future supply requirements.

- where grants are made available, they have often been made too late, and too restrictive - and will deter those who have made an investment in the past from doing so in the future.

- Is the method adopted in US during the Carter Administration a preferential one? - i.e. one where there are tax credits for those who invest in low carbon energy irrespective of whether they would otherwise qualify for a grant?

- historic lack of / or inadequate legislation to promote conservation (Latest Building Regulations do address some issues, but they are too late and there are many loop holes - so encourages minimum compliance rather than promoting conservation.). The new Code for Sustainable Homes – which has set targets of zero carbon homes by 2016 is admirable – but is it deliverable- and what about the missed opportunities of the last 35 years in existing buildings?

- delays in decision making favour supply rather than conservation

- reluctance in past at Local Government Level to implement tougher measures - e.g. Building Industry who argue against such measures - Exceptions:- Southampton City Council; Milton Keynes, Woking..

- reluctance to promote strategies which could cost Government votes at next election (e.g. higher taxation on petrol etc.) - many measures take a period longer than lifetime of Government to become effective.

- enactment of legislation which is has loose or incorrect wording:- 1947 Electricity Act in UK. Conservation Bill in US in 1979.

5.2 VESTED INTERESTS

- manufacturing industries continuing to promote out of date products and/or energy wasteful products - or to give *Pseudo-Conservation Information*.

- retailers/developers promoting products on the capital outlay, or other attributes, and not energy consumption. Are ESCO's a way forward?

- competition between supply industries leads them to promote their products which may not always be the most energy conserving - e.g. off peak heating with electricity. – although this is less an issue these days.

- scheduling of TV programs – once again with multiple channels this is less of a problem, but commercial channels still seem to bunch adverts at similar times.

- cowboy firms making unsubstantiated claims.

- preference to view Energy Conservation in terms of MONETARY saving rather than Resource saving.

5.3 ENVIRONMENTAL ISSUES

- incorporation of retrospective pollution controls usually INCREASES energy consumption.

e.g. Removal of SO_2 leads to:-

a) reduced efficiency at power stations, hence increased CO_2
b) as SO_2 is converted even more CO_2 is produced
c) Limestone required from Peak District etc.
d) Disposal of waste Gypsum
e) Additional Transport needed to power stations
f) FGD plant are large - comparable to size of power station (excluding cooling towers).

5.4 PHYSICAL LIMITATIONS

- laws of thermodynamics limit efficiency of energy conversion.

- climate affect energy consumption

- geological resources in a country will affect utilisation of energy.

e.g. it makes sense to use electricity for heating in
Norway which has abundant hydro-electricity,
but not in UK.

5.5 TECHNICAL PROBLEMS

- old buildings/appliances which have a long life so improvements in energy efficiency will take time to become effective.
- difficulty in making perfect machine
- difficulty in achieving high insulation standards in brick built buildings

5.6 SOCIAL ATTITUDES

- desire for greater thermal comfort. Comfort temperatures have risen over last 30 years.

- desire for greater mobility.

- desire for smaller households in larger and individual buildings (unlike many other European Countries).

- come to depend on reliability of energy supply (contrast situation in late 50's).

- purchasing larger and more energy wasteful appliances -e.g. tumbler dryers, freezers,cars etc. There is still a large potential growth in appliances such as dish-washers. Consumers are generally unaware that a tumble dryer consumes 4 times as much energy as a washing machine.

- Leaving appliances on standby

- sliding back into old habits.

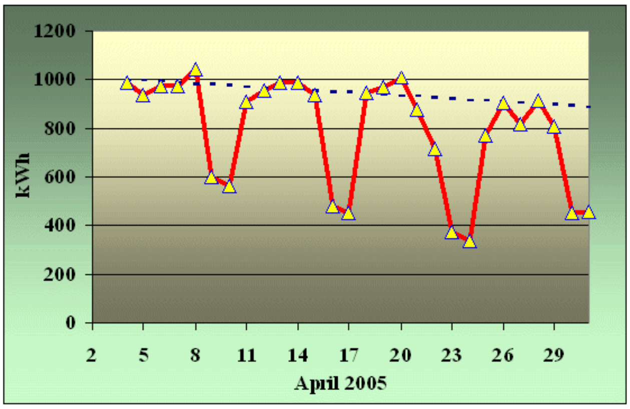


Fig. 5.1 UEA Switch off Campaign April 2005.

- disregarding notices/adverts designed to promote energy conservation.

- short memories - previous high costs of energy are forgotten when energy becomes cheap.

- energy conservation not often seen as important as direct investment even when the returns are much greater. Alternatively given lower priority than pleasure e.g. holidays etc.

- problem of comfort taking

5.7 ECONOMIC

- We expect a pay back for any investment in a short period. Is the idea of an Energy Service Company – a way around this?

How would an ESCO work? Many Housing Developers are reluctant to invest in higher standard buildings as they see the capital cost rising and are concerned that potential buyers would not be prepared to pay the extra. The concept of an ESCO only became a legal possibility a few years ago after the relaxation of the 28 day rule.

Suppose a developer was building houses and had considered including heat pumps as an energy conservation measure, but rejected them in terms of capital cost. The building would still have to conform to building regulations and require a condensing central heating boiler and radiators. The internals for the boiler, pipe work and installation may come to £5000, but a heat pump installation might be £10000. An ESCO would negotiate with the developer and suggest that he fit no internals and instead pay the saved capital cost (i.e £5000) to the ESCO who would then seek a loan for a further £5000 to pay for a heat pump installation. The ESCO would then negotiate with the householder saying that in the basic construction he would have been paying a given amount for energy, and this he would now pay to the ESCO. The ESCO would pay the actual bill to the utility which because of savings would be much less than normal, and the difference between what the householder pays the ESCO and the ESCO pays the utility company would building would pay back the loan and make the ESCO a profit for say 5 or so years. After that time the ESCO would move on to a new project and the householder would then benefit from much reduced energy bills.

- In this way the developer has to charge no more for the house,
- The householder pays no more initially for his energy but sees a reduction in the longer term,
- The ESCO makes money through the contract,
- The Environment wins.

This concept is a bit like monthy contracts for mobile phones where those on such contracts often get the phones free.

- Assessment of an Energy project depends not only on the rate of return we expect (allowing for inflation etc.) which is related to the Discount Rate, but on how fuel prices are seen to change in the future.

- In the mid 1970's, it was predicted by many that the REAL price of energy would at least double by the end of the century. In practice energy is now cheaper in real terms than in 1970's despite recent rises

- Widely fluctuating fuel prices, and expectations on return can create a STOP GO attitude towards rational spending on Energy saving projects.

- In Industry, Energy Saving has to compete with increased productivity.

    Thus a new process which takes half the space of an old equivalent one, produces the same number of items in half the time would be favoured EVEN if it consumed 50-100% more in Energy (as labour costs would be reduced and profits increased because the price of Energy is TOO LOW).

- The choice of a particular Discount Rate (which is often dictated by Government) will load the dice in favour of a particular option if only Economics is used in decision making EVEN IF EXTERNAL ENVIRONMENTAL COSTS ARE INCLUDED.

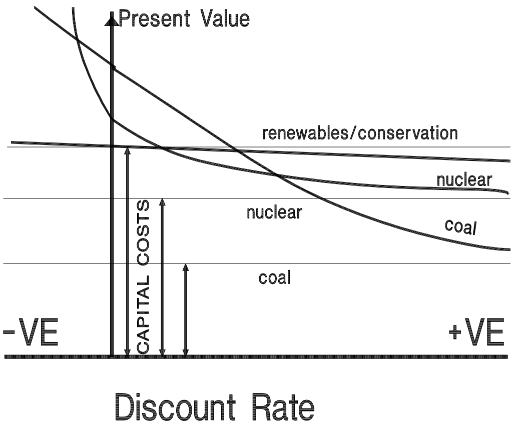


Fig. 5.2 Effect of Discount Rate on Economic Viability of Energy Projects

- High Discount Rates favour Coal
- Medium Discount Rates favour Nuclear
- Low/zero/negative Discount Rates favour Conservation and Renewables see Fig. 5.2**.**

Peter Chapman' book "Fuel's Paradise", though written in 1970 is a very interesting perspective of energy. The first two chapters are particularly relevant to thoughts about a low carbon economy where the value of currency is linked to a unit of energy. His ideas and those of his contemporaries started the move of "Energy Analysis" which was a forerunner of "Carbon Footprinting" and Life Cycle Analysis.

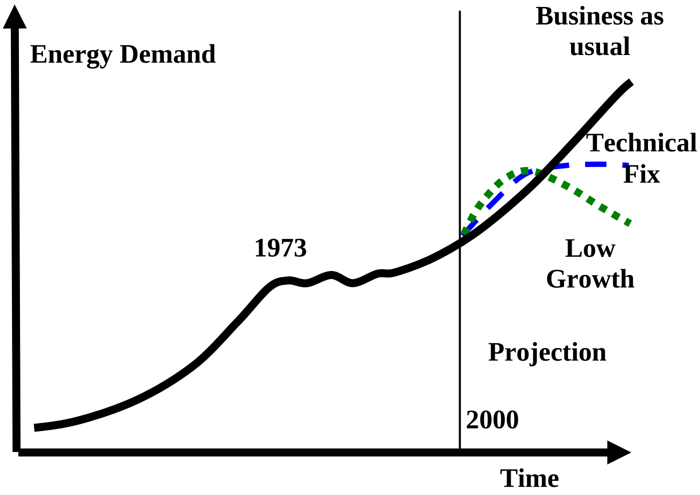


Fig. 5.3 Changing Energy demand with different strategies.

Chapman discussed a diagram such as Fig. 5.3 which has been modified in time scale to be more relevant to the present day. The trend shows a business as usual growth in energy demand. However, once a country or organisation moves towards a policy of reducing demand through technological means there will initially be an increase in energy consumption as the energy to provide the necessary infrastructure is expended – e.g. manufacture of double glazing units. Thereafter the consumption would stabilize and fall below that of the business as usual scenario. Chapman also perceived that a sustainable low growth scenario on his mythical Island or Erg could lead to an even higher initial increase in consumption

If any of you frequent Second Hand Book Shops or Amazon you will often find second hand copies available.

6. CONSERVATION POSSIBILITIES.

- **Technical**
  - **Energy Conversion**
  - **End use of energy**
- **Education**
- **Energy Management**

Technical Measures will have limited impact on energy consumption if people are not educated to use energy wisely.

Energy Management is a key aspect in energy conservation

A good Energy Manager will:-

- **Assess** Energy Demand - record keeping
- **Analyse** Energy Demand - examine trends relating to physical factors
- **Advise** of technical and other methods to promote energy conservation
- **Advertise** and publicise ways to save energy
- **Account** for energy consumed

OTHER POINTS

- **Significant saving are possible by reducing waste in conversion of energy to secondary fuels**
- **Effective Energy Conservation and Environmental Legislation may well see a rise in electricity consumption in the short term.**
- **promotion of heat pumps**
- **industry switching to more efficient electrically driven processes**
- **move towards electric cars.?????**
- **Hydrogen ????**

A Paradox

Despite in efficiencies in electricity generation, heat pumps and hydrogen offer significant opportunities for energy conservation and CO_2 emission reduction.

So effective promotion of energy conservation could lead to an increase in electricity consumption.

7. Summary of Consumption in UK (1993-2008) - per capita consumption

8.

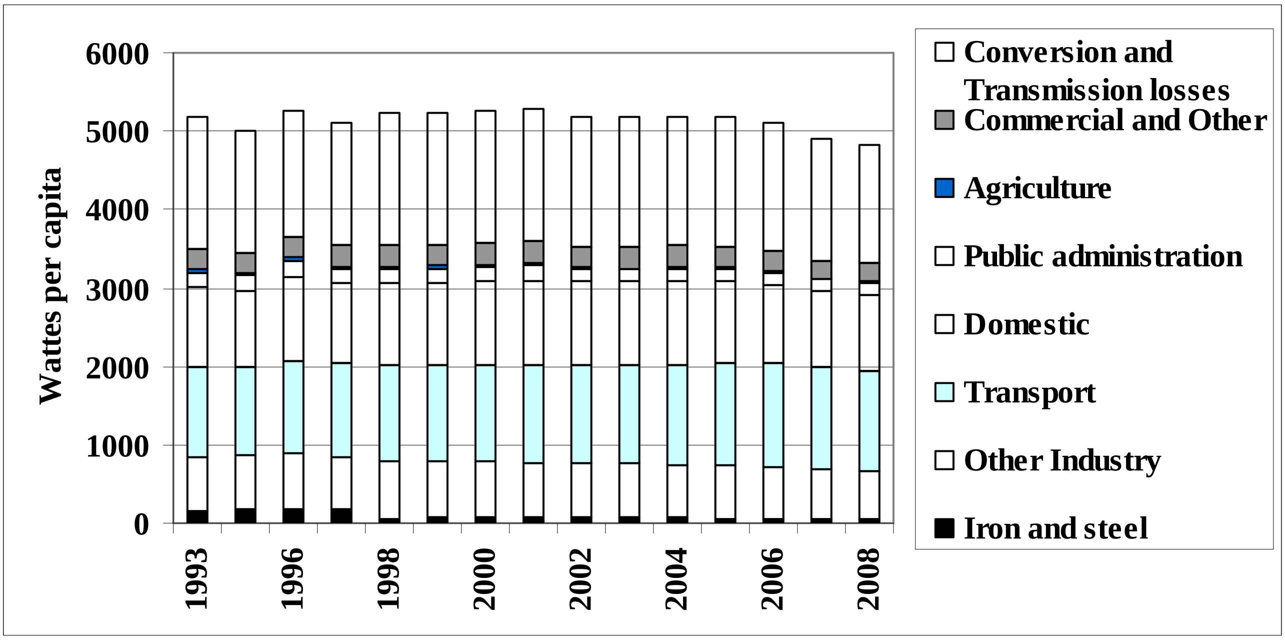


Fig. 7.1 Variation in Energy Consumption 1993 – 2008 – see table 8.1 for detailed information

Note:

1. Rate of Population increase has increased from
2. Overall UK consumption has remained nearly static although has shown a reduction in last two years.
3. Variations in Domestic, Administration, and Commercial are largely due to climatic effects.
4. Industry overall has declined slightly
5. Conversion losses declined
5. Transport demand has risen by 11.4% since 1993 although it has now declined from a peak of 15% in 2006.

Table 7.1 UK Per Capita Consumption in watts for different sectors

	Watts per Capita															annual % change			
	1993	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	1993-2008	1993-2000	2000-2005	2005-2008
Populations (thousands)	57714	58025	58164	58314	58475	58684	58886	59114	59322	59,557	59,846	60,209	60,587	60,975	61,383	0.41%	0.29%	0.45%	0.65%
Iron and steel	159	174	181	177	61	86	86	86	71	68	64	61	63	59	54	-6.95%	-8.41%	-6.64%	-3.98%
Other Industry	678	685	706	676	725	698	695	692	705	693	671	678	657	629	608	-0.72%	0.35%	-0.49%	-3.57%
Transport	1142	1138	1180	1193	1219	1238	1247	1234	1239	1260	1281	1302	1314	1309	1272	0.72%	1.26%	0.87%	-0.77%
Domestic	1039	967	1085	1008	1047	1043	1057	1090	1069	1063	1078	1040	1003	963	987	-0.34%	0.25%	-0.32%	-1.73%
Public administration	186	193	202	193	185	190	183	182	158	150	160	159	155	146	150	-1.42%	-0.23%	-2.77%	-1.92%
Agriculture	31	30	32	30	31	29	27	29	25	21	20	22	20	20	20	-2.88%	-1.95%	-4.01%	-3.13%
Commercial and Other	256	259	274	274	273	269	276	288	261	268	270	267	261	217	220	-1.01%	1.08%	-0.66%	-6.25%
Conversion and Transmission losses	1693	1555	1601	1554	1690	1684	1678	1672	1666	1649	1635	1649	1628	1552	1503	-0.79%	-0.13%	-0.35%	-3.04%
Total Direct Energy Use	**5184**	**5003**	**5261**	**5106**	**5231**	**5236**	**5249**	**5272**	**5194**	5172	5179	5178	5101	4895	4814	-0.49%	0.18%	-0.27%	-2.40%
Non energy use					281	280	279	278	277	268	270	267	261	217	220		-0.88%	-0.88%	-6.25%
Total Primary Demand					**5512**	**5516**	**5528**	**5550**	**5471**	5440	5449	5445	5362	5112	5034		-0.30%	-0.30%	-2.58%

8 CONVENTIONAL GENERATION OF ELECTRICITY

8.1 Introduction

There are major losses in delivering energy to point of end use. The majority of this is accounted for by conversion of fuel into electricity.

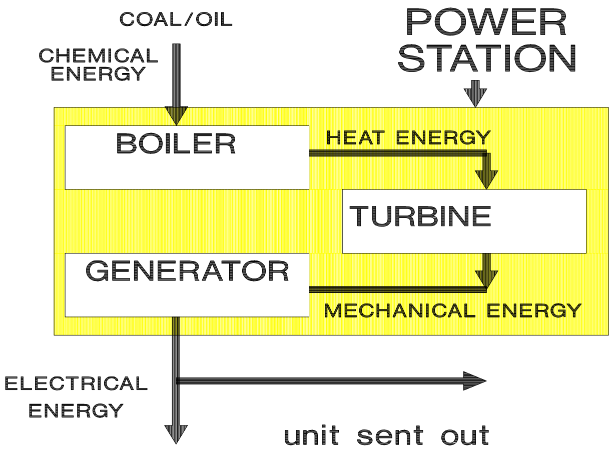


Fig. 8.1 Summary of Energy Conversions in a Power Station

Typically only 35-37% of energy in fuel in a conventional coal-fired power station is output as useful electricity, a further 3% is lost in transmission. Gas stations can reach 46-56% efficiency.

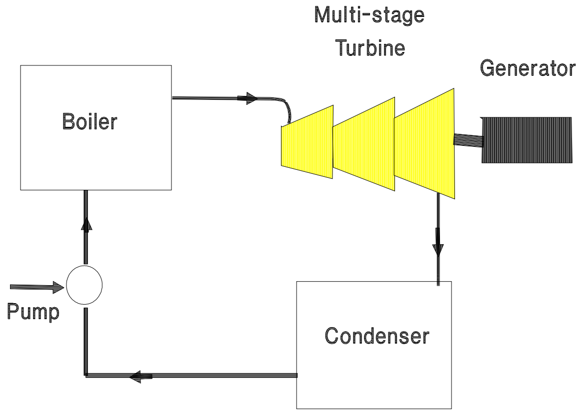


Fig. 8.2 Typical configuration for generation of electricity showing power circuit.

Supply of electricity

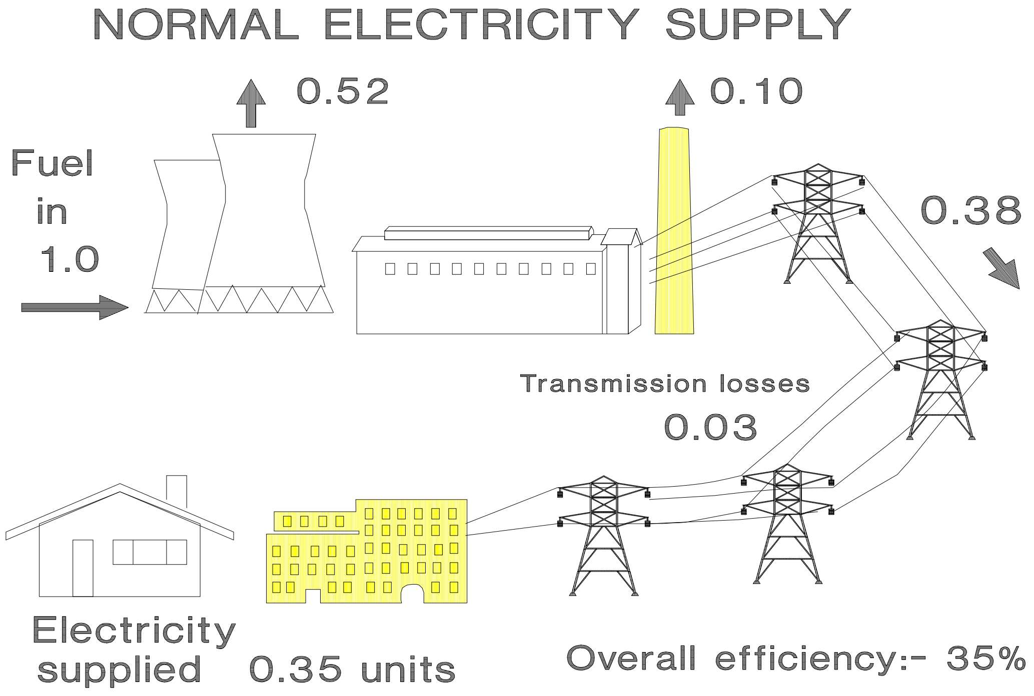


Fig. 8.3 Conventional Generation of Electricity

- Why not use the heat from power station? - it is typically at 30^{O}C?
- This too cold for space heating as radiators must be operated much hotter than this otherwise they will not be able to supply sufficient heat (alternative is to have radiators the size of walls).
- What about fish farming - tomato growing? - Yes, but this only represent about 0.005% of heat output.
- Problem is that if we increase the output temperature of the heat from the power station we get less electricity.
- Does this matter if overall energy supply is increased? 1947 Electricity Act blinked our approach for 35 years into attempting to get as much electricity from fuel rather than as much energy.

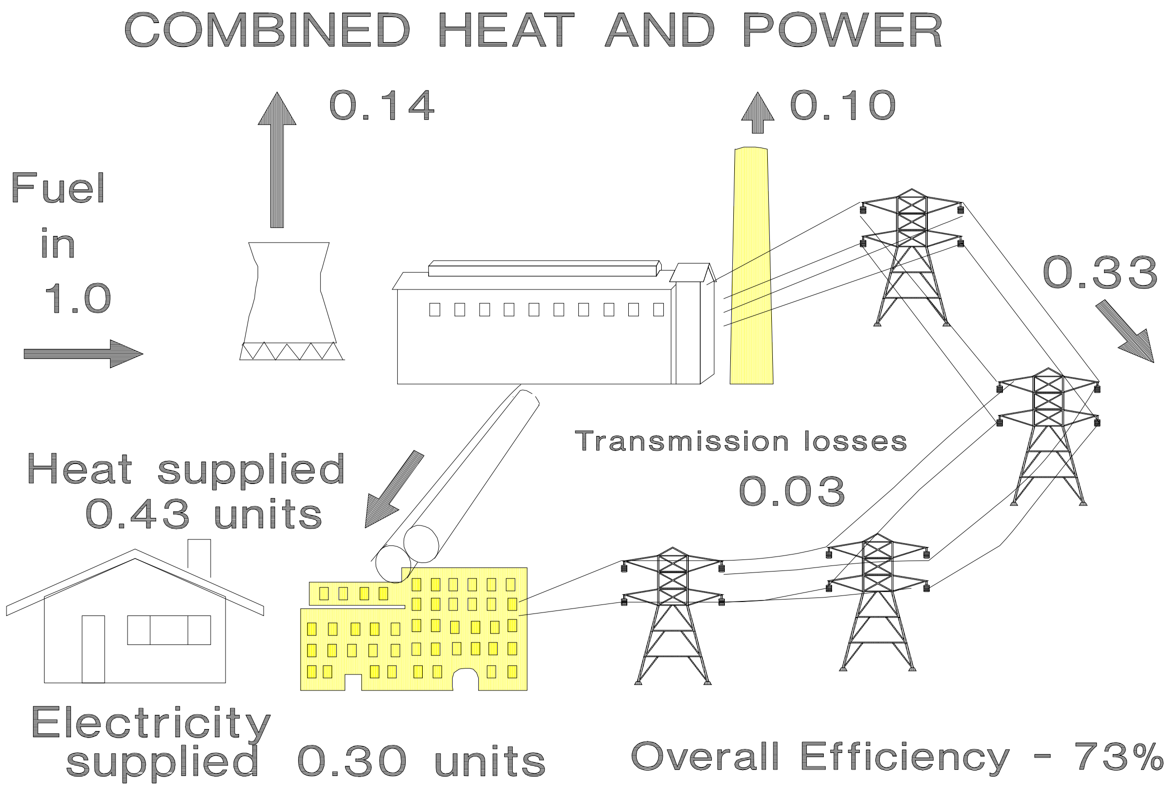


Fig. 8.4 Generation of Electricity using Combined Heat and Power

In this situation, the waste heat from the power station is rejected at about 90^{o}C and can be piped to homes etc. for space heating.

Though the amount of electricity has reduced, the overall amount of useful delivered energy has increased substantially.

To understand what is going on we need to consider thermodynamics.

9. BASIC THERMODYNAMICS

9.1 Introduction

Classical thermodynamics is an exact science and forms a fundamental requirement in the understanding of processes in many branches of science.

The beginnings of thermodynamics can be traced to the late eighteenth century when attempts were made to reduce the steam consumption of the early beam engines of the Newcomen type (Fig. 9.1). It was Watt's idea to condense the steam in a vessel other than the working piston that led to dramatic improvements in the performance of mechanical devices (Fig.9.2).

The improvement in the fuel consumption lead engineers and scientists to consider whether or not the fuel consumption could be reduced indefinitely. If the answer was no, then what laws governed the processes and what theoretically was the minimum fuel consumption for a given amount of work? In providing the answers, the science of thermodynamics was born.

It must be stressed that the initial considerations were for the extraction of the greatest amount of work or power from any process and not for the production of work at the greatest overall <u>useful</u> efficiency.

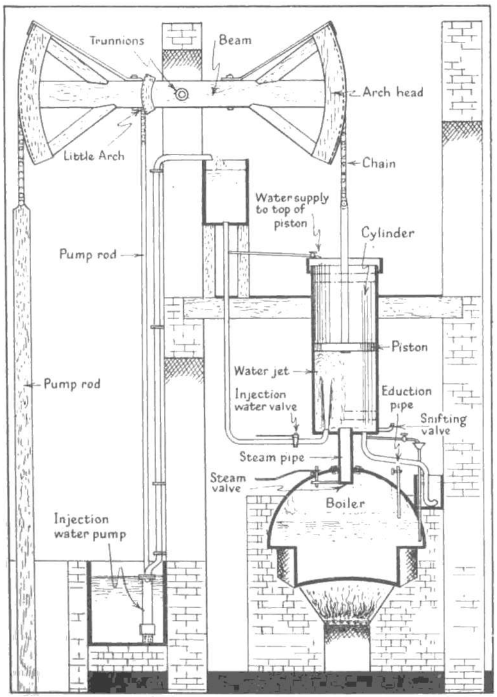


Fig. 9.1 The original steam engine - Newcommen

Even in the 196O's this philosophy existed in the design of power stations. Heat at low temperature was considered as being useless, and in the production of power we still see that even the most efficient methods reject vast quantities of heat at low temperatures which, until the recent so called energy crisis, were considered as being virtually useless. Students in Engineering Thermodynamics were taught that work was all important and that waste heat was useless, particularly as one could heat buildings readily by the burning of fossil fuel.

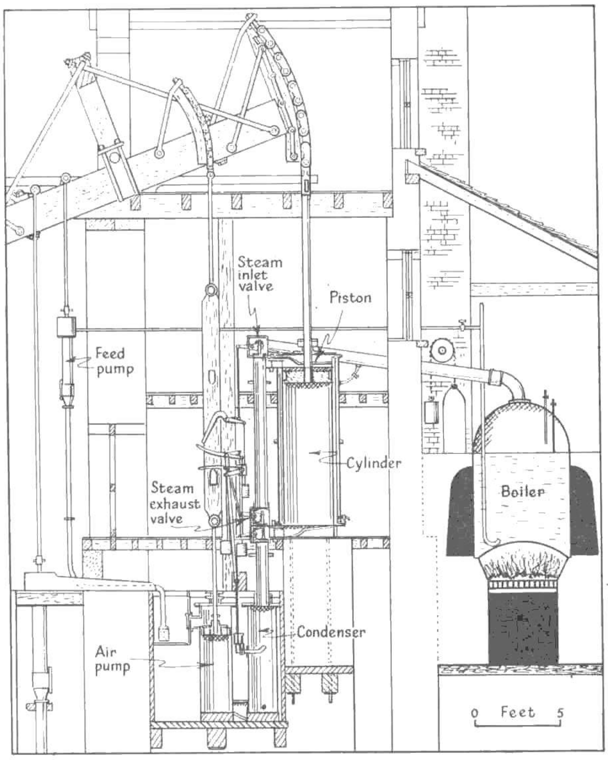


Fig. 9.2 Watt's Steam Engine increased efficiency of Newcommen Enegine by a factor of 4.

In the early days of the industrial revolution new ideas could be built and tested to see if they worked. In many cases the designs resulted in failures. In the current financial climate we cannot afford to advance our standards of living by costly failures, and although the testing of prototypes is absolutely necessary, the early designs will have invoked thermodynamics in the prediction of performances, and many inefficient processes can be eliminated before construction commences.

If, for instance, we have a plentiful supply of solar energy as we will have in many of the underdeveloped countries it would be possible at least in theory to estimate how much steam could be produced and at what temperature and pressure. From these latter two we can predict that maximum total power, work or electrical energy that can be produced by this steam.

We could, of course, have produced this steam by the combustion of a fossil fuel, and once again thermo-dynamics would enable us to predict the likely quantities and nature of steam or electricity.

The reader may think that this introduction is becoming over concerned about the production of power as have most of the texts on classical engineering thermodynamics been in the past.

It is, however, necessary to consider the uses of both the produced power and the hitherto 'useless' waste heat. The production of power is of importance even in considerations of the simple heating of buildings since the input of a small amount of power can lead to the transference of large quantities of heat into a building. In other words the input of one unit of energy in the form of power can lead to the transference of several units of energy in the form of heat, into a building. This apparent 'something for nothing' can only be explained with reference to applications of the Second Law of Thermodynamics.

Clearly thermodynamics is of importance in any consideration of the energy production whether it be in the form of burning of fossil fuels or in the use of alternative energy sources.

9.2 The discovery of the laws of thermodynamics

There are four laws of thermodynamics, namely the zero'th, first, second and third. Of these the first and second are of greatest importance to us, while the zero'th is of importance, as unless it were true, we should not be able to measure temperature.

Chronologically the first aspects relating to the Second Law of Thermodynamics were put forward by Carnot in 1824. Before Carnot it was appreciated that one had to put heat in to get work out, and the question which required solution was 'What laws governed the Conversion of heat into work?'

Carnot perceived that TEMPERATURE provided the key and he utilised the method of arguing by analogy. He likened the work produced for heat to that produced when water flows from a high level to a lower level to a low level. Could not high and low temperature be the counter- parts of the high or low levels? This analogy is indeed correct and is now embodied in what is now known as the second law of Thermodynamics.
In one respect Carnot was incorrect and this arose because he used the water analogy. In the case of water, the same quantity of water flows out at the low level as entered at the high level. In the case of heat it is now known that less heat flows out at low temperatures. In Carnot's day even the best engines had heat inflows and heat outflows which differed by less than 1O%, and such a difference would hardly have been detectable.

It was in 185O that Joule discovered that the 'lost' heat had "turned into" work and this law is now known as the First Law of Thermodynamics. This law is the one which most perpetual motion machines contravene. The remainder contravene the second law.

The remainder of this document is given to an elementary introduction to the thermodynamics but for further information it is suggested that the reader consult an appropriate text on thermodynamics.

9.3 KEY POINTS of THERMO-DYNAMICS:

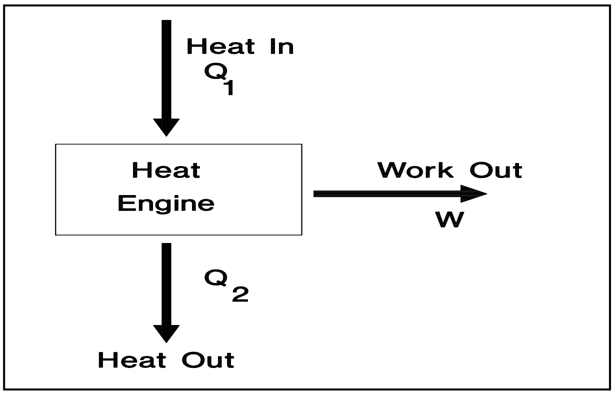


Fig. 9.3 Schematic Diagram of a Heat Engine converting Heat to Work

1: FIRST LAW equates the algebraic sum of the work done by a system to the algebraic sum of the heat transfers to/from the system.

- Heat into system is "positive":
- Heat rejected is "negative"
- Work done BY system is "positive":
- Work done on system is "negative"

$$\text{i.e.}\quad W_1 + W_2 + \ldots\ldots = Q_1 + Q_2 + \ldots\ldots$$

$$\text{In a typical system}\quad W = Q_1 - Q_2$$

2: SECOND LAW is more restrictive than the FIRST LAW and states that when WORK is obtained from heat, the conversion process must ALWAYS reject heat. This limits the theoretical (or CARNOT) efficiency.

3) Efficiency is defined as

$$\frac{\text{work out}}{\text{heat in}} \times 100$$

Since heat flow is proportional to temperature we can replace heat flows by temperature.

$$\text{i.e. } \eta = \frac{T_1 - T_2}{T_1} \times 100$$

This the theoretical or Carnot efficiency.

4) Practically, the efficiency will always be less than the Carnot Efficiency. To obtain the "real" efficiency we define the term *Isentropic Efficiency* as follows:-

$$\eta_{isen} = \frac{\text{actual work out}}{\text{work output from Carnot Cycle}}$$

$$\text{Thus "real" efficiency} = \eta_{carnot} \times \eta_{isen}$$

5) A power station involves several energy conversions. The overall efficiency is obtained from the product of the efficiencies of the respective stages.

EXAMPLE:

In a coal fired power station like DRAX, the steam inlet temperature is 566°C and the exhaust temperature to the condenser is around 30°C. The combustion efficiency is around 90%, while the generator efficiency is 95% and the isentropic efficiency is 75%. If 6% of the electricity generated is used on the station itself, and transmission losses amount to 5% and the primary energy ratio is 1.02, how much primary energy must be extracted to deliver 1 unit of electricity to the consumer?

$$\text{Carnot efficiency} = \frac{(566 + 273) - (30 + 273)}{566 + 273} = 63.9\%$$

so overall efficiency in power station:-

$$= \underset{\text{combustion loss}}{0.9} \times \underset{\text{carnot}}{0.639} \times \underset{\text{isentropic}}{0.75} \times \underset{\text{generator}}{0.95} \times \underset{\text{station}}{0.94} = 0.385$$

allowing for transmission losses and the primary energy ratio, 1 unit of primary energy will produce:-

$$\frac{1 \times 0.385 \times 0.95}{1.02} = 0.359 \text{ units of delivered energy}$$

i.e. 1 / 0.359 = 2.79 units of primary energy are needed to deliver 1 unit of electricity.

If we could increase T_1 or decrease T_2 then we could improve the Carnot Efficiency.

WE CANNOT change T_2, but we could increase T_1. However, the properties of water/steam means that there is an upper limit of around 600°C.

We can improve matters by the use of combined cycle gas turbine stations CCGTs.

9.4 Heat Pumps

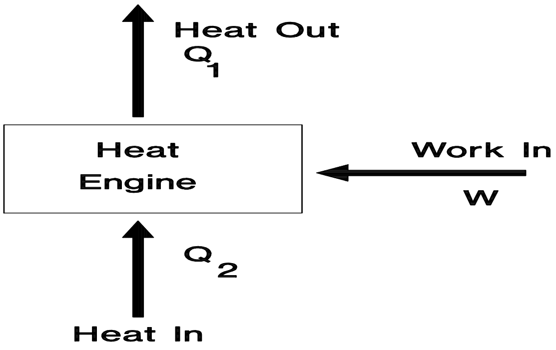


Fig. 9.4 Schematic Representation of a Heat Pump. NOTE: it is a reversed heat engine. **IT IS NOT A REVERSED REFRIGERATOR.**

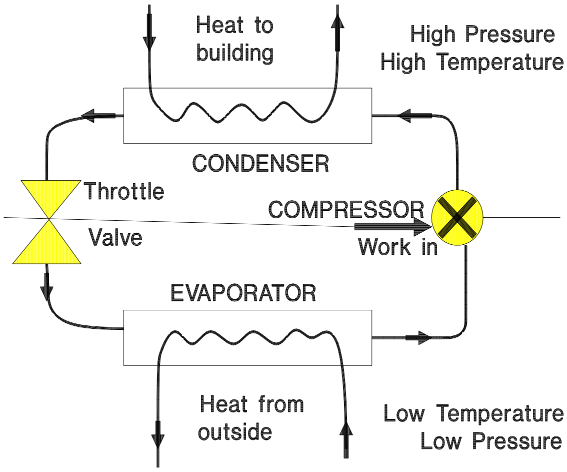


Fig. 9.5 A typical Heat Pump showing components

A heat pump consists of four parts:-

1) an evaporator (operating under low pressure and temperature)
2) a compressor to raise the pressure of the working fluid
3) a condenser (operating under high pressure and temperature)
4) a throttle value to reduce the pressure from high to low.

Low temperature heat from an external source (e.g. air, ground, or water) is pumped through the evaporator (a contra-flow heat exchanger). In this, the refrigerant is under low pressure typically 0.1-1.0 bar, and enters as a liquid but soon boils as it passes through. On leaving the evaporator, the fluid is entirely a gas but still under low pressure. The heat transfer from to the refrigerant is essentially at constant temperature (as the fluid is boiling) and therefore efficient. For a heat pump for a house using the ground as the heat source the temperature will typically be around 0^{o}C.

The fluid is now compressed to typically one bar in a compressor (usually a reciprocating one for small devices or a rotary one for large devices). The outlet gas is now under high pressure (typically 3-7 bar) and at high temperature. For a domestic application, this high temperature will typically be around $50+^{o}$C (for hot water systems it is likely to be somewhat higher (around 65^{o}C), and for hot air systems, rather lower.

Heat is released from the refrigerant in the condenser which is once again a contra flow heat exchanger and transferred to the heat medium to heat the building. The refrigerant condenses back to a liquid at constant temperature.

Finally, the high pressure condensed liquid is expanded through a throttle valve to complete the cycle. This expansion is unrestricted, and an obvious inefficiency, but the amount of work that could be recovered here is small (as the volume change in a liquid is small on expansion) that technically and economically it would not be feasible to utilise this work. (Indeed it affect the overall practical COP very little).

If Q_1 is the heat rejected to the building,, Q_2 is the amount of heat extracted from the source, and W is the work input, then by the FIRST LAW:-

$$\mathbf{Q_1 = Q_2 + W}$$

$$\textbf{i.e. COP} = \frac{\mathbf{Q_1}}{\mathbf{W}} = \frac{\mathbf{Q_1}}{\mathbf{Q_1 - Q_2}} = \frac{\mathbf{T_1}}{\mathbf{T_1 - T_2}}$$

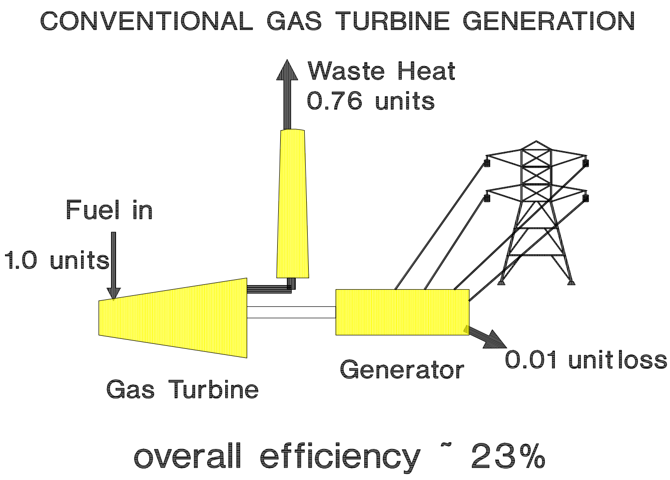


Fig. 9.6 Open Circuit Gas Turbine

If the heat pump has a heat source as the ground at 0^{o}C and supplies heat at 50^{o}C, then the Coefficient of Performance COP is given by:-

$$\mathbf{COP} = \frac{\mathbf{(273 + 50)}}{\mathbf{(273 + 50) - (273 + 0)}} = \mathbf{6.46}$$

Note the temperature used in the equation must be in Kelvin

Thus, theoretically, for every one unit of energy we put in we get 6.46 units out. Practically, we can achieve about 50% of the theoretical COP, i.e. about 3.23 in this case.

The heat pump allows us to work with the Laws of Thermodynamics and extract heat which would otherwise be unusable.

If we have an electrically driven heat pump, even allowing for the 3:1 inefficiency in generation, we can more than recover the "lost" energy in the power stations.

i.e. we need only 3 / 3.23 = 0.93 units of primary energy to supply 1 unit of useful energy as heat.

in the best alternative (using a condensing gas boiler), we would require:-

1 / 0.9 units = 1.11 units (i.e. a heat pump would save over 16% in the case and considerably more with other types of heating

9. 5. COMBINED CYCLE GAS TURBINE STATIONS

A combined cycle gas turbine station overcomes the problem in steam stations that the temperature cannot be raised too high because of the properties of water/steam. Instead gas is compressed and burnt at a significantly increased temperature in a gas turbine, which by itself is not that efficient. However, by using the waste gases to raise steam (replacing the conventional boiler), the overall efficiency is greatly improved.

A typical OPEN CIRCUIT gas turbine station, which was the only form of gas turbine in use until mid 1990s, is shown in Fig. 9.6 .

The turbine is nothing more than an enlarged aircraft engine. Gas is burnt and the gases expand through the turbine to provide motive power for electricity generation, but the temperature of the waste gases is very high so the overall efficiency is low. These stations were used at peak times only as they could be 'fired-up' in about 3 minutes.

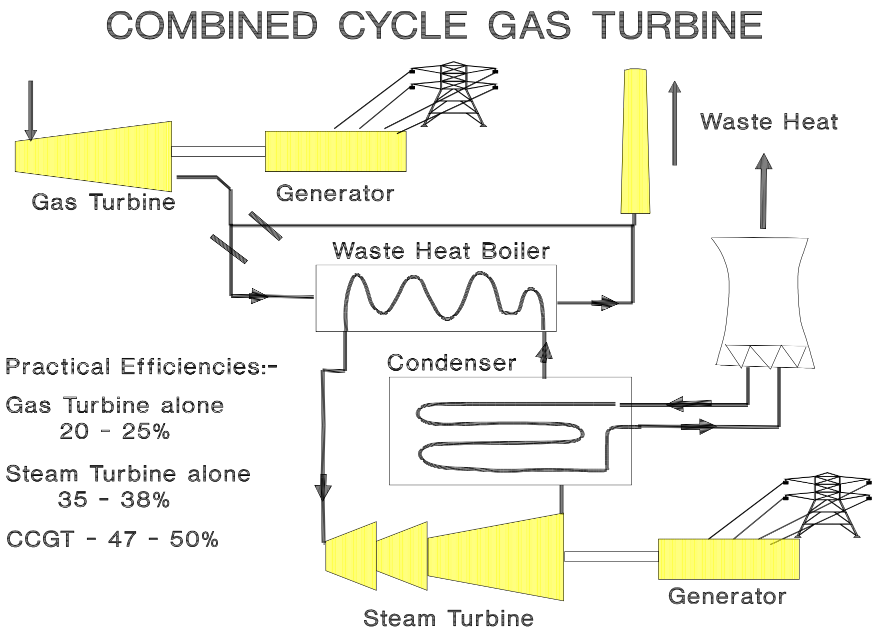


Fig. 9.7 A typical configuration for a CCGT

Combined cycle gas turbines (Fig. 9.7) generate electricity at two points - firstly from the gas turbine, and secondly from the steam turbine. The majority of the exhaust heat from the gas turbine can be used to raise steam, but in most cases there will still be a condenser to reject low-grade waster heat.

The first CCGTs had an efficiency of 47%, significantly above that of the coal fired power station. Newer CCGTs now achieve over 50% with claims of stations with overall efficiencies as high as 56%.

The CCGT station we shall be visiting on the field course has an efficiency of about 56% and is has the highest efficiency of any station in the UK.

10. ENERGY BALANCE TABLES

10.1 Introduction

Energy Balance Tables show in a reasonably concise way the energy supply and demand in different sectors in a given country. They may be used to ascertain key issues about the nature of energy consumption and consequential carbon dioxide emissions. Some countries like the UK have reasonably comprehensive Balance Tables. However, all countries have simplified Balance Tables published by the International Energy Agency.

The nature of (i.e. fuel types) used in the economy of a particular country will influence its overall carbon emissions, but although the carbon emissions from many fuels such as gas are generally consistent from one country to another, those emissions from electricity vary widely from one country to another, depending on the mix of fuels used for generation, the efficiency of generation in that country, and finally the losses in transmission to the point of end use.

There are three different areas to tackle with respect to Energy Conservation:-

1) The losses in conversion to and distribution of secondary fuels
2) The waste in converting energy into the form we want at the point of end use,
3) The social and behavioural issues which affect the use of energy.

- Energy Balance Tables allow us to estimate the magnitude of the first of these.

- Energy Balance Tables can also be constructed for a particular fuel such as electricity and these can be useful for assessing the carbon emissions factor in a given country.

10.2 Energy Balance Tables – the basics

- Energy Balance Tables are constructed to show the energy flows within a country. They provide a useful summary on a year basis to assess where energy losses are occurring.

- Energy Balance Tables are best constructed on a HEAT SUPPLIED BASIS (UK used to use Millions of Therms which was fairly accurate, but now uses MTOE which other countries use MTCE etc. The problem with this is that the actual values depend on the calorific values used. In the UK 1 tonne of oil is assumed to have an energy value of 41.87 GJ, but will vary from one country to another and between organisations. If displayed in MTOE or MTCE, then it is important that the calorific values of the fuel used to generate the information is know so that comparison can be made.

When comparing one country with another:-

- ♦ CHECK the calorific value of fuel if MTOE or MTCE are used.
- ♦ Check whether higher or lower CV is used. (UK Energy Statistics currently use the Higher CV)

- Primary Electricity (hydro, nuclear, renewable) creates a problem with convention. It is generally agreed that nuclear electricity should be treated as though electricity had been generated in a fossil-fired thermal station. In some countries, and also in the past in the UK, it was also common to lump renewables into this category as well. It is thus important to assess exactly what convention is used in a particular country of interest.

- ♦ All energy extracted in primary form is +ve
- ♦ All energy imports are +ve
- ♦ All energy exports are -ve

Energy Balance Tables in recent years have been condensed into Aggregate form, which reduces space taken up, but removes distinctions between different related fuels such as motor spirit and diesel and fuel oil, instead lumping them all under Petroleum Products. Similarly processed solid fuels are mostly aggregated. Instead, detailed Balance Tables for each fuel are given. The following explanation refers to the latest data available and is derived from the Aggregated Table 1.1 in DUKES (2009) which gives data for 2008. The data have been converted from the original units of Thousand Tonnes of Oil Equivalent into PJ. Subsequently data are also presented for 2006 from DUKES (2007):-

It should be noted that both Nuclear and large scale hydro are classed as primary electricity

10.3. Supply

- **Line A** is total supply allowing for extraction, imports, exports and stock changes. The Statistical Differences refer to the differences between the Primary Supply and Primary Demand. the reason for the differences are many fold, but include rounding errors from the many suppliers, differences in accounting periods etc.

  The figure of **9815.5 PJ**, or more correctly **9.815 EJ,** is the total annual UK consumption of Energy and represents a small increase of 0.7% from **9.75 EJ** since 1991. In 2000 this figure was **10.22 EJ** and there was little change until 2006 when it **10.215 EJ.** In the last two years there has thus been a decrease of 3.9% as a result of the very high oil prices in mid 2008 and the start of the recession. A small amount of energy in the form of oil/gas is uses as chemical feed stocks as shown in line K, and thus the true Energy use in the UK is **9.8155 - 0.4221 = 9.39 EJ** – a fall from 2000 when it was **9.70 EJ**. The fall over last two years is more dramatic as it was **9.72EJ** in 2006.

- **Line B** refers to transfer and arises partly because of the aggregation of data to simplify the table. It mostly represents reclassification between the raw suppliers and the energy conversion industries. For instance some gas under pressure at the well head would be in liquid form, but at lower pressure at use would be as gas. Equally, some gas is pressurised before pumping and is received in liquid form. Finally in the electricity column, electricity from Renewable resource appears in the transfer figure of **-44.2PJ** when it is transferred directly to the next column.

- **Line C** indicates the energy consumed (-ve numbers) or produced in (+ve numbers) in the Energy Conversion Industries. Thus of a Primary Demand of **1563.0 PJ** of coal **1488.5 PJ** were directly used in producing secondary fuels such as electricity, coke etc. Similarly **3688.5 PJ** of crude oil was converted in refineries while **3624.4 PJ** of petroleum products were produced. **1430.1 PJ** of gas and **148.1PJ** of renewables (mostly as waste/biomass) were used in conversions. Finally, of the **542.8 PJ** of primary electricity the **498.6 PJ** represents the nuclear electricity and was converted in the energy conversion stage, while the remaining **44.2PJ** of primary electricity was converted directly as renewable electricity.

  Note: the **498.6 PJ** of primary electricity assigned as nuclear **does NOT** represent the physical amount of electricity generated. This is the effective energy input to provide the actual amount of such electricity generated assuming that the electricity had been generated by fossil fuel means rather than nuclear [this is International Convention] The **-2162.0 PJ** in the final column is significant as this, being negative represents the losses incurred in converting energy.

- The lines shown by a “*****” beneath line C in the detailed table 18.2 show the distribution of each fuel for conversion. Thus of the **1488.5 PJ** of coal, **1252.3 PJ** went to the Power Stations, while **179.2 PJ** went to coke manufacture for the Iron and Steel Industry. Equally all the crude oil went to the refineries, while of the **1430.1 PJ** of gas used in conversion, the majority or **1346.7 PJ** was used in Power Stations with **83.4 PJ** in centralised Heat Production. The figure of 1346.7PJ **1117.3 PJ** represents an increase from just 49PJ in 1991 i.e. a 27 fold times increase in just 15 years and reflects the so-called dash for gas particularly in the middle years of the last decade. Furthermore in just 2 years since 2006 there was an increase in gas consumption from **1117.3 PJ** to **1346.7PJ** or **21%** just at the time when the UK is running out of gas. Row C in the detailed table 18.2 is in fact the sum of the values in the “*” rows.

  The line "Major Power Producers" refers not only to the established names such as E.ON and RWE, but also the Independents such as Lakeland Power etc. The Autogenerators refer to generators who produce electricity for their own use - such as UEA.

- The previous section refers to the actual energy use in the conversion process - e.g. the thermodynamic conversion in the case of electricity. It does not reflect the energy use by the supply industries. Row D (both tables) shows the amounts of energy used in these industries. For instance electricity is used in power station to drive pumps, grind coal, while electricity is also used in coal mine to cut coal. The aggregate amounts of each fuel used by the energy supply industries is shown in **Row D**.

  Thus electricity generation consumes **58.7 PJ** in station use and a further **4.6 PJ** in pumped storage, while the refineries use **18.4 PJ** of electricity, **200.0 PJ** of oil 6.8 **PJ** of natural gas and **3.0 PJ** of Heat.

- **Line E** refers to the transmission losses between the power station and the consumer in the case of electricity or the use of gas and leakages in the case of gas distribution.

Examples of losses in supply and distribution of Gas

1) Compression of gas for storage
2) Liquefaction of gas for storage
3) heating of gas on expansion
4) Pumping

- **Line F** is the net amount of energy available to the consumer.

Line F = Line A + Line B + Line C - Line D - Line E

This represents the main energy balance

Below Line F the table changes from the Supply and Conversion side to the demand sectors

10.4. Demand

- **Line G** shows the total amount of each fuel used by industry for each fuel type, while below that line in the full table the figures are disaggregated into the separate industrial sectors.

- **Line H** relates to transport, and once again, this section is also disaggregated in Table 18.2.

- **Line I** shows the aggregated Delivered Energy to all other sectors with a split between the different sectors in the following Rows in Table 18.2.

Line J shows the total amount of energy actually delivered for use while, as indicated above, **Line K** represents the Non-Energy uses.

10.5. Derived Statistics

The above raw table provides the raw statistics from which many parameters can be obtained.

We must however remember the implied definition of Primary Electricity which applies to all forms of electricity generated other than in waste or fossil fuel powered thermal stations. The terms includes renewables like hydro, wind, and also nuclear. In the tables, the figures entered in the supply sections are the ***equivalent thermal input*** i.e. the figures represent those that would have been required had the energy been produced by normal thermal generation. These thus represent grossly inflated figures of the electricity actually generated by these means.

10.5.1. Efficiency of Electricity Conversion

We need to first evaluate the efficiency of electricity conversion, and this may be done by looking at the second line C in Table 18.1 or the two shaded figures in the * line below line C in Table 18.2. These indicate that a total of **1343.8 PJ** of electricity were generated, while thermodynamic and other losses in generation amounted to **1979.3 PJ (Table 18.2).**

Thus the efficiency of conversion = 1343.8 / (1343.8 + 1979.3) * 100 = 40.44%.

While the efficiency represents a significant improvement over the 34.9% in 1991 and has been achieved primarily through the use of more gas fired electricity generation in Combined Cycle Gas Turbine (CCGT) stations associated with the so-called "dash for gas".

We can estimate thus estimate the true amount of electricity generated as primary nuclear electricity. We know that **498.6 PJ** was the net input of primary electricity equivalent. The actual amount entered as primary energy depends on the thermal efficiency of the nuclear power plants. In some countries this is a fixed value usually around 30%. In the uK this is the actual nuclear efficiency in the year in question which from Table 5.10 in DUKES(2009) is **37.894%** (note in the spreadsheet it is possible to increase the precision of that declared in the PDF version). Thus the actual amount generated in 2008 was and at an efficiency of 37.894% this represents and actual generation of **188.94 PJ** representing 14.1% of electricity supply compared to a figure around 27% in 1998 and 19.3% in 2006. This proportion will fall further over the next decade irrespective of what decisions are made on nuclear power.

We note that we have 1343.8 PJ of electricity generated However we also note that 58.7 PJ (column 9 in line below line D) are used in the stations themselves.

This represent a station use of 58.7/1343.8 * 100 = 4.37% compared to 4.5% in 2000 and 4.8% in 2006. The decreased percentage in 2008 is consistent with a higher use of gas in 2008 compared to 2006 as in these stations there is no requirement for activities such as grinding coal.

Finally we note that losses in electricity transmission amount to 98.7 PJ and so we can estimate transmission losses as 9.87 / (1343.8 – 58.7) * 100 = 7.68%, an improvement on 2000 when it was nearly 1% higher.

10.5.2. Overall efficiency of energy conversion and transmission

We may deduce the Overall efficiency of Supply of energy in the UK by noting that the total supply of energy is **9815.5PJ** while the net amount of energy available is **6907.1PJ PJ** i.e there is a (9815.5 – 6907.1)/9815.5*100 = **29.57%** loss in energy through conversion, compared to 29.5% in 2000, and **30.48%** in 2006. Much of the losses here could be minimised if city wide Combined Heat and Power was common as it is in Denmark, Russia etc. .

10.5.3 Primary Energy ratio for Electricity

From the electricity generation line below line C in the full table the total electricity generated = **1343.8** PJ with **1979.3** PJ losses. The total input is thus **1343.8 + 1979.3 = 3323.1 PJ**

The total losses associated with electricity generation are the transmission losses at **98.7 PJ**, the industry's own use at **58.7 PJ** and the **4.6PJ** electricity lost in pumped storage making a total loss of **162.1PJ.**

In attempting to estimate the Primary Energy Ratio (PER) of Electricity as it is supplied to the point of end use, it is noted that we have inputs from coal, oil, and gas, all of which have Primary Energy Ratios of their own. To begin with we shall ignore the overheads in extracting these fossil fuels (i.e. we shall assume a PER of 1.00) and will return to them later.

A very first approximation of the overall Primary Energy Ratio for electricity as it is delivered to the point of use is thus = 3323.1 / (1343.8 – 162.1) = **2.812**

This is our very approximate initial estimate, and we shall need to return to this later, but it does give us a basis on which to estimate the PER of other fuels.

10.5.4 Primary Energy Ratios for Oil and Gas

Approximate values for the Primary Energy Ratio for Oil, Gas and Coal may be obtained from an Energy Balance Table, but assuming this initial approximate PER for electricity of 2.81 we can refine the estimates of the PER for coal, oil and gas.

Thus in oil and gas extraction **220.7 PJ (full Energy Balance Table)** of gas are consumed. In addition, **2.2 PJ** of electricity are used, but since the primary energy ratio of electricity is **~2.81**, this in reality represents **6.18 PJ**. [as indicated above we don't know that **2.81** is the true value but we need an approximate value to proceed]. Also, strictly speaking as with the case of electricity above, we should also apply the Primary Energy Ratio to Oil and Gas, but at this stage we do not know the values and will assume that initially they are 1.00. In any case, the errors in these figures will be relatively small. Ideally we would estimate the PER by this method and then iterate to obtain more accurate values, but the full details of this are beyond this Module although values derived using such an iterative procedure are shown below.

Overall energy consumed in gas and oil production s represents **226.88 PJ (this is 220.7 + 6.18).**

We need now to make an apportion of this energy requirement between gas and oil. To do this we must make an assumption. Sometimes apportionment is done on economic value, sometimes on a mass or volume basis, and sometimes on an energy basis. In this case, it makes sense to use energy extracted as the basis of apportionment. A total of **3290.0 PJ** of oil and **2917.01 PJ** of gas are extracted i.e. oil represents **53.0%** of the energy extracted and thus we can attribute **0.530 * 226.88 PJ** or **120.3 PJ** to oil extraction.

In the Oil Refineries we use **200.0 + 6.8 PJ** of oil and gas respectively and **18.4PJ** electricity equivalent **to 51.7 PJ gross [i.e. 18.4 *2.81]**. This represents a total of **258.5 PJ**. In addition there is a loss of 11.1PJ [3688.5-3677.4] converting crude oil into petroleum products. The total losses thus amount to **269.6 PJ.**

Combining both the extraction energy and that used in the refineries gives **389.9PJ**. Noting that the total oil supply is **3829.0 PJ** the primary energy overhead for oil, to a first approximation is **10.2%** corresponding to a Primary Energy Ratio of **1.10.**

The analysis is strictly a little more complex, as in the above we have attributed the extraction energy to both the indigenous supply and imports, but since there is not too much difference in imports and exports, this approximation only affects the results a little. Strictly speaking we should account for the extraction and transportation energy for each country from which we import, but that then becomes a near impossible task. In addition the oil used in the refineries should have the PER included, and an iterative procedure is needed to get a more accurate value. While this is an approximate value it does demonstrate how such figures are derived. For a more detailed analysis it is necessary to consult more detailed tables in DUKES.

However, based on the 2008 data the PER derived iteratively for each UK fuel is as follows

Fuel	Primary Energy Ratio
Coal	1.0227
Oil	1.1292
Gas	1.062
Electricity	2.911

The following two tables show the simplified and full Energy Balance Table for the Uk in 2008. The data are produced annually in around July/August and refer to the 12 month period ending on 31st December of the previous year. For comparison, these tables are followed by the corresponding one from DUKES (2007).

Note: all values have been converted to PetaJoules from the original values quoted using the standard International Conversion factor of 1 tonne of oil equivalent = 41.868 GJ

Simplified Aggregate Energy Balance 2008 - derived from Table 1.1 of Dukes (2009)

Annotated for use in NBS-M016 and NBS-LM01E PetaJoules (PJ)

	Coal	Manufactured fuel*(1)*	Primary oils	Petroleum products	Natural gas*(2)*	Renewable & waste*(3)*	Primary electricity	Electricity	Heat	Total		
UK Production	475.7	-	3,290.0	-	2,917.0	182.6	542.8	-	-	**7,408.1**		
Net imports	1,087.3	22.0	544.6	-331.5	1,009.5	39.7	-	35.9	-	**2,407.4**		
Net Energy Available	1,563.0	22.0	3,834.6	-331.5	3,926.5	222.3	542.8	35.9	-	**9,815.5**	**A**	
Transfers	-	-5.3	-146.1	146.3	-0.2	-	-44.2	44.2	-	**-5.3**	**B**	
Net Consumption	**1,563.0**	**16.7**	**3,688.5**	**-185.2**	**3,926.3**	**222.3**	**498.6**	**80.1**	**-**	**9,810.2**	**A***	**A + B**
Energy Conversion												
inputs	-1,488.5		-3,688.5		-1,430.1	-148.1	-498.6			-	**C**	
outputs		69.9		3,624.4				1,343.8	53.6	-		
net energy balance	-	-	-	-	-	-	-	-	-	**-2,162.0**		
Energy Industry Use	0.2	35.6	-	200.0	249.1	-	-	95.6	3.0	**583.4**	**D**	
Transmission losses	-	9.9	-	-	49.1	-	-	98.7	-	**157.7**	**E**	
Delivered Energy Available	**74.4**	**41.1**	**-**	**3,239.2**	**2,198.0**	**74.2**	**-**	**1,229.6**	**50.6**	**6,907.1**	**F**	
Balance Check	**74.4**	**41.1**	**-**	**3,239.2**	**2,198.0**	**74.2**	**-**	**1,229.6**	**50.6**	**6,907.1**		**A* + C - D - E**
Energy Demand												
INDUSTRY	52.2	31.1	-	266.3	477.0	14.1	-	408.8	32.4	1,281.8	**G**	
TRANSPORT	-	-	-	2,397.7	-	34.4	-	30.4	-	2,462.4	**H**	
OTHER	22.1	10.0	-	186.5	1,687.6	25.7	-	790.5	18.3	2,740.7	**I**	
Final Consumption (Energy only	**74.4**	**41.1**	**-**	**2,850.5**	**2,164.6**	**74.2**	**-**	**1,229.6**	**50.6**	**6,485.0**	**J**	**G + H +_ I**
Non-Energy use	**-**	**-**	**-**	**388.7**	**33.3**	**-0.1**	**-**	**-0.1**	**-**	**422.1**	**K**	**F - J**

Note: This Balance Table for the UK is a simplified version of that shown in the following Table.

UK Energy Balance Table - Annotated for NBS-M016/LM01E Derived from DUKES 2009 Table 1.1

PetaJoules	**Coal**	**Manufactured fuel***(1)*	**Primary oils**	**Petroleum products**	**Natural gas***(2)*	**Renewable & waste***(3)*	**Primary electricity**	**Electricity**	**Heat**	**Total**	
Supply											
Indigenous production	475.7	-	3,290.0	-	2,917.0	182.6	542.8	-	-	7,408.1	
Imports	1,189.8	21.0	2,747.0	1,091.6	1,465.4	39.7	-	44.3	-	6,598.7	
Exports	-19.1	-6.0	-2,218.7	-1,311.8	-441.6	-	-	-4.6	-	-4,001.8	
Marine bunkers	-	-	-	-114.4	-	-	-	-	-	-114.4	
Stock change*(4)*	-90.1	6.5	10.7	0.5	-11.1	-	-	-	-	-83.5	
Primary supply	**1,556.2**	**21.5**	**3,829.0**	**-334.2**	**3,929.7**	**222.3**	**542.8**	**39.7**	**-**	**9,807.1**	
Statistical difference*(5)*	-6.7	-0.4	-5.5	-2.6	3.2	-	-	3.8	-	-8.4	
Primary demand	**1,563.0**	**22.0**	**3,834.6**	**-331.5**	**3,926.5**	**222.3**	**542.8**	**35.9**	**-**	**9,815.5**	**A**
Transfers	-	-5.3	-146.1	146.3	-0.2	-	-44.2	44.2	-	-5.3	**B**
Transformation [Energy Conversion]	**-1,488.5**	**69.9**	**-3,688.5**	**3,624.4**	**-1,430.1**	**-148.1**	**-498.6**	**1343.8**	**53.6**	**-2,162.0**	**C**
Electricity generation	-1,252.3	-35.9	-	-41.4	-1,346.7	-148.1	-498.6	1,343.8	-	-1,979.3	*
Major power producers	-1,213.7	-	-	-16.2	-1,227.8	-31.4	-498.6	1,229.8	-	-1,757.9	
Autogenerators	-38.6	-35.9	-	-25.2	-118.9	-116.7	-	114.0	-	-221.4	
Heat generation	-11.9	-2.2	-	-2.5	-83.4	-	-	-	53.6	-46.4	*
Petroleum refineries	-	-	-3,688.5	3,677.4	-	-	-	-	-	-11.1	*
Coke manufacture	-179.2	170.1	-	-	-	-	-	-	-	-9.1	*
Blast furnaces	-35.7	-71.9	-	-9.1	-	-	-	-	-	-116.7	*
Patent fuel manufacture	-9.3	9.8	-	-	-	-	-	-	-	0.5	*
Other	-	-	-	-	-	-	-	-	-	-	*
Energy industry use	**0.2**	**35.6**	**-**	**200.0**	**249.1**	**-**	**-**	**95.6**	**3.0**	**583.4**	**D**
Electricity generation	-	-	-	-	-	-	-	58.7	-	58.7	+
Oil and gas extraction	-	-	-	-	220.7	-	-	2.2	-	222.8	+
Petroleum refineries	-	-	-	200.0	6.8	-	-	18.4	3.0	228.2	+
Coal extraction	0.2	-	-	-	0.3	-	-	3.5	-	4.0	+
Coke manufacture	-	18.0	-	-	-	-	-	0.3	-	18.3	+
Blast furnaces	-	17.6	-	-	2.6	-	-	1.6	-	21.8	+
Patent fuel manufacture	-	-	-	-	-	-	-	-	-	-	+
Pumped storage	-	-	-	-	-	-	-	4.6	-	4.6	+
Other	-	-	-	-	18.7	-	-	6.2	-	25.0	+
Losses	**-**	**9.9**	**-**	**-**	**49.1**	**-**	**-**	**98.7**	**-**	**157.7**	**E**
Final consumption	**74.4**	**41.1**	**-**	**3,239.2**	**2,198.0**	**74.2**	**-**	**1,229.6**	**50.6**	**6,907.1**	**F**
Industry	**52.2**	**31.1**	**-**	**266.3**	**477.0**	**14.1**	**-**	**408.8**	**32.4**	**1,281.8**	**G**
Unclassified	-	9.9	-	101.6	0.1	14.1	-	-	-	125.7	
Iron and steel	0.0	21.2	-	0.5	24.5	-	-	17.5	-	63.8	
Non-ferrous metals	0.8	-	-	2.0	11.9	-	-	25.5	-	40.2	
Mineral products	31.8	-	-	7.3	39.9	-	-	27.9	-	106.9	
Chemicals	3.8	-	-	7.4	129.5	-	-	76.1	15.1	231.9	
Mechanical engineering etc	0.4	-	-	4.1	27.8	-	-	29.8	0.1	62.3	
Electrical engineering etc	0.2	-	-	2.0	14.0	-	-	25.1	-	41.3	
Vehicles	1.4	-	-	4.9	31.1	-	-	20.1	-	57.5	
Food, beverages etc	1.2	-	-	11.8	93.3	-	-	44.0	0.1	150.4	
Textiles, leather etc	2.2	-	-	4.4	22.0	-	-	11.5	-	40.0	
Paper, printing etc	4.4	-	-	2.7	38.4	-	-	47.6	0.1	93.2	
Other industries	5.9	-	-	111.2	35.1	-	-	78.2	17.0	247.4	
Construction	-	-	-	6.7	9.3	-	-	5.4	-	21.4	
Transport ***(6)***	**-**	**-**	**-**	**2,397.7**	**-**	**34.4**	**-**	**30.4**	**-**	**2,462.4**	**H**
Air	-	-	-	562.1	-	-	-	-	-	562.1	
Rail	-	-	-	31.3	-	-	-	30.4	-	61.6	
Road	-	-	-	1,730.5	-	34.4	-	-	-	1,764.8	
National navigation	-	-	-	73.9	-	-	-	-	-	73.9	
Pipelines	-	-	-	-	-	-	-	-	-	-	
Other	**22.1**	**10.0**	**-**	**186.5**	**1,687.**	**25.7**	**-**	**790.5**	**18.3**	**2,740.7**	**I**
Domestic	21.6	10.0	-	127.0	1,307.	18.0	-	424.2	2.2	1,910.9	
Public	0.2	-	-	19.8	170.2	4.2	-	79.6	15.7	289.7	
Commercial	0.2	-	-	16.8	136.6	0.5	-	272.0	0.4	426.5	
Agriculture	0.1	-	-	12.8	7.8	3.1	-	14.6	-	38.4	
Miscellaneous	-	-	-	10.2	65.0	-	-	-	-	75.2	
Final consumption	**74**	**41**	**-**	**3,239**	**2,198**	**74**	**-**	**1,230**	**51**	**6,907**	**J**
Non energy use											**K**

Calorific Values used 1 tonne oil equivalent = 41.87 GJ

The following two Tables show the corresponding data for 2006 base on DUKES (2007)

Simplified Aggregate Energy Balance 2006 - derived from Table 1.1 of Dukes (2007) – for comparison purposes

Specifically Annotated for use in ENV-M558 **Peta Joules (PJ)**

	Coal	**Manufactured fuel***(1)*	**Primary oils**	**Petroleum products**	**Natural gas***(2)*	**Renewable & waste***(3)*	**Primary electricity**	**Electricity**	**Heat**	**Total**		
UK Production	476.3	-	3,515.3	-	3,350.1	149.9	742.9	-	-	**8,234.5**		
Net imports	1322.5	17.6	407.5	-234.8	419.8	20.8	-	26.8	0.0	**1980.2**		
Net Energy Available	1798.8	17.6	3922.9	-234.8	3770.0	170.7	742.9	26.8	0.0	**10214.7**	**A**	
Transfers	-	-4.4	-118.7	120.1	-0.2	-	-31.8	31.8	-	**-3.1**	**B**	
Net Consumption	**1798.8**	**13.2**	**3804.2**	**-114.7**	**3769.8**	**170.7**	**711.0**	**58.6**	**0.0**	**10211.6**	**A***	**A + B**
Energy Conversion												
inputs	-1732.9		-3804.2		-1197.1	-145.4	-711.0				**C**	
outputs		75.4		3758.6				1388.4	56.4			
net energy balance										**-2311.9**		
Energy Industry Use	0.1	36.5	-	208.8	286.3	-	-	101.6	3.0	**636.3**	**D**	
transmission losses	-	7.4	-	-	43.2	-	-	111.3	-	**162.0**	**E**	
Delivered Energy Available	**65.8**	**44.7**	**-**	**3,435.2**	**2,243.1**	**25.3**	**-**	**1,234.1**	**53.4**	**7,101.4**	**F**	
Balance Check	65.8	44.7	-	3435.2	2243.1	25.3	-	1234.1	53.4	**7101.4**		**A* + C - D - E**
Energy Demand												
INDUSTRY	47.7	35.4	-	302.3	517.6	6.7	-	418.7	35.0	**1,363.3**	**G**	
TRANSPORT	-	-	-	2,472.3	-	-	-	30.7	-	**2,503.0**	**H**	
OTHER	18.1	9.3	-	200.1	1,691.3	18.6	-	784.7	18.3	**2,740.4**	**I**	
Final Consumption (Energy only	**65.8**	**44.7**	**-**	**2,974.7**	**2,208.9**	**25.3**	**-**	**1,234.1**	**53.4**	**6,606.7**	**J**	**G + H +_ I**
Non-Energy use	**-**	**-0.1**	**-**	**460.4**	**34.2**	**-0.1**	**-**	**-**	**-**	**494.6**	**K**	**F - J**

Energy Balance Table for UK 2006 for comparison

Derived from DUKES 2007 Table 1.1

	Coal	Manuf-actured fuel*(1)*	Primary oils	Petroleum products	Natural gas*(2)*	Renewable & waste*(3)*	Primary electricity	Elect-ricity	Heat	Total	
Supply											
Indigenous production	476.3	-	3,515.3	-	3,350.1	149.9	742.9	-	-	8,234.5	
Imports	1,365.7	28.6	2,716.2	1,228.2	878.5	20.8	-	37.0	-	6,275.0	
Exports	-14.3	-5.0	-2,297.6	-1,317.8	-434.1	-	-	-10.0	-	-4,078.9	
Marine bunkers	-	-	-	-104.1	-	-	-	-	-	-104.1	
Stock change*(4)*	-34.1	-6.4	-16.4	-38.4	-23.2	-	-	-	-	-118.4	
Primary supply	**1,793.6**	**17.2**	**3,917.5**	**-232.1**	**3,771.4**	**170.7**	**742.9**	**27.1**	**-**	**10,208.2**	
Statistical difference*(5)*	-5.2	-0.4	-5.3	2.7	1.4	-	-	0.3	-	-6.5	
Primary demand	**1,798.8**	**17.6**	**3,922.9**	**-234.8**	**3,770.0**	**170.7**	**742.9**	**26.8**	**-**	**10,214.7**	**A**
Transfers	-	-4.4	-118.7	120.1	-0.2	-	-31.8	31.8	-	-3.1	**B**
Transformation [Energy Conversion]	**-1,732.9**	**75.4**	**-3,804.2**	**3,758.6**	**-1,197.1**	**-145.4**	**-711.0**	**1,388.4**	**56.4**	**-2,311.9**	**C**
Electricity generation	-1,497.9	-40.5	-	-29.0	-1,117.3	-145.4	-711.0	1,388.4	-	-2,152.8	*
Major power producers	-1,460.0	-	-	-11.6	-1,001.3	-30.5	-711.0	1,274.7	-	-1,939.7	
Autogenerators	-37.9	-40.5	-	-17.4	-116.0	-114.9	-	113.6	-	-213.1	
Heat generation	-12.1	-2.2	-	-2.6	-79.8	-	-	-	56.4	-40.2	*
Petroleum refineries	-	-	-3,804.2	3,800.1	-	-	-	-	-	-4.0	*
Coke manufacture	-180.7	179.3	-	-	-	-	-	-	-	-1.4	*
Blast furnaces	-34.2	-69.7	-	-10.0	-	-	-	-	-	-113.9	*
Patent fuel manufacture	-8.1	8.5	-	-	-	-	-	-	-	0.3	*
Other	-	-	-	-	-	-	-	-	-	-	*
Energy industry use	**0.1**	**36.5**	**-**	**208.8**	**286.3**	**-**	**-**	**101.6**	**3.0**	**636.3**	**D**
Electricity generation	-	-	-	-	-	-	-	66.8	-	66.9	+
Oil and gas extraction	-	-	-	-	249.3	-	-	2.0	-	251.3	+
Petroleum refineries	-	-	-	208.8	9.3	-	-	15.9	3.0	237.0	+
Coal extraction	0.1	-	-	-	0.4	-	-	3.7	-	4.3	+
Coke manufacture	-	17.3	-	-	1.0	-	-	0.4	-	18.7	+
Blast furnaces	-	19.1	-	-	2.2	-	-	1.9	-	23.2	+
Patent fuel manufacture	-	-	-	-	-	-	-	-	-	-	+
Pumped storage	-	-	-	-	-	-	-	3.8	-	3.8	+
Other	-	-	-	-	24.2	-	-	7.1	-	31.3	+
Losses	**-**	**7.4**	**-**	**-**	**43.2**	**-**	**-**	**111.3**	**-**	**162.0**	**E**
Final consumption	**65.8**	**44.7**	**-**	**3,435.2**	**2,243.1**	**25.3**	**-**	**1,234.1**	**53.4**	**7,101.4**	**F**
Industry	**47.7**	**35.4**	**-**	**302.3**	**517.6**	**6.7**	**-**	**418.7**	**35.0**	**1,363.3**	**G**
Unclassified	-	9.5	-	126.4	0.2	6.7	-	-	-	142.7	
Iron and steel	-	25.9	-	0.8	29.4	-	-	21.1	-	77.2	
Non-ferrous metals	1.0	-	-	2.2	11.5	-	-	27.7	-	42.4	
Mineral products	28.9	-	-	8.4	44.0	-	-	28.7	-	110.0	
Chemicals	3.7	-	-	8.1	141.2	-	-	74.8	17.0	244.8	
Mech; engineering etc	0.4	-	-	4.4	30.6	-	-	30.8	0.1	66.4	
Electrical engineering etc	0.2	-	-	3.5	15.0	-	-	26.4	-	45.1	
Vehicles	1.5	-	-	5.2	33.4	-	-	21.0	-	61.1	
Food, beverages etc	0.7	-	-	11.8	99.4	-	-	44.0	0.0	155.9	
Textiles, leather etc	2.1	-	-	5.5	23.3	-	-	12.5	-	43.4	
Paper, printing etc	4.1	-	-	2.5	42.6	-	-	48.6	0.9	98.8	
Other industries	5.0	-	-	116.2	37.8	-	-	77.2	16.9	253.1	
Construction	-	-	-	7.3	9.2	-	-	5.9	-	22.4	
Transport *(6)*	**-**	**-**	**-**	**2,472.3**	**-**	**-**	**-**	**30.7**	**-**	**2,503.0**	**H**
Air	-	-	-	586.1	-	-	-	-	-	586.1	
Rail	-	-	-	30.4	-	-	-	-	-	30.4	
Road	-	-	-	1,779.9	-	-	-	-	-	1,779.9	
National navigation	-	-	-	75.9	-	-	-	-	-	75.9	
Pipelines	-	-	-	-	-	-	-	-	-	-	
Other	**18.1**	**9.3**	**-**	**200.1**	**1,691.3**	**18.6**	**-**	**784.7**	**18.3**	**2,740.4**	**I**
Domestic	17.4	9.3	-	136.1	1,312.5	11.0	-	419.2	2.2	1,907.7	
Public administration	0.3	-	-	20.5	175.9	3.7	-	79.2	15.8	295.3	
Commercial	0.2	-	-	16.5	123.4	-	-	271.4	0.3	411.7	
Agriculture	0.1	-	-	12.8	7.2	3.1	-	14.9	-	38.2	
Miscellaneous	0.1	-	-	14.2	72.3	0.8	-	-	-	87.5	
Final consumption	**66**	**45**	**-**	**3,435**	**2,243**	**25**	**-**	**1,234**	**53**	**7,101**	**J**
Non energy use	**-**	**-**	**-**	**460.5**	**34.2**	**-**	**-**	**-**	**-**	**494.7**	**K**

Calorific Values used 1 tonne oil equivalent = 41.87 GJ

NBS-M016 /NBSLM01E 2010

Points for Discussion

The following are some questions/statements which it is hoped will promote discussion in small groups. The questions and statements are all related to Energy or related matters, and the intention behind this is to promote awareness and to assess what is known already by students taking the course. Some of the questions are relatively easy and require just a few words to answer. Others need some thought.

Answers to these questions will be posted on the WEB after the session.

---

1 When cooking vegetables on a stove. How much energy (as a percentage) is saved by putting a lid on the saucepan.?

2. What are the major sources of heat loss from a house? List the conservation measures which should be adopted in order of effectiveness, and also cost? What measures would you take to improve the energy efficiency of your home?

3. How important is insulation to the fabric of a building in a warm climate compared to that in a cold climate?

3. By time switching the heating in a house so that it is off from 11pm until 7am the next morning, a saving of one third in energy will be possible. Is this correct? What disadvantages are there from time switching ?

4.
Either

a) It is often argued that with a well insulated hot water tank it does not matter if the heating source is left on. In what circumstances is this statement correct, and in what circumstances is it not?

Or

b) A well insulated house will save proportionally less energy than a poorly insulated one when the heating is time switched. Is this statement correct?

5. What problems does the Electricity Supply Industry in the UK have in meeting the targets set for CO_2 and SO_2 emissions? Does it make sense to fit Flue Gas Desulphurisation plant onto our coal or oil fired plant?

6. Fluorescent lights use as much energy when switched on as they do in running for 15 minutes [some people say 30 minutes] or is this a myth?. What evidence can you use to confirm this or otherwise..

7. If we effective in promoting Energy Conservation in the UK then we will obviate the need for between 2 and 5 large power stations. Is this necessarily correct? Under what circumstances would it not be?

8.
Either

a) Aiding those on Low Income to insulate their homes will provide significant savings in costs to those involved, and will also save substantial amounts of energy for the country as a whole.

Or

b) The Government should target Energy Conservation schemes which are the most effective in reducing the demand for Energy.

9. You return home to your house at 16:30 to find the house feeling cold. (you have time-switched the heating to come on at 16:00). Which of the following would you do?:-
   a) turn up the room thermostat;
   b) turn up the boiler thermostat;
   c) reset the time clock;
   d) nothing; set an alarm!

   Explain your answer

10. The radiators in your room is fitted with thermostatic valves. The room is only just OK with regard to temperature, but the radiator feels very cold. What would you do, adjust the valve or leave it as it is?

Space for notes.