LECTURE- ALTERNATIVE RESOURCES:TIDAL POWER

We have already seen that $S_\infty = 0.1Q$/year and so tidal power cannot contribute on a global scale.

Tidal power is negligible over the open sea and remains insignificant along most coastlines.

However it may contribute locally in suitable estuaries where tidal flow velocity can be substantial e.g. small tidal barrier at La Rance (240 MW).

In the best cases such as the Bay of Fundy/Bristol Channel/Severn Estuary the shape of the coast leads to resonance at or near the tidal frequency. This gives much larger tidal amplitudes (up to 40 m in the Bay of Fundy), re: Severn Bore.

This makes it possible to utilise the rising and falling tidal water by forcing it through turbines. A design study for the Bristol Channel has been estimated to produce 1400 MW.

However there are perhaps only 20 or 30 such estuaries worldwide, giving a global figure of 25GW or 8×10^{-4} Q/year.

Environmental problems need to be overcome; proposers of schemes failed to do this so far.

TIDAL POWER 2

Statistics for tidal power

Comparison of world tidal schemes:

	Completed	Tidal range	Capacity	Basin Area
La Rance, France	1966	8.0m	240MW	17 sq. km
Kislaya Guba, Russia	1968	2.4m	0.4MW	2 sq. km
Jiangia, China	1980	7.1m	3.2MW	2 sq. km
Annapolis, China	1984	6.4m	17.8MW	6 sq.km
8 others in China	1961-89	1.2-3.5m	-	-
The Severn barrage	Proposal	7.0m	8,640MW	520 sq. km
Gulf of Cambay, India	Proposal	7.0m	7,000MW	1,970 sq. km
Turnagain Arm, USA	Proposal	7.5m	6,500MW	-
Mezen, Russia	Proposal	9.1m	15,000MW	2,300 sq. km

Tidal potential in the UK:

Number of schemes proposed	34 small, 8 large
Range of generating capabilities	9MW-8,640MW
Total potential for tidal electricity in UK	50TWh per year
Total generated by all sources in 1993	300TWh
Tidal potential as percentage	17%

GEOTHERMAL ENERGY

The total flowing out from the interior of the Earth is about 1Q/year.

However this corresponds to an average/area of 60kW/m^2 – small, not viable.

Two possible ways of extracting useful energy:

1) "Hot spots" - Here flow of heat is unusually large, usually associated with volcanic areas.

   Some places have already been exploited in this way. The world's first geothermal power station is at Lardarello in Italy. It was developed in 1904 and now yields 400 MW of electrical power.

   The total installed around the world is ~ 4 GW including California, Iceland and New Zealand. (~10^{-4} Q/year and could possible increase by about a factor of 10).

2) "Hot dry rock" – Water is forced through shattered rock between two boreholes drilled into the rock strata at a few km depth.

   It returns to the surface at about 200-300 °C and is used to drive turbines.

   However experiments on this process have not yielded results. The rock strata proved to be more porous than expected and the water T fell much quicker than expected. No current experiments and therefore no projected resource estimate.

SOLAR POWER

Solar power is the largest environmental source.

Net input from the Sun is 3000 Q/year so the possibilities are great.

Now to make a useable “top down” estimate: area of world = A

If we assume that the land area of the world = 0.3A

Land used for growing food must be given a priority, given 50% of the world’s land area useless for either solar power generation or food production, suggest that only 5% remaining area could be given over to solar power generation so:

0.0075A

If the maximum efficiency of conversion to electrical power = 0.2

The total amount of incoming solar energy that is useable = 0.00153 x 3000 = 4.5 Q/year

If the radius of the Earth = 6360 km then the power density ~ 19 MW/km^2

Assuming that only 50% of the collection is effectively used.

This is significantly better than most other environmental energy sources and has been nearly achieved by a 7 MW demonstration plant in California.

SOLAR POWER 2

A “bottom-up” estimate is not possible at the moment as all proposed systems are too expensive for significant use (although costs are coming down quickly).

As a result no engineering estimates have been made of the total potential of the harvest, including weather, climate, seasons etc. not accounted for in the “top-down” estimate.

At the moment we should look at 0.5 Q/year as being attainable.

The present installed capacity is around 700 MW, half of which is in California.

However new technology is being tried in Australia and using these new approaches may increase yields considerably.

We will return to these approaches in the next lecture.

It must be stressed again that once we depend on a resource such as solar power for a substantial fraction of our energy then some form of storage becomes essential.

SOLAR POWER 3

An alternative way of collecting solar power is the use of **Biomass**.

Here we are effectively using the natural process of photosynthesis to convert solar energy to fuel.

A “top-down” estimate is obtained from total figure for photosynthesis of 1.3 Q/year, covering the entire biosphere.

However, we use about 40% of this for food.

As food is the priority we shouldn’t expect to use more than ~10% of the total productivity or around 0.13 Q/year.

The year round solar flux is 150 W/m^2 or 150 MW/km^2.

Fast growing plants which convert this energy efficiently fix about 1% of this as plant material. If we convert this to fuel at 25% efficiency then we get an output of 0.4 W/m^2.

In Brazil, energy from sugar cane has been retrieved at these kinds of rates and even better results are claimed for cassava root, a widespread tropical food.

Extrapolating to the US and supposing 10% of land available we get 10^{19}J/yr or 0.01 Q/y. For the world we get 0.17 Q/year, roughly in agreement with the previous estimate.

ALTERNATIVE SOURCES IN THE UK

Estimates of the potential yield of such sources in the UK:

	Potential Yield (S_2) TWh/y
Wind (probably including offshore sites)	230
Waves	60
Tidal	45
(of which the Severn Bridge would give	13)
Hydropower sites not yet developed	2
Waste material (treatment to yield oil/gas or direct incineration)	150
TOTAL	**487**

For comparison a continuously running 1GW power station delivers 9 TWh/y

The total power generated in the UK in 1975 was 210 TWh.

We are well placed for several of these sources, although not for solar power or hydropower.

ALTERNATIVE SOURCES IN THE UK 2

The potential yield from environmental resources exceeds the electric power generation in 1975 by over a factor of 2.

If we exploit these resources to the full we would manage to:

- replace all fossil fuel used in electricity generation: 900 TWh/year.

- Provide an **additional** 277 TWh/year to be converted to electrical power.

- if this additional energy is used to replace fossil fuel based heating at 75% efficiency then we can reduce the fossil fuel burden by a further 370 TWh/year.

-we can then reduce the total fossil fuel demand by 1270 TWh/year.

If we use a total of 2500 TWh/year then we reduce the total burden to 1230 TWh/year.

This would be very significant in terms of the required reduction in our contribution to the total CO_2 burden.

However it is not sufficient to replace coal and gas as the residual figure is larger than the 1975 contribution from coal. Coal contribution to UK energy production is much less now than in 1975 (it has fallen to only 300 TWh/year).

SUMMARY OF ALTERNATIVE RESOURCES

All power units in Q/year			Present Installed Capacity	Estimated Maximum Potential	Natural Energy Flow
	Power Density MW/km^2		S_1	S_2	S_∞
Hydropower	n/a		0.01	0.1	1.3
Wind	1-10		Small	0.2	12
Waves	20		V. Small	0.02	0.2
Tides	n/a		Small	10^{-3}	0.1
Geothermal	n/a		10^{-4}	10^{-3}	1
Solar	1.5		Small	4.5?	900 (land only)
Biomass	0.4		?	0.15	1.3
TOTAL			**0.01**	**~5**	**~916**

END OF SECTION – THE STORY SO FAR

We said that the end of a period of world population growth we would be using 5 Q/y

It would take us to the year 2080 or so to reach stability in population/energy use.

Oil and Gas Resources are finite and small.
These items are likely to be exhausted before the steady state is reached.

Coal Resources are more plentiful**.**
However, its use restricted because of “climate change” fears of increasing CO_2 source strength.

Nuclear Power comparatively large
The resources are likely to last through this “planning period” of change.

Except for **Solar Power** all the alternative sources are individually small and the sum total is, in the case of the UK, significant but not sufficient.

We will now look at the implications for energy consumption in Section III.

FUTURE IMPLICATIONS

A large fraction, although not all, of our energy is used in generating electrical power.

If we have to change our energy source the simplest substitution to make is to utilise sources that can be used in the same way.

If we consider global sources, but omit solar power for the moment, the S_2 total ~ 0.5 Q/y

This is about 10% of the projected demand..

However we have so far taken no account of the way the energy was provided/delivered.

We are faced with two constraints on our way to a 5 Q/year steady energy use by 2080.

1) The expiry of plentiful oil and gas resources
2) Increased pressure on “greenhouse gas” emissions.

We will need to exploit our alternative resources to their fullest extent.

THE GOOD NEWS

0.5 Q/year will replace existing uses of electrical power and so would displace 1.5 Q/year of fossil fuels currently used (30% efficiency of fossil fuel to electrical power)

FUTURE IMPLICATIONS 2

THE BAD NEWS

That is not enough. We will need to replace all the fossil fuel.

Coal will remain available but its use should be kept to a minimum because of climate change impacts.

This level should be no greater than the current level of fossil fuel use ~ total energy consumption ~ 0.4Q.

If we reserve coal for special applications only then l;et us say we will use it at 0.25Q/year.

The alternatives are **SOLAR, FISSION** and **FUSION** and we have 3.25 Q/year to find.

In practise using these sources means that most of our energy will come from large central facilities.

These may not necessarily be electricity producing but some transformation must take place to provide an energy source in a more transportable form. It is unlikely that any such system would operate with an efficiency greater than that of an electric power station**.**

See: hydrogen supply via pipelines

Exception: home solar heating - maintenance

FUTURE IMPLICATIONS 3

So we face the prospect of a complete change in the way energy is delivered.

Currently: the bulk of energy is delivered as fuel and is burnt at the point of use.

Future: the bulk may have to come from central power stations

-This will require a massive investment program.

However it will also require a change in the total energy demand.

The extreme case is the **All Electric Economy** (AEE)

Efficiencies:

	Present	**AEE**	**Factor Increase in Fuel Demand**
Fuel burnt at point of use:	75-80 %	50%	2
Transport	25%	16%	1.56

For AEE transport: most forms of transport will require some form of on board storage. The storage, extraction and use all add their contribution to the overall efficiency.

Batteries: charging and discharging both 75% efficient and motors also 75% efficient,

Overall efficiency 40% but 40% efficiency in generation so ~16% total.

FUTURE IMPLICATIONS 4

Returning to the US economy:

SECTOR	**Direct Fuel Supply**	**Present Efficiency**	**Useful Work**	**Efficiency in AEE**	**Primary Energy Demand in AEE**
Household & Commercial	12.9	75 %	9.7	40 %	24.1
Transport	16.3	25 %	4.1	16 %	25.6
Industrial	18.4	75 %	13.8	40 %	34.5
Total	47.6		27.6		84.2
Electric	17.0	31 %	5.2	40 %	13.0
TOTAL	**64.6**		**32.8**		97.2

Assumes that because of larger electricity generating utilities efficiency increases

Even so, the primary fuel demand rises by about 50 % for the same amount of work or put another way the waste heat rejected into the environment doubles.

FUTURE IMPLICATIONS 5

So where does this leave us?

Clearly we can fine tune the calculation but nevertheless we are in no doubt that large central stations are bad news for attempts to reduce the total energy demand.

In addition they are bad news commercially.

What can we do?

SOLAR POWER is the only alternative that is large enough to render nuclear power unnecessary.

We need to consider the efficiency question in a little more detail and assess ways we can overcome the Carnot factor.

The Carnot factor is central to the problem of maximising the efficiency of any energy conversion process that goes through a heat stage.

FUTURE IMPLICATIONS

SUMMARY

The resource question can be summarised as follows:

FOSSIL FUELS: exhausted quickly (oil, gas) or restricted by climate change fears (coal)

ALTERNATIVE ENERGY SOURCES: with the exception of solar power we are limited to about 10 % of the planning target of 5 Q/year (although they replace 30 % of the fossil fuels).

FISSION, FUSION, SOLAR: these sources must make up the shortfall. No-one wants nuclear power if we can help it so we also need to examine the target to see how rigid it really is.

MAXIMISING EFFICIENCY

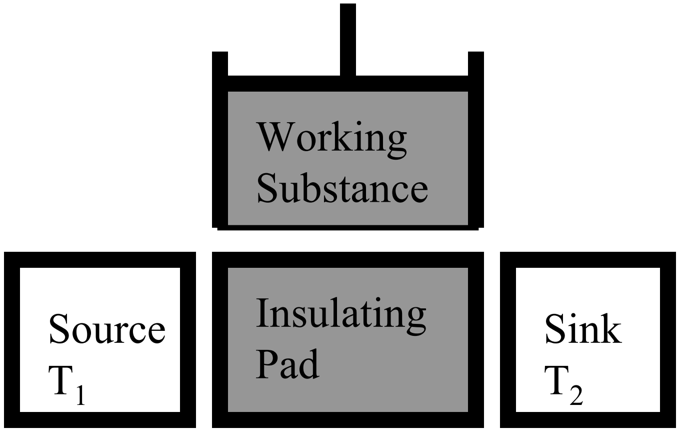
Power stations rely on using fuel (fossil fuel or nuclear) as a heat source. The hear is used to drive a heat engine in which a “working fluid”, usually steam, is taken round a cycle. Sadi Carnot devised an ideal heat engine, the **CARNOT CYCLE**.

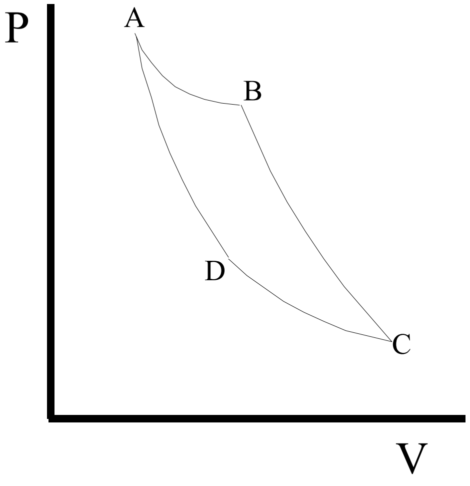
[a]Source : the source is maintained at a fixed higher temperature and has infinite thermal capacity. By infinite thermal capacity we mean that any amount of heat can be taken out of it without changing the temperature of the source.

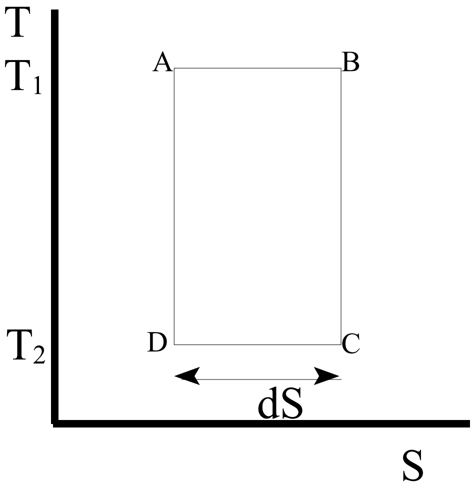
[b]Sink: It is the reservoir at lower temperature T_2 and it also has infinite thermal capacity i.e. any amount of heat can be added to it without changing its temperature.

[c]Working substance: the working substance in the Carnot engine is the ideal gas which absorbs heat from the source does some mechanical work and rejects the remaining amount of heat into sink. It is placed in a cylinder with insulating base but perfectly conducting bottom.

[d]Insulating pad: The pad is used in Carnot cycle for adiabatic expansion and contraction of the gas.







MAXIMISING EFFICIENCY 2

ISOTHERMAL EXPANSION: (A to B) Isothermal expansion of a gas is carried out by placing the gas in contact with a heat source so that it acquires the temperature of the source T_1. The gas allowed to expand slowly, which results in cooling and the decrease in temperature is compensated by gaining the required amount of heat from the source. Thus overall temperature of the gas remains constant during the expansion. The pressure and volume of the gas are (P_1, V_1) and the final pressure and volume are (P_2,V_2).

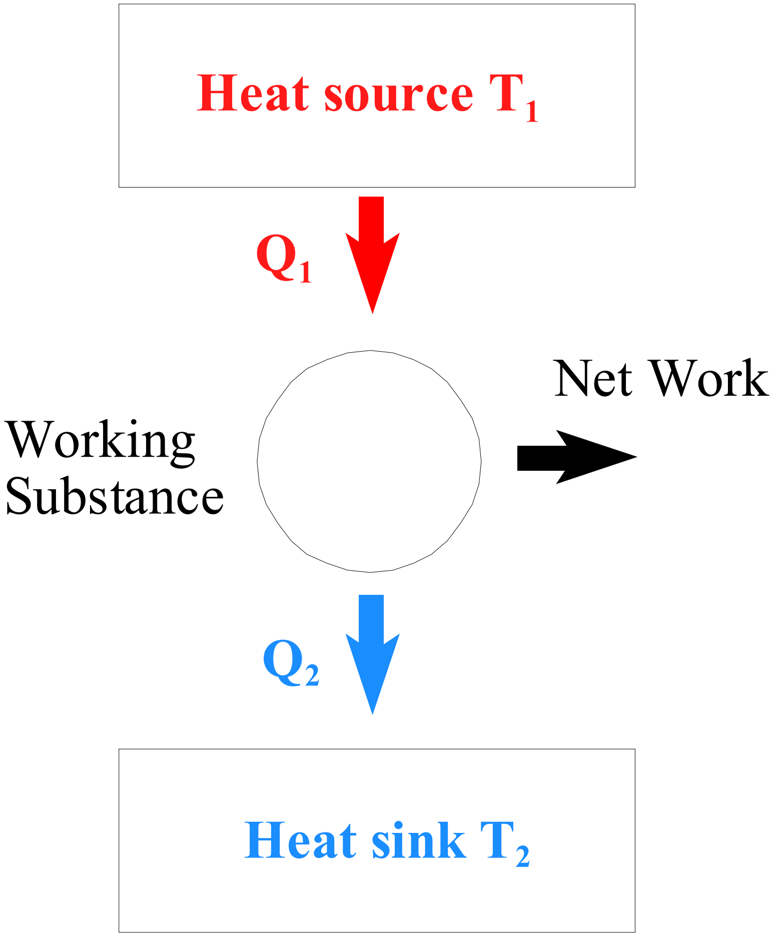
ADIABATIC EXPANSION: (B to C) The heat source is removed from the gas and the gas is insulated. The gas is allowed to expand further from (P_2, V_2) to (P_3,V_3). The process is adiabatic because the gas is thermally insulated from all the sides. Thus, because of the expansion of the gas, the temperature of the gas falls from T_1 to T_2.

ISOTHERMAL COMPRESSION: (C to D) the gas is no longer thermally isolated and is brought into contact withy the sink. The gas is then compressed, resulting in generation of heat. The temperature of the gas is kept constant by releasing the heat generated to the sink. The pressure and volume of the gas changes from (P_3, V_3) to (P_4, V_4).

ADIABATIC COMPRESSION: (D to A) The cylinder containing the gas is isolated once more and compressed so that the pressure and the volume of the gas returns to the initial value (P_1,V_1). The temperature of the gas increases to T_1.

In the first two steps the work done by the gas is positive as the gas is expanding whereas the work done by the gas in the compression is negative.

MAXIMISING EFFICIENCY 3



Heat source T_1

Q_1

Working Substance

Net Work

Q_2

Heat sink T_2

All heat, Q_1, enters at T_1 and all waste heat, Q_2, leaves at T_2.

Expansion and compression are adiabatic and there are no other losses. So

$Q_1=T_1dS$ and $Q_2=T_2dS$

$W=Q_1-Q_2$ and $Q_1/Q_2 = T_1/T_2$

Carnot efficiency, $\varepsilon= W/Q_1 = (T_1 - T_2)/T_1$.

MAXIMISING EFFICIENCY 4

Typical values of the hot and cold reservoirs in a production power station are:

T_1=800 C = 1073 K and T_2=160 C = 433 K so ε ~ 60%

This is for a perfect Carnot engine, where the upper and lower reservoirs are at fixed temperatures.

An ideal working cycle is the Rankine cycle. Neither isothermal expansion and compression or adiabatic heating and cooling, can be achieved. The efficiency of the ideal Rankine cycle is 53 %.

The actual efficiency of the heat engine is around 89% of this maximum.

Additionally:

The furnace in which the fuel is burnt is about 88% efficient (12% lost up the chimney).

The generator is slightly less than 100% efficient (~ 99%)

So our actual efficiency is ε ~ 0.53x0.89x0.88x0.99 ~ 41%

This value is achieved in large base-load stations, however, a mixture of these and smaller, less efficient, stations is required to match the pattern of demand.

ENERGY STORAGE

Nationally the only current form of energy storage is PUMPED WATER STORAGE, though large scale battery facilities and flywheels on service vehicles are being introduced.

The largest pumped storage system is in Dinorwig, Snowdonia, Wales and is built into the the mountain behind the old Llanberis slate quarries.

Water is pumped into the Marchlyn Mawr reservoir during a 6 hour period overnight.

The reservoir has a useable volume, V, of 7×10^6 m^3 at a height of 500 m, representing a gravitational potential energy of $\rho Vgh = 3.5 \times 10^{13}$ J.

It is used to power generators with an output of 1.8 GW.

Power consumption in the UK varies diurnally from 25 GW at night to 50 GW peak power.

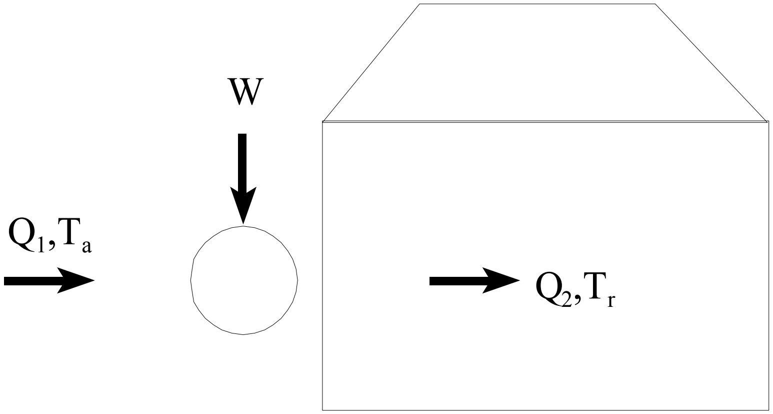
To smooth out the supply completely would require 12.5 GW storage for 12 hours.

So we need to store 5.4×10^{14} J.

A conversion to an electric economy with power generated remotely from the end use (this will not include PV and other technologies) would require around 10 Dinorwigs.

HEAT PUMPS – COMBINED HEAT AND POWER

Can reverse a Carnot style heat engine to generate heat (space heating for homes and businesses).



$Q_2 = Q_1 + W$ $\quad$ $Q_2/T_r = Q_1/T_a$

$COP = Q_2/W = T_r/dT$ $\quad$ where $dT = T_r - T_a$

COP is the coefficient of performance

It is the inverse of the Carnot efficiency

If $T_a = 5$ C and $T_r = 20$ C $\quad$ COP = 19.5

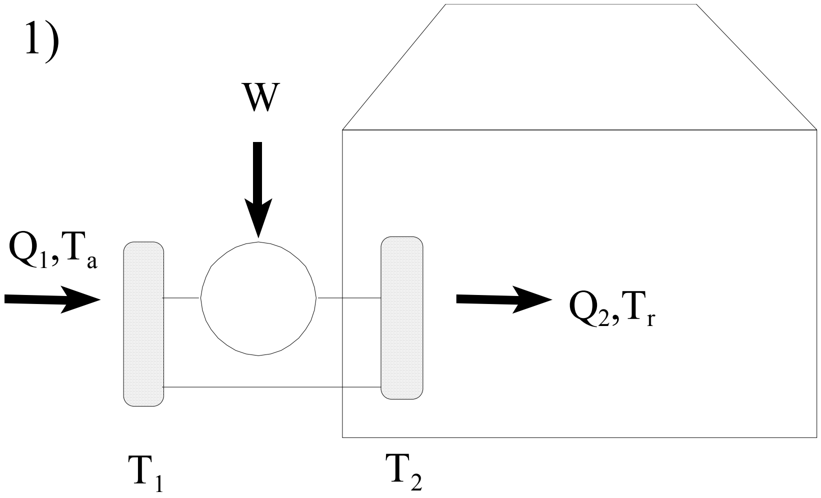
We get 20 kWh out for every 1 kWh in!

If electricity generated at 40% efficiency, we can just retrieve all the original fuel energy at a COP of 2.5.

HEAT PUMPS – COMBINED HEAT AND POWER 2

So far we have assumed a Carnot cycle, what will we get in reality? Several factors reduce the COP.

1)



We also have to consider heat transfer

Real systems have outside collectors at T_1 and inside radiators at T_2.

To transfer heat efficiently $T_2 > T_r$ and $T_1 < T_a$

e.g. if T_1 = -5 C and T_2 = 45 C are required to maintain T_a = 5 C and T_r = 20 C then the

COP = 6.4

HEAT PUMPS – COMBINED HEAT AND POWER 3

2) Like the steam cycle we can never realise a perfect Carnot cycle. The COP of the actual idealised cycle used (the Rankine cycle) is about 5.1.

3) Real efficiency is never as good as the ideal limit and we have to allow for the heat loss in circulating the pumps and fans.

A realistic value turns out to be around 3.0.

This is sufficient to "recover" all the waste heat lost in power generation.

It therefore has a slight advantage over the standard way of heating (burning fuel on site), which has an efficiency of 0.8 (80%).

HEAT PUMPS – COMBINED HEAT AND POWER 4

A REAL INSTALLATION:

House with 235 m^3 floor area and COP = 2.5:

In an all electric house (Energy in kWh)

	Electric Power Supplied	Energy Delivered	Fuel Energy Equivalent (@34%)
Heat Pump:	15000	37500	44100
Other uses:	12000	12000	35300
Total:	27000	49500	79400

Efficiency = energy delivered/Fuel energy in = 49500/79400 = 62%

If electrical power costed at 5.5 p/kWh then Energy is delivered at 3 p/kWh

HEAT PUMPS – COMBINED HEAT AND POWER 5

A CONVENTIONAL BOILER:

Conventional house with 235 m^3 floor area and oil fired boiler: (Energy in kWh)

	Electric Power Supplied	Energy Delivered	Fuel Energy Equivalent
Boiler:	-	40000	50000 (@ 80%)
Other uses:	6000	6000	17650 (@ 34%)
Total:	6000	46000	67600

Efficiency = energy delivered/Fuel energy in = 46000/67600 = 68%

If electrical power costed at 5.5 p/kWh and heating oil @ 20 p/litre. If energy of combustion of heating oil 3 x 10^7 J/litre Energy is delivered at 2.8 p/kWh

REVIEW OF ENERGY DEMAND IN THE FUTURE:

•By 2080 we predicted that energy consumption would reach a steady state of 5 Q/year

Uncertain, dependent on population trends etc. so dangerous to assume this is pessimistic.

• Assume that energy conservation measures (insulation, design, integrated transport etc. etc) reduce the demand by 40% to **3 Q/year**.

• Space heating, which is currently 16% of demand, will not be required by people living in the tropics (though air conditioning may be):

reduce by 0.3 Q to **2.7 Q/year**

•"Penalty" for conversion to electric power. The 50% penalty is extreme so take an arbitrary 40% and exempt space heating because of total use of heat pumps:

Increase the burden to **3.5 Q/year**.

REVIEW OF ENERGY DEMAND IN THE FUTURE 2:

The resources available are:

COAL:	should be kept down to 0.2 Q/year – specialist uses only.
ALTERNATIVE ENERGY SOURCES	(except solar power) yield up to 0.5 Q/year but will displace heat type sources up to 2.5 times this value.

We still have a 2.2 Q/year deficit: This **MUST** come from either solar or nuclear power.

*** Many of the assumptions we have made along the way are in many ways arbitrary ***

However we have always taken the upper bound estimates so it is unlikely that we are going to manage without such a deficit.

So we have to:

a) MAKE ENERGY SAVINGS	b) FILL THE DEFICIT
Savings of around 50% need to be Found over and above the 40% allowed for.	Solar power may go a long way towards filling the gap but this is unclear. A decision must be taken on the future of nuclear power.